Domestic water use in Samson Cree Nation

by

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Abstract

Samson Cree Nation partnered with researchers at the University of Alberta to conduct a water resources analysis of their water systems. This thesis describes a community-based research approach used to explore domestic water use in Samson Cree Nation, the variables that effect domestic water use in Samson Cree Nation, and the design of system dynamics models of Samson Cree Nation's water systems. Domestic water use in Samson Cree Nation averages 221 litres per capita per day although rural residents use 31 percent less water (195 litres per capita per day) than municipal residents (283 litres per capita per day). Outdoor water use is very low in Samson Cree Nation and no seasonal or climatic patterns were found. Average water use in Samson Cree Nation depends on water system type, drinking water source, household size, household occupancy during the day, leakage, and clothes washer use frequency. The system dynamics models highlight the importance of community-based work and community-lead initiatives to managing water resources.

Preface

This thesis is an original work by Travis Hnidan. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for the Samson Cree Nation”, Study ID Pro00032380, October 18, 2012.

While this thesis is my original work, the discussed research and stated conclusions are based partially on a collaboration with Fraser Mah, a fellow graduate student in environmental engineering. Fraser entered into this research relationship with Samson Cree Nation with me. We divided the work between water quality (Fraser) and water quantity (me). However, we assisted one another greatly beyond our respective scopes of research and these two fields of study are therefore not easily separated.

Fraser and I come from similar backgrounds: we both were born and raised in Alberta cities, completed undergraduate degrees in engineering at the University of Alberta, and volunteered with Engineers Without Borders Canada. Our knowledge of and experience with Indigenous peoples was limited, so beginning this shared research project was exciting but also wholly unfamiliar.

As we progressed in our research, living in Samson Cree Nation and interviewing community members, we discussed exhaustively our thoughts, feelings, confusions and questions, and how we could best support this community. Certainly we shared some of these discussions with members of Samson Cree Nation, friends, and other researchers but most were tested, filtered, or influenced by each other first. We tried to hold each other accountable to how we understood our research and relationships with folks in Samson Cree Nation, meaning challenging one another to think and work in ways which are more supportive of the community and its goals. As a result, despite the fact that we have produced separate theses, they represent very much a collaborative effort.

Our process of working together has been mutually enriching and I am grateful for Fraser’s support.

Acknowledgements

First and foremost, I thank everyone who has taken the time to speak to me about this research. In one way or another, you have influenced my thinking and the content of this thesis. Members of Samson Cree Nation, whether you participated in formal interviews or simply asked what I was doing in your community, I hope you can see the impact you have had in this work. Thanks to you and your families, especially those who welcomed me into their homes.

For teaching me how to research and manage the joys that come with it, thank you to my supervisors and professors at the university. The lessons I have learned should be evident and the ones I have not in no way reflect your abilities as instructors.

For working with me, or letting me work with you, in Samson Cree territory, thank you to Samson Cree Nation Chief & Council, and staff at the Band Office, Maskwacîs Health Services, and the Trades Centre for making this research a reality.

For providing me with a productive work environment and an optimism for consulting, thank you to the employees of Urban Systems; the work you all do and the way you do it is inspiring.

For keeping me fed and providing a research budget, thank you to those who financially supported this research: Health Canada, First Nations University, Natural Sciences and Engineering Research Council of Canada, and Urban Systems Ltd.

Finally, to my friends and family for tolerating and supporting me through the ups and downs of research and life, thank you all. It has been a blast.

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CHAPTER ONE

Studying domestic water use in Samson Cree Nation: Project background and research objectives

1.1 Research context

In 2011, concerns over the quality of life in First Nations reserves received significant media attention. The department of Aboriginal Affairs and Northern Development Canada (AANDC) released the *National Assessment of First Nations Water and Wastewater Systems* (Neegan Burnside, 2011a) which estimated that $1 200 000 000 was needed to bring First Nations water and wastewater systems up to “safe” levels. In October of that same year, Attawapiskat First Nation declared a state of emergency due to health and safety concerns from insufficient housing and infrastructure. About one year later, the Idle No More movement began and in February of 2012, the Assembly of First Nations hosted their National Water Conference.

