We Used to Drink Our Water

Understanding the causes and consequences of boil water advisories in rural drinking water wells

by

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Abstract

Access to safe, reliable drinking water in many First Nations in Canada lags significantly behind the access available in non-First Nations communities. This thesis explores the sources, pathways, and consequences of bacteriological contamination in drinking water wells in Samson Cree Nation. A historical data review showed that seasonal precipitation and well installation contractor are the two most significant factors that determine risk of bacteriological contamination. Contamination events are most frequent from August to October, two months after the peak in total precipitation from June to August. Well contractors typically operated over specific periods of time and wells installed by contractors operating during earlier periods were at greater risk of contamination than wells installed by more recent contractors. Isotope analysis of groundwater samples provided an indication that older, shallower wells were under greater surface water influence and greater risk of bacteriological contamination than newer, deeper wells. However, the sample size collected was not sufficient to provide a clear safe value for well depth and age based on these indicators. A survey of Samson Cree Nation residents was completed and found that distrust of their water source correlated with: increased use of bottled water for drinking, previous or current boil water advisory on the household, a higher priority on protecting Samson Cree Nation's water rights, and a greater willingness to pay for improved drinking water servicing. Other issues identified by interviewees that impact their access to safe, reliable drinking water include: communication barriers, oil and gas activity, shock chlorinations, insufficient funding and poor management of infrastructure, and general poor quality of groundwater and water infrastructure.

Preface

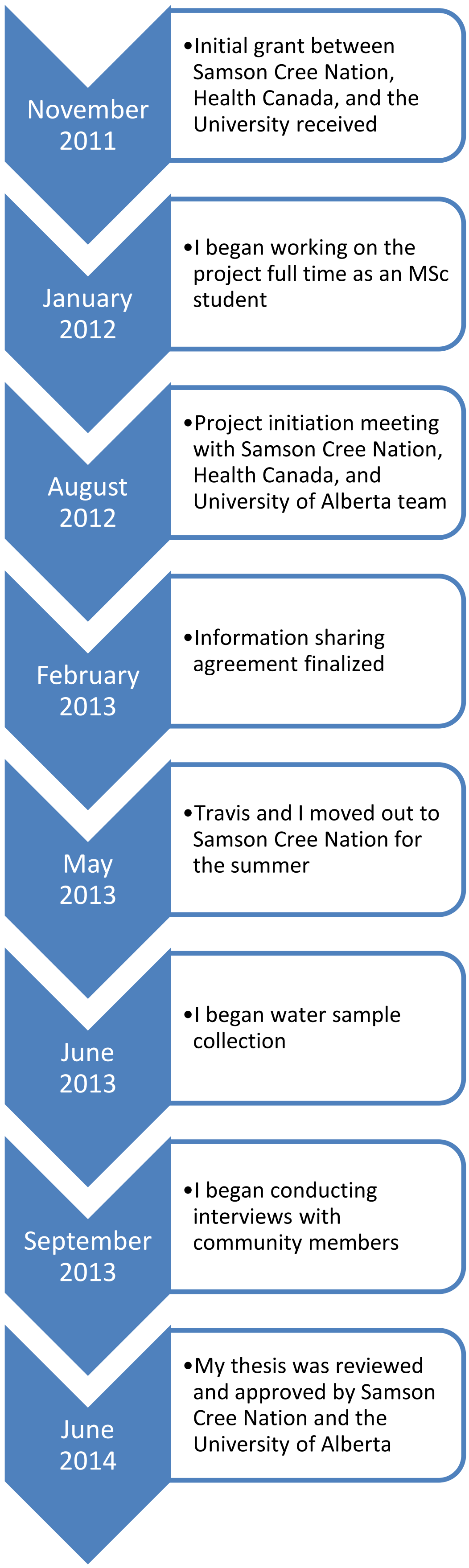
This is not your typical engineering research project. The work described in the following thesis represents a collaborative and community-based approach to undertaking engineering research which is sadly lacking from the "typical" engineering discourse. In studying a topic as vital to life as water, it was identified early on that we would need to take the time to understand the context within which water is used in Samson Cree Nation and the relationships that surround it. Working in a Plains Cree First Nation as outsiders to the community added an additional layer of importance that we learn the protocols and meaning of nipîy (water).

In preparation for this, my colleague Travis Hnidan and I sought out workshops, literature, courses, and individuals who could guide us on this journey. The topic of community-based research is a common one in fields such as sociology, anthropology, and other social sciences but is not often discussed in the engineering profession. Engineering philosophy treats research through a lens of positivism, reductionism, and disinterest that seeks to find the objectively "best" solution to a problem (Leydens et al., 2012). The engineer is more interested in the question of *How* than the question of *Why* in their problem-solving approach (Bucciarelli, 2003).

But the challenges that engineers seek to address do not exist in isolation, devoid of human context. Community-based research methodologies immerse the researcher in the context which defines the research questions they are seeking to answer (Wolcott, 2005). During the summer of 2013, Travis and I spent the majority of our time living and working in Samson Cree Nation and participating in as many events as we could in order to understand the community and its relationship with water. I participated in a Sun Dance, several sweats, Pow Wows, and rode a cow in a rodeo. Travis and I met with elders individually and in a larger consultation meeting, put on a presentation about water quality and quantity at the Samson Cree Nation high school, attended funerals and community meetings, and provided updates for the community newsletter on our work as it progressed. This participant observation allowed us to better understand how various recommendations might play out in practice in addition to generally building rapport with individuals in order to create genuine relationships (Lassiter, 2005).

Throughout this process, we sought to find ways to maintain the rigour of scientific engineering research while integrating proper protocols and practices from the community into our work. The University of Alberta Research Ethics Board approved the research project of which this thesis is a part, entitled Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for the Samson Cree Nation, on October 18, 2012. But in addition to this, Travis and I worked with many individuals in Samson Cree Nation to gain their perspective on the project and understand what they consider the real problems to be. Some people in the community told us that they were sick of being "studied to death" with engineering feasibility studies, university research projects, and government fact-finding missions, especially since they continue to see no improvement in their day-to-day lives as a result of these studies. It was apparent that for our research project to be successful we would need to be transparent about what we were doing in the community, honest about what we expected to accomplish and under what timelines, and responsive to the concerns and information that we received along the way.

Travis and I were uniquely advantaged in being able to undertake this project the way we did with the flexibility to spend a summer living in a single community working on a single project. Typically engineers in both research and industry are assigned to many different projects at a time and face numerous other barriers to performing community-based, participant observation research. However,



the need for engineers to be better able to understand the context surrounding problems they seek to address is vital to improving the profession. Relationship building takes time and long-term commitment, as seen in the timeline of major project milestones. One challenge that we faced was the question of data ownership since academic and granting agencies often seek to collect and manage data on their terms. Samson Cree Nation staff expressed that the data should belong to them as they are generated from the community and are ultimately representative of the Nation. We developed a structure where Samson Cree Nation retains ownership and control of the data with provisions for our usage and analysis. Information ownership is an important issue in many Indigenous communities, but the timelines required to negotiate such arrangements would be considered impractical for many engineering projects which are under immense pressure to complete projects on time and on budget.

Of course, our methodologies and practices have been far from perfect. As settler-Canadians, Travis and I are still representative of a system that requires Indigenous communities to legitimize their practices and processes through the validation of settler epistemologies. In an ideal world, the work we have undertaken would be conducted by Samson Cree Nation residents to their own standards, regulations, and protocols. As we move towards that goal, I hope that this work can offer a step in the right direction to more meaningful collaboration and service from the engineering profession.

Acknowledgements

My deepest thanks to everyone who has guided me to the point I am at today. As Thomas King writes, "The truth about stories is that that's all we are," and I am so appreciative of the cast of characters that have populated my story so far.

First, to my parents who taught me how to see the world - to be open-minded, earnest, and respectful.

To my many mentors and guides along the path who expanded my views and horizons while challenging me to think more deeply and push my boundaries. Dr. Evan Davies, Dr. Ania Ulrich, Mario Swampy, Murray Healy, Danika Littlechild, Joan Yee, Dr. Pat McCormack, Dr. Makere Stewart-Harawire, Dr. Yang Liu, Dr. Jean Birks, Elena Dlusskaya, Matt Brassard, Brian McCosh, Adam Greenwood, and Chad Fletcher.

To the community that made me feel at home and welcomed me into Samson's culture and community - from sweats to Sun Dances, dressing a moose to being kicked off a cow. Tony, Vern, Marlene, Kirk, Norine, Wayne, Josh, Jodi, BJ, Doreen, Nancy, Roy, Judy, and everyone else I had the chance to work with.

To my many friends, colleagues and peers who have helped celebrate and commiserate the path we've chosen. Especially to Travis for his depth of thought and observation and Patrick for his endlessly multifaceted perspectives.

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- Samson Cree Nation
- Natural Sciences and Engineering Research Council of Canada
- Mitacs Accelerate
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- Connect Canada

And to Alix, for having my back through it all.

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1.1 Introduction

Poor drinking water quality is a problem that faces many First Nations communities in Canada. A report from Neegan Burnside (2011) found that 39% of drinking water systems in First Nations in Canada are at high risk of contamination from microbiological 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 et al. (2006) found that 50 of a total 56 drinking water systems on First Nations in Alberta should be labeled as high risk. These risk assessments focus primarily on drinking water systems serving multiple homes, but many First Nations communities are in remote, rural areas where large portions of the population are served by private drinking water wells and not treated, piped distribution systems. Rural, private wells are facing their own crisis in Canada, both in Indigenous and non-Indigenous communities, with van der Kamp and Grove (2001) reporting that about 20-40% of individual wells fall outside of safe drinking water guidelines. A study in Alberta found that 32% of the private wells tested exceeded at least one parameter in the Canadian Drinking Water Quality Guidelines (Fitzgerald et al., 1997). The risk presented by individual wells is often greater due to infrequent monitoring and regulation that is difficult to enforce (Charrois, 2010). The regulatory framework surrounding water quality in rural Canada is insufficient for ensuring the reliable provision of drinking water, especially on First Nations where there is uncertainty regarding the jurisdiction under which they fall (Phare, 2009). In addition, Patrick (2011) reported that First Nations in Canada do not have sufficient resources for addressing the challenges they face with respect to providing clean, safe water. Many technological solutions have been attempted, but have seen only limited success. The combination of high use of rural, private wells and a uniquely complex management and regulatory structure results in rural, private wells in First Nations presenting a significant health concern. A greater understanding of the sources of contamination as well as better source water protection have the potential to improve the quality of drinking water for First Nations as well as other homes that rely primarily on rural, private drinking water wells (Patrick, 2011).

When a private drinking water well is experiencing problems with total coliform (TC) and *Escherichia coli (E. coli*) contamination, it is placed under boil water advisory (BWA). Considerable amounts of research have gone into understanding the sources of contamination and methods of addressing the issue of BWAs in private drinking water wells. The way that the monitoring system currently works for private wells on a First Nation is that Health Canada collects annual tap water samples and tests for TC and *E. coli*. If either of these two contaminants are consistently present in the drinking water, then a BWA is put into place. In this current system, TC and *E. coli* are utilized as indicator organisms for the presence of more serious pathogens under the assumption that various pathogens will enter the groundwater through the same transport mechanisms. Wallis et al. (2001) however found that testing for giardia and cryptosporidium oocysts in addition to total coliform and *E. coli* was highly valuable for getting a more comprehensive understanding of water quality risks associated with microbial pathogens. Danon-Schaffer (2001) incorporated an environmental forensic approach to investigate the source of contamination in the case of the Walkerton *E. coli* outbreak in 2000. Environmental forensics incorporates the broader system and actors involved in a contamination event as compared to conventional environmental contamination investigations which focus more narrowly on the specific contaminant location and distribution. Danon-Schaffer (2001) applied hydrogeological studies, environmental transport assessments, genetic characterization, and fate and transport mechanisms to gain a more comprehensive understanding of contamination sources. This framework can be adapted to a private well water scenario as opposed to a municipal treated water system in order to provide a more comprehensive, forensic review of contamination sources. GIS type maps of BWAs have been developed by Health Canada, but these maps and the resulting analysis are most often utilized for developing measures for dealing with high concentrations of BWAs after the fact, as opposed to proactively seeking out causes of contamination (Isfeld, 2009). In addition, Simms et al. (2010) examined the use of various tools and approaches to protecting source water as a means of ensuring the provision of clean, safe drinking water. These tools included integrating source water protection into all aspects of other water and land use management strategies and creating regionally appropriate source water protection plans to best serve the watershed where they are implemented (Simms et al., 2010).

A unique challenge that faces First Nations water protection in Canada is the regulatory grey area in which they exist. Water is a provincially managed resource under the Natural Resources Transfer Agreement, but because First Nations reserves are under federal jurisdiction, the responsibility for regulating water on First Nations has historically fallen to multiple different agencies without a clear legislated distinction of responsibility. While this grey area is being addressed through the passing of Bill S-8: The Safe Drinking Water for First Nations Act, the transition to a federal regulatory structure will not be without challenges (Senate of Canada, 2012). Jalba et al. (2009) examined the gaps in an inter-agency management system such as that which exists between Health Canada, Aboriginal Affairs and Northern Development Canada, and First Nations band councils with respect to the provision of safe drinking water. A significant finding of this report was the need to develop better evidence-based emergency management frameworks to define the roles and responsibilities of each organization in emergency situations such as BWAs (Jalba et al., 2009). The report recommended that this structuring should be undertaken through improving six main areas: proactivity, communication, training, sharing expertise, trust, and regulation. Hrudey et al. (2006) further examined the management of risk in public health and drinking water systems, focusing on the assurance of public trust in the quality of water. By evaluating over 70 case studies of waterborne illness outbreaks in affluent countries, it was found that incidences are always caused by multiple different problems occurring in conjunction with one another (Hrudey et al., 2006). When these problems fall under different areas of responsibility in an interagency management structure, and communications between the various agencies is insufficient, the risk of an incident occurring increases dramatically. There is a body of evidence for the need to build comprehensive trust-based water systems that include all stakeholders, especially the end users in the water system (Hrudey et al., 2006). By working together to improve communication and collaboration between the multiple agencies responsible for First Nation drinking water access, significant gains can be made towards improving reliable access to clean, safe drinking water on reserves.

To better understand these complex relationships, a project in Samson Cree Nation was undertaken to study how these issues exist within this particular community. Samson Cree Nation is located in Central Alberta adjacent to the community of Maskwacîs (formerly Hobbema), which is located approximately 20 kilometers north of Ponoka and 17 kilometers south of Wetaskiwin along highway 2A. Samson Cree Nation is located in Treaty 6 territory and is a member of the Confederacy of Treaty Six First Nations. The area surrounding Maskwacîs and Samson Cree Nation is home to three other First Nations: Ermineskin, Montana, and Louis Bull First Nations. Samson Cree Nation covers a land mass of approximately 128 square kilometers primarily to the south-east of the community of Maswacis as seen in Figure 1-1. Samson Cree Nation is bordered to the south and the east by the Battle River and the surrounding prairies are primarily used for farming.

The Nation had a total population of 7,373 members in 2009, though only 5,329 of these individuals live on-reserve (Crowther, 2011). The on-reserve 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 majority of the on-reserve population live in rural areas and acquire their potable water from private drinking water wells that typically service only one home. Rural homes are serviced by various septic systems including septic fields and tanks. The population living in the Samson Cree Nation section of the Maskwacîs townsite receives water from a small water treatment plant located on the south side of the townsite. This treatment plant only services homes and facilities within Samson Cree Nation and the other three First Nations of Maskwacîs have their own facilities and distribution systems. The treatment plant draws water from groundwater wells in the surrounding area as its source water. Groundwater is treated with chlorine disinfection and distributed out to the households in the townsite. Wastewater from the townsite is collected in an initial septic pond to the South East of the townsite. Open channels drain the initial septic pond to a larger pond near 4 mile road which is typically drained annually into another channel which eventually leads to the Battle River where the waste is discharged.

Solid waste disposal in Samson Cree Nation consists of a centralized waste transfer facility at 4 mile road near the secondary septic pond where solid waste is collected. There have been several other undeveloped, unlined landfill facilities across the nation that may present a threat to the groundwater supply from leachate infiltration. There has been significant oil and gas drilling in Samson Cree Nation and the surrounding area in the past though this activity has largely shut down. The oil and gas development was accompanied by seismic subsurface exploration to identify the extent of hydrocarbon reserves.

The surficial subsurface geology in Samson Cree Nation is composed primarily of clay till to depths of approximately 30 metres with pockets of sand and gravel spread throughout the surficial layer in isolated pockets up to five metres thick (HCL, 2003). This surficial layer is underlain by bedrock composed primarily of shale and sandstone where groundwater occupies the pore space within the bedrock (HCL, 2003). Surficial aquifers under the reserve are typically confined to the sand and gravel layers and are recharged through precipitation infiltration. Groundwater in the bedrock layer is reported to have an upward hydraulic gradient which contribute to the recharge of surficial groundwater aquifers. Wells in Samson completed to less than 25 metres (80 feet) are considered to be tapping into surficial groundwater whereas wells completed to a depth greater than 25 metres utilize bedrock groundwater (Crowther, 2011).

Across Samson Cree Nation, 732 of the households rely on private wells for their drinking water but of these, as many as 132 have been reported as being on BWA at a given time. 65 of these BWAs were issued in the last year alone. Poor water quality has resulted in distrust and fear amongst community members regarding the safety of their drinking water and many families use bottled water which is a costly and unsustainable solution. The current water safety practice for the private wells is to test once per year for TC and *E. coli* and to respond to any exceedances by implementing a BWA followed by shock chlorination of the well, followed by additional testing to verify the well has been cleaned (Health Canada, 2007). This framework is reactionary and fails to ensure the prevention of future contamination events.

In response to these challenges, band leadership at Samson Cree Nation is actively working to find solutions to the water quality issues and the distrust that members of the community have towards their water source. There are several priority areas related to water for the nation including ensuring sufficient water availability for future growth, building greater understanding amongst community members of their water resources, and identifying the factors that impact groundwater quality and cause TC or *E. coli* exceedances, in addition to other forms of contamination. Ultimately, Samson Cree Nation's leadership want to develop an internal water policy for regulating and administering the water utilized by the Nation. My research seeks to examine the relationships between several environmental factors such as precipitation, well age, well depth, and water chemistry that can affect groundwater quality. In addition, I will examine the impact that water quality and the monitoring system can have on perceptions of water quality within the community.

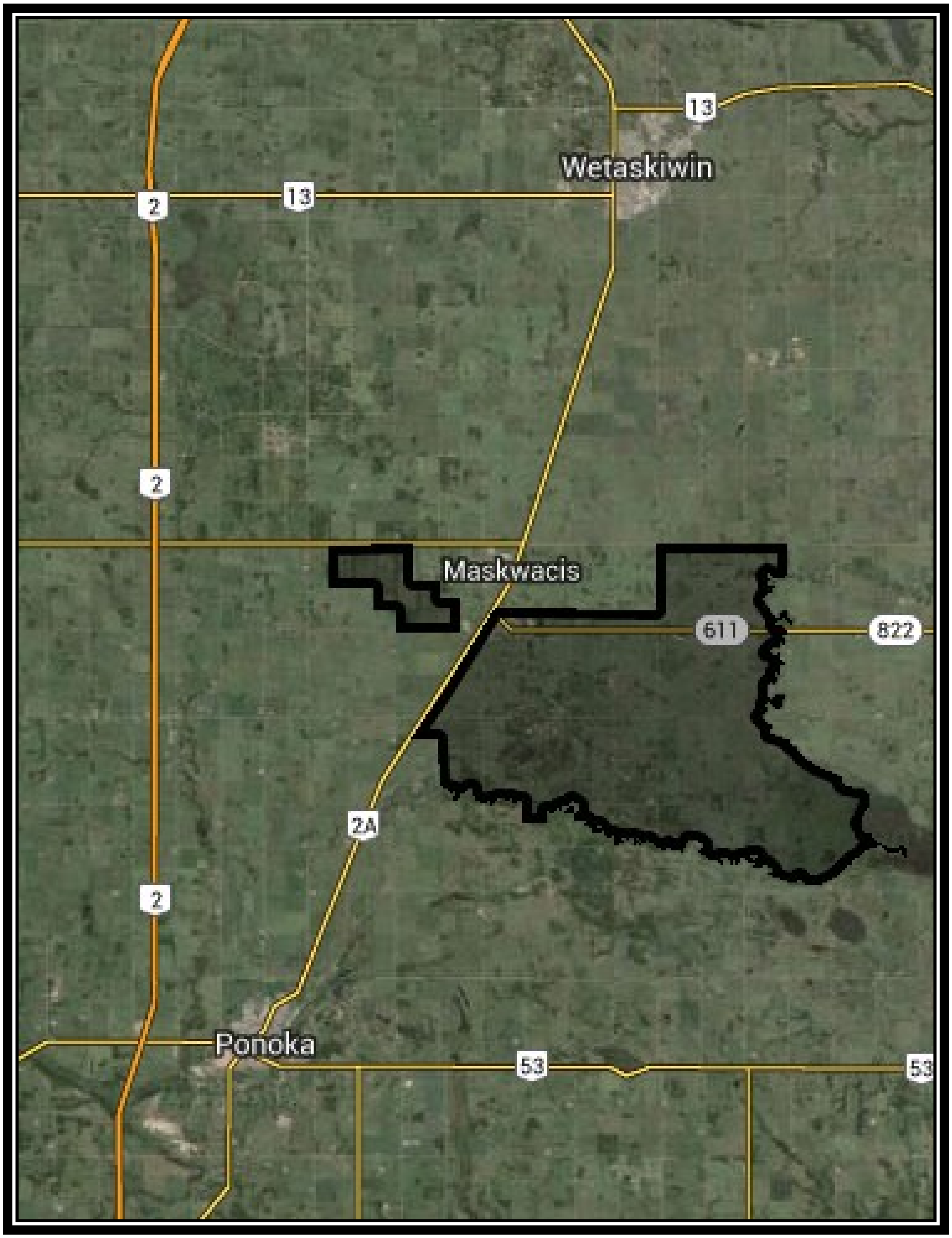

FIGURE 1-1: MAP OF SAMSON CREE NATION RELATIVE TO PONOKA AND WETASKIWIN

1.2 Project Inception

The project was initiated by Joan Yee (Health Canada) and Philip Simpson (Samson Cree Nation) in response to the water quality concerns that exist in Samson Cree Nation. The specific challenge initially identified was the numerous wells in Samson Cree Nation that show chronic contamination by TC or *E. coli* despite repeated BWAs and shock chlorinations. In order to more adequately and permanently address the contamination at these and other homes, a research project was developed to determine the sources of contamination in the wells. This can allow for remedial action to be taken which can interrupt the method of contamination, preventing future problems. In addition, by determining the sources of contamination and environmental factors that may indicate contamination, better monitoring programs can be developed that work more proactively to prevent contamination before it can occur. Joan Yee engaged Dr. Ania Ulrich at the University of Alberta to develop the research program. The project was initiated under the Health Canada Drinking Water Quality Program as a partnership between Samson Cree Nation, Heath Canada, and the University of Alberta research team. A band council resolution was passed in the fall of 2011 to establish the relationship between Samson Cree Nation and the other parties involved in the project.

The project team has evolved over the course of the project based on the various components involved, but the individuals who have been most directly involved over the duration of the project have included:

Samson Cree Nation

- Mario Swampy: Band Councilor and Chair of the Maskwacîs Water Committee
- Murray Healy: Senior Water Technician
- Danika Littlechild: Nipiy Committee member and legal support
- Philip Simpson: Band Engineer
- Rod Buffalo: Trades Center Manager

Health Canada

- Joan Yee: Senior Environmental Health Officer
- Amy Forward: Environmental Public Health Data Technologist
- Stephanie Amoah: Environmental Health Officer
- Kyle Wonsiak: Environmental Health Officer

Maskwacîs Health Services

- Doreen Johnson: Maskwacîs Community Health Center Manager
- Jodi Ellen: Community Based Water Monitor
- Nancy Omeasoo: Community Based Water Monitor

University of Alberta

- Dr. Ania Ulrich: Principal Investigator
- Dr. Evan Davies: Principal Investigator
- Fraser Mah: MSc. Student
- Travis Hnidan: MSc. Student

1.3 Positionality

As a researcher working in any field, the experiences and biases of the researchers will influence the direction that the research moves and ultimately the conclusions that are drawn. Consideration of these biases is especially relevant for field research involving community engagement.

- As a settler colonist of Chinese and Scottish origins, I have obligations to honour the treaties that establish the relationship between the Indigenous Nations of this land and the settler society that I belong to;
- I grew up in Red Deer, Alberta, though my experiences with First Nations culture and community were relatively limited prior to engaging with this project;
- I was educated under the Alberta curriculum to grade 12 and completed my BSc. in Environmental Engineering at the University of Alberta prior to beginning my graduate program
- I have spent the majority of my life living in urban environments with ready access to clean, reliable drinking water that I trusted to be readily available when needed.

As I undertook this research and reported the results, I have taken steps to maintain awareness of my background and my particular viewpoint on ideas that may impact the research direction and conclusions. While this thesis is written within the engineering discourse avoids the use of first person pronouns, I have used first person pronouns where appropriate.

A note on Non-Interference

It is typical within engineering practice to conduct research with the intent of producing a list of recommendations and proposed interventions to address the specific problem identified. In acting as an expert, the engineer offers the steps along the pathway to be taken towards a solution. This approach is highly directive which can run counter to an ethos in Cree culture of non-interference, which has been identified by many authors (Kanu, 2011, Ross, 2006, Aboriginal Justice Implementation Commission, 1999, Prince, 1993). Non-interference stems from a respect for the autonomy of every individual and assumes that that person is responsible for their own actions. It discourages coercion or direct instruction since it identifies that each individual is best positioned to know what is best for them. Learning is done through observation and first-hand experience, and teaching is done by providing anecdotes or stories from which someone may take information to inform their own decision.

The ethos of non-interference has been discussed largely in terms of how it can affect systems of education, justice and health care but little discussion exists as to how it relates to engineering. As the engineering field focuses on providing recommendations and implementing solutions, it is important to understand how this work is communicated and interpreted in cross-cultural contexts. This thesis has been written with this idea in mind and where recommendations are provided they are provided as information and knowledge to be acted upon in the context of Samson Cree Nation. As an outsider, I acknowledge that I do not know the full story of Samson Cree Nation and offer my research findings as knowledge that can support the ongoing work of those within the community.

1.4 Research Questions

As discussed in the introduction, 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 thesis project has sought to answer the following research questions:

1) **What correlations exist between TC/*E. coli* contamination and various environmental factors in the historical data specific to Samson Cree Nation?**

The historical data analysis will look at Health Canada and other agencies' existing archives of water quality data for the First Nation and analyze 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.

The following hypotheses are proposed:

1a) The factors that will have a positive correlation to incidence of BWA are: well age, well shallowness, increased precipitation, proximity of septic system and wellhead, and number of residents living in the home; and

1b) Correlations that exist between TC/*E. coli* contamination and environmental factors can be used to predict incidents of contamination and provide indications of risk of contamination of a well based on a set of environmental factors.

2) What environmental factors and sampling parameters can be used to identify the source of TC/*E. coli* contamination in drinking water wells?

This question is important for developing and utilizing more proactive measures to ensure the safety of drinking water. The current monitoring system is reactive in that it measures for contaminants and responds accordingly based on the results of testing. This can potentially lead to residents consuming harmful drinking water prior to their water being tested. By looking for correlations between bacterial presence in the drinking water and other factors, alternative monitoring methods can be evaluated to reduce the risk of exposure to bacterial contamination.

The following hypotheses are proposed:

2a: Based on correlations found in answering research question 1, specific parameters can be found that directly anticipate correlated environmental factors with TC/*E. coli* contamination; and

2b: In addition to TC/*E. coli* contamination, issues with other chemical contamination such as exceedances in allowable metal concentrations, are also present in well water.

The water quality sampling will involve visiting the First Nation to collect water samples from rural households to measure additional parameters not currently tested by Health Canada including the influence of septic seepage, the infiltration of surface water, and chemical constituents such as metals and other groundwater constituents (FPT Committee on Drinking Water, 2010).

3) **How does the current system for monitoring and reporting water quality information for private drinking water wells in Samson Cree Nation impact the real and perceived water quality in wells and the minds of residents?**

The impact of poor drinking water quality can extend beyond the direct impacts such as illness caused by waterborne pathogens. In addition to the presence of potentially pathogenic bacteria in the water, drinking water organoleptics significantly impact the perceived quality of the water. This includes the taste, smell, texture, and other properties that affect the perceived quality of the water by the consumer. While these characteristics may not have direct health effects, they can impact wellbeing of residents in several ways such as influencing the purchase of alternative water supplies such as bottled water, or impacting the overall amount of water consumed which may have unexpected health consequences. By assessing the relationship between perceived and real water quality with general household wellbeing, monitoring programs can be adapted to best address any concerns experienced by Samson Cree Nation residents.

The following hypotheses are proposed:

3a: Lack of reliable, clean safe drinking water can impact other aspects of life such as stress levels, household financial resources, time available for partaking in other activities, etc.;

3b: In the absence of readily available information about drinking water quality, individual homeowners will err on the side of caution and seek out alternative water sources; and

3c: Samson Cree Nation residents consider the provision of safe, reliable drinking water to be a high priority for leadership to address.

The community survey will seek to link the collected water quality data with the community's perceptions of their water value. The survey will focus on water use patterns, safe water handling and sanitation behaviours, site assessments, and general perceptions of the safety of the drinking water. This information will inform the development of a water policy by contextualizing the research results into the community understanding of the water challenges being faced.

Chapter 2: Drinking Water Quality Monitoring System

2.1 Introduction

> "States shall consult and cooperate in good faith with the indigenous peoples concerned through their own representative institutions in order to obtain their free and informed consent prior to the approval of any project affecting their lands or territories and other resources, particularly in connection with the development, utilization or exploitation of mineral, water or other resources."
>
> - Article 32.2 of the UN Declaration on the Rights of Indigenous Peoples

Drinking water quality in rural private groundwater wells in Samson Cree Nation is currently monitored by Maskwacîs Health Services staff. Community Based Water Monitors collect water samples and send them to the Edmonton Provincial Laboratory for analysis of total coliforms (TC) and generic *Escherichia coli* (*E. coli*). This data is used to implement boil water advisories (BWAs) and inform further courses of action. For any water quality monitoring system to be successful, there must be clearly defined roles and responsibilities between various parties and clear lines of communication to inform all actors what is happening at any given time. Crucially, the homeowners and residents must be included in this communication chain and must be regarded as active participants in maintaining the quality of their own drinking water well.

This chapter evaluates the efficacy of the current water quality monitoring system in Samson Cree Nation (annual *E. coli* and TC sampling followed by shock chlorination for BWAs) by reviewing the literature and discusses how the current system is arranged as understood through reviewing policy documents and interacting with the specific actors within the system. This chapter also serves as an introduction to the water quality monitoring system to provide context for the following chapters which delve deeper into the system and the quality of water in Samson Cree Nation.

2.2 Indicators of Fecal Contamination in Groundwater

Under the current water monitoring system in Samson Cree Nation, every well is tested annually for *E. coli* and TC. Chemical parameters are tested at varying intervals and on an as-needed basis. If a home is placed under BWA the well is shock chlorinated to destroy the bacteria present. I discuss this in further detail later in this chapter; this literature review examines research that has been performed in the use of these practices (*E. coli* and TC testing and well shock chlorinations) as well as water quality monitoring systems in general to form a basis from which to evaluate the current system in place.

2.2.1 Assessment of Indicator Organisms

E. coli was first identified as a preferred indicator organism for water treatment safety in the 1890's as it was found to be present in all mammal feces ,thus giving a clear indication of fecal contamination in a water sample (Edberg et al., 2000). Generic *E. coli* testing refers to a class of bacteria which fall under the category of TC but that are more specific to mammalian digestive tracts. Not all *E. coli* species are pathogenic and specific tests exist for detecting pathogenic species such as *E. coli* O157:H7. At the time of its discovery, it was not practical to test for *E. coli* directly due to limits in the methodology, so fecal coliforms and TC were used instead as an indicator for *E. coli* presence. *E. coli* are a type of fecal coliform and fecal coliforms are a form of TC but not all species included in TC testing are necessarily fecal coliforms or *E. coli*. Fecal coliforms are those coliform species which grow at 44.5^{o}C which was believed to be representative of the *E. coli* bacteria from human fecal matter (Reynolds and Richards, 1996). In the 1980s, methodologies were developed to test for *E. coli* directly (Edberg et al., 2000). *E. coli* was identified as a preferred indicator organism for drinking water samples because:

- *E. coli* can survive in undisinfected water for 4 – 12 weeks (Edberg et al., 2000);
- *E. coli* testing is cheap, fast, sensitive, and easy to perform compared to methodologies for other organisms (Edberg et al., 2000; Tallon et al., 2005);
- *E. coli* is more specific to mammal feces than fecal coliform or TC tests so it is less likely to return a false positive triggered by environmental coliform species (Soller et al., 2010; Gauthier and Archibald, 2001; Gavini et al., 1985);
- Since *E. coli* is more specific to mammal feces, it has a higher correlation to the presence of pathogenic fecal organisms such as *E. coli* O157:H7 (Soller et al., 2010; Edberg et al., 2000; Tallon et al., 2005); and
- *E. coli* is not able to regrow significantly in the environment as compared to fecal coliform and TC so *E. coli* presence indicates specific, direct contamination (Baudizsova, 1997; LeChevallier, 1990)

While it is clear that *E. coli* testing provides a better indication of fecal contamination than testing for fecal or total coliforms, the real challenge is the ability of any indicator organism to indicate the presence or absence of more harmful pathogenic species which can cause waterborne illnesses. The studies discussed in this section highlight the limitations of *E. coli* and TC to provide an indication of this. These studies typically compare the presence of general *E. coli* against a variety of other known human pathogens.

Laboratory scale testing is one method to compare the presence or absence of various organisms relative to indicator organisms. Bitton et al. (1983) performed a study to compare the decay rates of *S. typhimurium, E. coli,* and *S. facecalis* bacteria in addition to poliovirus type 1 and bacterial phage (f2) to understand the decay rates of each of these organisms in laboratory simulated groundwater conditions. Under laboratory conditions, all organisms were stable with the exception of the bacterial phage. *S. faecalis* survived the best amongst the bacteria species and had a decay rate similar to poliovirus type 1. Conboy and Goss (2001) tested the decay of TC, fecal coliform, fecal streptococci and C*lostridium perfringens* in a simulated groundwater environment over six months. At six months, all organisms were still present but fecal streptococci had decreased most significantly. By measuring relative organism concentrations at frequent time intervals, differences in decay rate could provide an indication of contamination timing in a natural groundwater contamination scenario.

In a study of fifty groundwater wells in Wisconsin, Borchardt et al. (2003) sought to determine a link between various virus and microbe species with chemical concentrations in the water. Enteroviruses, rotavirus, hepatitis A virus, Norwalk-like viruses, TC, *E. coli,* fecal enterococci, F-specific RNA coliphages, nitrate and chloride were tested. There was no link between the presence of viruses and the other parameters. Most notably, there was no relationship between viruses and TC or *E. coli* presence indicating that TC and *E. coli* are poor indicators of virus presence. Tallon et al. (2005) and the Federal-Provincial-Territorial Committee on Drinking Water (2002) similarly reported that no current bacterial indicator species provide reliable indication of the presence or absence of enteric viruses in water. Won et al. (2013) sampled 180 randomly selected drinking water wells in Northeastern Ohio and found that seven of them were contaminated with *E. coli* O157:H7. In addition to *E. coli* O157:H7 they tested for generic *E. coli* and TC and found that only one of the seven samples that were positive for O157:H7 was also positive for generic *E. coli*. In this case, generic *E. coli* testing would have failed to adequately detect the presence of the more pathogenic *E. coli* species. Soller et al. (2010) reviewed incidences of *E. coli* O157:H7 outbreaks compared to the generic *E. coli* testing being performed in the area. The ratio of generic *E. coli* testing to incidences of *E. coli* O157:H7 was found to be between 6:1 and 90:1, indicating an over-approximation in using generic *E. coli* as an indicator organism.

While generic *E. coli* can be an ineffective indicator organism of many different pathogenic species on its own, several studies have sought to identify a statistical relationship between a combination of indicator organisms and pathogenic waterborne microfauna. Harwood et al. (2005) tested water samples from six different wastewater reclamation facilities for the following parameters: total and fecal coliforms, enterococci, *Clostridium perfringens*, F-specific coliphages, enteric viruses, *Cryptosporidium,* and *Giardia*. The first four organisms listed above are indicators and the last three are pathogenic organisms that can cause waterborne illness. In analyzing their data, Harwood et al. (2005) found no statistically significant link between any of the indicator organisms and any of the pathogenic organisms. However when all of the indicator organisms were combined using a discriminant analysis, the presence or absence of *Giardia* cycsts, *Cryptosporidium* oocysts, infectious *Cryptosporidium,* and infectious enteric viruses was predicted for over 71% of the effluent samples. Tallon et al. (2005) also identified that no single indicator organism is effective for providing all of the required data to assess a contamination event. *Clostridium perfringes* and *Enterococci*, when used in conjunction with generic *E. coli,* were able to provide an indication of a wider range of potential pathogenic species. Additional information such as the source of contamination, the specific pathogen present, the timing of the contamination event, or the severity of the contamination event could be better determined by using a combination of indicator organisms in addition to *E. coli* and TC. This could better protect public welfare and save water monitoring agencies money in the future through more specific remedial actions such as well replacements or rehabilitations instead of repeated shock chlorinations where it is not effective.

2.2.2 Bacteriological Contamination Treatment Methodologies

After a well is placed under BWA, it is shock chlorinated by pouring a solution of hypochlorite and clean water down the well and running the taps in the house to permeate the entire distribution system. The chlorine is then left overnight to infiltrate into the groundwater surrounding the well screen and to allow the chlorine to disinfect the system. The extent to which the chlorine will permeate the surrounding groundwater varies depending on the hydrogeology of the area. Homeowners are provided with sufficient drinking water for this period of time so they do not consume the highly chlorinated treatment water. After approximately 24 hours, the chlorinated water is drained out of the system through the household taps until no chlorine is detected in the system. Homeowners are then instructed to use as much water as possible for the next few days to ensure that any precipitate that is liberated during the process is removed from the system.

While shock chlorination can provide a thorough disinfection process for some problems in drinking water systems, it is not always an effective long-term solution to certain contamination sources and vectors (Bergsrud et al. 1992). Oliphant et al. (2002) regularly tested three wells in a floodplain aquifer for *E. coli* and TC following a shock chlorination event and found that all three wells had a return in contamination within 1-21 weeks. In the case of these wells, further investigation indicated that there was biofilm growth within the well which proved resistant to standard shock chlorination practices and therefore was able to regrow and cause further contamination after the shock chlorination. Clumping and biofilm formation were identified by Rusin and Gerba (2001) as potential challenges which chlorination disinfection are ill suited to address. In addition, some waterborne organisms are more resistant than others to chorine which can further complicate the use of *E. coli* and TC as indicators for the removal of other, more pathogenic organisms from drinking water. Not surprisingly, Rusin and Gerba (2001) measured multi-antibiotic resistant bacteria species before and after chlorine disinfection and found that the percentage of isolates that were multi-antibiotic resistant was higher in the treated water than the untreated water.

In addition to this inability to address all contamination problems, shock chlorination is well known to cause the release of other chemicals and precipitates into the water. While home residents are informed that this may happen and instructed to use plenty of water in order to flush the system, perceptions of water quality are closely linked to changes in the organoleptics of the water. A shock chlorination event can negatively impact a resident's perception of their water quality. Seiler (2006) analyzed four wells in Nevada following shock chlorination and found immediate and significant increases in the concentrations of copper, iron, lead, and zinc. After approximately 24 hours, lead, zinc, iron, and copper concentrations were all still highly elevated. The lead concentration in the wells exceeded USEPA maximum drinking-water standards. Gotkowitz et al. (2008) tested the concentration of arsenic in a well in Wisconsin before and after a shock chlorination event and found an increase in the arsenic concentration following the shock chlorination event. This elevated concentration decreased to pre-treatment levels soon after the well was purged. Bergsrud et al. (1992) identified the potential for shock chlorination events to produce trihalomethanes, a disinfection by-product, though this is considered a low risk for groundwater sources since groundwater is typically low in organic content, a necessary precursor for trihalomethane production. Walker and Newman (2011) measured the concentration of lead, copper, arsenic, radionuclides, and disinfection by-products in two wells before and after shock chlorination. Concentrations of lead, copper, trihalomethanes, and haloacetic acid were all found to increase immediately after the shock chlorination event but dissipated with free chlorine concentration.

Bergsrud et al. (1992) identified that shock chlorination events are effective for treating non-recurring bacterial contamination events such as new well installations but shock chlorination is not a useful solution for recurring water quality problems. There are many alternatives to shock chlorination for treating drinking water from private groundwater wells. Bergsrud et al. (1992) pointed to continuous chlorination as an effective treatment method however through my research I have found that many folks living in the rural areas of Samson Cree Nation do not like the taste of chlorine. Other point of use treatment technologies such as reverse osmosis, UV disinfection, silver nanoparticles, or ozone generators may provide other continuous use treatment options though these must all be evaluated based on acceptability to homeowners, cost, robustness of operation and many other factors. Tehrani et al. (2011) applied a system dynamics model to evaluate various options for rehabilitating contaminated water wells based on water demand information and other factors that could point to the most effective method.

2.2.3 Monitoring System Criteria

The current water quality monitoring system for wells in Samson Cree Nation consisting of annual testing for *E. coli* and TC coupled with shock chlorination for contamination events does not completely address challenges such as identifying the source and timeline of contamination or addressing more systemic contamination sources and vectors in the system. Oliphant et al. (2002) tested wells over a six month period and found that the *E. coli* and TC concentrations fluctuated significantly over this time period, naturally moving above and below the maximum allowable concentration. Edberg et al. (2000) stated that annual testing does not provide nearly enough granularity to address intermittent contamination events and more frequent testing or other alternatives are required to identify these contamination events. One such alternative is the use of monitoring well networks that can provide representative samples for an entire area while only collecting samples from a certain number of representative wells within that area. This has been demonstrated by Grieef and Hayashi (2007) at West Nose Creek near Calgary. Conboy and Goss (2001) identified that current practices can give an indication of fecal contamination in a well but do not provide a timeline of contamination nor a source of contamination if there are multiple sources in effect. These limitations decrease the available responses and as a result wells are shock chlorinated by default even if this does not address the specific problem (eg. Surface water infiltration through a nearby, improperly abandoned well).

Regardless of what type of monitoring and treatment system is implemented, the Bonn Charter for Safe Drinking Water (International Water Association, 2004) identifies many key points that a drinking water system should fulfil. As stated within the Bonn Charter, “(s)ystems established should be transparent. The provision of safe drinking water demands the participation of all stakeholders.” These terms require clear and timely communication of drinking water quality information from those agencies performing the monitoring to the homeowners and consumers of the water being produced.

2.3 Rural Well Drinking Water Quality Monitoring

Drinking water quality in Samson Cree Nation in monitored by staff at Maskwacîs Health Services. The focus of this project is on the rural private drinking water wells in Samson Cree Nation and the following discussion does not cover the monitoring practices for the townsite which is serviced by a water treatment plant and piped distribution network. TC and *E. coli s*amples are typically collected once a year from houses utilizing private groundwater wells. The flow chart in Figure 2-1 outlines the process by which sample results are screened and BWAs are implemented. If a water sample tests positive for TC or *E. coli,* a second sample is collected. If the second sample tests positive, the home is placed under BWA implementation and is shock chlorinated to treat the bacterial contamination. The time between BWA implementation and well shock chlorination varies depending on the capacity of the Samson Trade Center and Maskwacîs Health Services to perform shock chlorinations. Once the shock chlorination is completed, the well water is sampled again and must test negative for TC and *E. coli* twice consecutively before it is taken off of BWA. In cases when repeated shock chlorinations do not treat the bacteriological contamination and tests continue showing the presence of bacteria, the Environmental Health Officer at Maskwacîs Health Services will perform further investigation to determine the source of the contamination and remedy the issue.

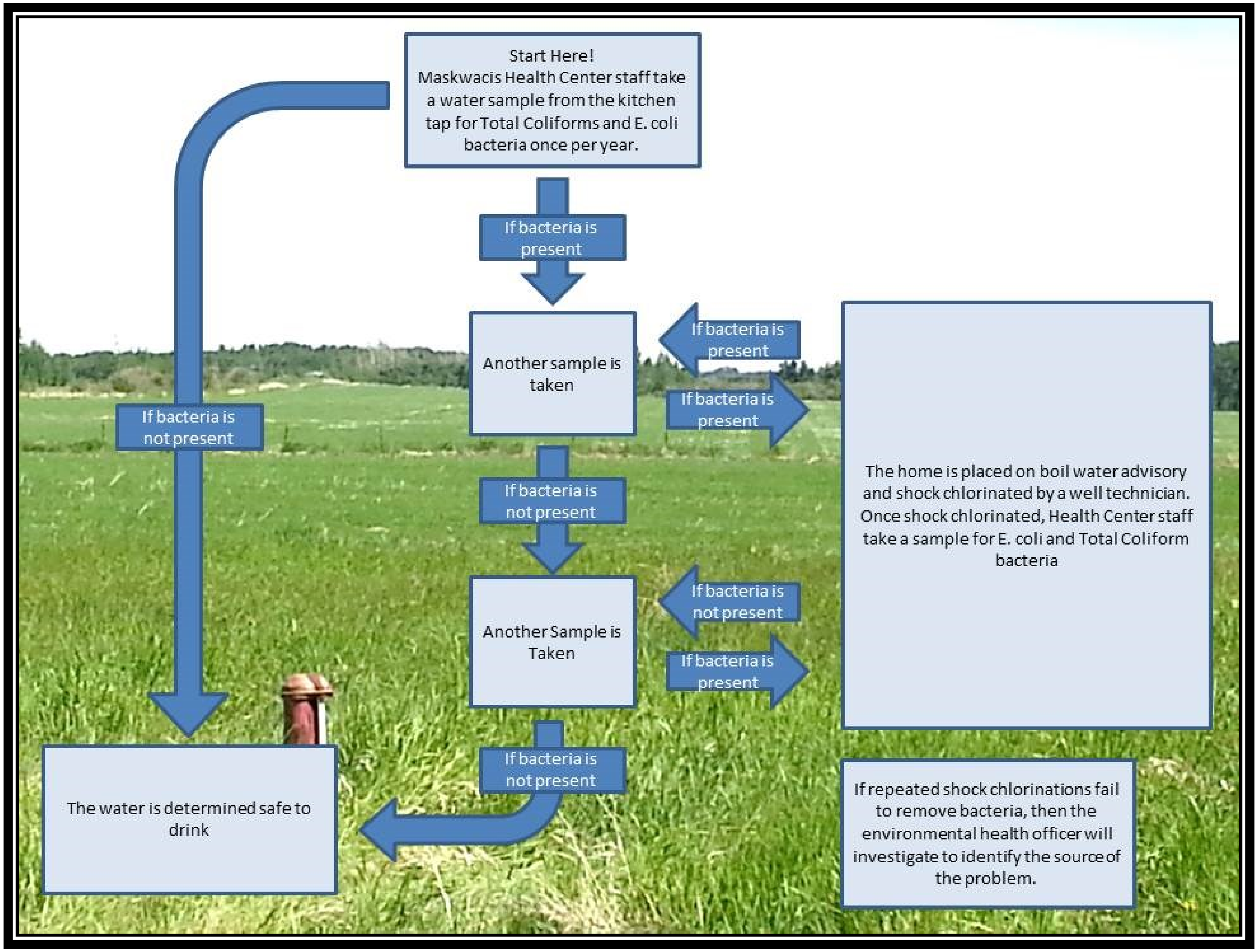

Figure 2-1: Flow chart of drinking water monitoring and disinfection for rural private drinking water wells in Samson Cree Nation

2.3.1 Actors and Roles

This section outlines the roles and responsibilities held by individuals and entities involved in the water quality monitoring system in Samson Cree Nation. The following is based on a combination of official protocols and documents as well as conversations and observations from my time spent collecting water samples and living in Samson Cree Nation. The roles and responsibilities described here are my attempt to describe how the system actually operates as opposed to how it is supposed to operate.

Homeowners

Homeowners are expected to protect the area around their wellhead from vehicles and animals, in addition to performing inspections and preventative maintenance to protect their water and wastewater systems from damage. Homeowners can contact Maskwacîs Health Services if they have concerns over their water quality or the Samson Trade Center if they are in need of repairs or services. As the primary user of the drinking water systems, it is important that homeowners are informed of their water quality and have ready access to information regarding maintenance practices and other information relating to water quality.

Samson Cree Nation Chief and Council Members

Individual Band Council members are sometimes approached with requests from Samson Cree Nation members to receive renovations or remedies for ongoing problems with their homes and water and wastewater systems. In addition, some Council members sit on the committees responsible for housing and public works who are responsible for allocating funding to different programs and projects for community development. These committees review reports on infrastructure and development projects and contribute to the development of policy within Samson Cree Nation.

Samson Cree Nation Administration Staff

The various band office departments that relate to water include housing/trades, community and capital planning, public works, and water/waste management. The directors of each department are responsible for allocating resources, reporting to Chief and Council on the activities of their department, and managing staffing allocations.

Health Canada

Health Canada and Maskwacîs Health Services are the primary agencies responsible for collecting water samples from homes in Samson Cree Nation and managing water quality data for the Nation. The First Nations, Inuit Health Branch of Health Canada in Edmonton manages the water quality data for Samson

Cree Nation and provides information as required or requested from the band administration. Health Canada funds the water quality monitoring work performed and many other health programs for Samson Cree Nation as part of their fulfilment of the "Medicine Chest Clause" in Treaty 6, which is understood by Indigenous peoples and the Canadian judiciary to include the provision of health care and health service delivery (Catellier, 1877).

Maskwacîs Health Services

Community Based Water Monitors (CBWM) based at the Maskwacîs Health Services are responsible for collecting water samples and informing homeowners when they are under BWA or should be aware of other concerns. CBWMs are responsible for communicating how the monitoring system works to homeowners and how they will know if there water is contaminated or not. CBWMs typically sample a particular region at a time within the reserve and try to go house by house but sometimes are assigned to perform follow up samples on houses which have recently been shock chlorinated or require a second sample after the initial sample showed presence of *E. coli* or TC. There is also an Environmental Health Officer (EHO) based at the Maskwacîs Health Center who is responsible for the four Nations of Maskwacîs. The EHO is responsible for investigating and addressing more systemic issues within individual drinking water issues, particularly when there is recurring contamination occurring despite multiple shock chlorinations.

In addition to the monitoring staff, Maskwacîs Health Services employs a well technician who performs shock chlorinations on wells on BWA across the Four Nations. Maskwacîs Health Services is able to provide support to any of the Maskwacîs Four Nations if they experience a high number of BWAs at a time.

Aboriginal Affairs and Northern Development Canada (AANDC)

AANDC provides funding support for infrastructure projects on First Nations in Canada, however funding does not currently meet the demand that exists. This includes water treatment plants and wastewater treatment facilities but does not extend to individual wells on reserve. AANDC also specifies the amount of federal funding that Samson Cree Nation will receive for operations and maintenance of water and wastewater systems through the annual funding agreements signed with Chief and Council.

Engineering Consulting Companies

Samson Cree Nation has retained several engineering consulting companies to undertake studies and projects to improve the availability of safe, reliable drinking water for all nation members. Reports that have been undertaken in the past have included a water needs assessment for the Maskwacîs Four Nations and a comprehensive community plan for Samson Cree Nation. One challenge with these relationships is that the engineering components are often politically motivated or perceived as such despite being purported to be apolitical and concerned primarily with the challenges at hand.

Samson Trade Centre

Trade Centre staff include plumbers and well technicians who are responsible for maintaining the houses and water systems on Samson Cree Nation. The Trade Centre staff often repair damaged plumbing and can also perform services on wells such as shock chlorinations.

Well Drilling Contractors

Contractors employed to drill new wells, drill existing wells to a deeper depth, or otherwise rehabilitate an existing well are typically employed directly by the Nation as opposed to the homeowner, however homeowners are able to engage with contractors of their own volition. Most drilling contractors come from outside of the Nation.

2.4 Conclusion

The current system of drinking water well monitoring in Samson Cree Nation consists of annual *E. coli* and TC sampling by the Maskwacîs Health Center followed by shock chlorination in the event of a BWA. It has been seen that the use of *E. coli* and TC as indicators for human fecal contamination of groundwater does not adequately correlate with the presence of many pathogenic bacteria and viruses that have been known to cause outbreaks of waterborne disease. Testing annually has several limitations in its ability to identify seasonal fluctuations in contamination in addition to identifying the source of contamination, particularly when multiple sources are present. Shock chlorination does not adequately address all potential sources of contamination, particularly recurring contamination sources such as surface water infiltration and biofilms. The water quality monitoring system is composed of many different actors who perform various roles which presents unique interagency challenges in communications, role definition, and emergency response protocols. It is vital that there is clear understanding of each actor’s role and timely communication between parties to ensure that homeowners have reliable access to safe, clean drinking water.

Chapter 3: A Review of Historical Data to Identify Risk Factors for Bacteriological Contamination

3.1 Introduction

Poor drinking water quality in Samson Cree Nation is a recurring concern and various well water testing programs have been undertaken to examine the water quality, integrity of wells, water availability and other factors that can potentially impact the drinking water quality for residents. Additional data is available for Samson Cree Nation including meteorological data and well installation records which can offer insights into the factors that are impacting groundwater quality, specifically in terms of total coliform (TC) and *Escheria coli* (*E. coli*) contamination. This section will compare multiple data sets in order to identify possible sources of bacteriological contamination of drinking water wells in Samson Cree Nation.

3.2 Factors Related to Bacteriological Contamination

There is a large body of research that has aimed to identify correlations between pathogenic contamination of private drinking water wells and a myriad of environmental, chemical, historical, meteorological, geological, and geographical parameters. Private drinking water wells are often regarded as higher risk for pathogenic exposure than other drinking water systems since they typically lack a treatment or disinfection system (Brodsky, 2001). In a review of waterborne illness outbreaks in Canada, Brodsky (2001) found that 53.3% of all incidents involved municipal or private systems utilizing groundwater as the source and 36.7% of all incidents involved private drinking water wells. One significant challenge in reviewing historical water quality data is that it can be difficult to link the various parameters being reviewed with historical medical records (Rose et al., 2001). Often, gastro-intestinal illnesses may be treated but not necessarily tested for the specific source of illness (water-borne, food-borne, etc.) or individuals may not seek medical attention at all leading to incomplete medical records for incidences of water-borne illness.

There has been considerable research into connections between meteorological activity and groundwater quality to understand the hydrogeological connections between surface and groundwater. Surface water infiltration typically occurs very slowly through the soil strata which filters out contaminants and results in relatively pure groundwater (Smith and Conboy, 2005). But surface water can infiltrate more quickly when certain mechanisms are in place such as high permittivity soils, improperly abandoned wells, or high precipitation events (Smith and Conboy, 2005). Improperly abandoned wells occur when a well is no longer being used to draw water but is not properly sealed by filling and sealing the well casing. This can shortcut infiltration through the soil strata leading to untreated surface water entering the groundwater table. Atherholt et al. (1998) found a positive correlation between rainfall events and the concentration of *Giardia lamblia* and *Cryptosporidium* in the Delaware River. This increase was attributed to the increase in particulate matter in the water from runoff and resuspension of river sediments. Weniger et al. (1983) identified a positive correlation between incidences of giardiasis in Montana and heavy rainfall events. A lag of approximately 3 weeks was observed between the rainfall event and the giardiasis outbreak for these systems, all of which utilized surface water for their source. Drayna et al. (2010) reviewed meteorological and hospital data for major metropolitan areas in the United States from 2002-2007 and found a statistically significant link between rainfall events and an 11% increase in pediatric acute gastrointestinal illness with a lag period of four days between the two events. These systems included both groundwater and surface water sources. Curriero et al. (2001) examined the link between extreme precipitation events and outbreaks of waterborne illness in 548 different cases in the United States. These outbreaks included systems with both surface water and groundwater sources. They found that 51% of the outbreaks were preceded by a precipitation event in the 90th percentile of rainfall intensity events and 68% of the outbreaks were preceded by an event in the 80th percentile. For groundwater sources, they observed a lag period of approximately 2 months between the peak of the precipitation event and the peak in the outbreak of disease (Curriero et al., 2001). Naumova et al. (2005) further identified a positive correlation between incidences of cryptosporidiosis and precipitation events in Northwest England. Arnade (1999) found that the concentration of fecal coliforms in drinking water wells in Florida nearly doubled during the wet season compared to the concentration in the dry season. Simpkins et al. (2012) performed a detailed assessment of groundwater activity following a 500-year flooding event in Ames, Iowa. In this case, it was found that the rapidly infiltrating flood water did not significantly mix with the existing groundwater aquifer and instead “sat on top” of the old groundwater, pushing it lower. As a result, the flooding event did not pose a risk for deep drinking water wells that tapped into the lower groundwater; however, shallower wells drawing from the “newer” layer of surface water infiltration would be susceptible to contamination. These findings relating precipitation events and groundwater contamination are particularly significant in light of the current climate change projections which anticipate an increase in the frequency and unpredictability of extreme precipitation events (IPCC, 2014). Public health professionals and water plant operators will need to update their current practices to be able to predict and respond better to these heavy precipitation events.

Well characteristics have also been examined in several previous studies, with a focus on features such as installation method, materials used, well depth, and well age. Murphy (1992) surveyed 343 different groundwater wells in New Jersey for nitrates concentrations and found an inverse correlation between concentration and depth - wells deeper than 30 meters (98 feet) had a significantly lower nitrate concentration. Ervin and Lusch (1992) further examined the nitrate concentration – well depth relationship and found that in addition to having lower concentrations of nitrate, deeper wells also had more stable seasonal nitrate concentrations. Shallow wells were found to have a seasonal nitrate concentration flux as high as 300% (Ervin and Lusch, 1992). Sievers and Fulhage (1992) sampled 226 wells in Missouri and found that the strongest indicator of nitrate concentration was the well depth, with lower nitrate concentrations in deeper wells. They also identified well age as an influencing factor, but as less important than well depth. In addition to the studies that have looked at nitrate concentrations, several other studies have focused more specifically on TC and other microorganisms. Gonzales (2008) sampled 30 private drinking water wells and found that deeper, better maintained wells had lower TC concentrations in the well water. 71% of wells less than 199 feet deep tested positive for TC compared to 9.5% of samples below 200 feet. Wallrabenstein et al. (1994) set the minimum depth between 50 – 100 feet reporting that 12.2% of the wells they sampled shallower than 50 feet tested positive for TC compared to only 0.9% of wells deeper than 100 feet. Based on the variability in a "safe depth" for these different studies, it can be said that the depth varies between different areas and may be dependent on soil structure, local climate, concentration of bacteria in an area or other factors. In a study of a variety of different environmental factors in Pennsylvania, Zimmerman et al. (2001) found an inverse correlation between aquifer depth and TC concentration in areas underlain by carbonate bedrock, but a positive correlation between aquifer depth and TC concentration in areas underlain by noncarbonated bedrock. Conboy and Goss (2010) further found that the soil stratigraphy is a significant determining factor in the contamination of groundwater by fecal bacteria. They found that wells installed in older limestone or dolostone bedrock, and clay or clay loam soils were more vulnerable to chronic bacterial contamination. Sandy soil, shale, and hardpan layers were found to offer some protection to groundwater quality. In contrast to all of the aforementioned studies, Won et al. (2013) did not find a statistically significant correlation between the age or depth of a well and the presence or absence of TC or *E. coli*.

Land use has also been shown to have a significant impact on the risk of contamination from microbial pathogens and chemical contaminants. Ramirez et al. (2009) studied the relationship between agricultural land uses and surface water infiltration, specifically finding that tilled soils were significantly less permeable than non-tilled soils to the infiltration of cryptosporidium oocysts from the application of cow manure under laboratory conditions. Warnemuende, et al. (2007) also found that no-till soils allowed greater infiltration of herbicides than tilled soils. Conboy and Goss (2010) did not find a correlation between tilling practices and groundwater contamination but did observe that wells in areas where manure spreading occurred daily were highly susceptible to bacterial groundwater contamination.

In rural areas with higher household density, the close proximity of septic tanks and drinking water wells can cause drinking water 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. The United States Environmental Protection Agency states that a septic system density of greater than 40 systems per square mile poses a risk of groundwater contamination (Yates, 2006). Wilcox et al. (2010) applied the use of standard groundwater modeling software to identify the impacts of two high-density rural developments where each house was on a separate septic system and drinking water well. The modelling indicated that the drinking water wells would need to be drilled to a deeper depth than would be required in lower-density rural areas in order to ensure access to clean drinking water. Alternatively, the homes could be connected to one centralized well located in an area protected from the septic systems and other threats. Wilcox et al. (2010) further recommended that local authorities and developers work with hydrogeologists when developing rural, high-density communities to ensure that septic systems do not negatively affect the drinking water quality. Arnade (1999) identified an inverse correlation between the distance between the septic tank and the wellhead and fecal coliform, nitrate, and phosphate concentrations. Scandura and Sobsey (1997) further found an inverse correlation between the distance between the septic effluent discharge and the wellhead with the concentration of enterovirus released into the septic system. First Nations populations are the fastest growing of all demographics in Canada (Stats Canada, 2006) and the population density of Samson Cree Nation will continue to rise which will present challenges as more and more individual septic and drinking water systems are located increasingly close to one another.

3.3 Methodology

3.3.1 Water Quality Data Reviewed

An analysis of historical data was undertaken to identify correlations between measurable parameters that may influence water quality. The specific data for Samson Cree Nation available for analysis included:

- Health Canada's historical water quality sampling data from 2006-2012 for TC and *E. coli*. The TC and *E. coli* tests were performed at the Alberta Provincial Laboratory for Public Health in Edmonton.
- Health Canada's historical water quality sampling data from 2002-2003 for assorted chemical and physical parameters. The chemical parameters included total and phenolphthalein alkalinity (as $CaCO_3$), hardness, bicarbonate, carbonate, chloride, fluoride, hydroxide, nitrate, nitrite, sulfate, aluminum, arsenic, barium, boron, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, potassium, selenium, sodium, uranium, zinc, colour, conductivity, ion balance, pH, temperature, total dissolved solids, and turbidity. The chemical testing was performed by ALS Environmental Labs in Edmonton.
- Health Canada's boil water advisory records for Samson Cree Nation from 2006 – 2012.
- Health Canada's inventory of houses and private wells operating within Samson Cree Nation as updated to March 2012.
- Well installation records from the Alberta Environment and Sustainable Resource Development department's Alberta Water Well Information Database (AESRD, 1995-2014).
- Precipitation records from Environment Canada's National Climate Data and Information Archive as measured at Red Deer, Alberta, approximately 75 km from Samson Cree Nation (Environment Canada, 2013).
- Instream flow measurements of the Battle River from Environment Canada's Water Survey of Canada Hydrometric Data as measured at Ponoka, Alberta, approximately 20 km from Samson Cree Nation (Environment Canada, 2010).
- Data from a rural well inventory performed by Health Canada in 1999 to assess the proximity of well heads to septic systems. In addition, information was collected on the proximity of the septic system and the house, the number of residents in the house, the frequency of septic system backups, and several other criteria.