Although the concerns raised by Indigenous communities were diverse, there was and continues to be a focus on water and infrastructure problems in these communities, and legislation and engineering seemingly hold the solutions to these problems. While this focus on technical problems does not address the root problem of colonization, there are significant technical details about the uneven water status between First Nations reserves and other communities in Canada:

- boil water advisories are 2.5 times more common in First Nations communities (Patrick, 2011);
- 30 percent of First Nations community water systems are classified as “high risk” (Neegan Burnside, 2011a); and,
- water borne infection rates in First Nations communities are 26 times higher than the national average (Patrick, 2011).

Generally, water-use in rural areas is a field with little data or understanding. Typically lacking in centralized distribution, each rural community faces unique challenges in managing water resources with fewer opportunities for knowledge transfer compared to urban water utilities. The largely rural nature of many First Nations or Indigenous communities exacerbates the unique challenges they face. Rural water systems like cisterns, truck-fill stations, or regional water lines provide some indication of water demand among users but private groundwater wells—since source, treatment (if any), distribution, and consumption are all localized—require household-level data collection to measure demand. Neegan Burnside (2011a) reported that 14 479 First Nations households across the country receive water from rural private wells. In Alberta, 31% of First Nations households and 75% of Samson Cree Nation households receive water from private wells (Neegan Burnside, 2011b). This is a significant number of water users for whom there is no water use data, and thus no method to properly manage their water resources in response to their water demand, or vice versa, and plan for future water use scenarios.

There are also concerns about the municipal water distribution system. According to Aquatic Resource Management (2011), at current water demand rates Samson Cree Nation could exceed their water treatment plant supply capacity by 2015. In their *Water Needs Assessment to Support Anticipated Population Growth on Maskwacîs Cree Nation Lands*, Aquatic Resource Management (2011) recommended using water meters to determine exact water demand for this unmetered community. This thesis focuses on characterizing water demand on a household level to ensure adequate water supply for future generations in Samson Cree Nation. Specific household-level information helps determine what the main drivers of residential water demand are in Samson Cree Nation and by collecting data and speaking with residents we can understand the components of Samson Cree Nation's water systems. All of this information will support Samson Cree Nation in deciding the best ways to manage their water resources.

I am a settler engineering student, living and working on Indigenous land in Treaty Six territory. My family is of Ukrainian and western European descent. I was born and raised in Calgary, Alberta (Treaty Seven territory) and—at the beginning of this research—had only lived in Albertan urban centres. I came to this particular research project after completing my undergraduate degree in civil engineering and seeking a research topic in water resources engineering—particularly one that would address the apparent water needs in First Nations communities discussed above. While I tried to approach this project with an open mind, I realized that a much *more* open mind was required, one grounded in acceptance of other ways of knowing and thinking. For this reason, I included the personal information above so that the information I present throughout this thesis is first and foremost contextualized as my understanding. And while my understanding has been deeply informed by Samson Cree Nation residents, meaning that not only did they provide data but also ways of understanding the data, it remains fundamentally shaped by my upbringing and education in the western school of thought.

In the autumn of 2011, Samson Cree Nation Chief and Council passed a band council resolution to establish relationships between Samson Cree Nation and the University of Alberta and Health Canada. Initially, Joan Yee and Philip Simpson—from Health Canada and Samson Cree Nation, respectively—conceived of this research project to investigate persistent total coliform and *Escherichia coli* contamination in rural, private wells on the Samson Cree Nation reserve. Joan Yee connected the University of Alberta research team to Samson Cree Nation through Dr. Ania Ulrich in the Department of Civil & Environmental Engineering. Samson Cree Nation, Health Canada, and the University of Alberta research team jointly initiated the project through the now defunct Health Canada Drinking Water Quality Program, and Chief and Council passed the enabling resolution.