FIGURE 3-1: REVIEWING HISTORICAL ENGINEERING REPORTS AND WATER QUALITY ANALYSIS RECORDS HELD IN SAMSON CREE NATION BAND ADMINISTRATION ARCHIVES

In addition to these various databases of sampling data, I reviewed old engineering and regulatory reports in Samson Cree Nation's archives at the main band office in Maskwacîs. These reports ranged from 1990 – 2011 and included items such as Health Canada sampling activities, engineering inspection reports, feasibility studies for water system upgrades, long-term water supply studies, and risk assessments of the Samson Cree Nation water treatment facility. The Health Canada sampling reports dealt almost exclusively with exceedances in concentrations of water quality parameters above the Guidelines for Canadian Drinking Water Quality in the groundwater supply for the drinking water treatment plant and distribution system (FPT Committee on Drinking Water, 2010). The parameters identified as exceeding the Drinking Water Quality Guidelines over this time period include:

- pH
- Total dissolved solids
- Fluoride

- Sodium
- Total alkalinity
- Iron
- Manganese
- Hardness
- Sulphate
- Total trihalomethanes

It is expected that these compounds may have exceedances in the private drinking water well samples as well, with the exception of trihalomethanes which are disinfection byproducts that result from the use of excess chlorine in the disinfection process. Since none of the private wells utilize chlorine disinfection on an ongoing basis, trihalomethane is not expected to be a recurrent problem. However, the shock chlorination of problem wells may present problems with trihalomethane contamination.

3.3.2 Bacteriological Contamination Categories

To determine the relationship between various environmental factors and TC/*E. coli* contamination, it was first necessary to develop contamination categories for characterization of the wells in Samson Cree Nation. In the context of this project, the primary concern is pathogenic contamination, for which TC and *E. coli* monitoring is undertaken by the Maskwacîs Health Center in partnership with Health Canada's First Nations and Inuit Health Branch. This data is collected and aggregated by Health Canada to evaluate exceedances and recommend boil water advisories to households. By Health Canada's recommended practices, water quality tests are performed once each year on each well on reserve, or by 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 a year and ensure their water is tested two or three times per year for bacteriological parameters (Health Canada, 2010).

The frequency of testing varies widely between households in Samson Cree Nation, from houses where nine samples are collected per year to houses with no reported testing within the data set available. In the cases where bacteria presence is suspected, multiple samples are collected to confirm the presence or absence. The high variability in sampling frequency meant that establishing a continuous spectrum of the degree of contamination was not possible. Instead, categories were used to define the degree of contamination for each well - specifically "systemic contamination", "acute contamination" and "never contaminated".

Systemic contamination refers to any well with more than one consecutive contaminated sample obtained at a time interval greater than 24 hours apart. This is the criteria for putting a boil water advisory into place by Health Canada, and is the most severe category of bacteriological contamination. In this study, houses that currently have a boil water advisory in place and that historically have had a boil water advisory were placed in this category. Once a boil water advisory is implemented, the well is shock chlorinated and if two consecutive samples come back as uncontaminated, then the boil water advisory is lifted. Because no action is taken to identify and remediate the source of contamination and the transport mechanism by which the water is becoming contaminated, it is assumed that the well is still susceptible to future contamination.

Acute contamination refers to any well that has had a water sample register TC or *E. coli* contamination, but no two consecutive contaminated samples. As such, a boil water advisory has never been placed on the household despite the water having been contaminated under specific circumstances. Since there is a source of contamination and a transport mechanism to the aquifer, future contamination is possible. A finding of acute contamination can also indicate poor sampling technique or other sources of cross-contamination that lead to a false positive sample occurring.

Never contaminated refers to any well that has never had a water sample test positive for TC or *E. coli*. This categorization may be misleading for households that have a very limited number of samples available – for example, some homes have only 2 recorded samples over 5 years. Given the seasonal variation that can occur in water quality throughout the year, wells with low sample counts over the 5-year period may not give an accurate indication of overall well water quality during that time. For the purposes of this analysis, wells that have never tested positive for TC or *E. coli* are believed to be of lower risk than wells categorized as systemically contaminated or acutely contaminated. This categorization methodology can be improved through a more rigorous data record of all wells.

Never sampled wells are those without any TC or *E. coli* sampling records available over the period assessed. In speaking with Health Canada staff and Community Based Water Monitors, there are several reasons why a house may not have been sampled: the house has been destroyed, the house has been abandoned, the homeowner has told the Maskwacîs Health Center that they do not wish to have their water sampled, or the house is deemed unsafe for water monitoring staff to visit.

3.4 Results and Discussion

Figure 3-2 shows the proportion of wells in Samson Cree Nation that are in each of these four contamination categories. More than half the wells (55%) are categorized as never contaminated but 23% of the wells have experienced a boil water advisory at some point between 2006 and 2012. 10% of the wells have never been sampled. The never sampled wells merit further investigation to understand how they fit into the overall water monitoring strategy across Samson Cree Nation.

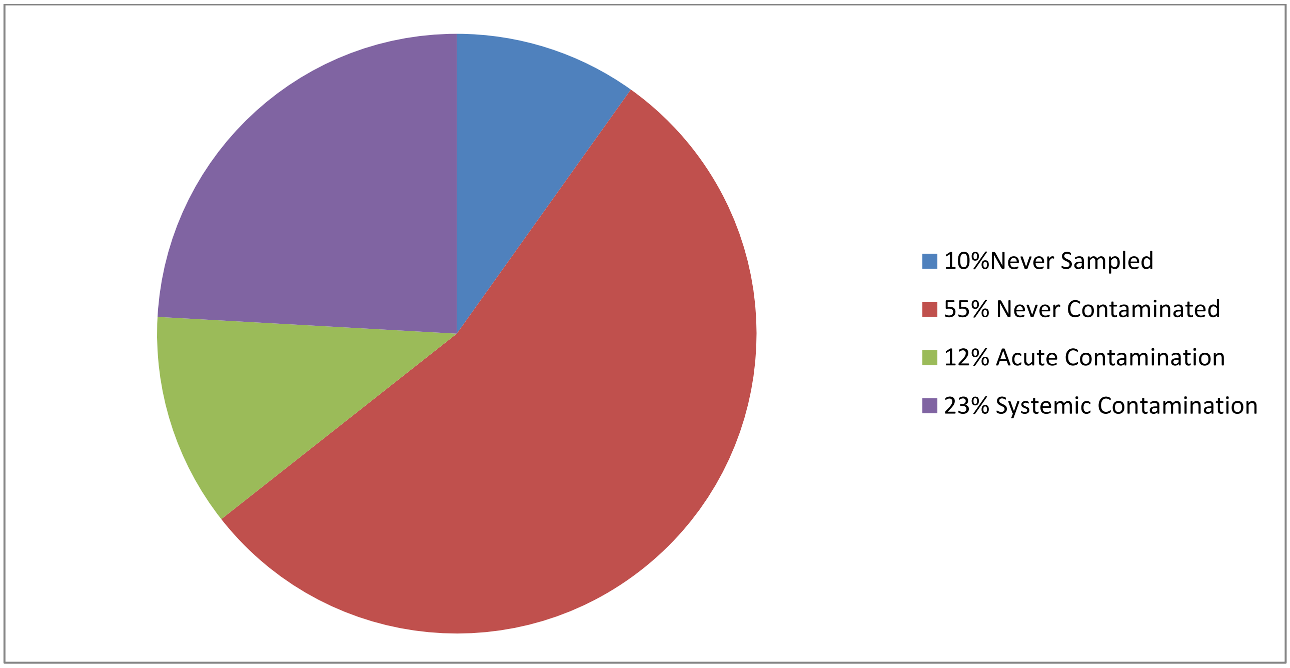

FIGURE 3-2: PROPORTION OF WELLS IN SAMSON CREE NATION CHARACTERIZED INTO FOUR DIFFERENT CONTAMINATION CATEGORIES BASED ON HEALTH CANADA WELL WATER SAMPLING FOR TC AND E. COLI FROM 2006 – 2012. THE NUMBER OF WELLS IN EACH CONTAMINATION CATEGORY ARE AS FOLLOWS: 72 NEVER SAMPLED, 398 NEVER CONTAMINATED, 84 ACUTE CONTAMINATION, 176 SYSTEMIC CONTAMINATION.

3.4.1 Historic Chemical Data

In 2002-03, chemical water testing was completed for 646 of the 730 private wells in Samson Cree Nation. This data is the most recent chemical sampling data available for Samson Cree Nation despite Health Canada documents recommending that each house be sampled for a full suite of chemical parameters once every five years (Health Canada, 2007). The testing included those parameters listed in Table 3-1. The sample concentrations were separated into different categories based on the bacteriological contamination categories described above and an analysis of variation (ANOVA) was performed to identify any statistical trends in the concentration of the parameters in each category.

Table 3-1: Analysis of Variation (ANOVA) for chemical and physical parameters of groundwater from private drinking water wells in Samson Cree Nation. NA indicates that the majority of the samples were below the detection limit.

Analyte	Units	Bacteriological Contamination Category						BtwnMS> WithinMS?*	Trend between categories?	P-Value <0.10**
		Never Contaminated		Acute Contamination		Systemic Contamination				
		Average	Variance	Average	Variance	Average	Variance			
Alkalinity (Total)	mg/L	569.04	5958.84	539.68	4089.06	573.60	8464.09	Yes	No	Yes
Alkalinity (Phenolphtalein)	mg/L	21.04	324.95	23.84	370.92	23.69	347.94	No	No	No
Hardness	mg/L	50.50	8968.64	19.35	555.52	60.63	12788.89	Yes	No	No
Bicarbonate	mg/L	647.42	11759.36	605.11	10010.21	645.92	13881.09	Yes	No	No
Carbonate	mg/L	25.27	466.57	28.57	528.64	28.37	498.75	No	No	No
Chloride	mg/L	25.52	326.52	34.32	427.41	26.48	279.41	Yes	No	Yes
Fluoride	mg/L	1.20	0.97	1.61	1.05	1.41	0.98	Yes	No	Yes
Hydroxide	mg/L	<5***						NA	NA	NA
Nitrate	mg/L	<0.1***						NA	NA	NA
Nitrate + Nitrite	mg/L	<0.2***						NA	NA	NA
Nitrite	mg/L	<0.05***						NA	NA	NA
Sulfate	mg/L	153.56	39389.57	83.19	23653.14	122.15	31740.09	Yes	No	No
Aluminum	mg/L	0.0107	0.0003	0.0088	0.0001	0.0154	0.0009	Yes	No	No
Arsenic	mg/L	0.000957	0.000003	0.001454	0.000005	0.000877	0.000003	Yes	No	No
Barium	mg/L	0.0454	0.0013	0.0406	0.0005	0.0579	0.0017	Yes	No	Yes
Boron	mg/L	0.40	0.02	0.41	0.02	0.41	0.02	No	No	No
Cadmium	mg/L	<0.00001***						NA	NA	NA
Calcium	mg/L	14.73	641.54	6.12	45.61	16.04	700.82	Yes	No	No
Chromium	mg/L	0.00321	0.00002	0.00393	0.00003	0.00445	0.00003	Yes	Yes	No
Copper	mg/L	0.01	0.00	0.01	0.00	0.00	0.00	No	Yes	No
Iron	mg/L	0.68	3.03	0.88	6.88	1.03	23.91	No	Yes	No
Lead	mg/L	0.000861	0.000007	0.001027	0.000001	0.001185	0.000008	No	Yes	No
Magnesium	mg/L	3.34	65.12	0.98	2.89	4.73	142.86	Yes	No	No
Manganese	mg/L	0.08	0.05	0.04	0.00	0.05	0.01	Yes	No	No

Mercury	mg/L	<0.0001***						NA	NA	NA
Potassium	mg/L	2.17	28.14	1.64	6.83	1.48	2.61	No	Yes	No
Selenium	mg/L	<0.0002***						NA	NA	NA
Sodium	mg/L	329.00	8158.29	303.19	4483.49	310.30	7104.96	Yes	No	No
Uranium	mg/L	<0.0005***						NA	NA	NA
Zinc	mg/L	0.18	0.39	0.07	0.02	0.23	0.46	No	No	No
Color	ACU	13.21	125.12	11.81	125.77	12.42	82.13	No	No	No
Conductivity	mS/cm	1352.84	142821	1208.65	73789.79	1327.17	106488.5	Yes	No	Yes
Ion Balance	%	100.16	23.43	100.86	26.23	99.46	29.63	No	No	No
pH	unitless	8.34	0.09	8.36	0.08	8.31	0.12	No	No	No
Temperature	^{o}C	23.89	7.01	23.33	8.24	22.73	9.58	Yes	Yes	Yes
TDS	mg/L	869.71	79874.06	752.70	44719.10	825.15	60236.52	Yes	No	Yes
Turbidity	NTU	8.83	1170.26	3.46	32.82	12.28	1747.48	No	No	No

*Mean square (MS) between categories must be greater than the MS within each category to indicate that the different categories represent unique sample sets, ie. there is a statistical difference between the groups.

**A P-value of 0.05 is a more typical statistical threshold value but given the highly variable nature of this experimental data a threshold of 0.1 was selected to allow for a wider range of analysis.

***These parameters were below the detection limit for all or the vast majority of the samples collected and the ANOVA could therefore not be completed for that parameter. The detection limit is the value listed.

The majority of the samples collected were below the experimental detection limit for cadmium, hydroxide, mercury, nitrate, nitrite, selenium, and uranium. For the other water quality parameters, the following criteria were used to evaluate a potential relationship between contamination category and chemical parameters: a mean square of the variance between groups greater than the mean square within groups, an increasing or decreasing trend from never contaminated to acute contamination to systemic contamination, and a P-value of the ANOVA analysis less than 0.1. A key assumption in the analysis is that there will be a consistent increase or decrease in the numerical value of chemical and physical parameters between never contaminated, acute contamination and systemic contamination if the parameter being evaluated is linked to the TC or *E. coli* contamination of the well. However, the only parameter for which these three criteria were observed was temperature with higher temperatures observed in wells that have never been contaminated and lower temperatures observed in wells categorized as systemically contaminated. Page et al. (2012) and Bonton et al. (2010) did not find a significant link between groundwater temperature and other chemical and biological water quality parameters in rural groundwater wells.

In addition to the ANOVA between bacteriological contamination categories, the concentrations of each parameter were compared to the Federal-Provincial-Territorial Committee on Drinking Water (2010) Canadian Guidelines for Drinking Water Quality. The Guidelines are divided into maximum allowable concentrations (MAC) which must not be exceeded to protect human health, and aesthetic objectives (AO) which must not be exceeded in order to maintain aesthetically-pleasing water quality. Table 3-2 summarizes the parameters for which the MAC or AO is exceeded within this data set in addition to the maximum concentration recorded and the number of wells that exceeded the MAC or AO in the 2002-03 samples. These parameters align with many of those included in the historic reports of the Samson Cree Nation archives. However no archived reports were found for exceedances in arsenic, aluminum, lead, or zinc. The exceedances identified in Table 3-2 are significant and could lead to health consequences for residents who consume water with these sustained concentrations.

TABLE 3-2: CHEMICAL AND PHYSICAL PARAMETERS THAT EXCEED THE CANADIAN GUIDELINES FOR DRINKING WATER QUALITY (2010) MAC OR AO VALUES DURING A WATER SAMPLING PROGRAM COMPLETED IN 2002-03 ON RURAL PRIVATE DRINKING WATER WELLS IN SAMSON CREE NATION

Parameter	MAC/AO (mg/L)	Maximum Sampled Concentration (mg/L)	Number of Exceedances
Arsenic	0.01 (MAC)	0.0117	2
Fluoride	1.5 (MAC)	3.26	103
Lead	0.01 (MAC)	0.0295	3
Aluminum	0.2 (AO)	0.211	1
Iron	0.3 (AO)	35.3	82
Manganese	0.05 (AO)	1.67	64
Sodium	200 (AO)	674	238
Sulfate	500 (AO)	987	16
Total Dissolved Solids	500 (AO)	2067	241
Zinc	5 (AO)	6.75	1

3.4.2 Surface Water Infiltration

Surface water runoff can play a significant role in the level of bacteriological groundwater contamination, especially where old wells have not been abandoned properly or where private well casings have not been sealed properly by the installation contractor. Pathogens in the soil from septic fields, septic "shoot-outs" (damaged or modified septic discharges that result in excess sewage draining overland), manure, or other sources can be picked up by surface water and carried into the groundwater supply. At times during the year when surface runoff is highest, more pathogens will be carried into the groundwater increasing the risk of disease. With a better understanding of the relationship between groundwater contamination and surface runoff, monitoring and treatment policies and practices can be improved to prevent the incidence of disease.

To assess the relationship between well contamination and climatic events, historical data records were accessed for precipitation, as measured at Red Deer, Alberta which is approximately 75 kilometers from Samson Cree Nation, and in-stream river flow in the Battle River as measured at Ponoka, Alberta which is approximately 20 kilometers upstream of the border of Samson Cree Nation. The monthly total precipitation (rain and snow) data and monthly river flow data was averaged for the years of 2006-2012. Since this data is more seasonal in nature and less specific to each individual well, the well contamination categories were not used in this section of analysis. Instead, all of the TC and *E. coli* samples taken for all wells in Samson Cree Nation 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 was then averaged across the 5 years for which data is available.

Figure 3-3 shows the monthly total precipitation data compared to percentage of contaminated samples. A correlation is apparent between the percentage of total coliform hits and total precipitation with a delay of approximately two months between the peak in precipitation and the peak in contaminated samples. The total precipitation peaks from June to August (inclusive) while the total coliforms 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. TC include bacteria that live in the digestive tracts of mammals of which *E. coli* is a subcategory so it follows that the frequency of TC presence would be higher than the frequency of the presence of *E. coli* (Soller et al., 2010). These two bacteria types are used to indicate fecal contamination of the drinking water.

The peak in TC and *E. coli* positive samples from August to October could be the result of several different factors such as:

- The groundwater sources being impacted by surface water contamination as a result of the increased precipitation that occurs from June to August. There is a lag phase that occurs during which the soil becomes saturated and surface water makes its way into the groundwater sources (Curriero et al., 2001);
- Due to the difficulty in locating wellheads during the winter when snow might be covering them, it is hypothesized that shock chlorination of wells under BWA may occur more frequently during the spring and summer months (Oliphant et al., 2002). After a well has been shock chlorinated, health center staff collect water samples and need to have two samples in a row with negative results for TC and *E. coli*. Since the wells being sampled have been under BWA they are categorized as systemically contaminated and are therefore suspected to be more likely to return a positive sample. As a result, wells categorized as systemic contamination will be tested more frequently during the time period when the spike in TC and *E. coli* contamination is seen;

- Seasonal activity could also play a factor since children will be at home more frequently throughout the day during summer months, which could overload the septic system and cause increased incidences of TC or *E. coli* (Postma et al., 1992, Butler and Payne, 1995); and
- Other seasonal environmental factors such as a higher bacterial load in the surface water during August to October (Wilkes et al., 2009).

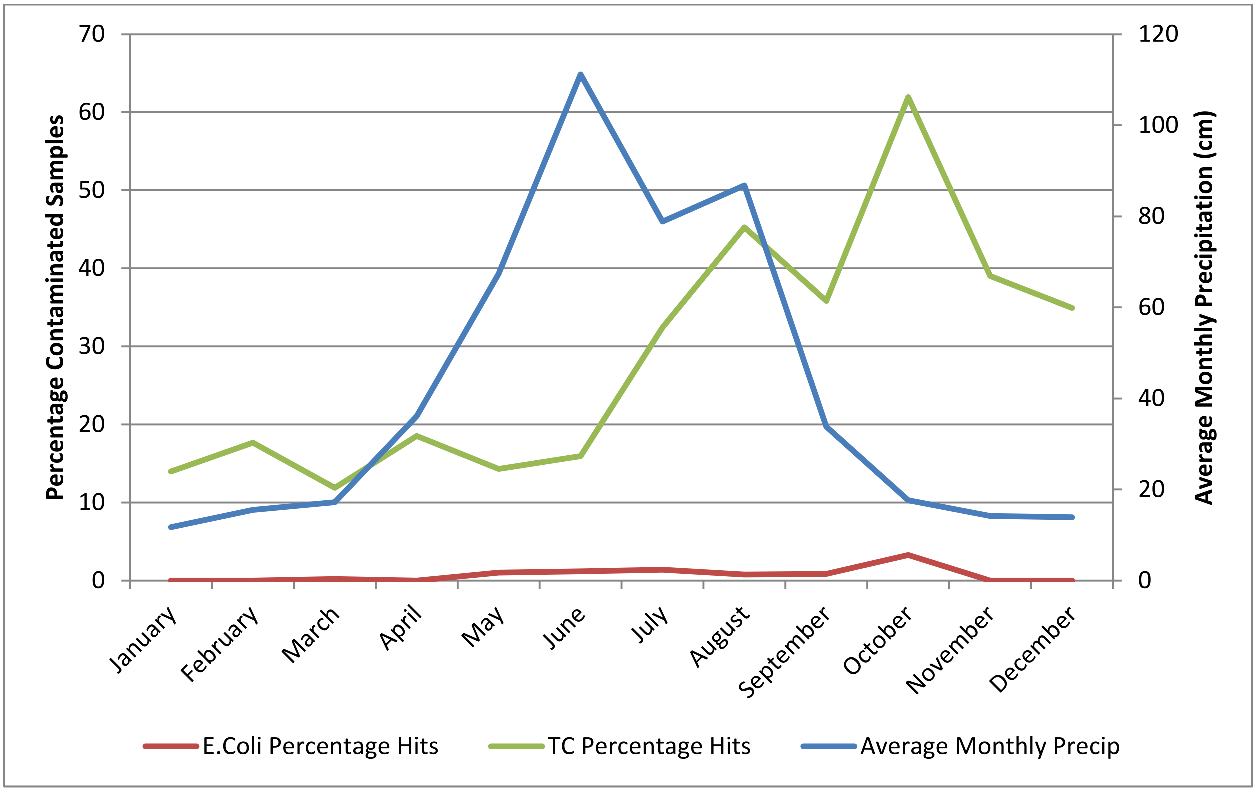

FIGURE 3-3: MONTHLY TOTAL PRECIPITATION DATA AS COLLECTED AT RED DEER, ALBERTA FOR JANUARY, 2006 – MAY, 2012, AND THE PERCENTAGE OF TOTAL TC AND E. COLI SAMPLES COLLECTED THAT RETURNED A POSITIVE TEST RESULT AVERAGED MONTHLY OVER THE SAME PERIOD

The use of total precipitation data is not completely representative of surface water flow since during the winter months, the majority of precipitation is in the form of snow which will largely remain as snowpack until the spring melt. The distance between Red Deer and Samson Cree Nation is enough that the specific precipitation data will have some differences, but since the data are averaged across six years, the general seasonal trend will be similar in both areas.

To produce a more direct correlation between surface water runoff and bacteriological contamination, river flow data for the Battle River were compared with the same data set of the contaminated sample percentages across the same time period. The river flow follows a similar pattern as the precipitation data, although it peaks earlier between April and July. Figure 3-4 below shows the river flow data relative to the contaminated sample frequency for *E. coli* and total coliforms.

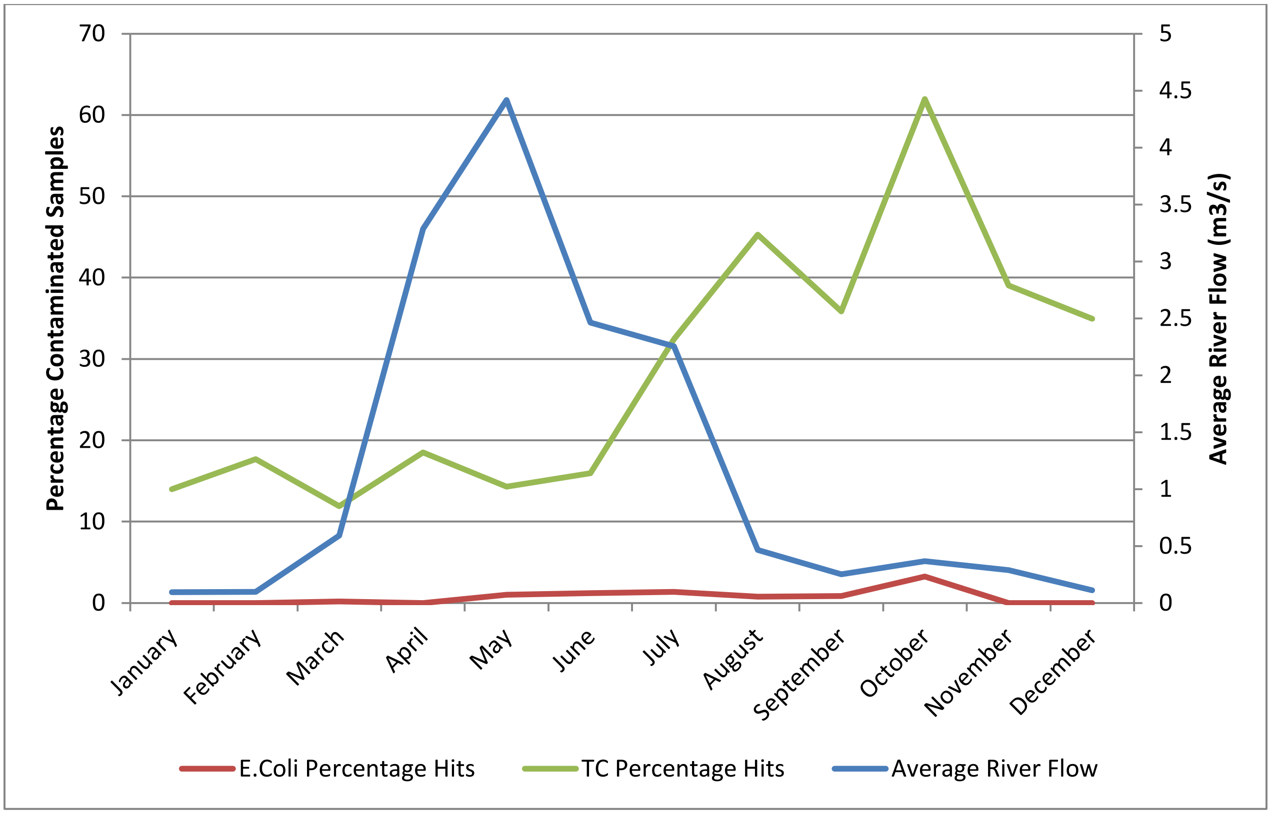

FIGURE 3-4: MONTHLY VOLUMETRIC WATER FLOW FOR THE BATTLE RIVER AS MEASURED AT PONOKA, ALBERTA AVERAGED FOR JANUARY, 2006 – MAY, 2012 AND THE PERCENTAGE OF TOTAL TC AND E. COLI SAMPLES COLLECTED THAT RETURNED A POSITIVE TEST RESULT AVERAGED MONTHLY OVER THE SAME PERIOD

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 lag period is consistent with the findings of Curriero et al. (2001), who suggested that its cause may be the time required for the 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 regularity of the seasonal spike in contamination frequency and the apparent relationship between precipitation and contamination frequency.

3.4.2.1 Soil Infiltration Time

Darcy's law can be used to evaluate the expected infiltration time for the wells in Samson Cree Nation. The resulting value is a highly conservative estimation since Darcy's law assumes completely saturated soil conditions, therefore, the infiltration time will be higher since the soil will not be completely saturated in reality. In addition, soil porosity data is not available so the infiltration rate is approximated as a typical hydraulic conductivity value for the area. Based on the Alberta Environment Well Records (2013), the aquifer overburden in the area is typically comprised of clay till to a depth of approximately 100 feet and a combination of shale and sandstone below that depth. The shallowest well for which installation records could be located was 70 feet deep while the deepest well was 540 feet deep. The majority of wells were completed to a total depth ranging between 200 and 300 feet. For the infiltration from 0-100 feet, a hydraulic conductivity of 10^{-10} m/s was used (Das, 2008) based on the well records indicating this soil to be composed primarily of clay till. Below that depth, a hydraulic conductivity value of 10^{-9} m/s was used for shale and sandstone soils. The infiltration time vs. well depth can be seen in Figure 3-5 below.

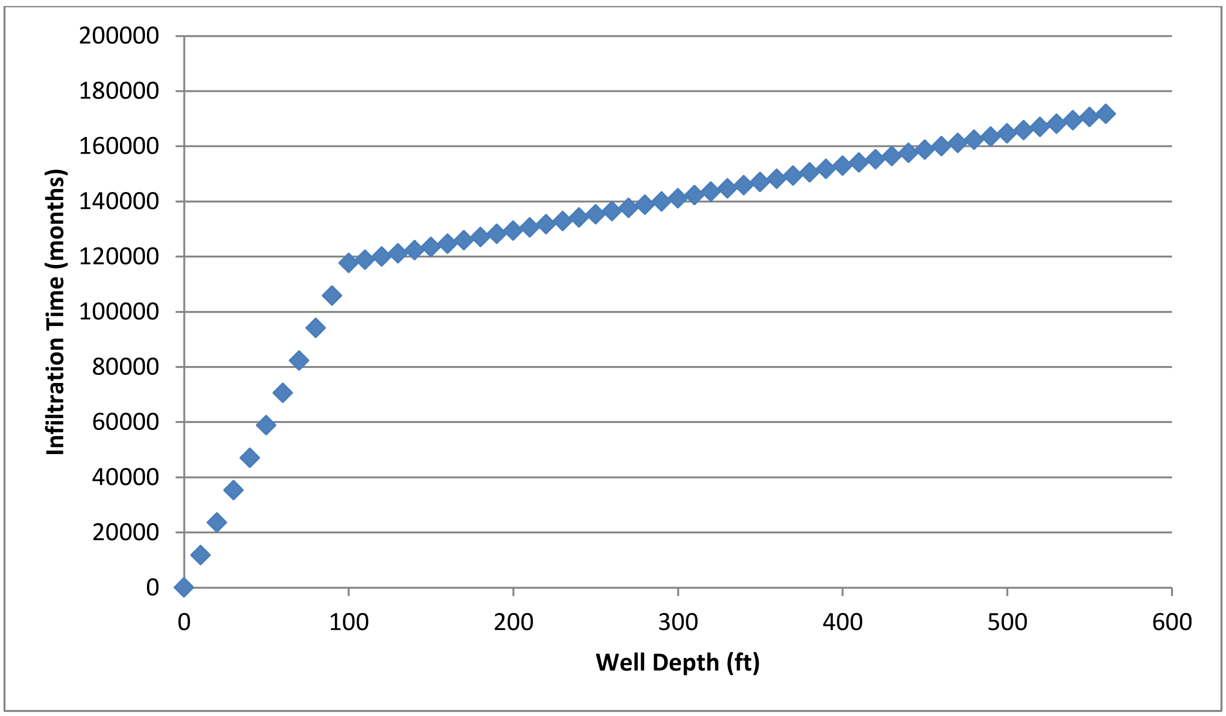

FIGURE 3-5: TIME IN MONTHS FOR SURFACE WATER TO REACH SUBSURFACE DEPTH BASED ON TYPICAL VALUES FOR SOILS DESCRIBED IN WELL INSTALLATION RECORDS

Based on the calculations utilizing hydraulic conductivity, the time required for water to infiltrate from the ground surface to the well depth would range from 6859 years at 70 feet to 14111 years at 540 feet. For the majority of the wells ranging from 200-300 feet in total depth, the infiltration time will range from 10779 years to 11759 years respectively. Clearly, these values are much higher than the anticipated two month lag period seen in Figures 3-3 and 3-4. Additional data is therefore required regarding the soil porosity, permeability, and specific hydraulic conductivity in the soils within Samson Cree Nation to estimate the infiltration time more accurately.

The presence of short-cutting mechanisms may also be relevant when considering contamination pathways. Surface water could come into contact with drinking well water more quickly than through traditional soil infiltration through several mechanisms including infiltration through cracks in well casings, infiltration through improperly abandoned water or gas wells, infiltration into drinking water through distribution system cracks, or more rapid infiltration through cracks and lenses in the soil (Smith and Conboy, 2005).

3.4.3 Well History

Inadequate sealing of a well head or the space between the well wall and the pipe can permit the infiltration of surface water and surficial groundwater into the well's groundwater supply. This infiltrating water has a higher likelihood of containing pathogenic microbial species from septic fields, septic shoot outs, or manure fertilizer. Surface water and shallow groundwater also has better growing conditions for bacteria and other contaminants since there is greater access to organic matter (Balkwill and Ghiorse, 1985). Well-sealing can often be poor due to shoddy or incomplete installation, aging infrastructure, or subsurface movement causing cracking. In addition, the drilling method used, and the casing and sealing materials used, may impact a well's susceptibility to cracking and allow the infiltration of surface water (Zimmerman et al., 2001).

Well installation data were collected from Alberta Environment's online registry (AESRD, 1995-2014) for Samson Cree Nation. Alberta Environment has a large inventory of installation records with many wells listed for Samson Cree Nation, however linking specific wells with installation records was difficult because Health Canada archives and Alberta Environment archives used different ID numbers for the wells. The Alberta Environment well records and Health Canada well list and water sample data both collected the name of the homeowner, but this did not always match in each database since many of the wells were installed decades ago and primary homeowners have changed since that time. The database was searched for matching names where available and the well history information was matched to the corresponding water sampling records from Health Canada. For situations where more than one well was attributed to a 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.

Well records were retrieved for 234 wells out of 730 wells on Samson Cree Nation. Of these wells, 12 were classified as never sampled, 130 were classified as never contaminated, 25 were classified as acutely contaminated, and 67 were classified as systemically contaminated as per the classification descriptions above. The main factors from the well installation records that were examined were the installation date, the depth of completion of the well, and installing contractor. The installation date was used to determine the age of the well. The well completion depth was used to assess the depth at which groundwater is drawn from each well. The installing contractor was used as a proxy for comparing the installation methods and the quality of the well completion and sealing based on the assumption that these factors will be similar across all wells installed by the same contractor.

3.4.3.1 Installation Contractor

There were 12 different drilling contractors employed in Samson Cree Nation in the well records examined, seven of whom installed between one and five wells. The other five contractors installed 17 or more wells. Wells constructed by the seven contractors who installed five or fewer wells were not included in the analysis since insufficient data were available. The wells installed by the remaining five contractors were analyzed to determine the percentage of wells installed by that contractor which fall within each of the contamination categories as shown in Figure 3-6. 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 included in the data set.

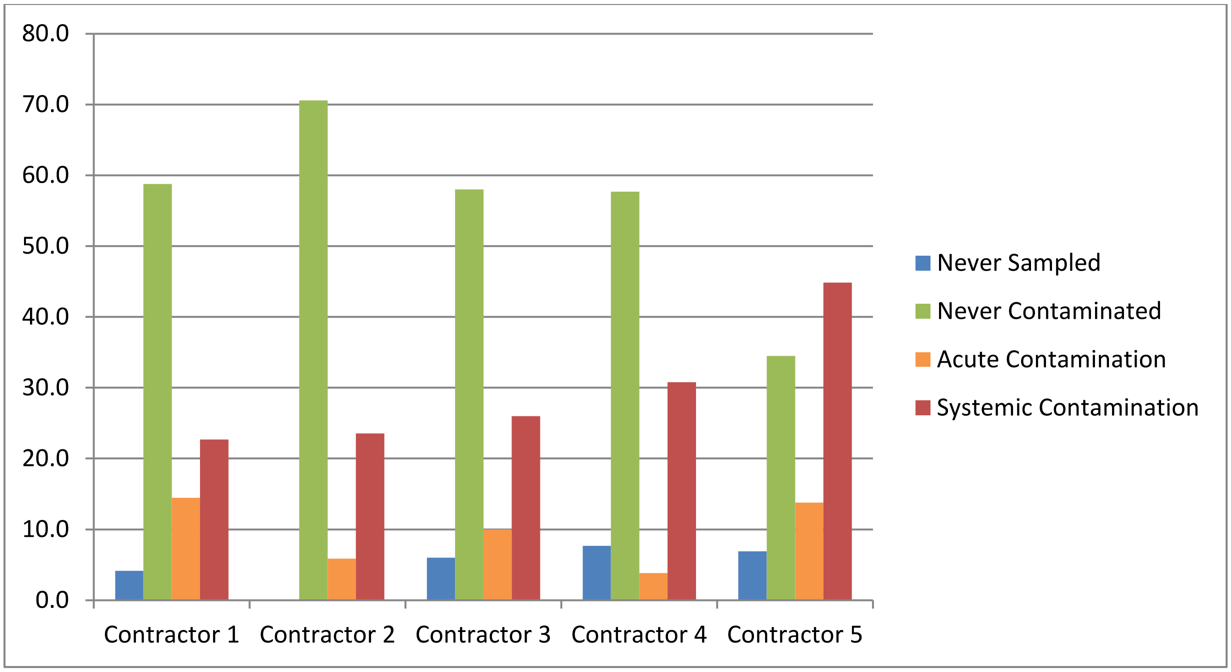

FIGURE 3-6: PERCENTAGE OF WELLS IN EACH BACTERIOLOGICAL CONTAMINATION CATEGORY FOR EACH CONTRACTOR THAT HAS INSTALLED 17 OR MORE WELLS IN SAMSON CREE NATION BASED ON ALBERTA ENVIRONMENT WELL INSTALLATION RECORDS. THE NUMBER OF WELLS INSTALLED BY EACH CONTRACTOR ARE: CONTRACTOR 1 (N=97), CONTRACTOR 2 (N=17), CONTRACTOR 3 (N=50), CONTRACTOR 4 (N=26), AND CONTRACTOR 5 (N=29).

Contractor 5 is the only contractor for whom the percentage of wells categorized as Systemic Contamination exceeds the percentage of wells categorized as Never Contaminated. The ratios of never contaminated to systemic contaminated wells for each contractor respectively are 2.6, 3.0, 2.2, 1.9, and 0.8. The well records did not give information on the specific method utilized by the contactors to install the wells so it is not possible to compare various methods directly. This information was further analyzed in Figure 3-7 to compare the combined relationship between well installation contractor, well depth, and well age. Wells are plotted by age and completion depth and different coloured plot points indicate the five different contractors in Figure 3-6 above. There is a very clear temporal difference between the five different contractors with each contractor installing the majority of their wells at different points in time. Table 3-3 shows the ratio of never contaminated wells to systemically contaminated wells as grouped by contractor in order of most recent to oldest based on the temporal clustering of each contractor's installations.

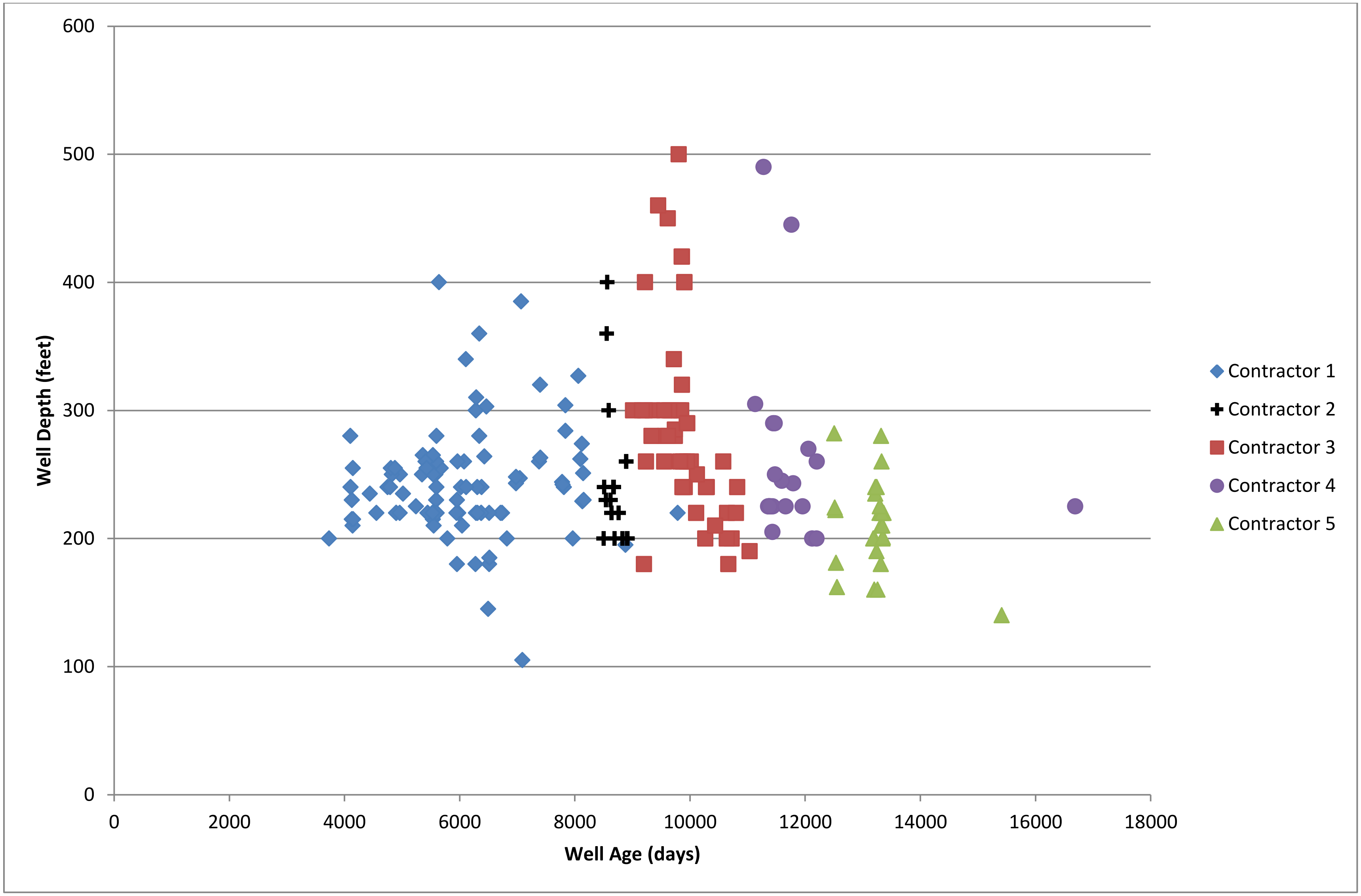

FIGURE 3-7: GROUNDWATER WELLS IN SAMSON CREE NATION PLOTTED BASED ON WELL AGE, DEPTH AND INSTALLATION CONTRACTOR

TABLE 3-3: RATIO OF NEVER CONTAMINATED TO SYSTEMIC CONTAMINATION WELLS BY WELL INSTALLATION CONTRACTOR AS RANKED BY MOST RECENT INSTALLATIONS TO OLDEST INSTALLATION

Contractor #	Ratio of never contaminated to systemic contamination
Contractor 1	2.6
Contractor 2	3.0
Contractor 3	2.2
Contractor 4	1.9
Contractor 5	0.8

It can be seen in Table 3-3 that the wells installed by contractors operating at an earlier point in time have a lower ratio of never contaminated to systemically contaminated wells. In other words, older wells, installed using older installation methods may be at a higher risk of bacterial contamination.

3.4.3.2 Well Age

Installation and completion dates recorded for each well can be used to calculate the age of the well by simply subtracting the installation date from the current date. The installation and completion dates were typically the same date or 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 this represents the date that the well began operating. The age of each well was compared to the contamination category of the well as shown in Figure 3-8 below.

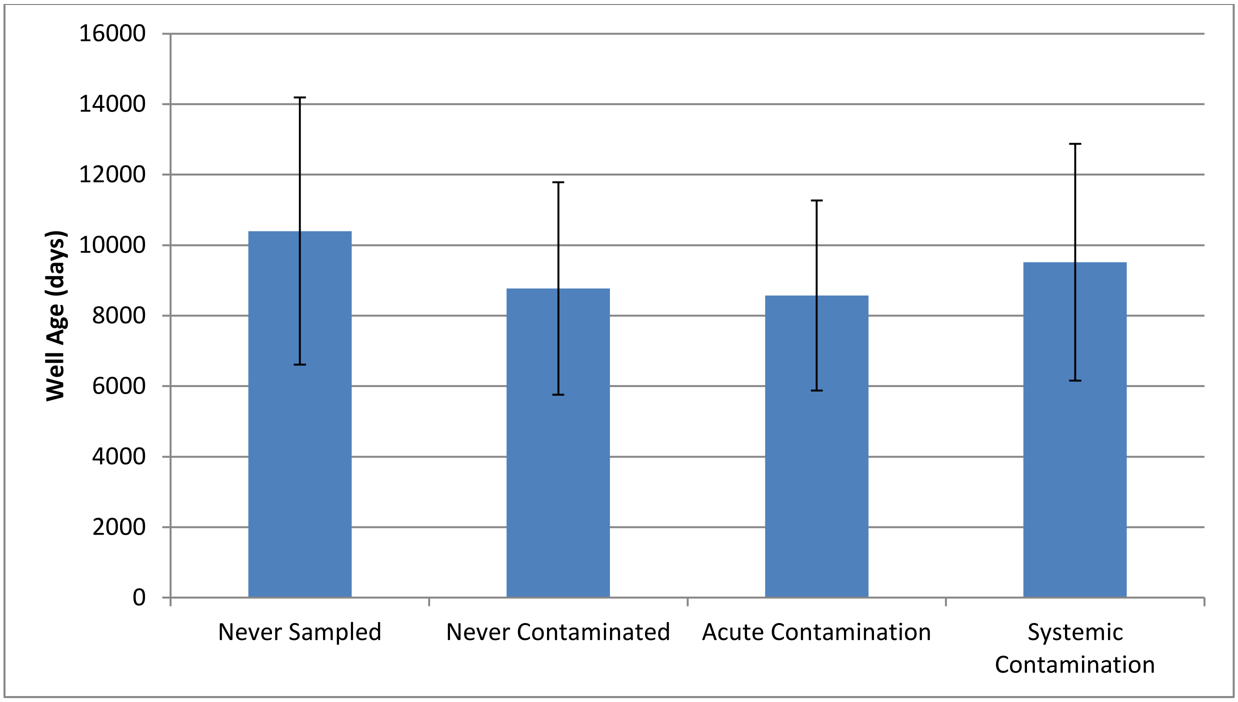

FIGURE 3-8: AVERAGE WELL AGE FOR RURAL GROUNDWATER WELLS IN SAMSON CREE NATION BASED ON BACTERIOLOGICAL CONTAMINATION CATEGORIES. ERROR BARS REPRESENT ONE STANDARD DEVIATION. SAMPLE SIZES: NEVER SAMPLED (N=12), NEVER CONTAMINATED (N=130), ACUTE CONTAMINATION (N=25), SYSTEMIC CONTAMINATION (N=67).

It was found that the wells were installed over a wide range of time with the earliest records from the 1960's and many into the 2000's. When querying the Alberta Environment database, there were often multiple records for a particular name and location indicating that many wells have been replaced or reconditioned. The Never Sampled category showed the oldest average age 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 well age could explain why the wells were never sampled during the period of 2006-2012. The wells could have fallen into disrepair and are no longer used because of their age. These abandoned wells could be integrated into future analysis to determine if proximity to abandoned wells impacts well water quality. Improperly abandoned wells can pose a hazard to groundwater quality in nearby wells since they create a pathway for surface water infiltration (Sievers and Fulhage, 1992).

3.4.3.3 Well Depth

Well depth is perceived as a strong determinant of the quality and security of a groundwater source by Samson Cree Nation members. The conventional wisdom states that deeper wells are less susceptible to contamination from surface water sources. Figure 3-9 below shows the average well depths for the various contamination categories.

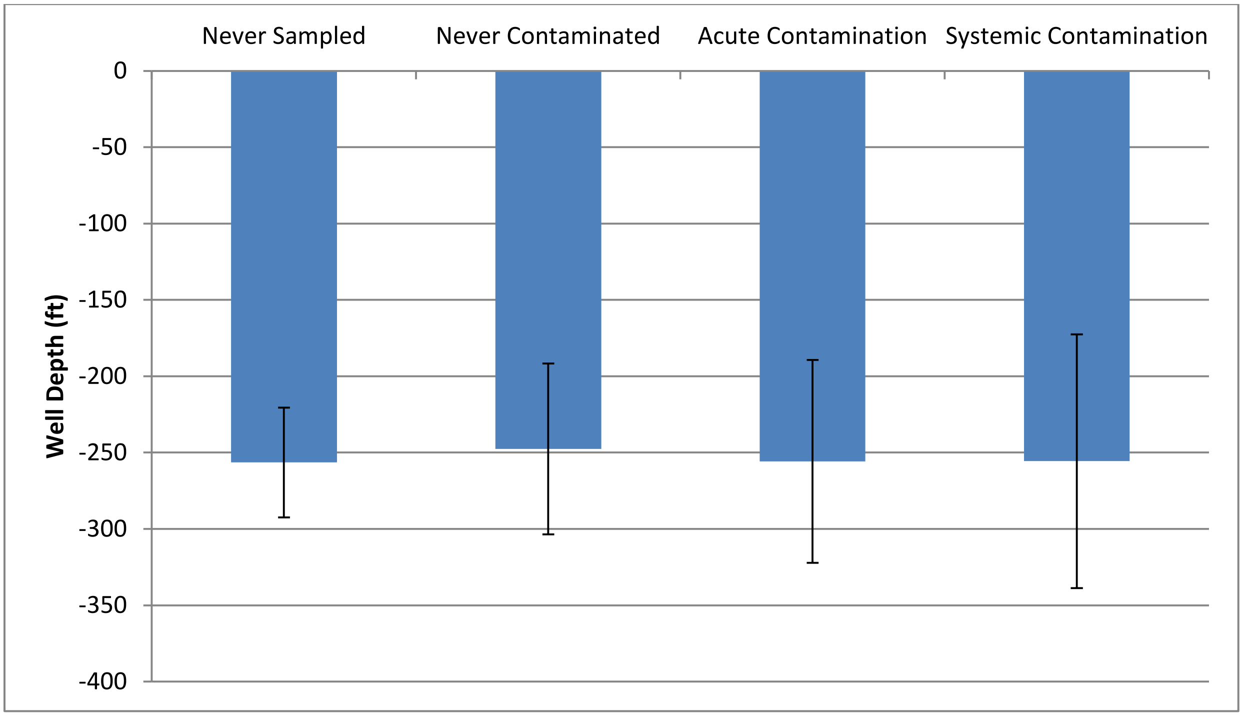

FIGURE 3-9: AVERAGE WELL DEPTH FOR RURAL GROUNDWATER WELLS IN SAMSON CREE NATION BASED ON BACTERIOLOGICAL CONTAMINATION CATEGORIES. ERROR BARS REPRESENT ONE STANDARD DEVIATION. SAMPLE SIZES: NEVER SAMPLED (N=12), NEVER CONTAMINATED (N=130), ACUTE CONTAMINATION (N=25), SYSTEMIC CONTAMINATION (N=67).

Figure 3-9 shows that the difference between the various categories is minimal and well 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 the groundwater with deeper wells experiencing lower nitrate levels, an indicator of surface water infiltration. Balkwill and Ghiorse (1985) further found that bacterial concentrations in shallower groundwater were greater and that the variety of bacteria was also greater in shallower groundwater, which would indicate that shallower wells are more susceptible to bacterial contamination. The analysis above does not indicate that there is a correlation between bacterial contamination and well depth or well age in rural wells in Samson Cree Nation, a finding that aligns with those of Won et al. (2013) for wells in Northeastern Ohio.

Based on Figure 3-10, the majority of wells from all categories fall within the range of 5000 – 14000 days old (13 – 38 years) and 200 – 300 feet deep. There appears to be a potential cluster of systemically contaminated wells at 14000 days old. All of these wells were installed by Contractor 5. For the wells that have never been sampled within the available data set, there is a wide range of ages running across the entire range of wells.

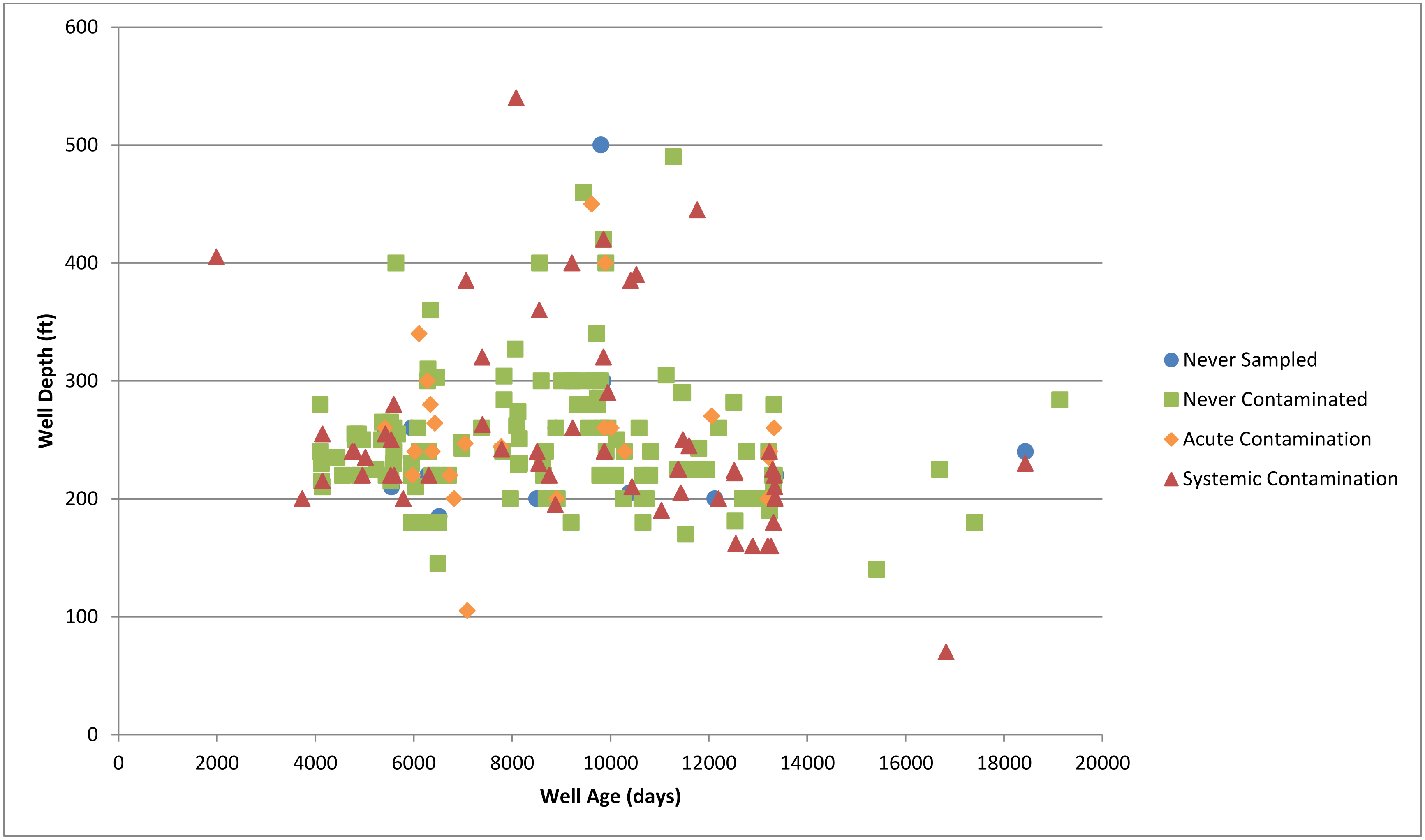

FIGURE 3-10: RURAL GROUNDWATER WELLS IN SAMSON CREE NATION PLOTTED BASED ON WELL AGE, WELL COMPLETION DEPTH, AND BACTERIAL CONTAMINATION CATEGORY

3.4.4 Septic System Survey

In 1999, Health Canada and Samson Cree Nation staff investigated rural households for 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 compiled data were received from Health Canada staff in Edmonton for this study. The data were never published widely and were used for internal reviews only and as such do not include details on how the data were collected, how the houses assessed were selected, or the exact questions asked. 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, based on the occurrence and frequency of water samples containing TC and *E. coli.* Based on these categories, the data collected during the survey were disaggregated and evaluated by each category.

The main factors examined here are 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 3-11 and 3-12 below.

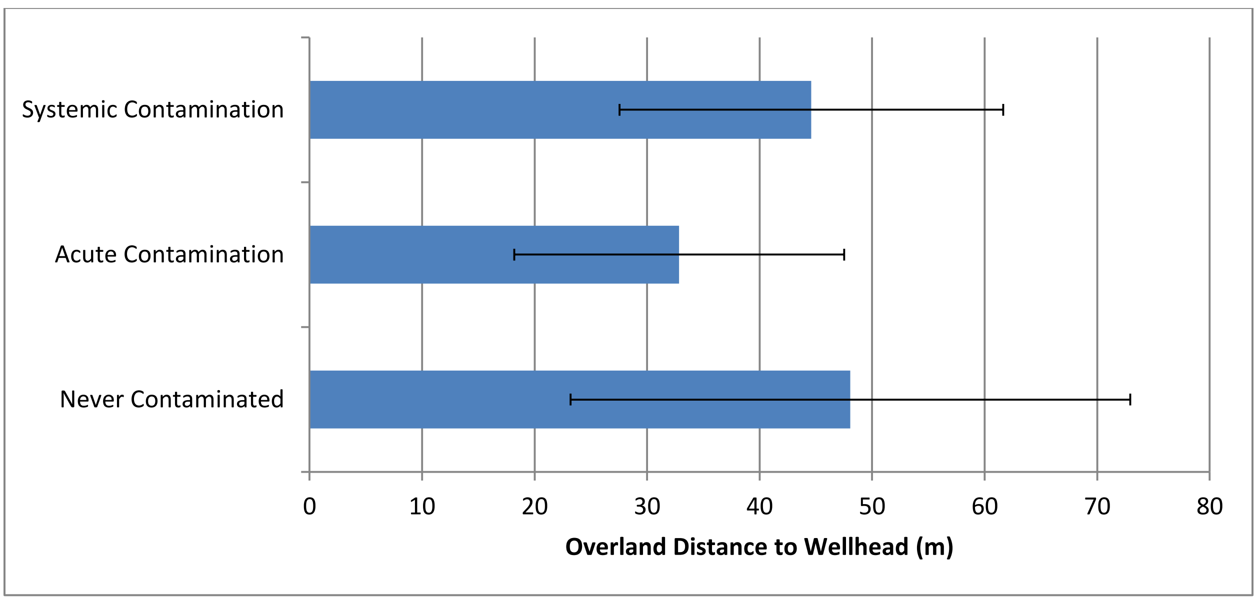

FIGURE 3-11: AVERAGE OVERLAND DISTANCE BETWEEN THE SEPTIC SYSTEM DISCHARGE AND THE DRINKING WATER WELLHEAD FOR RURAL HOMES IN SAMSON CREE NATION. THE NUMBER OF HOMES FOR WHICH DATA WAS AVAILABLE WAS: SYSTEMIC CONTAMINATION (N=20), ACUTE CONTAMINATION (N=9), NEVER CONTAMINATED (N=33).

The average distance between the septic discharge and the drinking water wellhead for the various contamination categories is summarized in Figure 3-11. The largest average distance is for the Never Contaminated category, although the standard deviations of the various categories overlap significantly such that there is no discernible relationship between the distance categories. The number of wells for which septic discharge to wellhead distance was available is 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 since there were only three wells for which there were data and also because there is no expected relationship between overland distance from septic discharge to well head and wells having never been sampled.

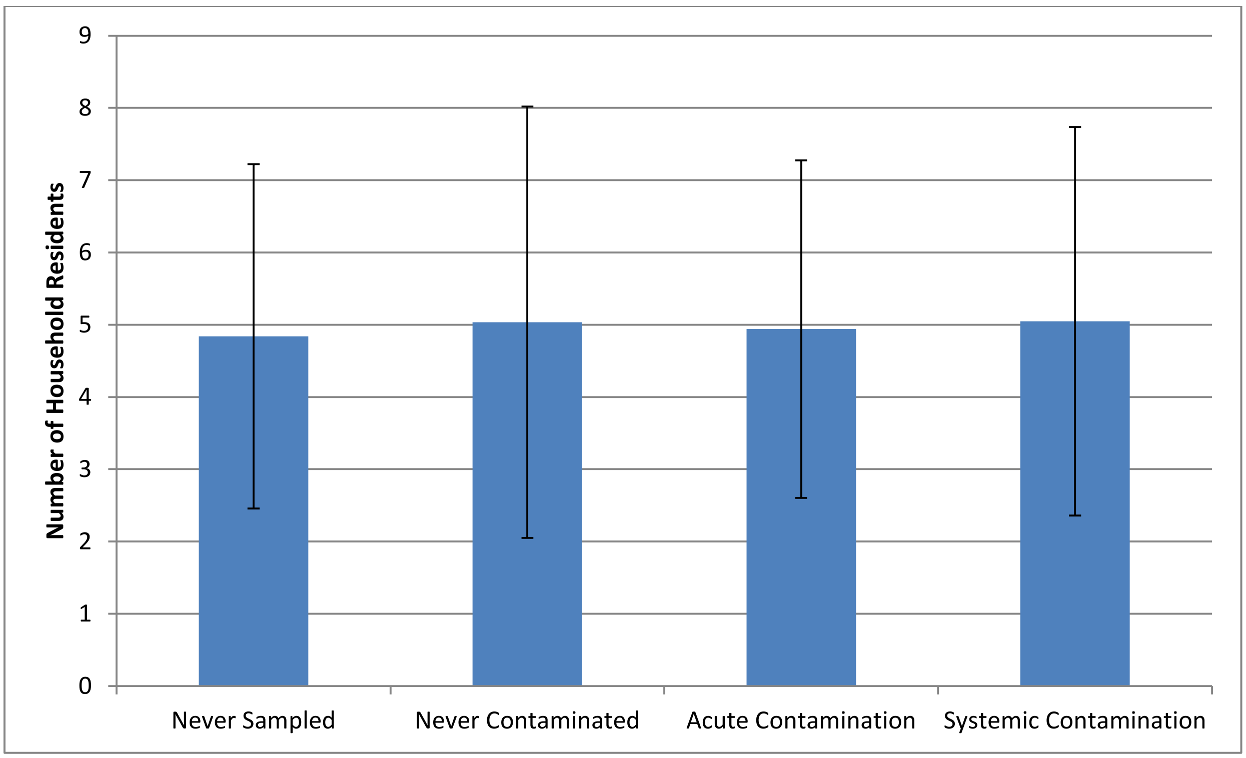

FIGURE 3-12: AVERAGE HOUSEHOLD OCCUPANCY FOR HOMES BASED ON BACTERIOLOGICAL CONTAMINATION CATEGORY IN SAMSON CREE NATION. THE SAMPLE SIZE FOR EACH CATEGORY WAS: NEVER SAMPLED (N=31), NEVER CONTAMINATED (N=260), ACUTE CONTAMINATION (N=67), AND SYSTEMIC CONTAMINATION (N=104).

Household occupancy provides an indication of the amount of sewage expected to be produced by a particular home as well as the amount of water being utilized by residents. Figure 3-13 below combines the two data sets analyzed in a scatter plot to examine any trends that may exist over the entire range of data. It would be expected that the combination between high household occupancy and short distance between the septic system and the wellhead would lead to more systemic contamination.