The following individuals have been directly involved with this research project:

Table 1.1 Summary of organizations and people involved in this research project

ORGANIZATION	NAME	TITLE
Samson Cree Nation	Mario Swampy	Band Councilor, Chair of Maskwacîs Water Committee
	Murray Healy	Senior Water Technician

	Danika Littlechild	Treaty Lawyer for Treaty Six
	Shannon Buffalo	Band Councilor
	Cameron Saddleback	Contractor
	Rod Buffalo	Trades Centre Manager
	Philip Simpson	Band Engineer
Health Canada	Joan Yee	Senior Environmental Health Officer
	Amy Forward	Environmental Public Health Data Technologist
	Doreen Johnson	Maskwacîs Community Health Center Manager
	Jodi Ellen	Community Based Water Monitor
	Nancy Omeasoo	Community Based Water Monitor
	Stephanie Amoah	Environmental Health Officer
	Kyle Wonsiak	Environmental Health Officer
University of Alberta	Dr. Ania Ulrich	Principal Investigator
	Dr. Evan Davies	Principal Investigator
	Fraser Mah	Masters of Science Student
	Travis Hnidan	Masters of Science Student

1.2 Research questions

Chapter two, "Just add water: Engineering, Indigenous, and community-based research methodologies in Samson Cree Nation", details the community-based research methodology we (Mah and Hnidan) used in this research and includes discussion about engineering research methodologies and Indigenous research methodologies. The key question explored in this chapter is:

- What is community-based research and how did we apply it working with Samson Cree Nation?

Chapter three, "Domestic water consumption in Samson Cree Nation: Water metering program, resident interviews, water use patterns and residential end purposes", details the more conventional data collection methodology we used in this research and broad analysis of domestic water use. The key question explored in this chapter is:

- How much water, and for which purposes, do Samson Cree Nation residents and households use domestically (i.e. in the home)?

Chapter four, “Factors affecting domestic water use in Samson Cree Nation: Water source, household demographics, and perceptions of drinking water health risk”, uses the water meter and interview results from chapter three to investigate relationships between metered water use and household data. The key question explored in this chapter is:

- What are the main variables that affect domestic water use in Samson Cree Nation?

Chapter five, “Domestic water use and forecasts in Samson Cree Nation: A system dynamics approach”, details the development of system dynamics models of Samson Cree Nation’s water systems. The key question explored in this chapter is:

- What insights can system dynamics models provide about the complexity, causes, and effects of water stress in Samson Cree Nation or other Indigenous communities or other rural communities?

Chapter six, “Domestic water use in Samson Cree Nation: Results discussion and conclusions”, summarizes key results and conclusions from chapters two through five and presents them as part of a larger discussion. Recommendations for future work are also presented here.

First Nation reserves are facing a number of external challenges to managing their water resources. LaBourcane-Benson et al. (2013, pg. 1) highlighted an excerpt from the *Federal Water Policy* (Environment Canada, 1987, pg. 26 as cited in LaBoucane-Benson et al., 2013):

> “Water is of special value as a sustaining force for the essentials of life for Canada’s native people. In recent years, native people have demonstrated they are prepared to assert their interest in, as well as participate in, managing water resources. In this way, they are taking steps to protect their distinctive way of life and to determine their won destiny.”

Samson Cree Nation leadership and the University of Alberta research team completed this research in the spirit of cooperation. I have tried my best to keep this in mind while writing the chapters that follow and to write in a way that is deliberately and consciously informed by those who I have met during my time in Samson Cree Nation. Enjoy.

CHAPTER TWO

Just add water: Engineering, Indigenous, and community-based research methodologies in Samson Cree Nation

2.1 Introduction

As stated previously, a great deal of media attention has recently surrounded infrastructure and housing concerns in First Nations communities across Canada. The *National Assessment of First Nations Water and Wastewater Systems* released by Aboriginal Affairs and Northern Development Canada (AANDC) (Neegan Burnside, 2011a) points to an apparent need for western, technical engineering work in First Nations. With an increased frequency of engagement between engineers and Indigenous communities—due partly to making the improvements recommended in AANDC's report—and their respective epistemological frameworks, it is necessary for engineers to consider adopting alternative methodologies while conducting engineering work with Indigenous nations. To undertake Western engineering work with an Indigenous community without explicitly considering non-technical and technical methodologies—especially by the non-Indigenous engineer—is to risk reinscribing oppressive ideologies through engineering work, a point to which I will return later.

In this chapter I detail a methodology employed by Fraser Mah and myself (the Masters of Science students in Table 1.1) in our respective research projects with Samson Cree Nation through the University of Alberta. I attempt to outline the theoretical frameworks of both engineering and community-based research to understand the positionality of this particular research project. Then I move into the practical, describing how we conducted and continue to conduct engineering research with a community-based approach. Here I explicate tangible benefits provided by using a community-based approach in engineering research over a more conventional model. This methodology is by no means the only methodology available for use with an Indigenous community, or any community for that matter; however, I hope that by sharing successful and unsuccessful practices, a larger discussion can take place about how engineering can best serve Indigenous peoples who are under tremendous pressure to conform to standards of neo-liberal development.

2.1.1 Positionality

The lens through which we, as individuals, perceive and understand the world is built by our unique experiences. Absolon and Willet (2005) describe positioning or locating of the self as one aspect of an Indigenous research methodology. By acknowledging the place and circumstances from which one originates, locating oneself simultaneously foregrounds the subjectivity of one's experience and provides context for the interpretations one offers. It also holds the researchers accountable for their positionality (Absolon & Willet, 2005); the researcher accepts responsibility for what they find and how they interpret it.

2.2 Engineering

2.2.1 Engineering Philosophy

What is engineering? Surely, we cannot answer definitively this question that, on occasion, stumps engineers and non-engineers alike. But, in this chapter, we can provide an idea of what engineering means. A favourite definition is that engineering is the process of design, negotiating the truths and constraints of an object world (the scientific world, governed by natural laws, i.e., gravity, electro-magnetism, etc.) into a subject world (the human world of function and experience, i.e., bridges, stereo systems, etc.) (Bucciarelli, 2003). More simply, engineering can be seen as the process of building (both the physical and the abstract), whether it be construction, designing, or modeling. Another appropriate definition would be one that says engineering is that which is done by engineers; engineering is a self-defining profession (Davis, 2010). In Alberta, this self-imposed definition is regulated by the Association of Professional Engineers and Geoscientists of Alberta (APEGA). This regulatory process defines what type of work requires the approval of a professional engineer. The idea being that the engineer, holding "paramount the health, safety and welfare of the public" (APEGA, 2014) creates designs built on the fundamental heuristic models of science and mathematics (Bucciarelli, 2003). As explained by Theodore Von Kármán, "Scientists discover the world that exists; engineers create the world that never was".

In this way, engineering has inherited a certain scientific spirit; it is defined or restricted most immediately by the natural laws "discovered" by science. This coding manifests itself through positivism, reductionism, disinterest, and objectivity that guide engineering (Leydens et al., 2012). Engineering as an *applied* science, uses the truths of an object world reality (the natural world) provided by science to create the possibility of subject world artifacts (the products of engineering) through models, simulation, testing, theorizing, design, and construction. The engineer, in navigating and translating between the concrete and the abstract, or the universal and the particular, strives to build a world that is optimized, efficient, and practical (Bucciarelli, 2003).

In the instruction of engineering students within this culture, a compartmentalized and narrowed worldview is fostered in which the engineer is an expert and is valued, whereas non-technical learning is devalued (Leydens et al., 2012). Through the belief in this discoverable, neutral, object world, the products and processes of design and technology must also be unbiased, so that value is equated with function: if it works then it is good (Leydens et al., 2012). In the problem-solving approach used by engineers, failure—whether or not it works—defines value judgment while purpose or intent do not (Bucciarelli, 2003). We are not suggesting that purpose or intent are not considered on some level (or even by the occasional engineer) but socially-based questions on value are not typically found in engineering's wheelhouse. Maintenance and enhancement of functionality and maximization of efficiency are of interest to engineers rather than the questioning of these aims or their social consequences (Leydens et al., 2012).