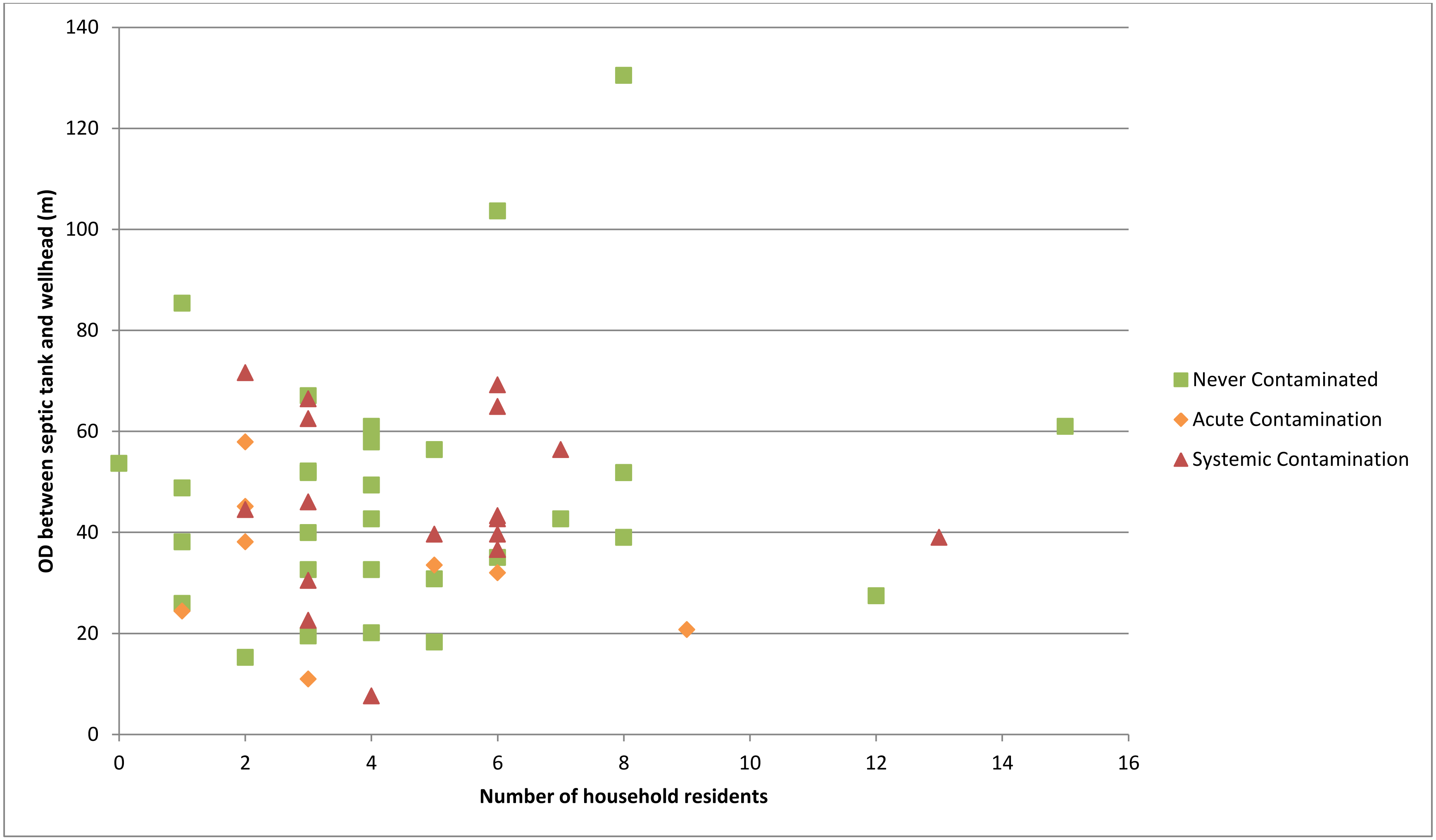

FIGURE 3-13: NUMBER OF HOUSEHOLD RESIDENTS VERSUS OVERLAND DISTANCE BETWEEN SEPTIC TANK AND WELLHEAD, LABELED BY BACTERIOLOGICAL CONTAMINATION CATEGORY FOR RURAL HOMES IN SAMSON CREE NATION BASED ON A 1999 SURVEY PERFORMED BY HEALTH CANADA.

Figure 3-13 shows that there is 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. This observation could be supplemented by the addition of more data points by measuring the overland distance between septic discharge and wellhead for more wells. Based on the available historical data, there are only three wells which are further than 80 meters from the septic discharge, all of which 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 to adding additional data points for overland distance between septic discharge and wellhead, further investigation into the density of the septic systems in an area should be investigated. While septic system density data were not available for this study, 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 with the highest household occupancy of 15 individuals being a well that has never been contaminated.

3.5 Conclusions

In chapter 1, it was hypothesized that the incidence of BWA (ie. systemic contamination) is 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 based on the data available:

1) The analyzed chemical and physical groundwater parameters and the bacteriological contamination categories are not correlated with the exception of temperature. The temperature data indicates an increase in temperature for wells that have never been contaminated and lower temperatures for those homes which have been under BWA;
2) Both total precipitation and the Battle River flow are correlated with the percentage of water samples contaminated with TC or *E. coli.* This correlation is preceded by a lag period of approximately two months during which time it is hypothesized that the surface water is saturating and infiltrating the soil into the groundwater table;
3) The ratio of never contaminated wells and systemically contaminated wells is lower for those wells installed by contractors who operated at an earlier time period. The wells installed by contractors more recently are less likely to have been placed under BWA than the wells installed by contractors operating at an earlier time;

4) There is no direct relationship between the age or completion depth of a well and the well's bacteriological contamination category. This result runs counter to those of some previous studies which found that shallower, older wells are more susceptible to bacteriological contamination; and
5) There is a potential threshold value of 80 meters overland distance between septic system discharge and wellhead above which wells have never been contaminated. This observation requires further investigation as the sample size above the 80 meter threshold was extremely low.

These observations support the hypotheses of a positive correlation between incidence of BWA and increased precipitation (with a lag period), well age (as measured on aggregate by contractor), and the proximity of the septic system discharge and 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 as discussed throughout the body of this chapter.

3.6 Further Study

There are many opportunities for further assessment of the conclusions 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 density of septic tanks/drinking water wells in a particular area with the frequency of TC or *E. coli* contamination of the wells in that area;
- The proximity of drinking water wells to historical oil and gas wells or seismic exploration activity with the frequency of TC or *E. coli* contamination in addition to salt and hydrocarbon contamination;
- The proximity of drinking water wells to the Battle River, sloughs and other sources of surface water with the frequency of TC or *E. coli* contamination;
- The proximity and density of abandoned drinking water wells in a particular area with the frequency of TC or *E. coli* contamination in that area;
- Land use mapping of different land uses including natural fields, agriculturally cultivated fields, livestock grazing fields, residential development and other land uses with the frequency of TC or

E. coli contamination in addition to herbicides, pesticides, nitrates, and other agricultural chemicals; and

- The proximity of active or abandoned landfills or waste transfer stations with the general water chemistry.

Further study could also involve an assessment of the bacteriological contamination categories framework developed for the purposes of this study. There are several limitations to the framework as described including:

- The possibility of false-positive samples leading to uncontaminated wells being labeled as acutely contaminated;
- The limited number of samples available for each well limiting the accuracy of each categorization;
- The uncertainty as to why wells categorized as never sampled have never been sampled

Further study could be undertaken to assess the categorization framework, specifically investigating:

- Any correlation between the bacteriological contamination categories defined and the generalized chemical and physical quality of the water beyond the parameters assessed in this study;
- The validity of the bacteriological contamination categories with the addition of more frequent and regular sample collection; and
- The validity of the bacteriological contamination categories as applied to other data sets which may include different testing parameters and sampling regimes.

This additional research would aid in identifying the thresholds of various risk factors within Samson Cree Nation which will support the ongoing effort to ensure safe, clean drinking water for all residents of the Nation.

Chapter 4: Determining Bacteriological Contamination Source and Pathway

4.1 Introduction

Based on the review of historical data collected for Samson Cree Nation in Chapter 3, I developed a sampling program to investigate: 1) the link between surface water infiltration and groundwater contamination in rural private drinking water wells, and 2) the metals exceedances observed in the 2002-03 Health Canada sampling program discussed in Chapter 3. This will help identify sources and pathways of bacteriological contamination in drinking water wells to inform Samson Cree Nation of the most prevalent water quality challenges facing rural private wells. Moving forward this will support the development of specific strategies to address the challenges that are most prevalent.

This chapter reviews the literature for indicators of various contamination sources and pathways for rural private drinking water wells. The sampling program undertaken during the summer of 2013 is summarized and the results are analyzed to determine the sources of contamination and identify useful indicators for assessing how well water quality can become contaminated.

4.2 Indicators of Bacteriological Contamination Source and Pathway

The primary sources of contamination of private drinking water wells with bacteriological contamination are septic system infiltration, agricultural runoff, biofilm growth and other contamination mechanisms within the drinking water distribution, and general surface water infiltration. Previous studies were reviewed to identify water quality indicators of particular contamination sources. Based on the detected and suspected prevalence of these indicators in drinking water wells in Samson Cree Nation, as discussed in the historical data review in Chapter 3, specific contamination sources of concern are identified. Based on these suspected contamination sources, the 2013 sampling program was developed to further characterize and identify the nature of contamination in drinking water wells and the source of that contamination.

4.2.1 Domestic Waste and Sewage

Septic system impacts on drinking water quality in private wells can be observed through a combination of chemicals that are unique to human waste such as caffeine and pharmaceuticals. Glassmeyer et al. (2005) set out to identify chemical indicators of domestic wastewaters as alternatives to traditional culturing methods. Culturing methods typically take too much time and do not differentiate between human and non-human sources. Glassmeyer et al. (2005) identified 35 compounds with higher concentrations downstream of a wastewater treatment plant than upstream. The compounds which offered the greatest potential as indicators were ethyl citrate, galaxolide, tonalide, carbamazepine, diphenhydramine, and caffeine. Human populations consume large quantities of caffeine through food and drink and excrete approximately 0.5–10.0% of this caffeine, primarily through urine (Ferreira, 2005). Seiler et al. (1999) detected the pharmaceuticals chlorpropamide, phensuximide, and carbamazepine in addition to caffeine in waters impacted by domestic wastewater effluent. Journey (2000) identified caffeine, cholesterol, cotinine (an indicator of nicotine), codeine, and non-ionic detergent agents in surface waters in high density residential areas which correlated strongly with *E. coli* and fecal coliform concentrations. This was compared to a surface water stream that collected runoff from a dairy farm where medium-high *E. coli* and fecal coliform counts were detected but none of the wastewater indicators were present. Peeler et al. (2006) found similar results using caffeine and nutrients in surface waters. A strong correlation was observed between caffeine and other nutrient concentrations with fecal bacteria presence for heavily populated areas whereas no relationship existed in more rural settings where fecal bacteria was assumed to be originating from non-human sources. While the majority of this work has been conducted on surface water systems, Hillebrand et al. (2012) found correlations between caffeine concentrations and the concentration of the human metabolite paraxanthine in a high flow aquifer system. They found that caffeine could be applied as an indicator for human wastewater contamination of groundwater on an event-based leakage level based on spikes and fluctuations in concentration. Verstraeten (2005) found that for groundwater wells in Nebraska, the presence of antibiotics and other drugs was related to contamination from coliphages which indicated that septic tank contamination was the source of the coliphage contamination. Sand-point wells that were less than 14 metres deep and within 30 metres of a septic system were found to be the most susceptible (Verstraeten, 2005). The use of caffeine and other pharmaceuticals as indicators of human septic contamination in groundwater systems still requires further study before it can be implemented on a wide scale basis. The fate and transport of these compounds in groundwater systems is relatively unknown and as such is not a reliable indicator (Cimenti et al., 2007). Cimenti et al. (2007) and Glassmeyer et al. (2005) both identified that the best indicator of contamination will ultimately be a combination of microbial and chemical parameters to identify the source of contamination and offer reliability for the case when a particular parameter might not be present. How these parameters actually relate to the incidence of waterborne illness requires further analysis (Glassmeyer et al., 2005).

4.2.2 Agricultural Impacts

Indicators of agricultural activities impacting groundwater quality are typically based on concentrations of chemical fertilizers and other agricultural inputs, or indicators of farming practices and other environmental conditions that affect the survivability of bacteria. The source of bacteriological contamination from agricultural activities is typically the land application of manure as a natural fertilizer. The chemical concentrations of other agricultural compounds such as nitrates or pesticides can also be a source of concern if these compounds exceed safe levels in drinking water. Van der Werf and Petit (2002) assessed 12 different methods of evaluating the impacts of farming on the environment. They found that the best methods are:

- those that measure direct environmental impacts as opposed to methods that evaluate farmer behaviours;
- those that produce an actual value with a tangible meaning such as a chemical concentration or amount of erosion as opposed to methods that produce an abstract score or risk factor without any clear real world meaning;
- those methods that take into account a broad set of objectives at various ranges of impact from local, regional, and global; and
- those methods that can be expressed in terms of the impact per unit of surface area cultivated or per unit of output produced.

Schröder et al. (2004) identified that there is little agreement amongst various agencies as to the best methods of evaluating agricultural impact on the environment and water quality specifically.

Environmental conditions which affect the survival of fecal bacteria after the land application of manure are soil moisture, soil type, temperature, pH, manure application rate, nutrient availability, and competition with other bacteria (Jamieson et al., 2002). Cool, moist soil environments are optimal for the survival and transport of fecal bacteria into groundwater systems from agriculturally developed fields. In addition to these environmental conditions, chemical concentrations in the groundwater can indicate agricultural contamination. Pionke and Urban (1985) found elevated concentrations of nitrates, chlorides, and phosphates in groundwater underlying crop lands when compared to groundwater samples collected from areas overlain with forests in Pennsylvania. Böhlke (2002) expands upon this list by identifying the direct and indirect impacts of agricultural runoff on groundwater quality. Agricultural activity can affect the concentration of nitrates, nitrogen, chloride, sulphates, hydrogen, phosphorous, calcium, potassium, magnesium, carbon, strontium, barium, radium, arsenic, and pesticides. Nitrates are typically found to be the most significant indicator of groundwater influenced by agricultural development. Forrest et al. (2006) studied a variety of nutrient concentrations in shallow groundwater wells in Alberta and found that the strongest correlation was a link to the nitrate concentration in the shallow groundwater and the amount of land cover in the surrounding area being used for agricultural activities. In a study of groundwater in five different agricultural areas of the United States, Hamilton and Helsel (1995) found that between 12-46% of the wells sampled exceeded the USEPA maximum contaminant level for nitrates of 10 mg/L. Oenema et al. (2005) further identified that there is a direct link between agricultural nitrate levels and underlying groundwater nitrate levels by correlating a decrease in the agricultural nitrate surplus for an area and the concentration of nitrates in nearby groundwater wells. Thompson (2001) further found that nitrates were an important parameter to test for in agricultural areas where 14% of wells sampled in rural areas exceeded the nitrate Drinking Water Quality Guidelines value of 45 mg/L.

4.2.3 Distribution System Contamination

Microbial growth within the distribution system can act as a source of waterborne bacteria and other problem organisms even if the water source is clean and safe. It has been estimated that between 1991 and 1996 in the United States, 22% of outbreaks of waterborne pathogens in piped water distributions systems were due to contamination within the distribution system (Payment and Robertson, 2004). These contamination sources included corrosion pockets, private cross-connections, backflow problems, poorly protected or cleaned storage tanks, and repairs to the distribution system and plumbing. A challenge within rural private drinking water wells is the formation of biofilms within the distribution system including storage tanks, water heaters, water softeners, and other water contact surfaces (van der Kooij, 2003, LeChevallier, 2003). Biofilms form when planktonic microbes settle onto a surface and are able to form colonies, which offer protection from disinfection and water hydraulics (Block, 1992). While biofilms do not necessarily harbour pathogenic organisms, their proliferation will offer readily available locations for pathogens to grow and develop if they are introduced into the system (Percival and Walker, 1999). In addition, biofilms can offer a regular source of non-pathogenic coliform bacteria, which will decrease the effectiveness of water quality monitoring programs by introducing more false positives into the sample set (USEPA, 2002). Other negative impacts that biofilms can have include bad tastes and odours, reduction of dissolved oxygen, stains and precipitate formation, corrosion, decreased hydraulic conductivity, and reduced material life (USEPA, 2002, LeChevallier, 2003). Van der Kooji (2003) identified that the best methods for preventing the development of biofilms within drinking water distribution systems are to: ensure that water being distributed and the materials comprising the distribution system are biologically stable; maintain sufficient residual disinfection within the distribution system; and optimize the distribution system to prevent stagnation and sediment accumulation.

There are several factors that can influence the growth and proliferation of biofilms within a drinking water distribution system and increase the risk of contamination. These factors include nutrient availability, surface roughness, pipe material, diversity and concentration of microbial species within the water, pipe water flow and stagnation, water temperature, and availability of residual disinfectant (Percival and Walker, 1999, LeChevallier, 2003). Batté et al. (2004) found that between cast iron, stainless steel, and PVC pipes all showed similar levels of biofilms but had distinctly different bacteriological communities. Copper pipes were found to have lower susceptibility to biofilm formation due to the toxicity of the copper ions released. Batté et al. (2004) further found that corroded pipes had much greater bacterial growth than smoother pipes due to surface roughness created by corrosion. Since older systems are more likely to be corroded, they are presumably more susceptible to biofilm growth, but Wingender and Flemming (2004) found that there was no correlation between pipe age and the degree of biofilm growth across several pipe materials. Nutrient availability offers another indication of biofilm growth potential but does not give a clear indication of current formations (van der Kooji, 2003). Testing water before and after distribution is one option for assessing the change in water quality, particularly bacteriological contamination, between the source and the tap. Better methods are needed for identifying when contamination is coming from the drinking water distribution system as current methods typically rely on testing for indicator organisms in the treated drinking water (Van der Kooji, 2003).

4.2.4 Surface Water Infiltration

Surface water infiltration into groundwater zones is not inherently a concern for bacteriological contamination. Surface water recharge is the mechanism by which aquifers replenishment as they are depleted through use. Typically, the surface water percolates slowly through the subsurface passing through multiple soil zones. This gradual flow through porous media removes pathogens and other contaminants through adsorption, interception and other filtration methods. Because of this, properly managed groundwater aquifers can serve as clean, safe drinking water sources (Stewart and Morgenstern, 2001). But when surface water infiltrates into groundwater sources more directly, it can lead to biological, chemical, and physical contamination of the well water. This can occur through cracks in the well casing, improperly abandoned wells, fractures in the subsurface layers, or other mechanisms. Identifying the infiltration pathway is an important mechanism for protecting the quality of groundwater sources.

The use of water isotopes is a good indicator of water age and source to determine the connection between groundwater and surface water interactions (Seiler, 2001). The isotopes in water molecules are preferentially precipitated and evaporated based on the climatic regimes such that meteoric water has a different isotope signature than groundwater within a particular area (Peng et al., 2004, Stewart and Morgenstern, 2001). Deuterium and oxygen 18 have been used as stable isotope indicators of water sources since they do not react with local geochemistry (Seiler, 2001). Factors that have been found to change the deuterium/oxygen 18 signature of a water source include: latitude, altitude, precipitation volume, continentality, surface air temperature, and seasonality (Peng et al., 2004). Lee et al. (1999) found that deuterium monitoring was an effective method for determining the degree to which precipitation impacted groundwater on an island in Korea. Singleton et al. (2005) measured nitrogen and oxygen isotopes to determine the source of nitrate contamination within groundwater and Borchardt et al. (2004) measured oxygen and hydrogen in an attempt to predict the presence of enteric viruses. Borchardt et al. (2004) did not find a relationship between the presence of enteric viruses and the degree of surface water contamination within the groundwater. When evaluating for tritium alone, it was found that wells that show atmospheric tritium levels were found to have higher likelihood of enteric virus presence (Borchardt et al., 2007).

4.3 Sample Collection and Analysis Methodology

Surface water infiltration, well history, and high metals concentrations are the most relevant factors in assessing risk of water quality concerns in drinking water wells in Samson Cree Nation. These factors were identified based on the relationships between precipitation data and well installation contractor with risk of bacteriological contamination in addition to the exceedances of the Canadian Drinking Water Quality Guidelines of certain metals detected in the 2002-03 Health Canada sampling program.- Septic system impacts are not a strong indicator of bacteriological contamination based on the results of the septic system study completed by Health Canada in 1999. The 2002-03 Health Canada chemical sampling program found very low concentrations of nitrates in the wells sampled and sporadic pesticide testing has found no detectable pesticide concentrations in drinking water wells in Samson Cree Nation.

Agricultural impacts are therefore not a significant source of bacteriological contamination. The historical data review did not provide an indication that the distribution system itself may be a prevalent source of contamination in Samson Cree Nation but the limited budget available for this project could not accommodate a thorough investigation of this potential source of contamination. Based on these details, samples were collected to examine surface water infiltration, well history, and high metals concentrations.

4.3.1 Sample Collection

For the collection of the majority of the water samples, I accompanied Maskwacîs Health Services staff during their regular *E. coli* and TC sampling activities to collect additional samples for metals concentrations and surface water infiltration indicators. I collected samples with Health Services staff as opposed to going door to door by myself for several reasons:

- I could directly compare my results with those of the TC and *E. coli* samples collected at the same time;
- As an outsider to the community, I was advised against approaching individual households by myself for both safety and sample collection reasons. Dogs are common in the community and have attacked water sampling staff in the past. In addition, some homeowners would be less likely to participate if approached by a stranger under unexpected circumstances;
- Maskwacîs Health Services staff are often assigned houses to sample based on previous positive bacteriological test results. By accompanying staff, I was able to sample from more homes that are suspected of bacteria presence than if I had collected samples randomly; and
- By relying on the sampling programs of the Health Services staff, I was able to achieve a fairly wide geographic spread of sample collection without biasing for a particular area.

I collected samples in clean plastic 500 mL containers from kitchen taps in homes that all use rural private drinking water wells for their water source. Figure 4-1 shows a typical sample collection arrangement. Samples were collected by removing any filter or accessory attached to the end of the kitchen tap, dipping the tap in a chlorine bleach solution, turning on the cold water faucet and allowing the water to flow for three minutes prior to sample collection.

Bottles were filled at an angle to ensure that the water struck only the inside surface. Bottles were filled to the point of overflowing and capped to ensure minimal headspace. Water samples were then labelled with a unique sample ID. The house number and homeowner were noted in my field notebook along with the time of sample collection and whether or not the homeowners drank their tap water. A GPS shot was taken using the Canada Topo Maps Pro (ATLOGIS, 2013) application on a Samsung Galaxy S3 phone. The waypoint was recorded as the sample ID. Samples were transported in a cooler with ice packs to the university laboratory where they were hand filtered using a syringe and a 0.4 μm filter into a sterile, plastic 50 mL centrifuge tube. The tubes were filled to overflowing and capped so as to have as little headspace as possible. Samples were then stored in a cold room wrapped in aluminum foil to avoid light exposure.

FIGURE 4-1: WATER SAMPLES WERE COLLECTED IN CLEAN PLASTIC BOTTLES FROM KITCHEN TAPS AFTER DISINFECTION WITH CHLORINE SOLUTION AND RUNNING THE WATER FOR THREE MINUTES.

4.3.2 Laboratory Analysis

Water samples were analyzed for *E. coli* and TC presence, deuterium and oxygen 18, and selected metals concentrations. Maskwacîs Health Services samples were sent to the Provincial Laboratory for Public Health in Edmonton for *E. coli* and TC concentrations using the enzyme substrate technology method (Rompré et al., 2002). Samples were analyzed for the presence of absence or the most probable concentration of colony forming units for both bacteria groups depending on if the house was under boil water advisory or not. The sampling and testing procedure for these samples is the same as the procedure used for the 2006-2012 bacteriological sampling data set discussed in Chapter 3.

The 500 mL samples collected for the purposes of this field study were divided into two separate 50 mL centrifuge tubes. One of these tubes was preserved with nitric acid for mass spectrometry analysis while one tube did not receive any preservative and was sent to the Isotope Science Laboratory at the University of Calgary for hydrogen and oxygen isotope analysis. The unpreserved samples were analyzed for deuterium and oxygen 18 concentrations using a Low Gatos research water isotope analyzer that employs the cavity ringdown spectroscopy technique (Berden et al., 2000).

Samples preserved with nitric acid were sent for mass spectrometry analysis in the Earth Sciences department at the University of Alberta. Inductively coupled plasma mass spectrometry was completed using an Elan 6000 ICP-MS to determine the concentrations of the following compounds: boron, sodium, magnesium, aluminum, calcium, chromium, iron, manganese, copper, zinc, arsenic, selenium, silver, cadmium, antimony, barium, lead, and uranium (Cheng et al, 2004).

4.4 Results and Discussion

The houses that were sampled are shown in Figure 4-2. The main landmass of Samson Cree Nation is outlined in black, which is where all sample collection took place. The red diamonds indicate sample locations where the sample collected by the Health Center detected a presence for TC or *E. coli.* The blue circles indicate sample locations where the sample collected by the Health Center did not have a presence for TC or *E. coli.* . The majority of samples were collected from the North East corner of the Nation since this is an area of concern for bacteria contamination and, as a result, is an area visited regularly by the Health Services staff. I received the results of the bacteriological tests collected by the Health Services staff for the presence or absence of TC or *E. coli* bacteria from Health Canada. Since the samples were a combination of presence/absence tests and most probable number (MPN) tests, all samples were reduced to either a present or absent result in order to compare the two. Six of the samples that were collected were analyzed for isotopes and metals but did not have a corresponding TC and *E. coli* sample collected. These six samples were collected from homes having their water use metered as a separate component of this project and were not collected in conjunction with the Maskwacîs Health Services staff. These homes were selected through the recruitment of volunteers instead of collecting samples at home being visited by the Maskwacîs Health Services staff.

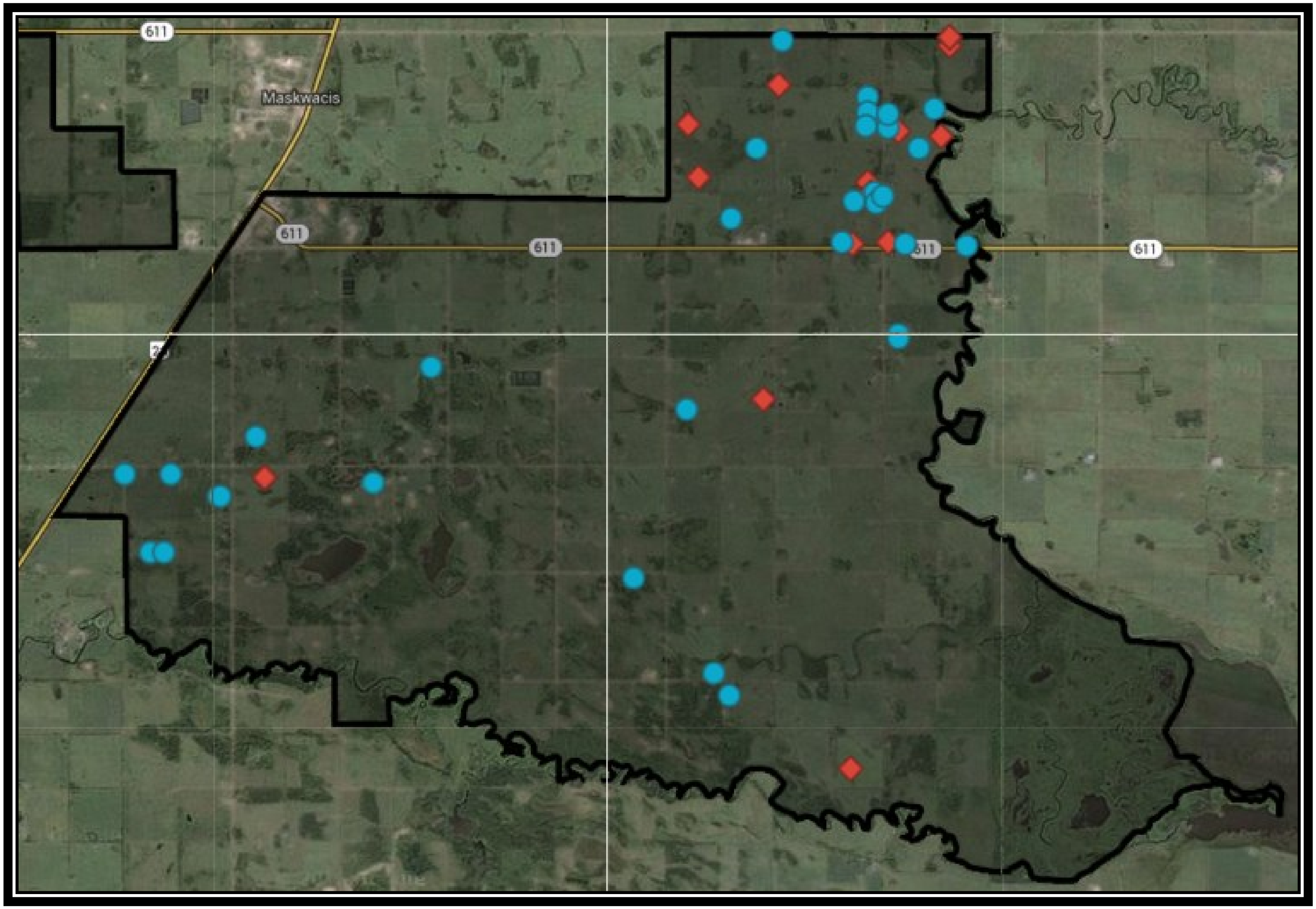

FIGURE 4-2: WELL WATER SAMPLING LOCATIONS FROM HOMES IN SAMSON CREE NATION. RED DIAMONDS INDICATE HOMES THAT WERE POSITIVE FOR THE PRESENCE OF TC OR E. COLI WHEREAS BLUE CIRCLES WERE NEGATIVE

4.4.1 Depth and Age of Wells Sampled

Based on the historical data review summarized in Chapter 3, one significant factor was the history of the well, particularly the age and depth of the well as sorted by well installation contractor. In order to assess the validity of this finding, well records were located for as many of the sampled wells as possible. In total, 23 of the 54 samples collected had associated well records in AESRD's database (AESRD, 1995-2014). Of these, eight samples had detectable TC or *E. coli* and 15 samples did not have any detectable TC or *E. coli* present. The number of wells with available information was too small to perform an analysis based on installation contractor as described in Chapter 3. Instead, well age and depth was collected and analyzed based on the categories of Present or Absent for TC or *E. coli* in the water. It was hypothesized that shallower, older wells would be at greater risk of contamination.

4.4.1.1 Well Depth

The historical data review conducted in Chapter 3 showed no discernible difference between the different contamination categories (never contaminated, acute contamination, and systemic contamination) and the well depths retrieved from the AESRD database. The original hypothesis stated that deeper wells would be less susceptible to TC and *E. coli* contamination due to the filtering effects of the soil removing these bacteria as the surface water infiltrates into the soil.