This worldview has consequences for society. The engineer's belief in objectivity is applied to social systems whereby, intentionally or not, engineering and engineers are attracted to structural fundamentalist frameworks (Leydens et al., 2012). Similar to how the engineer is interested in whether something does or does not function and not the question of "Why?" (Bucciarelli, 2003), structural fundamentalism provides a world where understanding substantive structure is more important than questioning why that structure has come to exist (Leydens et al., 2012). Significant questions in relation to engineers are: who benefits from, and who is limited by, a particular social structure? Structural fundamentalism is an understanding of society which says: social stratification is universal, natural and socially beneficial; functional importance is proportionately rewarded with wealth, power, and status; important work is incentivized to promote cohesion, and; society perpetuates itself through the promotion of function, order, and stability (Leydens et al., 2012). The engineer, as expert, in theory removed from trope, ambiguity, and metaphor (Bucciarelli, 2003), is valued in his ability to practice without bias and with the necessary detachment to categorize and comprehend effectively the information available (Leydens et al., 2012).

In contemporary Canadian society, knowledge rests in the hands of experts and those who police discourses (Strega, 2005). In this, engineering is no exception. Discourse theory says that each discourse has a unique and flexible language which holds certain truths and that most discourses do not recognize their own partiality (Strega, 2005). Engineering holds that data or artifacts can exist in isolation, are neutral, and can be clearly defined and that engineering represents the truths of *the* object world—as opposed to *an* object world (if science is developed within human culture, how could it truthfully claim to represent something *outside* of that culture?)—through proper language and knowledge use (Bucciarelli, 2003). This makes up most of engineering theory. If our contemporary technological advancement is any indication, this approach is successful for solving purely technical problems but may be insufficient in addressing broader socially or environmentally sensitive issues.

2.2.2 Engineering Practice

Ironically, most engineers do not seem to hold this belief in objectivity (the existence of an objectively best solution) as truth in engineering practice—only in engineering theory. While engineering is steadfast in the scientific belief behind engineering, there is much acknowledgement that the practice itself and the process of design are social processes built on negotiation, iteration, and rectification, which are rich in ambiguity and uncertainty (Bucciarelli, 2003). So engineering practice purports that it follows an objective theory when in reality it recognizes its subjectivity; so much so, in fact, that flow charts demonstrating design processes incorporate the mechanisms of negotiation and iteration. Other disciplines are just as practical in recognizing that their ideal measures are seldom achieved in reality.

While I have separated engineering "theory" from "practice" here, I acknowledge that the "practice" is guided by its own theories (e.g. construction management) and is not entirely "practiced". Since engineering requires some form of building—physical and non-physical alike—what we have separated as "theory" and "practice" are both necessary and work together to make up engineering philosophy.

In addition to an awareness of its non-technical nature in practice, many engineering societies follow codes of practice or ethics to which they hold their professionals accountable. In Alberta, the practice is governed by APEGA whose rules of conduct are provided below:

> Rules of Conduct (APEGA 2014)
>
> Professional engineers and geoscientists shall, in their areas of practice, hold paramount the health, safety and welfare of the public and have regard for the environment.
>
> Professional engineers and geoscientists shall undertake only work that they are competent to perform by virtue of their training and experience.
>
> Professional engineers and geoscientists shall conduct themselves with integrity, honesty, fairness and objectivity in their professional activities.
>
> Professional engineers and geoscientists shall comply with applicable statutes, regulations and bylaws in their professional practices.
>
> Professional engineers and geoscientists shall uphold and enhance the honour, dignity and reputation of their professions and thus the ability of the professions to serve the public interest.