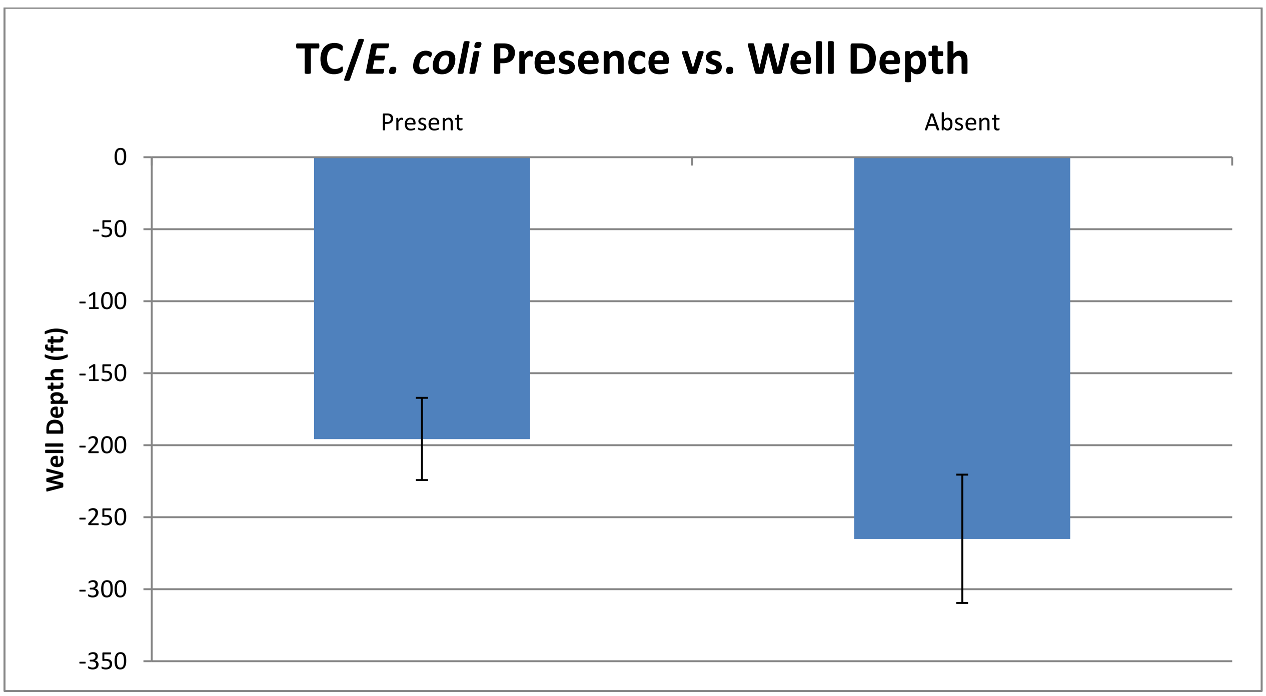

FIGURE 4-3: AVERAGE WELL DEPTH FOR PRESENCE OR ABSENCE OF TC OR E. COLI FROM 2013 SAMPLING PROGRAM. ERROR BARS REPRESENT POPULATION VARIANCE. N(PRESENT)=8, N(ABSENT)=15

It can be seen in Figure 4-3 that TC or *E. coli* absent wells are on average deeper than wells where TC or *E. coli* was detected. This finding supports our hypothesis that wells completed to a deeper depth are less susceptible to contamination. The difference in average depth between the two categories is 69 feet which is greater than the standard deviation within each category. This result does not agree with the historical data review where no discernible difference existed between different contamination categories and the average well depth of each category. One possible explanation for this discrepancy is that the samples that were collected for this project were all collected between June and August, 2013. Based on the seasonal TC/*E. coli* contamination change seen in the Precipitation Infiltration section of Chapter 2, August is one of the peak months for TC/*E. coli* contamination. Since all of the samples collected for this sampling program were collected between June and August, the influence of seasonal infiltration may be a more significant contamination factor than at other times of year. As a result, during this period when surface water infiltration is the most significant contamination concern the difference between shallow wells and deeper wells is more noticeable with shallower wells being more susceptible to surface water infiltration. During the remainder of the year when seasonal infiltration is less of a factor, the impact of well depth is less noticeable leading to an averaging out of the various contamination categories and the lack of a clear link between well depth and contamination as seen in the historical data review. If well depth is most directly linked to surface water infiltration as the source of contamination, then shallower wells will show higher contamination frequency at the time of year when surface water infiltration is greatest. The summer of 2013 was a particularly wet summer in Alberta so the impacts of infiltration could have been higher than in other years leading to the observed difference between well depths and the presence or absence of TC or *E. coli.*

4.4.1.2 Well Age

As with well depth, there is no discernible difference in well age between the different contamination categories for the wells examined in the historical data review. The original hypothesis was that older wells would be more susceptible to TC/*E. coli* contamination based on the general wear of the well components and the use of older materials. One limitation of the historical data review methodology for comparing well ages is that the well age changes over time but the method of classifying wells into various contamination categories was independent of time: if a well was ever under BWA it is classified as Systemic Contamination indefinitely. By comparing the samples collected with the current well age at the time the samples were collected, a more accurate relationship can be assessed. The average well age for the presence or absence of TC/*E. coli* is shown in Figure 4-4 below.

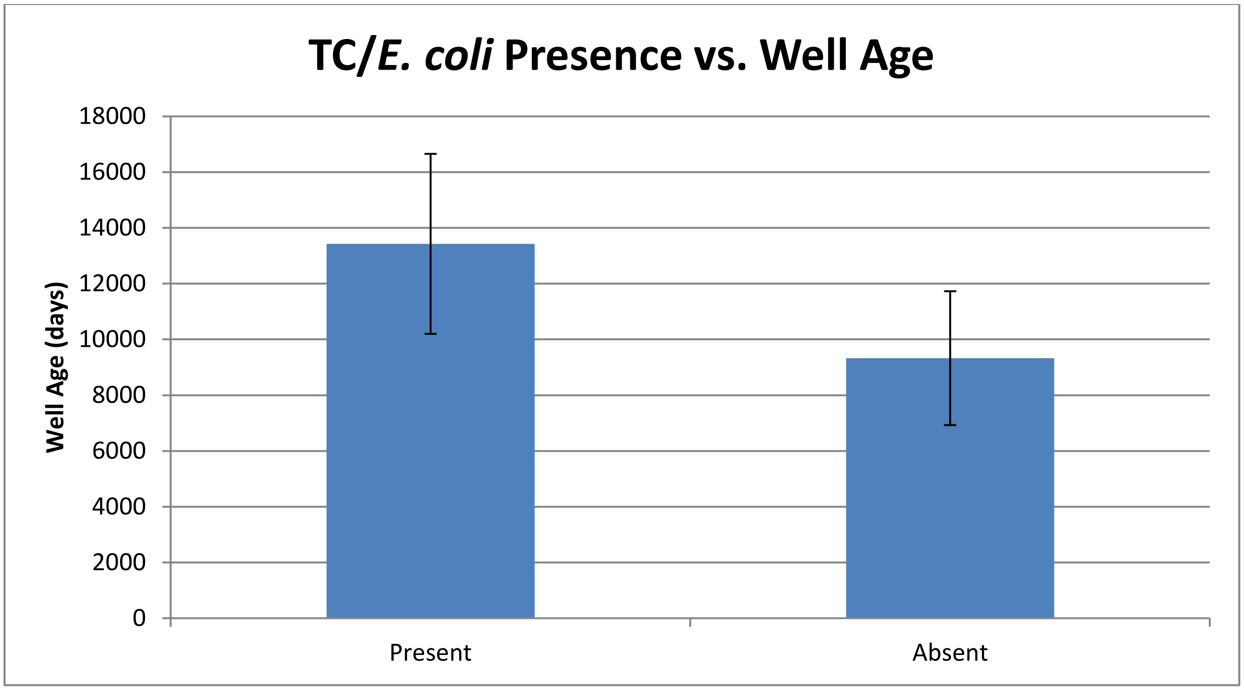

FIGURE 4-4: AVERAGE WELL AGE FOR PRESENCE OR ABSENCE OF TC OR E. COLI FROM 2013 SAMPLING PROGRAM. ERROR BARS REPRESENT POPULATION VARIANCE. N(PRESENT)=8, N(ABSENT)=15

Figure 4-4 indicates that, on average, TC or *E. coli* absent wells are newer than TC or *E. coli* present wells. The difference in average age is 4098 days which is greater than the standard deviation of either category. While this indicates support for the hypothesis that older wells are more susceptible to contamination, the sample size of wells with installation records was small (8 presence and 15 absence).

By combining the well depths and ages for the wells sampled, threshold values may be established at which wells begin to show greater susceptibility to contamination. As seen in Figure 4-5, samples that showed a presence of TC or *E. coli* are typically shallower and older as hypothesized. 80% of the wells completed to a depth less than 200 feet showed TC or *E. coli* presence setting 200 feet as a minimum threshold value for well completion. 66% of the wells older than 12 000 days (33 years) also showed TC or *E. coli* presence indicating a potential threshold of 33 years at which time wells should be replaced. All of the wells completed to a depth of 250 feet or deeper did not show evidence of TC or *E. coli* contamination and all of the wells less than 9000 days old (24 years) similarly showed no evidence of TC or *E. coli* contamination. In the historical data review, 90 of 240 wells for which there were installation records were deeper than 250 feet. Of these, only 53% were categorized as never contaminated (48 wells in total). 119 of the wells for which there were well records were newer than 9000 days. Of these, only 58% were categorized as never contaminated (69 wells in total).

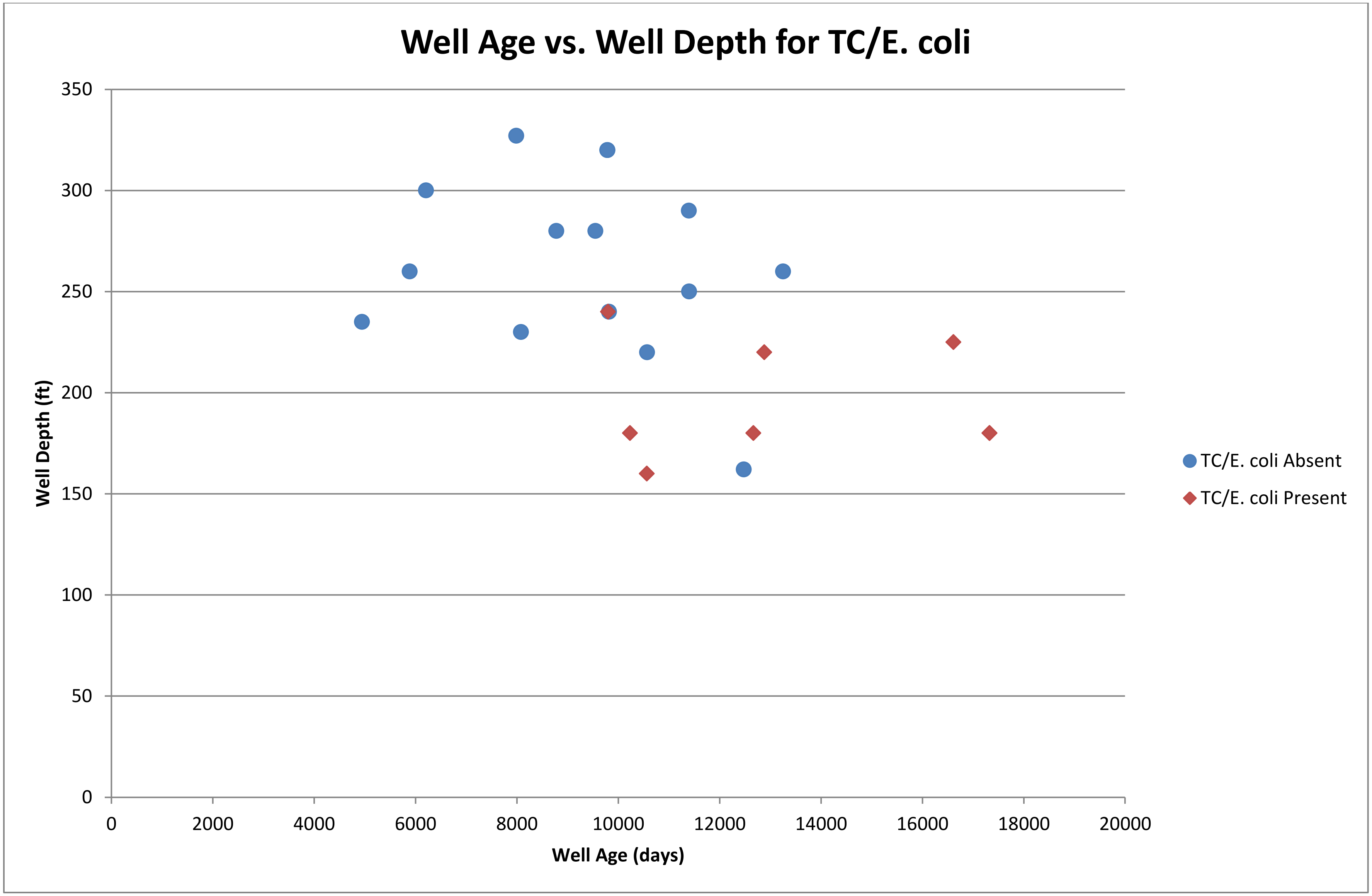

FIGURE 4-5: WELL AGE VS. WELL DEPTH FOR TC OR E. COLI PRESENCE OR ABSENCE FROM 2013 SAMPLING PROGRAM. N(PRESENT)=8, N(ABSENT)=15

4.4.2 Stable Isotope Analysis

The historical data review, summarized in Chapter 3, showed an indication that surface water infiltration into wells was a seasonally significant factor based on the relationship between seasonal precipitation and percentage of contaminated wells. This observation is supported by the analysis of the well history in the preceding section which found a relationship of shallower, older wells being more susceptible to contamination, likely through infiltration of surface water. In order to evaluate the degree to which surface water is impacting different wells, oxygen and hydrogen isotopes can be analyzed to determine the amount of influence surface water infiltration has on each well. For this sampling program, oxygen 18 and deuterium were analyzed. Oxygen 18 (^{18}O) is expressed as a the relative ratios of ^{18}O and ^{16}O in the sample water compared to the ^{18}O:^{16}O ratio in Standard Mean Ocean Water (SMOW). The concentration is described by Equation 4-1 (Sklash et al., 1976). The primary cause of fractionation of ^{18}O and ^{16}O in water is the result of a change in state. Since ^{18}O has a lower vapour pressure than ^{16}O, it will preferentially remain in the liquid phase. This causes groundwater to have a fairly uniform $\delta^{18}O$ concentration when not under the influence of surface water (Sklash et al., 1976). Groundwater will typically have a higher $\delta^{18}O$ concentration than meteoric water (Gat, 1996).

$$\delta^{18}O = \left(\frac{O18/O16_{Sample}}{O18/O16_{Standard}} - 1\right) \times 1000 \qquad \text{[Equation 4-1]}$$

Similar to Oxygen 18, hydrogen isotopes within a water sample will differentially evaporate based on mass. Deuterium (^{2}H) analysis can provide an indication of the meteoric signature of a groundwater sample and the amount of surface water infiltration that is affecting it. Figure 4-6 below shows the relative $\delta^{18}O$ and $\delta^{2}H$ values for all of the samples collected. These are graphed alongside the Global Meteoric Water Line (GMWL) and the Local Meteoric Water Line (LMWL) for Central and Southern Alberta.

As seen in Figure 4-6, the water samples all plot below the LMWL and the GMWL which is consistent with groundwater sources in Central Alberta. The samples were differentiated by colour based on the presence or absence of TC or *E. coli*. Snow samples were collected from various locations in Samson Cree Nation to indicate stable isotope concentrations in surface water in the region which could be infiltrating well water. As seen on Figure 4-6, the snow samples cluster to the bottom left of the graph with highly negative $\delta^{18}O$ and $\delta^{2}H$ values. The contaminated wells are distributed across the extent of the range for both $\delta^{18}O$ and $\delta^{2}H$ so there is no clear indication that surface water infiltration is a stand-alone factor in determining well water bacteriological contamination.

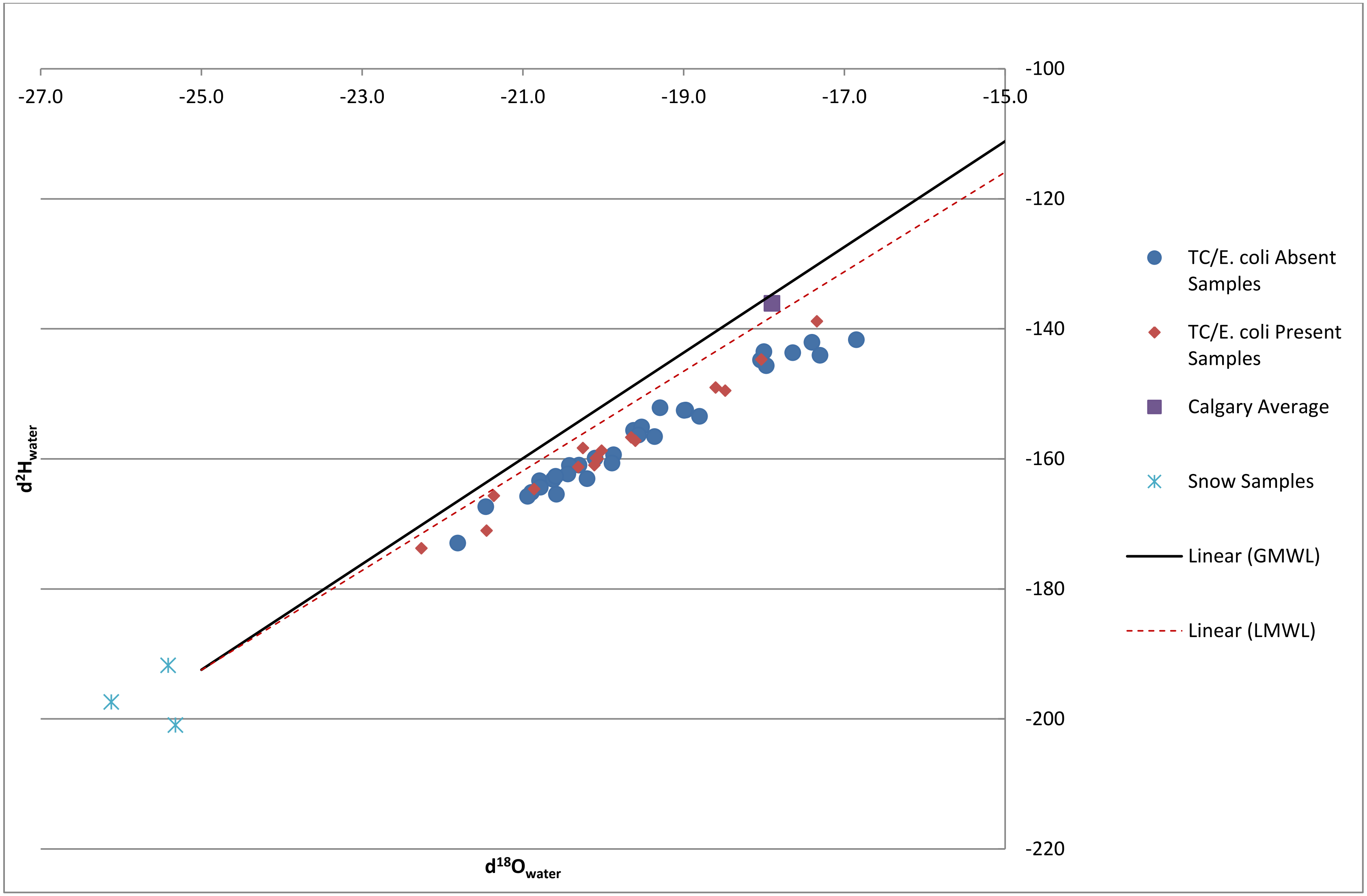

FIGURE 4-6: D18O VS. D2H FOR WATER SAMPLES COLLECTED IN SAMSON CREE NATION COLOUR CODED TO IDENTIFY THE WHETHER TC OR E. COLI WERE DETECTED IN THE WATER SAMPLES. DATA FOR THREE SNOW SAMPLES COLLECTED AT VARIOUS POINTS AROUND SAMSON CREE NATION ARE ALSO SHOWN.

4.4.2.1 Well Depth

Well depth and surface water infiltration are related by the rate at which surface water can infiltrate into the soil and mix with groundwater sources. When soil characteristics and all other environmental considerations are the same, a deeper well will take longer to infiltrate than a shallower well. In the historical data review, there was an observed relationship between annual precipitation and surface water runoff with the percentage of samples returning a presence for TC or *E. coli*. This indicates a potential connection between surface water infiltration and bacteriological well contamination.

Of the 53 well water samples collected, 23 wells had available installation records. The well depths for each of these wells was plotted relative to the $\delta^{18}O$ values for each sample in Figure 4-7 below. Water samples from wells at shallower depths and that had a more negative $\delta^{18}O$ were more likely to return positive samples for TC or *E. coli*. As seen in Figure 4-6, the surface snow samples collected and analyzed showed highly negative $\delta^{18}O$ values, so samples that have lower $\delta^{18}O$ values may indicate surface water infiltration impacts. Samples completed to a depth of less than 200 feet and that had a $\delta^{18}O$ value lower than -21‰ were all positive for TC or *E. coli.* All of the samples that were completed to a total depth greater than 200 feet and that had a $\delta^{18}O$ value greater than -19.5‰ did not show evidence of TC or *E. coli* presence in the well water. A lower $\delta^{18}O$ value indicates that the water has undergone less evaporation and has been more freshly deposited than water, that has resided on the surface for an extended period of time. Therefore, the lower $\delta^{18}O$ values for the shallower wells could indicate that these wells are under the influence of surface water through shortcutting through subsurface fractures in the soil stratigraphy, cracks in the well casing, or poorly abandoned wells in the surrounding area.

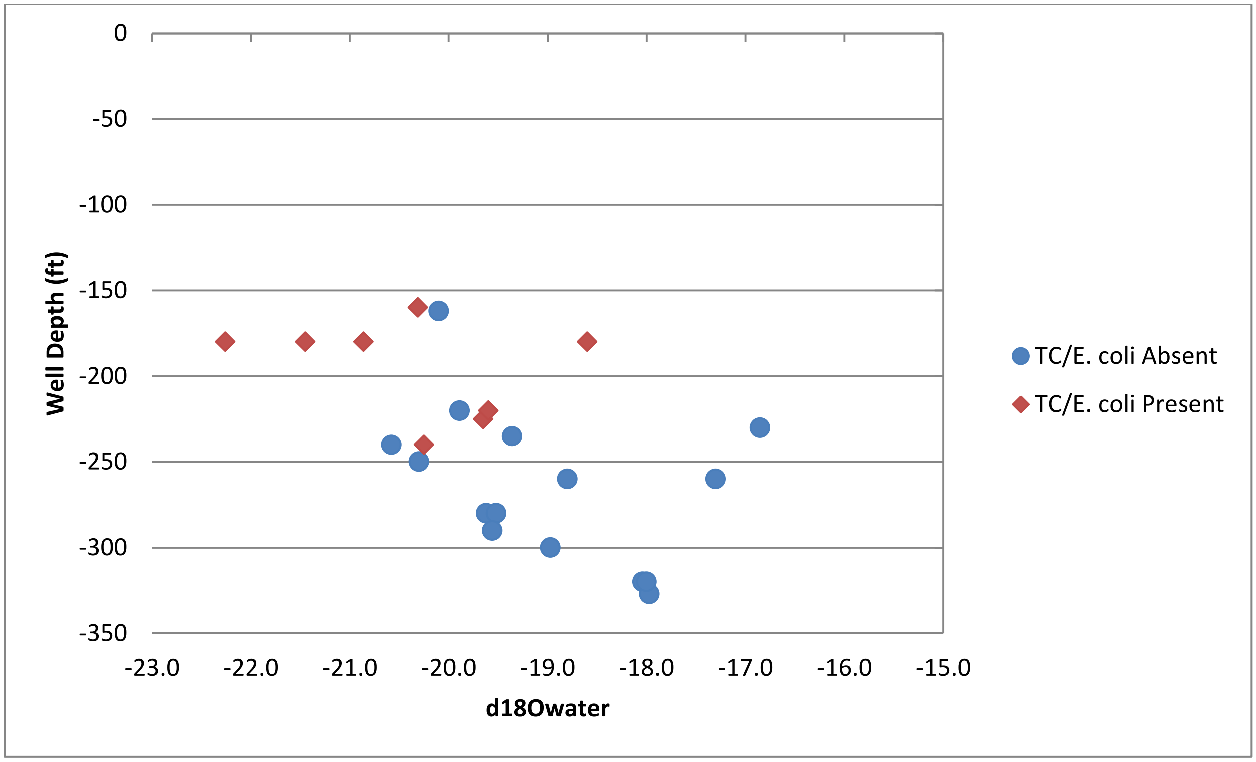

FIGURE 4-7: WELL DEPTH AND Δ18O VALUES FOR WELL WATER SAMPLES COLLECTED FROM SAMSON CREE NATION WITH DATA POINTS DIFFERENTIATED FOR WHETHER OR NOT THE SAMPLES SHOWED TC OR E. COLI CONTAMINATION. N(PRESENT)=8, N(ABSENT)=15

Additional sampling at other times during the year will help to further evaluate the relationship between well depth, stable isotope data, and presence of TC or *E. coli* as well as the fluctuation of $\delta^{18}O$ and TC or *E. coli* presence over time. As was seen in the historical data review, the percentage of samples that are bacteriologically contaminated peaks from August to October. Stable isotope data sampling throughout the year could indicate whether or not the oxygen 18 concentrations correlate to the presence or absence of TC/*E. coli* over time.

4.4.2.2 Well Age

In the historical data review, there is no clear relationship between bacteriological contamination category and well age. The initial hypothesis stated that there would be a correlation between well age and the susceptibility of a well to contamination based on older wells being more likely to be worn and cracked and the ongoing improvement of installation methods for more recently installed wells. Of the 53 well water samples collected, 23 wells had available installation records. In the well depth analysis, there is a trend indicating that the wells with lower $\delta^{18}O$ values are more susceptible to TC or *E. coli* contamination. This trend is not seen in the overall stable isotope data, as seen in

Figure 4-6, but when combined with the well age data, there is a noticeable trend of wells that are both older in age and that registered lower $\delta^{18}O$ values returning presence of TC and *E. coli*. As in the well depth section, the $\delta^{18}O$ values could be indicating the age of the well water and the climatic conditions that it was subjected to where lower $\delta^{18}O$ values indicate less evaporation due to differential vapour pressures and isotope fractionation. This could indicate a relationship between well age, surface water infiltration and risk of bacterial contamination of the well.

Figure 4-8 below shows the $\delta^{18}O$ values versus the age of each well for which data was available. There is a general trend from older wells with more negative $\delta^{18}O$ values to newer wells with less negative $\delta^{18}O$ values. This indicates that older wells may be more susceptible to surface water infiltration. In addition, it can be seen that the samples that showed presence for TC or *E. coli* cluster towards the top left, ie. older wells that show higher surface water influence. The snow samples collected showed lower $\delta^{18}O$ values than all of the groundwater samples. Lower $\delta^{18}O$ values in the contaminated samples could therefore indicate greater impact from surface water in these wells.

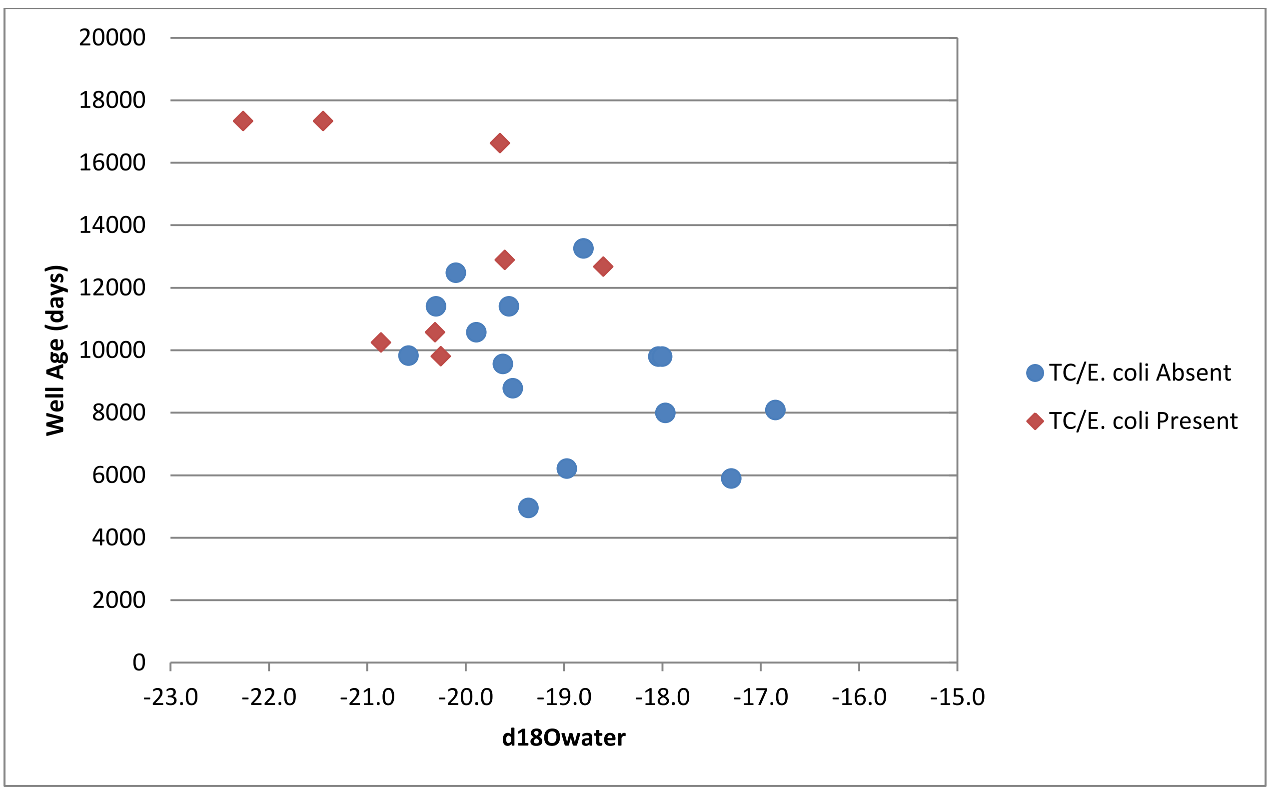

FIGURE 4-8: WELL AGE AND Δ18O VALUES FOR WELL WATER SAMPLES COLLECTED FROM SAMSON CREE NATION WITH DATA POINTS DIFFERENTIATED FOR WHETHER OR NOT THE SAMPLES SHOWED TC OR E. COLI CONTAMINATION. N(PRESENT)=8, N(ABSENT)=15

The wells for which installation data was available is considered to be small with only 23 of the 53 well water samples having corresponding installation records. Thus further sampling should be performed, particularly on those wells for which there are well installation records. Further work to identify well records using the Alberta Environment Well Records Database and the Health Canada Well Database for Samson Cree Nation could provide additional data for the sampled. This additional data could refine the connections between well age, well depth, groundwater age, and bacterial contamination by TC and *E. coli.*

4.4.3 Metals Analysis

The historical data review summarized in Chapter 3 identified exceedances in some wells of the Canadian Drinking Water Quality guidelines for several compounds including arsenic, fluoride, lead, aluminum, iron, manganese, sodium, sulfate, and zinc. The results of the spectrometry metals analysis was analyzed to determine if any exceedances were detected in the 2013 sampling data. The Health Canada Guidelines are divided into two different categories, aesthetic objectives and maximum allowable concentrations. Aesthetic objectives are the concentrations which drinking water should be kept below in order to avoid unpleasant organoleptic qualities to the water such as poor taste, smell, appearance, or usability. The aesthetic objective concentrations will not have health impacts on typical populations but could be detrimental to individuals who are sensitive (eg. individuals with high blood pressure can have negative health effects from sodium concentrations at the aesthetic objective). Maximum allowable concentrations are the concentrations that drinking water must stay below in order to not have negative health impacts for typical populations. Long term consumption of drinking water above the maximum allowable concentration will have health impacts for typical individuals. These health impacts vary depending on the compound exceeding the maximum allowable concentration (FPT Committee on Drinking Water, 2010). Different compounds can have: an aesthetic objective, a maximum allowable concentration, or both an aesthetic objective and a maximum allowable concentration.

Every sample that was collected was found to exceed the aesthetic objective of 200 mg/L for sodium. The sodium concentration for the samples ranged from 238-490 mg/L. This high sodium level is not anomalous for groundwater sources in the area but could impact the health of individuals with high blood pressure. Five of the samples collected exceeded the aesthetic objective of 0.050 mg/L for manganese. The manganese concentrations ranged from 0.0016-0.343 mg/L with five exceedance samples having concentrations of 0.055, 0.075, 0.100, 0.187, and 0.343 mg/L.

Four samples exceeded the maximum allowable concentration for arsenic of 0.010 mg/L. The samples ranged in concentration between 0.00014-0.0436 mg/L with the exceedance samples having concentrations of 0.0112, 0.0136, 0.0321, and 0.0436 mg/L. These levels of arsenic in the drinking water can have health impacts for typical populations. One sample exceeded the maximum allowable concentration for antimony of 0.006 mg/L. The samples ranged from non-detect–0.00706 mg/L with the exceedance sample having a concentration of 0.00706 mg/L.

The metals concentrations were analyzed for the average and standard deviations of the TC/*E. coli* present vs. TC/*E. coli* absent categories to identify any difference between these analytes and the presence or absence of TC/*E. coli*. Table 4-1 summarizes this analysis below. There is no significant difference between the averages of the presence/absence categories for any of the compounds analyzed.

TABLE 4-1: AVERAGE METALS CONCENTRATION FOR GROUNDWATER SAMPLES COLLECTED FROM SAMSON CREE NATION DIVIDED BETWEEN SAMPLES SHOWING PRESENCE OR ABSENCE OF TC OR E. COLI

Analyte	CDWQG (2010) Concentration (mg/L)	TC or *E. coli* Present		TC or *E. coli* Absent	
		Average	Std Dev	Average	Std Dev
Boron	5 (MAC)	0.48470	0.05240	0.49222	0.05030
Sodium	200 (AO)	303.47150	38.24551	312.36690	56.19454
Magnesium	NA	1.71596	3.58534	0.70939	1.74059
Aluminum	0.2 (AO)	0.01064	0.00489	0.01813	0.03241
Calcium	NA	8.38455	13.64241	3.23406	2.64659
Chromium	0.05 (MAC)	0.00090	0.00028	0.00094	0.00026
Iron	0.3 (AO)	0.04906	0.04800	0.05254	0.04503
Manganese	0.05 (AO)	0.02776	0.04667	0.01167	0.01689
Copper	1.0 (AO)	0.00794	0.00825	0.00874	0.00917
Zinc	5.0 (AO)	0.03984	0.05093	0.02712	0.07311
Arsenic	0.010 (MAC)	0.00374	0.00784	0.00296	0.00812
Selenium	0.01 (MAC)	0.00025	0.00020	0.00031	0.00063
Silver	NA	0.00001	0.00000	0.00001	5.17E-21
Cadmium	0.005 (MAC)	0.00006	2.8E-20	0.00006	4.13E-20
Antimony	0.006 (MAC)	0.00024	0.00041	0.00044	0.00132
Barium	1.0 (MAC)	0.06354	0.02923	0.04826	0.01655
Lead	0.010 (MAC)	0.00053	0.00070	0.00061	0.00070
Uranium	0.02 (MAC)	0.00043	0.00091	0.00036	0.00090

4.4.4 Statistical Modeling

To identify overall trends within the complete data set collected, several different statistical analysis methods were utilized to identify key contributing factors to the differentiation between the presence and absence of TC or *E. coli* in the well water. The bacteriological data was reduced to either a presence or absence of bacteriological contamination and the data collected in the sampling period were used as inputs for the model. The best model for the data available is provided through the use of Support Vector Machine (SVM) analysis. SVM is a supervised learning algorithm process that utilizes discriminative classifiers to differentiate data into different classes based on a set of supporting data (Cortes and Vapnik, 1995). The data points are divided into a training set used to develop the algorithm's formulas and a validation set used to test the algorithms for efficacy. In the case of the well sampling data, the total number of samples was 47 since 6 of the samples collected did not have accompanying bacteriological data. The elements used for analysis were the metals and stable isotope data discussed above. Well age and well depth were not included in this analysis since data could not be found for all of the wells rendering the sample size too small. Of the 47 wells sampled, 30 wells were taken for the training set (10 bacteria present and 20 no bacteria present) and 17 wells (6 bacteria present and 11 no bacteria present) were used to validate the model. Linear, quadratic-kernel, and radial basis function SVM algorithms were tested using inbuilt Matlab operators to develop the support vectors (Matlab, 2012). The quadratic-kernel SVM model had the highest accuracy for predicting the bacteriological contamination of the validation samples, though even this model was only able to correctly classify 47% of the validation samples.

A sensitivity analysis was conducted to determine the accuracy of the algorithms when each of the various test parameters are removed one at a time. The accuracy of the quadratic-kernel SVM model increased to a maximum of 70% when manganese was removed from the analysis and 65% when arsenic or oxygen 18 were removed. The results from the sensitivity analysis are shown below in Table 4-2.

TABLE 4-2: SENSITIVITY ANALYSIS OF QUADRATIC-KERNEL SVM MODEL AS SHOWN THROUGH THE ACCURACY OF THE MODEL AFTER EACH ELEMENT IS REMOVED. TRAINING SAMPLE SIZE WAS 30 (10 BACTERIA PRESENT, 20 BACTERIA ABSENT), VALIDATION SAMPLE SIZE WAS 17 (6 BACTERIA PRESENT, 11 BACTERIA ABSENT)

S. No.	Element Removed	% Accuracy
1	B	47
2	Na	42
3	Mg	47
4	Al	53
5	Ca	53
6	Cr	59
7	Fe	41
8	Mn	70
9	Cu	53
10	Zn	47
11	As	65
12	Se	53
13	Ag	53
14	Cd	53
15	Sb	53
16	Ba	53
17	Pb	53
18	U	53
19	$d^{18}O_{water}$	65
20	$d^{2}H_{water}$	53

4.5 Conclusions

Based on the historical data review summarized in Chapter 3, surface water infiltration is a concern for drinking water well contamination in Samson Cree Nation based on the seasonal relationship between precipitation and increased frequency of sample contamination. In addition, exceedances of the Canadian Drinking Water Quality Guidelines for several metals were identified. A sampling program was developed in 2013 in an attempt to characterize the relationship between surface water infiltration, bacteriological contamination and metal concentrations in Samson Cree Nation. It was found that there is a general relationship between older wells being more susceptible to surface water infiltration and bacteriological contamination. In addition, shallower wells showed higher susceptibility to surface water contamination and bacteriological contamination. There was no significant relationship between any of the metal concentrations and the presence or absence of bacteria. The isotope and metal data were combined using support vector machines and a predictive accuracy of 70% was achieved for predicting bacteriological contamination using various combinations of parameters.

4.6 Further Research

While these parameters provide good potential indicators of fecal contamination of water and should be investigated further to assess their utility and correlations in other circumstances, this data needs to be further validated by integrating public health data into the sampling information. This can provide an indication of the relationship between the various indicator parameters and the actual occurrence of pathogenic organisms. This further study could include:

- Comparing chemical sampling data with incidence of human gastroenteritis and other water borne illnesses as documented in the health care data of hospitals and clinics in Maskwacîs, Wetaskiwin, and Ponoka.

In addition, more detailed analysis of the various mechanisms of water contamination should be examined, particularly further refinement of the septic impact indicators and distribution system biofilm growth. This further study could include:

- Performing a water quality survey to compare the difference in water quality between samples collected directly from the well and that collected from the kitchen tap. This research would provide an indication if there is significant bacterial growth or chemical contamination that occurs within the distribution system itself;
- Differentiating between homes that regularly drain their hot water heaters, pressure tanks, and water softeners with homes that do not drain these units and comparing water quality data for these different categories to determine if regular system maintenance has a significant impact on water quality. During the field research component, I was told that this was the reason why one man's home had never experienced a BWA;
- Testing of the water quality coming from the hot water heater, pressure tank, or water softener when it is drained could give an indication of bacterial growth within these units.

By further characterizing the sources and pathways of bacteriological and chemical contamination in drinking water wells, Samson Cree Nation and Maskwacîs Health Services will be able to better monitor and protect the water available to Samson Cree Nation residents. Better remediation strategies that address the specific contamination source will ensure the effective use of the limited resources available.

Chapter 5: Perceptions of Water Quality in Samson Cree Nation

5.1 Introduction

> "The elders said that we wouldn't have any water soon. They said that in the future there'll be hard times; there will be no water, no power, no natural gas."
>
> Samson Cree Nation resident, September 9, 2013

While water quality monitoring is an important component of ensuring that water is clean and safe to drink, it is vital to remember that water quality data does not exist in isolation. The ultimate goal of public health work is the protection and enhancement of public wellbeing and must therefore consider the perspectives, actions, and beliefs of the population being served. As such, the impacts poor drinking water quality has on individuals within a community must be understood, and monitoring, communications, and management strategies must be structured accordingly. Community perceptions of water quality can impact behaviour and have far reaching, complex consequences on their daily lives.

This chapter will review the literature to identify general factors that affect a community's perceptions of water quality, including a community's willingness to pay for improved water quality. A summary of a community survey program undertaken by Travis Hnidan and me then follows – these surveys aim to clarify the factors that influence water quality perceptions and corresponding behaviours in Samson Cree Nation. I discuss the potential implications of these perceptions for community wellbeing.

5.2 Factors Influencing Water Quality Perception

Perceptions of water quality can have a significant effect on water-use behaviours. Consideration of such perceptions is important when evaluating drinking water supply, treatment, and distribution systems since it is ultimately the consumer's interactions with their water source that determines the effectiveness of the entire system. The Bonn Charter for Safe Drinking Water states that a drinking water system and all of the actors within it should strive to provide "Water that is not just safe to drink but considered of good aesthetic quality by consumers; and water supplies in which consumers have confidence." (International Water Association, 2004, pg. 8) It is therefore not enough to provide water that is technically safe to drink if users believe the water to be unsafe for drinking or unusable for other household uses. Recently, the use of bottled water for drinking in place of tap water has been on the rise (Spence and Walters, 2012) with one study finding that 36% of residents in a Southern Alberta county preferred bottled water compared to 40% preferring tap water (Lee, 2009). Dupont (2005) reported a detrimental shift in public perceptions of the reliability and safety of drinking water, resulting in an increase in the purchase of bottled water and home treatment units. In First Nations in Canada, 64% of homes use bottled water for drinking purposes (Spence and Walters, 2012). A survey in Montana First Nation, one of the four bands around Maskwacîs found that 59% of households use bottled water for their cooking and drinking needs (Crowther, 2011). On average, each household surveyed used approximately 183 litres of bottled water per month (Crowther, 2011).

Research into the perception of water quality has shown that public perception is informed by a complex set of relationships between diverse and sometimes unexpected factors (Doria, 2010). Curry (1988) studied the reasons homeowners used bottled water or home treatment systems and found that the most common responses were a combination of aesthetic, health, and social reasons. The primary aesthetic concerns that homeowners identified were the taste and hardness of the water. Curry (1988) found that those homes using home treatment units were more concerned about aesthetic problems with the tap water whereas homes that utilized bottled water for drinking were typically more concerned with health problems. Talatala (2008) found that safety was a more significant concern than taste for individuals who had chosen to use bottled water for drinking instead of tap water. Such findings are in contrast with the results for a study population in Quebec, Canada, where households using bottled water instead of tap water for drinking were more concerned with poor taste of the tap water rather than perceived health and safety risks (Doria, 2006).

Spence and Walters (2012) studied the perceptions of water quality on Indigenous communities in Canada in addition to the factors that impact that perception. They found that 73.1% of the Aboriginal population surveyed living on-reserve felt that their drinking water quality was satisfactorily safe. Spence and Walters (2012, pg. 10) found the following factors were positively correlated with a perception of greater risk from tap water: “being female, being highly educated, having children less than 15 years of age, being in poor health, having less attachment to Aboriginal culture, living in a residence requiring major repairs, reporting water contamination during the previous year, or being uncertain of the contamination of water.” Spence and Walters (2012) found no correlation between the perception of water quality and the age or marital status of the interview respondent. Talatala (2008) identified a positive correlation between household income and the consumption of bottled water, indicating either that more affluent homes tend to buy bottled water or that a financial barrier prevents lower-income homes from purchasing bottled water. In a survey of homes in Gurgaon, India, the factors found to increase the household’s tendency to purchase bottled water or treatment units were higher education and being informed of the presence of fecal coliform in their primary water source (Jalan and Somathan, 2004). After water from households was sampled for fecal coliform, those households informed of a presence of fecal coliform were 11% more likely to purchase an alternative water source within the next seven weeks than homes that did not receive any information about their water quality (Jalan and Somathan, 2004). Households informed that there was no presence of fecal coliform were no more likely to purchase an alternate water source than homes that received no information.

Perceptions of water quality and safety have been most directly linked to organoleptic qualities of the water such as taste, odour, texture, and colour. Indeed, Doria (2010) identified that the organoleptics of a water source are typically more important in influencing perceptions of water quality than perceptions of health risks. In a study conducted of private groundwater wells in Western Newfoundland by Sarkar et al. (2012), the chemical and biological water quality was found to often be misaligned with the perceived water quality reported by consumers. Communities that complained of sulphur and sodium contamination in the water were found to have concentrations of these two compounds below the drinking water quality guidelines. Conversely, some homes that were found to have exceedances of arsenic and fluoride reported never having any concerns with their water quality in the past. In the Sarkar et al. (2012) study, opinions on the preferred water source were highly variable, with some homes reporting that they would prefer to be on a centrally treated and distributed system since this would assure greater regulatory monitoring, while other surveyed homes preferred maintaining their private wells due to concerns of the high cost of purchasing water, fear of chlorination leading to poor taste, and a general loss of autonomy and control over their water supply.

Familiarity with particular water tastes or characteristics also greatly influences individuals' perception of water quality. Doria (2006) identified that people typically prefer water that they are "used to" – in other words, water that they either grew up drinking or have adjusted to over time. Spence and Walters (2012) reported similar findings where familiarity was a major factor in perceived water quality and any change from what was considered "normal" caused significant concern among residents. Such results are understandable since changes in the organoleptics are the immediate sources of feedback available to consumers (Sarkar et al., 2012). For families in Samson Cree Nation who spend time living off- and on-reserve, the water available off-reserve might supplant the harder groundwater as the preferred choice, leading to perceptions of poor water quality on-reserve even if water quality is not necessarily less riskier.

Water quality perceptions can be influenced by media, authority figures, and the presence of particular developments or projects. While the perceived problems do not always align with the challenges of greatest scientific significance, it is important to identify which challenges the public is most concerned with in order to improve public trust and address the spread of misinformation. A survey of public perceptions related to water quality in Wheatland County in Southern Alberta found that the top five land use activities believed to be damaging water quality in the area, in order from greatest to least impact, were confined livestock feeding operations, oil and gas activities in the area, pesticide and fertilizer application, livestock access to water bodies, and urban wastewater (Lee, 2009). This included impacts to surface and groundwater quality. Lee (2009) did not identify which factors have the greatest actual impact on water quality but discussed the need to acknowledge the concerns of the public in moving forward. Water quality testing and reporting has been found to influence perceptions of water quality strongly. Meerveld et al. (2011) reported that in four different communities in coastal British Columbia, residents expected "growth and development" to have the greatest effects on water quality and quantity in future years. In some First Nations communities, water treatment is perceived to cause contamination problems, particularly the addition of chemicals to the water to disinfect it (White, 2012). Matsui (2012) identified that there are often strong social determinants which influence how water is managed and for whom or for what uses it is protected. This creates a difficult situation for First Nations communities where regulations and guidelines for water management - as well as for land use, pollution control, resource development, and other human activities - are created by external regulators that often have different perspectives on regulatory priorities. Richmond and Ross (2009) conducted interviews with 26 community health representatives from First Nations and Inuit communities in Canada and identified the inseparability of the physical environment from culture when ensuring good health for Indigenous communities. This link between environment, culture and health does not hold the same importance in non-Indigenous communities which can lead to problems when non-Indigenous government agencies are developing regulations that will affect how things are done in First Nations.

Many preventative maintenance steps exist for residents to protect source water in private wells, but the uptake and implementation of these practices is influenced by many factors. For example, Kreutzwiser et al. (2011) identified two main criteria that led to homeowners undertaking regular preventative maintenance: the perception of a problem and sufficient knowledge of the water and wastewater systems servicing their home. Simpson (2004, pg. 1679) further identified the following topics as important for homeowners to understand to motivate them to undertake preventative maintenance: "different types of wells, why some wells are at greater risk of contamination than others, and sources of groundwater contamination; groundwater contaminants, how they can move through soil and water, and potential risks to human health; benefits of ensuring that wells are properly maintained and operate efficiently; and importance of a regular well water quality testing program." Sarkar et al. (2012) interviewed numerous health officials for their opinions on why homeowners do not undertake preventative maintenance. Health officials believed that the limiting factor is not a lack of knowledge but instead homeowners do not consider themselves to be responsible for their water systems and wait for someone else to address their problems for them. The health officials interviewed pointed to the fact that although the provincial government offers free testing services when homeowners send in their own water samples, health officials still observe many homeowners fail to send in samples because they think that it is not their responsibility (Sarkar et al., 2012). Environmental officials interviewed argued for stricter regulations to govern the management of private drinking water wells. Lee (2009) surveyed residents of Wheatland County in Southern Alberta to identify their views on responsibility for managing water quality; the residents responded that the provincial and municipal governments should be responsible while individual citizens should have less responsibility. According to homeowners, the top three barriers to undertaking preventative maintenance, in order of priority, were cost, lack of incentives, and lack of knowledge (Lee, 2009). It is apparent that greater clarity is required regarding who is responsible for what and accountable to whom.

Willingness to pay for improved water quality is a common metric for determining how strongly homeowners feel they need access to better water quality. Willingness to pay can either take the form of payments to a utility responsible for managing and improving drinking water infrastructure or the amount that homeowners are willing to pay for bottled water or home treatment units. Janmaat (2007) performed a survey in the Annapolis Valley on perceptions of water quality and willingness to contribute to improving water quality. He found that people who did not perceive a problem with their water quality did not want to pay for improving the system, while people who viewed their water quality as unsatisfactory did not feel they should be obligated to pay disproportionately for a system that is not providing them with good quality water. Such results are in contrast to the findings of Cho et al. (2005), who found that when facing iron and sulphate contamination issues, homeowners who were experiencing more significant water quality concerns were willing to pay more for improved water quality services. Polyzou et al. (2011) identified social capital as the main driver of the willingness to pay for improved water for a population in Greece. The main determinants of social capital included the trust a homeowner had in the general population, trust that the homeowner had in the government and local authorities (institutional trust), the involvement of a homeowner in formal and informal social networks as well as their interest in collective issues facing their community, and a homeowner's compliance with social norms. Wendimu and Bekele (2011) assessed willingness to pay in Ethiopia and found the following factors to have a positive correlation with willingness to pay for improved water quality: higher education level of respondents, higher household income, perceived poor water quality, smaller family sizes, and decreased age of survey respondent.

Water management and well maintenance information dissemination is not an easy process and authorities can become exasperated when they perceive that information is available but residents complain that they don't receive information that they would like. In their survey, Lee (2009) asked homeowners what topics they would most like to learn more about and their preferred methods of information access. The top three topics in order of priority were: a better understanding of the current water quality and quantity health in the county where the survey was undertaken, clarification of the true impacts on water quality and quantity of various human activities, and additional information on best practices for reducing the impact of agricultural activities (Lee, 2009). The top three preferred modes of communication, in order of preference, were demonstration sites, educational courses, and newsletters (Lee, 2009).

5.3 Interview Methodology

An interview process was undertaken in Samson Cree Nation to evaluate the influence that the factors discussed above have on the perceptions of water quality among Samson Cree Nation residents. This section provides details on the specific steps to complete community interviews for the research. The data utilized in this chapter is an amalgamation of interviews conducted by Travis Hnidan and me. The same survey was used for all interviews, included as Appendix C.

5.3.1 Ethics Review and Interview Development

The initial set of interview questions were developed by Travis Hnidan, my research supervisors and me. The focus of the interviews was to understand water use behaviour in homes, perceptions of water quality and boil water advisories, demographic information on the home and residents, and perceptions of the challenges to ensuring safe, reliable water for Samson Cree Nation. By performing personal interviews with Samson Cree Nation residents who have been involved in other components of the project we seek to provide context and discussion for the data while also allowing research participants a chance to provide their perspective on how the research can be best utilized in the community. The interview questions were reviewed by Joan Yee and Kyle Wonsiak from the Health Canada First Nation and Inuit Health Branch, and Mario Swampy and Murray Healy at Samson Cree Nation for comments and additions. In addition, the final set of interview questions was informed through the informal conversations that Travis and I had with community members during our first two months living in Samson Cree Nation which helped to inform us of the concerns and priorities of the general community. The interview questions were approved by the Research Ethics Board at the University of Alberta.

5.3.2 Conducting the Interviews

The interview participants were recruited from households where water samples were collected or where water meters were installed. The houses where tap water samples were collected were selected randomly based on the current water monitoring program of Maskwacîs Health Services. Metered households were selected through recruitment of volunteers at settings such as the band office and community events, and from households where well water was sampled. I conducted interviews with individuals who had their drinking water sampled and Travis conducted interviews at the households where water meters were installed.

Interviews were typically conducted in respondents' homes, although some were conducted in the band office. For my interviews, each home was visited initially without prior arrangement. If the homeowner or a long term resident was available at that time, the interview was conducted; otherwise a future time was arranged for the interview. In some cases, residents did not wish to participate in the interview component of the research. If, upon visiting the home at three different pre-arranged times, the home owner or a long term resident was not available the household was removed from the list of interviewees.

At the beginning of the interview, I provided a short introduction of the research project and objectives. Once the interviewee had a preliminary understanding, tobacco, tea, and water was offered to the interviewee to thank them for their participation and to acknowledge their involvement. Offering tobacco is a customary Cree protocol to acknowledging the time and knowledge being offered during ceremony and can preface requests or inquiries (Council on Aboriginal Initiatives, 2012). Prior to conducting interviews, we consulted with local elders in Samson Cree Nation to ask what the appropriate offering should be for the requests we were making. Interviewees were provided with the information and consent forms to review and sign to fulfil Research Ethics Board requirements. Travis and I helped to explain details of the study and address any concerns. Interviewees could choose to have their water quality data, their water meter data, and their interview data anonymized for distribution between the researchers, Samson Cree Nation, Health Canada, and in publication.

The survey questions in Appendix C were used as a guideline to ensure all required data was collected, but interviews were typically organic conversations during which we discussed the topics identified with interviewees free to ask questions and change topics as they liked. Interview responses were recorded both through written and audio recordings. Once the interview was completed, interviewees were given the opportunity to ask any further questions they had. Additional conversation was highly variable, and ranged from no further questions to two hour conversations during which interviewees provided additional thoughts on the challenges that Samson Cree Nation faces, ideas on how to move forward, and even personal histories and experiences. Interviewees were then given contact information for the research team if they had any concerns with, or corrections to, the information provided or if they wished to discuss anything further. Interviewees were also reminded that they may withdraw their participation from the project as per the information form provided.

A copy of the interview transcript and the signed information and consent form was returned to the interviewees at a later date, when they were once again invited to provide any corrections or changes to their responses. This open communication was considered important to engage interviewees as key contributors to the project. While none of the interviewees I spoke with had significant changes to their responses, several did appreciate the opportunity to review their responses and to be more engaged on a sustained basis.

5.3.3 Data Compilation

After completion of each interview, we transcribed responses into summary documents that we returned to interview participants in addition to a copy of the signed information and consent form. Interviewees were once again invited to offer any corrections or additions to the information they shared. The questionnaire included questions related to both water quality and water quantity however this chapter focuses on questions related to water quality. The survey results include houses on rural wells and houses on the Samson Cree Nation municipal system in the townsite near Maskwacîs. For homes on the municipal system, adapted questions were asked during the interview (for example, instead of “Do you trust your well?” the question “Do you trust your water source?” was asked) and this data is included in the results and analysis. The data were divided into quantitative and qualitative information for analysis. Quantifiable data included questions that could be analyzed numerically and sorted based on specific criteria. Qualitative data included the additional discussions and comments shared after the interview, particularly as they related to problems affecting their water quality and challenges that Samson Cree Nation faces in protecting their water.

Quantitative questions included:

- Do you trust your well (yes/no)?
- Number of residents in different age categories
- How old is the well?
- Have you ever had any problems with water quality or quantity (yes/no)?
- Do you use a water cooler (yes/no)?
- How much do you spend on bottled water or other source?
- Have you ever had a boil water advisory for your drinking water supply at this home?
- On a scale from 1-10, how highly do you think Samson Cree Nation leadership should prioritize protecting water rights?
- Would you be willing to pay a monthly fee for your water supply to cover maintenance and infrastructure upgrades (yes/no)?

Qualitative questions include:

- What do you do if you have a water quality or quantity concern?
- What do you think might be causing the contamination of your drinking water?
- Are you aware of the federal government's current structure for providing clean, safe water? Is it sufficient?
- Are you aware of proposed changes to the way provincial water resources will be managed? Do you think these will help or hinder water supply for Samson Cree Nation?
- What steps do you think could be taken to continue improving the provision of safe, sufficient water supplies to reserves?
- What topics do you think require further research to improve the quality of water and life on reserves?
- What do you hope to see as a result of this water study?

5.4 Results and Discussion

The results section is divided into quantitative and qualitative sections. The quantitative section focuses primarily on identifying the factors that affect the trust residents have in their wells as well as the impacts that their level of trust has on their behaviours. Based on these survey results, it is difficult to establish a causal relationship (for example, does bottled water use cause a decrease in trust of well water or does decreased trust in well water cause an increase in bottled water use?). Regardless, several correlations are identified and discussed. In the qualitative results section, a summary of some of the specific concerns brought up by interviewees are discussed.

5.4.1 Quantitative Results

Dividing the interview responses based on trust in water sources provides several interesting results. Table 5-1 summarizes the key findings which are discussed in detail below. The interview data were divided into whether or not the interviewee trusted their water source

TABLE 5-1: AVERAGED RESPONSES TO QUESTIONS ON WATER QUALITY PERCEPTION DIVIDED BY TRUST IN THEIR WATER SOURCE. N(YES)=8, N(NO)=14

Do you trust your well?	Yes	No
Average responses	- 62% use bottled water - 25% Presently or previously on BWA - 7.4 priority for water rights (out of 10) - 44% willing to pay for improved water - Average willingness to pay is \$42/month - 33% had children 5 years old or younger - 44% had residents 60 years or older	- 100% use bottled water - 92% Presently or previously on BWA - 9.7 priority for water rights (out of 10) - 62% willing to pay for improved water - Average willingness to pay is \$30/month - 50% had children 5 years old or younger - 38% had residents 60 years or older

For bottled water usage, 100% (14 of 14) of homes that do not trust their water source use bottled water for at least part of their water consumption while only 62% (5 of 8) of homes that trust their well use bottled water. Spence and Walters (2012) reported that on aggregate, 64% of households on reserves in Canada use bottled water which is 18% higher than the general Canadian population. This finding agrees with Talatala (2008) who found a moderate correlation between the perceived health risks of the tap water available and the use of bottled water. An important question, then, is: do people use bottled water because they do not trust their well, or do they not trust their well because they use bottled water? While the former relationship is the more logical explanation, factors such as the marketing of bottled water, conditioning to particular water quality characteristics, or variations in individual preference could lead to distrust of well water as a result of becoming conditioned to bottled water. One interviewee, who did not wish to be identified by name, commented that they were thinking of getting a water cooler in the near future. When I asked if they had had any previous problems with their water quality to justify purchasing a water cooler they replied that they had not, but that they had heard the water coolers used mountain spring water, which they considered to be a better water source. If a home switches to a bottled water source as a result of marketing, the residents may become accustomed to the bottled water and begin to distrust their well water even if it does not present any direct health risks. A better understanding among community members of the potential health concerns related to their water source may help save residents money in unnecessary bottled water costs. But more importantly, it can help to bring greater peace of mind and empowerment to be able to address their concerns and protect their own water.

When asked if they have ever been on BWA, 25% (2 of 8) of the interviewees who trusted their water source answered in the affirmative, compared to 92% (12 of 13) of interviewees who did not trust their wells. Such a difference in opinion based on previous BWAs makes sense - individuals who have been told they are on BWA either currently or in the past will be less likely to trust their water source in the future. This result agrees with the findings of Spence and Walters (2012) who found a positive correlation between the perceived risk of harm from consuming tap water and the water having been reported as contaminated within the past year. The connection between BWA and trust in well water is complicated however by the accuracy of residents' knowledge of their BWA status. For the interviewees who utilized wells for their water source, 12% (3 of 26) replied that they did not know whether or not they were currently under BWA. In addition, 18% (2 of 11) of the interviewees who reported they were under BWA were actually not under BWA, while 14% (1 of 7) of the interviewees who did not think they were under BWA were in fact on BWA. This discrepancy between a resident's perceived BWA status and their actual status according to Health Canada's records indicates a communication problem between Maskwacîs Health Services and individual homeowners. Kellie Soosay (October 25, 2013) told me that her family purchased a water cooler after a Community Based Water Monitor from Maskwacîs Health Services collected a water sample, explaining that they were testing for the presence of bacteria. This was the first time Kellie had ever thought that their water could be contaminated by bacteria, and they purchased a water cooler to prevent the possibility of getting sick from the water. When asked about the results of the testing, she replied that Health Services staff did not return to tell them - this indicates that the samples did not contain any bacteria. Improved communication between Maskwacîs Health Services and community residents about the purpose of the testing plus the results and follow-up activities would help to address these challenges.

When asked to rank the importance from low (1) to high (10) that band leadership should place on protecting water rights, residents who trusted their water source responded on average with 7.4 compared to an average of 9.7 from residents who did not. Once again, these results do not necessarily indicate causality; however, there is clearly a connection between trust in one's water source and the degree to which water rights require protection. This result agrees with the findings of Janmaat (2007) who reported that households that trusted their water source did not prioritize taking steps to ensure the future protection of their water quality as highly as those that did not trust their water source.

Willingness-to-pay for improved water is a common metric for prioritizing investment in improving water infrastructure (Cho et al., 2005, Polyzou et al., 2011, Wendimu and Bekele, 2011) with the value individuals and households place on having safe, clean drinking water is assessed to determine a monetary value for their water service. This is typically undertaken through market experiments but can also be assessed through interviews and opinion polls. In the case of Samson Cree Nation, we directly asked interviewees what they believe to be a fair monthly cost for water servicing to cover maintenance and infrastructure upgrades. Of those interviewees who trust their drinking water source, 44% (4 of 9) responded that they would be willing to pay for improved water services. Compare this to 62% (10 of 16) of interviewees who do not trust their water source responding that they would be willing to pay for water service, provided that their water improved in quality and reliability. These results agree with the findings of Cho et al. (2005) who reported that homes currently experiencing water quality problems were more likely to be willing to pay for improved water quality services. Counter to this finding however, many interviewees rejected the idea of paying for water for three main reasons: 1) water is a human right or a natural commons and should therefore be free for everyone, 2) water is a treaty right and the responsibility of the federal government to provide sufficient infrastructure and maintenance, and 3) because many households in Samson Cree Nation would simply not be able to afford to pay for water. Among those who responded that they would be willing to pay, the amount of money was typically based on their current expenditures for bottled water or in some cases, the amount of money that they paid for water utilities while living off-reserve.

Another factor which may impact household trust in their drinking water is the presence of vulnerable populations within the household: young children and elderly residents who may be more susceptible to the health effects of poor water quality. For example, 33% (3 of 9) of households that trust their water source had children five years of age or younger residing in the home compared to 50% (8 of 16) of households that did not trust their well. This result suggests greater concern about susceptibility of water to contamination in households with young children. Conversely, 44% (4 of 9) of the homes that trust their water source had at least one person living at the home 60 years of age or older compared to 38% (6 of 16) homes that do not trust their well indicating that the susceptibility of young children may be of greater concern than that of elders.

5.4.2 Qualitative Results

Qualitative questions pertained to: the parties responsible for ensuring safe, clean drinking water; the factors believed to negatively affect groundwater; and improvements that could be undertaken to ensure clean, safe drinking water. This section offers several observations from interview responses as they relate to drinking water quality. Residents' concerns do not represent objective measurements of safe, clean drinking water but instead represent barriers community residents perceive to be impeding their access to reliable drinking water access. Incorporating activities to address these perceived challenges when developing water quality strategies will help to ensure that Samson Cree Nation residents not only have access to clean water but also feel that they can trust their drinking water system.

The topics discussed below were mentioned a minimum of six times by interviewees and are the most commonly-heard concerns expressed by Samson Cree Nation residents during the interview process. Each section is prefaced with representative quotations from community interviews. Several interview participants requested that they not be identified by name and therefore the quotes are anonymized. However, the quotations provided in each section are from different individuals to highlight the diversity of perspectives held among Samson Cree Nation residents.