By explicitly invoking the idea of public interest and welfare, engineering societies recognize the significance of and give significance to their profession. The theory of engineering as a discipline may not question or encourage questioning of social implications (as explored above) but the practice, at the very least, acknowledges a human and humane component.

Most notably, engineers by and large place emphasis on social order and avoid being seen as "political" (Leydens et al., 2012). The notions of neutrality and objectivity placed on the object world by engineering, through structural functionalism, are similarly applied to society in advocating for social cohesion, order, and efficiency (Leydens et al., 2012). By representing the status quo and the dominant view, this stance appears to be neutral and apolitical, while in reality serves to promote an inherent conservative agenda (Potts and Brown, 2005).

This motivation can create some tensions with other disciplines with which engineers may have to collaborate, especially if a call for social justice or social change is made as these views are described as political in their deviation from the dominant viewpoint.

2.2.3 Engineering and Water Research

The sheer number of specializations within the field of engineering is evidence of the role of reductionism in directing the profession. So while the above descriptions and implications of engineering may be useful, one wonders how they truly affect the process.

Water use research in this project involves the quantification and characterization of water use in the home: how much water residents use and for which activities. The domestic end uses of water have been studied comprehensively within civil engineering across North America (Mayer et al., 1999; Dziegielewski & Opitz, 2002; Coomes et al., 2010; to name a few). Much legwork is required in the collection of domestic water use data, and many methodologies use mail surveys or questionnaires to collect household-level data (Edwards & Martin, 1995; DeOreo et al., 1996; Mayer et al., 1999; DeOreo et al., 2001; Loh and Coghlan, 2003; Mayer et al., 2003; Roberts, 2005; Heinrich, 2007; and Willis et al., 2009). Mayer et al. (1999) describe the statistical analysis necessary to evaluate the results of the mail out survey. But while this analysis is no doubt useful, especially considering the scope of their research, one is left wondering how effectively a mail–out survey would work in other communities, Indigenous communities for example.

Many cultural assumptions are made when considering a mail–out survey as a feasible option, let alone one that provides accurate results. The willingness of residents to share personal information with researchers/strangers via a survey, the existence of a water utility or authority to connect with water users, participants' comfort with communicating in technical written language, households with water meters in their homes and their familiarity with external water management—these are just a few of the tangible necessary conditions that make a lot of water use studies possible and reliable. Since engineering research uncovers some part of an objective, physical world, the social or cultural processes used in engineering research to achieve its ends are usually obscured or ignored in favour of technical processes. Why might this be the case? Well, for engineering, the social or cultural processes do not matter. The subjective process of engineering— while acknowledged by its practitioners—is typically hidden in or excluded from publications and official communications. The information, the data, is presumed to exist independent of the process or observer. So regardless of the methodology employed, in theory, the same data, the same depiction of the object world, would be or could be captured. Additionally, the artifact created or observed masquerades as consistent, as the principles on which it is founded are constant and immortal (Bucciarelli, 2003). This subjective world is then misidentified as the objective world in an approach that strips the original cultural and social context from the solution to define a single, unified situation within which non-conforming data is labeled as deviant.

To give credit to engineers, their methods are typically consistent with and reflective of the dominant culture such that the desired data can be collected without much thought as to *how* (aside from the more technical/statistical aspects). But how could conventional engineering process be consistent with a culture, which does not have its own history with Western, regulated engineering practice? More specifically, knowing about the "infrastructure crisis" in First Nations communities and that these communities are distinct from dominant Canadian society in myriad ways, how might engineering be adapted to be consistent with and reflective of an Indigenous (or any non-conforming) community? To answer this question, a community-based research approach is necessary.

2.3 Community-based research

Community-based research is research that addresses the following five criteria (McCormack, 2014):

1. Research must have a perceived benefit to the community;
2. Research is either initiated by the researcher, the community, or both together;
3. Research concerns a defined community;
4. Research involves some level of community participation like training or interviews; and,
5. Research serves a socially-relevant goal.