5.4.2.1 Communications Barriers

> "I didn't get a reply when the health center came and tested our water so we didn't know if it was clean or not."
>
> Peter Harvey, September 12, 2013

> "They have big band meetings but it's not worth going. It ends up being the same people repeating the same information. They should be sending someone to go door-to-door to explain the information to us."
>
> Judy Crier, September 12, 2013

One of the most significant limitations of Samson Cree Nation's existing water monitoring and treatment system, as identified by rural residents, is insufficient communication regarding water quality concerns. As noted in the quantitative results section, 12% of residents on a drinking water well were unsure as to their BWA status at the time of the interviews. Interviewees reported that they did not understand how the BWA system worked or that they assumed they were on BWA since Maskwacîs Health Services collected a sample but never returned with additional information. Rogan and Brady (2009) described the problems that communication breakdowns can cause vulnerable populations relying on rural groundwater wells. They recommended the development of systems to ensure full and complete information is provided to all actors in the health system, including residents, regarding groundwater quality and testing data as well as any incidences of waterborne illness. Kreutzwiser et al. (2011) identified insufficient information regarding water well operation as a limiting factor for undertaking preventative maintenance by residents and that a lack of information can lead to perceived problems with the water system. Improved access to information regarding water sampling results for individual wells and methods for maintaining wells and distribution system components would help to engage homeowners and educate them on best practices for ensuring safe, reliable water. Literacy levels and internet accessibility must be taken into consideration when planning information distribution strategies. Elderly interviewees commented that they would appreciate periodic visits from Samson Cree Nation staff to inform them of community events in addition to distributing information regarding water quality and well maintenance.

5.4.2.2 Oil and Gas Development

> "I'm against that fracking; it gets into the soil and the water. Once they crack that shale and let the gas out, they're not going to be able to get all of it."
>
> Samson Cree Nation Resident, September 13, 2013

> "Oil and gas wells have been causing trouble for a long time."

Samson Cree Nation Resident, September 13, 2013

Interviewees believed that oil and gas activities in Samson Cree Nation and the surrounding area has significantly affected groundwater quality in the Nation. Activities included seismic exploration and well development activities throughout the 1970's, 80's, and 90's. Interviewees noted that their water quality was good prior to the oil and gas activities in Samson Cree Nation but that problems such as increased turbidity, poor taste, and the presence of hydrocarbons in water appeared after oil and gas activities intensified. At the time of this research, extraction activities had largely ended and the consultation department was in the process of reclaiming many of the sites from salt damage. In addition, a project investigating the suspected presence of hydrocarbons in wells in close proximity to oil and gas activities was currently under way. The results of this study were not available at the time of writing this thesis.

5.4.2.3 Issues related to shock chlorination

> "The Health staff have been coming by and testing and shocking the well for a while now. We've sort of given up on it."

Samson Cree Nation Resident, September 13, 2013

> "Before they came and shocked the well the water was good. Now they're saying that it's not good and there's black stuff that comes out of the tap. After they shocked it the water quantity dropped too."

Keith Rain, October 25, 2013

As discussed in Chapter 2, when a home is placed under BWA, the usual course of action is shock chlorination. Shock chlorination disinfects the well and the drinking water system but can also release significant amounts of precipitate into the water depending on well and pipe materials. Household residents are told to run their water as much as possible immediately following shock chlorination to remove this precipitate and the remaining high chlorine concentrations. Despite this, interviewees responded that they experienced significant water quality problems following shock chlorination of their well, describing increases in precipitate and chlorine presence in the water. When asked if the problems went away, most individuals confirmed this, although some noted persisting impacts. This concern is significant and some interviewees reported no longer trusting Maskwacîs Health Services when the "solution" they proposed (shock chlorination) resulted in their water quality problems worsening. White (2012) reports that some Indigenous communities consider the addition of chemicals such as chlorine for water treatment to be disrespectful to water. Source water protection is often regarded as a more effective means of providing clean drinking water than water treatment processes since it prevents the need for treatment in the first place (White, 2012). For wells this would mean ensuring that groundwater is not contaminated in the first place.

5.4.2.4 Funding and Infrastructure Management

> "Traditionally, everything used to be based on nepotism where families would help each other out and share resources so that others would share with them when they needed it. But nowadays it's always the same families in power so that system doesn't work anymore. Some people get renovations on their homes every year while others have had problems for a very long time."
>
> Judy Crier, September 12, 2013

> "The feds release one lump of money to be spread out amongst all of the reserves. We're always going to have problems with the government. They only respond to national media, not to the actual demands of the people on the ground."
>
> Samson Cree Nation Resident, September 13, 2013

> (On a scale from 1-10, how highly do you think Samson Cree Nation leadership should prioritize protecting water rights?)
>
> "They should do whatever they can but I don't really see anything that they can do."
>
> David More, October 25, 2013

Interviewees expressed dissatisfaction with resource and infrastructure distribution to Samson Cree Nation on the part of the Federal Government. They believe that the Federal Government is not living up to their treaty commitments and that First Nations health programs are underfunded. Interviewees also pointed out that the distribution of funds between First Nations across Canada is often politically biased and not based on the needs of the people on the ground. In addition, interviewees stated that some families within Samson Cree Nation received more support from Band Administration than others. This perceived unequal distribution of resources at a local and national level produces distrust in institutions intended to ensure the provision of safe, reliable drinking water. Distrust can lead to future challenges with implementing programs and infrastructure projects to improve water quality in Samson Cree Nation if residents are less willing to participate in future programs. Investigating whether these concerns actually impact access to safe water is outside the scope of this thesis but they are noted here as concerns raised by interviewees.

Several interviewees commented that the way in which housing and infrastructure is managed on reserve may be an additional source of infrastructure degradation. Houses and the associated infrastructure is owned and maintained by Samson Cree Nation and upkeep is provided through the various band departments. However these departments are underfunded and are not provided with enough resources to address all of the challenges that exist. Interviewees pointed out that since houses are band-owned and managed, there is a lack of responsibility on the part of residents to perform maintenance on their wells and septic systems. Greater support empowerment of house residents to take part in maintaining their water systems was believed to be one way to ensure better access to clean drinking water.

5.4.2.5 Poor Quality Source Water/Shallow Wells

> "To me, I think we need a new well. The other well we used to have was a lot deeper and had better water."

Samson Cree Nation Resident, September 13, 2013

Interviewees generally believe that deeper wells provide better quality drinking water. Several interviewees reported that their well is too shallow which has contributed to the bacteriological contamination of their drinking water. Some interviewees simply stated that groundwater is not good, without explaining why they believed this to be the case. It is not clear what factors cause this generalized perception of poor water quality, although as Doria (2010) found, it is the organoleptics of the water that often play a larger role in influencing people's perceptions of their water quality. Common water quality concerns in Samson Cree Nation include precipitate particles, rust staining, sulfur odor, and general poor taste.

5.5 Conclusions

Interview data collected from residents of Samson Cree Nation showed that a lack of trust in their drinking water source impacts both residents who use private drinking water, and those who rely on the municipal treated water distribution system. Factors related to a lack of trust in water source included:

- increased use of bottled water;
- past or present BWA;
- increased priority placed on band leadership protecting water rights; and

- an increased willingness to pay for improved drinking water provision compared to individuals who do trust their water source.

Interview respondents identified challenges that contribute to poor drinking water quality or poor understanding of water quality issues: poor communication of testing data and well management practices, oil and gas development in Samson Cree Nation, problems created during shock chlorination, and poor management of resources on behalf of the federal government and Samson Cree Nation leadership. Improving the communication between various actors within the drinking water monitoring system may create greater trust among residents and provide new ways to address the contamination problems they face. These communication strategies must acknowledge the specific context of Samson Cree Nation including limited transportation for many residents, limited internet access, language and literacy barriers, levels of technical understanding, and appropriate cultural protocols.

Perceived poor water quality was most often associated with poor organoleptic qualities of the water or changes in organoleptics such as precipitate presence, bad smell or taste, and rust staining of clothing and sinks. It is evident based on this information that Maskwacîs Health Services' current practice of testing for total coliform and *E. coli* is not sufficient to identify and address community concerns. As Myron Applegarth told me, "The water smells terrible, there are black bits that come out, it's unusable, undrinkable but the water samplers came and took a sample and told us that it's fine" (November 1, 2013). Consideration should be given to the perceptions discussed in this chapter when implementing strategies to address poor drinking water quality in Samson Cree Nation. This will help to ensure that residents not only have access to safe drinking water, but also will help to ensure that they trust their drinking water system.

5.6 Further Research

The interview findings provide a general impression of perceived water quality problems, and a variety of future research questions may clarify the specific relationships between perceptions and behaviours related to water quality, and the management and testing of water quality. A better understanding of the causal relationships between water quality parameters, environmental factors, motivating factors to empower residents, and perceptions of water quality will provide a better understanding of how water quality testing and management can done to support the wellbeing of Samson Cree Nation residents. Specific future research questions for investigation are listed below.

- What is the level of understanding that Samson Cree Nation residents have of water well maintenance practices and the employment of those practices to improve their water quality?
- What are the causal relationships between water quality indicators, environmental factors, and perceptions of water quality?; and
- What is the relationship between the marketing of water alternatives, including point-of-use treatment units, bottled water, and others, and perceptions of water quality?

There are also many questions relating to the impact of perceived poor water quality on household behaviour and wellbeing. Research questions that will help explain this relationship are listed below.

- What is the relationship between perceptions of poor drinking water quality and the incidence of diabetes as related to the consumption of high sugar alternatives such as soda and fruit juices?; and
- What is the relationship between the incidence of waterborne illness as verified through epidemiological investigation and the perceptions of water quality?

By improving the understanding among Samson Cree Nation residents of the way their water systems operate they can be more directly engaged as active members of ensuring their access to safe, clean drinking water.

Chapter 6: Moving Forward

6.1 Conclusions

This chapter will provide an overview of those items discussed in the previous chapters and summarize the key findings and ideas which may be of benefit to Health Canada and Samson Cree Nation in ensuring clean water access for all residents. The findings of this thesis are discussed in terms of steps that may be taken to move forward with improving the quality of drinking water of residents within Samson Cree Nation.

6.1.1 Water Quality Monitoring

The current system of water quality monitoring for rural drinking water wells in Samson Cree Nation involves annual sampling for total coliforms and *Escherichia coli* by staff from Maskwacîs Health Services. If bacteriological contamination is confirmed, the house is placed under boil water advisory and is shock chlorinated to eliminate the bacteriological contamination. If a well is repeatedly shock chlorinated and the bacteriological contamination persists, the Environmental Health Officer performs further testing and investigation to determine the cause of contamination and propose a strategy to remediate the problem.

While this system works towards ensuring the provision of safe, clean drinking water, it has several limitations including:

- Limited monitoring of physical and chemical water quality parameters which are often of greater concern for Samson Cree Nation residents than bacteriological contamination;
- Limits to the effectiveness of *E. coli* and total coliform monitoring as indicators of more pathogenic bacteria, protozoa, and viruses;
- Limited ability to identify the source of contamination;
- Limited ability to detect seasonal variation in drinking water quality from a single well;
- Poor perception of shock chlorination by many residents; and
- Poor communication of monitoring results and uncertainty on behalf of residents as to the quality of their water.

6.1.2 Sources of Contamination

Historical sampling data and records of other factors that may influence groundwater quality in Samson Cree Nation were analyzed to identify the primary sources and pathways of contamination in drinking water wells. The data records analyzed included: well installation records, weather data, chemical and bacteriological sampling data, and results from a septic system inventory. The most significant factors found to influence the risk of bacteriological contamination in wells were:

- Seasonal precipitation. A two month lag was observed between the months receiving the greatest amount of precipitation (June – August) and a peak in the percentage of samples showing total coliform or *E. coli* contamination (August – October). This could indicate that surface water infiltration has a significant effect on groundwater contamination and the incidence of boil water advisories in Samson Cree Nation.
- Well age as divided by well installation contractor. By categorizing wells based on whether or not they have ever been on boil water advisory, I found that the installation contractor had a significant impact on the susceptibility of the well to bacteriological contamination. Well contractors tend to operate in Samson Cree Nation over a fixed period of time, during which they install the majority of wells. Wells installed by contractors over 33 years ago are more likely than not to have been on boil water advisory at some point whereas newer wells were not as susceptible to contamination.

Septic systems in Samson Cree Nation are often regarded as a potential source of contamination of drinking water wells. Data was analyzed for household occupancy and overland distance between septic system discharge and water well head. Neither of these factors was found to have a significant impact on the risk of contamination in the drinking water wells assessed.

Based on this historical data review, a water sampling program was undertaken in the summer of 2013. The main focuses of the sampling were the relationship between surface water infiltration, well age and depth, and bacteriological contamination. In addition, the concentration of metals were analyzed to investigate high metals concentrations found in the historical data review and to examine relationships between chemical and bacteriological contamination. Wells older than 27 years and shallower than 250 feet were more prone to surface water infiltration and bacteriological contamination than newer, deeper wells. Exceedances of the Canadian Drinking Water Quality guidelines were detected for sodium, manganese, arsenic, and antimony but there was no clear relationship between exceedances in chemical compounds and bacteriological contamination.

6.1.3 Perceptions of Water Quality

Following the water sampling, a set of interviews was conducted with Samson Cree Nation residents to understand their perceptions of water quality and the problems that they face with ensuring access to safe, clean drinking water. Factors that were related to distrust of drinking water quality included:

- 61% more likely to use bottled water for drinking;
- 268% more likely to have been previously or currently be on boil water advisory;
- 31% higher priority on Samson Cree Nation leadership protecting the Nation's water rights; and
- 41% more likely to be willing to pay for improved drinking water servicing.

Interviewees were also asked to identify what they believe to be impacting their access to safe, reliable drinking water. Many interviews did not share additional thoughts but the most common challenges identified (brought up by interviewees in >6 interviews) included:

- Insufficient information about monitoring results and activities to improve the drinking water system;
- Oil and gas development and exploration within Samson Cree Nation and the surrounding area;
- Problems caused by the shock chlorination of wells;
- Insufficient funding and poor management of infrastructure and programs by the federal government and Samson Cree Nation leadership; and
- Generally poorly built infrastructure and poor quality groundwater.

6.2 Final Thoughts

Access to safe, reliable drinking water in First Nations across Canada is significantly lower than non-First Nations communities. This challenge exists and is perpetuated by a myriad of factors which must be considered when developing short- and long-term strategies for ensuring water access on reserve. These include political, social, cultural, historical, technical, and economic factors which obviously fall outside of the scope of this thesis. But these factors must still be kept in mind when discussing solutions to avoid developing strategies in isolation which will not work in the "real world". As an outsider to Samson Cree Nation, I acknowledge that the strategies and policies utilized to move forward on the water portfolio are ultimately the prerogative of Samson Cree Nation's leaders and broader membership. I offer the following thoughts as conclusions and recommendations informed by my experiences and research within the community to support this ongoing work.

6.2.1 Implement multi-barrier approach strategies to water management

Throughout this thesis, I have identified that the current monitoring regime has many limitations to providing comprehensive water quality protection for homes using rural wells in Samson Cree Nation. Implementing additional water quality testing several times per year and at times when risk is higher will likely improve the ability of Maskwacîs Health Services and Samson Cree Nation staff to detect and remediate problems when they occur. However, this will not come without increased cost and time and will continue to be more reactionary than proactive in addressing water quality problems. Multi-barrier approaches are strategies for ensuring safe, reliable drinking water by implementing interventions at multiple points along the water system and not just at the tap (Thompson et al., 2003, Davies and Mazumder, 2003). The multi-barrier approach consists of five main components: source water protection, robust water treatment, secure water distribution network, water quality monitoring, and prepared response plans. The approach is typically discussed in the context of municipal drinking water systems but can be applied to rural drinking water wells in the following manners:

1. Source Water Protection
   a. Identifying and properly capping abandoned water and hydrocarbon wells throughout the Nation;
   b. Properly maintaining septic systems; and
   c. Managing land use policies within the Nation and working with other entities in the Battle River watershed to protect groundwater supply.
2. Robust Water Treatment
   a. Reverse osmosis, point-of-use UV disinfection, or other treatment technologies in homes with recurring contamination problems; and
   b. Shock chlorinating problem wells when contaminated and supporting residents in performing their own chlorinations seasonally.
3. Secure Water Distribution Network
   a. Ensuring proper maintenance of hot water heaters, water softeners, pressure tanks and other infrastructure between the well and the tap; and
   b. Provide training for residents to support household level maintenance.
4. Water Quality Monitoring
   a. Continuing to monitor for bacteriological and chemical contamination on regular intervals and ensuring residents are informed of the quality of their water; and

    b. Identifying representative wells that can be used for periodic monitoring of additional concerns such as hydrocarbons, pesticides, or other contaminants.
5. Prepared Response Plans
    a. Developing strategies for addressing contamination concerns from various sources;

These strategies will require dedicated planning and implementation over time as well as adequate funding.

6.2.2 Improve communication channels between band administration, Maskwacîs Health Centre, Samson Trade Centre, and residents

Communication barriers are a challenge that Samson Cree Nation residents identify as a source of their distrust in their water quality. When it comes to public health from the perspective of an individual or household, no news seems to be taken as bad news, and a dearth of information often leads people to fear the worst and take potentially unnecessary preventative actions. Conversely, if homes are not adequately informed of problems with their water supply or actions they could take to protect their water they may be put at risk of illness from contaminated drinking water. Clearer communication is necessary to ensure that Samson Cree Nation residents are well informed and equipped to play an active role in protecting their drinking water.

Residents interviewed identified several outreach strategies they would find helpful including:

- sending staff members door-to-door to speak with residents;
- hosting regular open band meetings to discuss issues related to drinking water;
- provide information online for residents to access test results and maintenance information; and
- distributing pamphlets and other information at the band office.

Communication strategies should be cognizant of literacy rates within Samson Cree Nation, internet access in the rural areas of the Nation, and attitudes towards whose responsibility it is to provide drinking water. The strategies implemented must also seek to achieve the greatest impact with the limited staff and resources that may be available to such work. By engaging Samson Cree Nation residents as active participants in the drinking water system the system can be made more resilient through their involvement.

6.2.3 Develop comprehensive data storage and management tools for Samson Cree Nation

There exists a large volume of data relating to water quality and drinking water infrastructure in Samson Cree Nation. However, this data is stored in numerous different locations and in a variety of incompatible formats. I have attempted to synthesize a body of this data and identify numerous concerns that can form the foundation of interventions. But this project was not completely exhaustive and further data analysis may answer additional questions detailed in the "Further research" sections of Chapters 3 and 4. Currently the available data is dispersed between multiple different entities, departments, and formats. On one visit to the Samson Trade Centre to ask about what information they had available relating to boil water advisories in the rural wells, I was shown a stack of paper two feet tall which represented the database available to the Trade Centre staff. By compiling all of the available data in a single format, Samson Cree Nation will be able to analyze new and emergent challenges to identify the sometimes unexpected relationships between a variety of factors.

6.2.4 Establish a water department within band administration

Currently, services related to water quality including monitoring, well servicing, infrastructure planning, negotiating funding with the federal government, and information dissemination is distributed among several different departments within Samson Cree Nation's administration. All of these different actors within the system are typically more focused on addressing the short-term, immediate challenges being faced. This limits Samson Cree Nation's ability to perform long-term planning and strategy development for ensuring the provision of safe, reliable drinking water for Samson Cree Nation residents in ways that are driven by Samson Cree Nation's interests. As a result, problems are often approached with "band-aid" solutions that do not solve the deeper, more systemic problems that Samson Cree Nation faces in protecting their water and providing access to all residents.

The development of a dedicated water department within Samson Cree Nation's band administration will provide a hub for the long term planning of water infrastructure development and advocating on behalf of Samson Cree Nation's interests when it comes to funding and regulating this infrastructure. This work has already begun with the establishment of the Nipiy Committee under the leadership of Councillor Mario Swampy and the findings of this thesis support the continued development of this committee. Nipiy means "water" in Cree and this committee represents an assertion of self-governance on the part of Samson Cree Nation to address water issues on the Nation's own terms.

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Appendix A: Raw Data

The raw data which has been collected as part of this project is the property of Samson Cree Nation and is to be accessed and utilized at the discretion of the appropriate personnel at the Samson Cree Nation band administration office. If you wish to access the raw data which formed the basis of this thesis, please contact Fraser Mah at fjmah@ualberta.ca.

Appendix B: Information and Consent Form for Individual Interviews

INFORMATION LETTER and CONSENT FORM

Study Title: Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for the Samson Cree Nation

Research Investigators:
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Background

Our study is a collaboration between Samson Cree Nation, Health Canada, the Research Investigators named above, and their supervisors at the University of Alberta to 1) identify the causes of water contamination leading to boil water advisories throughout Samson Cree Nation and 2) determine how residents in Samson Nation use water in their homes, and thus how they may be exposed to water contaminants. The project is focusing on private drinking-water wells as the main water sources affected by boil water advisories.

You have been asked to participate in this study to improve our understanding of the environmental factors that may be contributing to water contamination. Your perspective and insight will help us to understand how water is used and how challenges can be addressed. You've been selected to participate in the research through a connection to the Research Investigator.

This project is being funded by Health Canada, NSERC, and Mitacs and the data collected will be used to develop a strategy to reduce the number of boil water advisories affecting Samson Cree Nation. The data collected will also be used as a component of our thesis work at the University of Alberta.

Purpose

The research project seeks to develop an understanding of the causes of boil water advisories in Samson Cree Nation and propose a strategy for reducing the frequency and duration of boil water advisories there. This strategy seeks to be both technically effective at reducing boil water advisories, but also culturally and socially effective with respect to citizens of Samson Nation and the partnerships between Health Canada and Samson Nation.

We aim to develop a better understanding of common causes of water well contamination as well as a strategy applicable to other Nations facing similar water contamination problems. In addition, the effect of water well contamination on daily life and water use will be examined in order to support better response strategies for contamination when it does occur.

Therefore, the research project will collect information on how residents of Samson Nation use water within their homes. This will allow for a comparison of water use between residents served by the municipal water system, residents using a private water well, and residents using a private water well currently under a boil water advisory. This information will be used to create a robust future water supply plan for Samson Cree Nation.

Study Procedures
Research participation will involve three main components. You may be asked to participate in all of the components or only a few. These components are 1) interviews, 2) water use monitoring, and 3) water quality testing. Each section is detailed below.

1) Interviews

The interview component of the research procedure seeks to understand water uses and the impact of boil water advisories on daily life. Interviewees will be selected by Research Investigators. Criteria for selecting interviewees include, but are not limited to, the interviewee's: willingness to have a water meter installed in their home; willingness to participate in an interview; geographical or other statistical relation to other interview participants, and; drinking water being tested previously by a Research Investigator. Your confidentiality is explained below under "Confidentiality and Anonymity".

The interview will take approximately 30-45 minutes. During the interview, an audio recording (referred to as the "Interview Recording") will be collected with your permission in order to ensure accurate information is collected. Notes will be taken during the interview ("Interview Notes"). Information pertinent to environmental engineering and water resources engineering will be transcribed ("Interview Transcript").

The Interview Recording will be stored on the computers of the Research Investigators. Hard copies of the Interview Notes will be scanned and the digital copies will be stored on the computers of the Research Investigators. The Interview Transcript will be stored on the computers of the Research Investigators and their supervisors at the University of Alberta. All computers containing research materials will be password protected.

The Interview Transcript will be provided to you for review and the information in it can be amended at this time.

2) Water Metering

To understand the impact of boil water advisories on water usage, some households will be asked to volunteer for the installation of a water meter to measure the amount of water that is used for daily uses such as drinking, washing, and bathing. This information will provide information on how much water is used by households that are affected by boil water advisories compared to those that are not or those on the municipal system. The water meters do not take up significant space. The installation of the water meter will take approximately two hours and monthly inspections may be performed to collect the data. Data collection will take only half an hour per month and will be scheduled with household residents. This data will be collected over the course of up to 12 months in order to collect data through a full year period.

3) Water Quality Testing

To improve understanding of the potential sources of bacterial contamination of water sources, water samples will be taken from several households to identify the probable source of contamination. Samples may be taken at several points between the well and the tap to identify contaminant source. The water sampling will be performed in conjunction with regular Health Canada water sampling or the interview visit, and may take up to 20 minutes.

Benefits
You will not directly receive any financial compensation from the study. All data from your water use and water quality monitoring will be provided to you. The completed data will be utilized to develop a strategy for reducing boil water advisories on Samson Cree Nation which will improve public health and the standard of living across the entire Nation. The data will also be used by Samson Cree Nation in the development of best management practices and for future water resource management and planning. In addition, we hope that the data collected will provide a framework and information that can be utilized on other First Nations and rural communities to decrease the incidence of well water contamination.

Risk
This study will not result in any foreseeable risks. Sampling will be performed and monitoring equipment will be installed by trained individuals.

Voluntary Participation
Participation in this project is entirely voluntary and you are under no obligation to participate. During any component of the study, if you no longer wish to participate please inform Fraser Mah or Travis Hnidan. If you do not wish to answer any of the questions asked during the interviews, you are under no obligation to do so; please let your interviewer know and they will move to the next question.
If you wish to change or withdraw your data from the information collected, you may do so by contacting Fraser Mah or Travis Hnidan at the contact information at the top and bottom of this form. You can withdraw participation from water metering within one month of water meter installation. You can withdraw participation from water quality sampling within two months of sample collection. You can withdraw or change your interview data within two months of the interview date. Your water metering, water quality sampling, or interview data will then be removed from the information reported and not utilized for future analysis.

Confidentiality & Anonymity
The data that is collected will be used by Samson Cree Nation, Health Canada (at the discretion of Samson Cree Nation), the Research Investigators named on this form, and their supervisors at the University of Alberta. Data will be compiled into internal reports between the University of Alberta researchers named on this form and Samson Cree Nation. Data will be used for publishing in journals and at conferences, and for research theses. No personally identifying information will ever be used in published materials without the explicit consent of the individual who provided it.

1) Interview Data

The Interview Recording and Interview Notes will not be distributed to anyone other than the Research Investigators and their supervisors at the University of Alberta. Portions of the Interview Transcript may be used in publications and will be provided to Samson Cree Nation and Health Canada (at the discretion of Samson Cree Nation).

I am willing to be personally identified as the source of the information I provide in the Interview Transcript available to Samson Cree Nation, Health Canada, and in publication.
_____ Yes _____ No

If 'No', I consent to being personally identified in the Interview Transcript to the following parties:

2) Water Metering Data

The data collected from the installed water meter will be used in publications and will be provided to Samson Cree Nation and Health Canada (at the discretion of Samson Cree Nation).

I am willing to be personally identified as the source of the data collected from the water meter installed in my home available to Samson Cree Nation, Health Canada, and in publication.
_____ Yes _____ No

If 'No', I consent to being personally identified as the source of information for the Water Metering Data collected from my residence to the following parties:

3) Water Quality Testing Data

The data collected from the water quality testing done on the water provided to my home will be used in publications and will be provided to Samson Cree Nation and Health Canada (at the discretion of Samson Cree Nation).

I am willing to be personally identified as the source of the data collected from the water quality testing in my home available to Samson Cree Nation, Health Canada, and in publication.
_____ Yes _____ No

If 'No', I consent to being personally identified as the source of information for the Water Quality Testing Data collected from my residence to the following parties:

Data will be stored on the password-protected computers of the Research Investigators and their supervisors at the University of Alberta for the duration of the study (August 2014). At the discretion of Samson Cree Nation this data will be stored indefinitely on the password-protected computers of the Research Investigators named on this form and their supervisors at the University of Alberta. The data to which the participant has consented to sharing with Samson Cree Nation will be stored on the password-protected computers of Samson Cree Nation Staff upon completion of the study (August 2014) indefinitely. The data stored by Samson Cree Nation may be shared with Health Canada at the discretion of Samson Cree Nation and would then be stored on the password-protected computers of Health Canada staff.

A summary of the participant's interview, water metering data, and water quality data will be provided in hard copy or digital copy (at the preference of the participant) to the participant within six months of the completion of data collection.

The data obtained from this study may be used in future research, but any future use must first be approved by a Research Ethics Board.

Further Information

If you have any further questions regarding this study, please do not hesitate to contact:

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The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

If there are any additional conditions which you would like to add to this agreement, please fill it out on the lines below and discuss the conditions with the researcher you are working with:

____

Statement of Consent

I, __________________________ , have reviewed and understand the participant information for the project titled Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for the Samson Cree Nation and consent to my participation in the project as requested. My participation can be ended at any time upon request during the interview with no consequence.

Name (printed)	**Signature**	**Date**

Appendix C: Interview Questions

INTERVIEW FORM

UNIVERSITY OF ALBERTA

Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for the Samson Cree Nation

Interview Participant | Name: ______

Contact Information | House #: ______ Phone: ______
Email: ______

Interview Details | Location: ______ Start Time: ______
End Time: ______
Address: ______
______ Date: ______

Interviewer | Name: ______

Home and Well

Who is the homeowner? ______

How long have you lived here? ______

How many people live here full-time?

- infants and toddlers <3 years old ______
- younger children age 3 – 5 years old ______
- older children age 6 – 12 years old ______
- teenagers age 13 – 17 years old ______
- adults age 18 – 59 years old ______
- elderly people >60 years old ______

Does this change throughout the year? ______

How many people are away from the house during the day? ______

What times of day are you typically using the most water? ______

What is the date of well installation? ______

Who installed the well? ______

Anything around the wellhead? ______

Livestock around the well? ______

Septic tank or septic field? ______

How often is your septic tank emptied? ______

Do you have a septic shootout? ______

Where does the waste go? ______

Do you have a water softener? ______

Any systems between your well and your tap?

reverse osmosis ______ other ______
uv system ______

Are they maintained? ______

By whom and how often? ______

Any problems with water quality? ______
______

Any problems with water quantity? ______
______

What do you do if you don't have water? ______
______

Who can you contact if you don't have water?

What do you do if you have a water quality concern?

Who can you contact about water quality?

Where do you get drinking water?

Do you trust your well?

Toilet

How many?

Low flow?

Make and model?

Clothes Washer

Front or top loading?

Make and model?

Loads per week?

Time of day?

Shower

How many showers with tubs?

Solo showers?

Tubs only?

Tubs with jets or indoor spa?

Showers per day?

Baths per week?

Low flow showerheads?

Hand-held sprayer?

Multiple showerheads?

Faucet

How many faucets in home?

Garbage disposal?

Garage or utility sink?

Leak

Do you know of any leaks in your home?

Dishwasher

Loads per week?

Make and model?

Outdoor

Do you have any of the following?

Hot tub?

Pool?

Garden?

Lawn?

Livestock?

How often do you wash a car?

Do you water your landscape?

How much of your landscape is lawn?

How often do you water your lawn during the summer?

How much of your landscape is garden?

How often do you water your garden during the summer?

How much of your landscape is other landscape plants?

How often to you water your landscape plants during the summer?

Do you have any other sources of water?

Canal/Ditch

Stream

Cistern

Rainbarrel

Sprinkler system

Other

Do you use water for any other purpose that has not been asked?

Boil Water Advisories

Where do you get your drinking water from if it is not your water well?

Have you ever had a boil water advisory for your drinking water supply at this home?

When and how long were you on boil water advisory?

If yes, do/did you boil your water before drinking?

Why do you not drink your well water?

How much do you spend on bottled water or other source?

When on BWA, do you still use well water for other purposes?

Which purposes?

What do you think might be causing the contamination of your drinking water?

Other

Are you aware of the federal government's current structure for providing clean, safe water? Is it sufficient?

Are you aware of proposed changes to the way provincial water resources will be managed? Do you think these will help or hinder water supply for Samson Nation?

What steps do you think could be taken to continue improving the provision of safe, sufficient water supplies to reserves?

On a scale from 1-10 how highly do you think Samson leadership should prioritize protecting water rights (1 is not a priority, 10 is top priority)?

What role do you see band leadership having in ensuring clean, safe drinking water?

What role do you see the federal government having in ensuring clean, safe drinking water?

Would you be willing to pay a monthly fee for your water supply to cover maintenance and infrastructure upgrades?

How much is a fair price?

Why not?

What do you think the role of research projects to be in improving the quality of water and life on reserves?

Do you know any studies that impacted life on reserve?

What do you hope to see as a result of this water study? What outputs do you think would best support quality of life for Samson residents?

Site Assessment

Follow Up

Thank you very much for your participation. The information you've shared will help Samson Nation to develop a plan for improving water management on the Nation.

Did you have any questions for us?