We can now describe our research project in reference to these criteria. In so doing we hope to provide a sufficient explanation of the research we are conducting while positioning it as community-based research.

In brief, this research seeks to collect and interpret water quality and quantity data. Samson Cree Nation is a largely rural First Nation located near the small townsite of Maskwacîs, Alberta, with an on-reserve population of around 7 000 people—6 000 of whom live in the rural area. Rural homes are serviced by private groundwater wells. Approximately 20% of rural homes in Samson Cree Nation are under boil water advisory at any given time due to bacteriological contamination. Mah's (2014) research focuses on potential sources and pathways for the widespread contamination of the Samson Cree Nation's rural water system and risk-management strategies to reduce contamination. My research partner, Mah (2014), collected tap water samples from rural homes and tested them for indicators to show potential contamination pathways. He also conducted interviews with residents to understand sources of contact with contaminated water and how residents perceive their water system. My work focused on domestic water use in Samson Cree Nation—through water meter installation in volunteer households to measure hourly water use—and interviews with residents to understand their household water use. I used this data to determine average water use so that Samson Cree Nation can plan for future water use and manage its water resources appropriately. Water-use data complements the water quality data to identify exposure pathways to water such as drinking water and showering.

The perceived benefit to the community (point 1) from a technical engineering perspective is probably clear: we both hoped to identify and mitigate water contamination and collect necessary information on water use to ensure sufficient and safe water supplies for residents of the Nation. However, since we are outsiders to Samson Cree Nation, our research could also be seen as another opportunity for external, colonial expertise to be imposed on an Indigenous community. Further, structural barriers limit which solutions are feasible, and it is unlikely that our research will lead to immediate improvements. What perceived benefit, then, remains for the community?

During the development of this project, Mario Swampy, a Samson Cree Nation councillor, repeated the need for Indigenous nations in Canada not only to speak about sovereignty, but to demonstrate it. For him, the very act of conducting this research is a demonstration of Indigenous nationhood in the management of their water resources (UNDRIP, 2008). For example, the legitimacy of project findings required Samson Cree Nation to seek the services of qualified engineers (who are generally non-Indigenous), and Samson Cree Nation has taken the initiative to participate in this research. As researchers, we support this demonstration of Indigenous nationhood and have attempted to align our research with the goals (point 2, above) of Samson Cree Nation.

The second criterion of community-based research addresses the responsible parties for project initiation. Although one could reasonably ask who would initiate a research project if not the researcher or the research subject, the reason for identifying both the researcher and the research community is that the development of a community-based research project is iterative. It must involve both parties, since the community must identify study topics of interest to the community, while the researcher must define and outline a researchable (usually academic) question. By including both parties at the onset, the groups work together to create a project that will benefit each to the greatest degree. This is consistent with the iterative design process of engineering.

In creating this project, researchers presented questions with academic value, and Samson Cree Nation leadership identified those questions whose answers would be useful for their community. Samson Cree Nation leadership also helped develop interview questions and provided questions of their own to pose to interview participants.

It seems simple to say that the on-reserve population of Samson Cree Nation is the defined community for this research (point 3, above). Yet complications quickly arose. Our project was under the aegis of Chief and Council and was approved through a band council resolution. However, an elected government seldom successfully represents its entire electorate, and some community members do not recognize the authority of Chief and Council. Further, we were not able to include each individual in this research. Therefore, it is problematic to say that the community is the entire on-reserve population of Samson Cree Nation, but attempts to define a specific "community" with which we are working remain vague. For example, our ability to engage the entire community has been limited by socio-economic factors such as homelessness—which leaves no home to meter for usage—and employment, since the most convenient means of recruiting participants has been through band office connections, which has introduced a bias towards residents with stable jobs. Remaining conscious of these biases, we have developed methodologies that attempt to mitigate their effects or explicitly identify them when reporting our results. Regardless of who is included, the question of community is central.

With respect to point four: interviews form a significant source of the data collected for this project, both for water quality and water quantity. Fraser and I conducted formal interviews with homeowners and residents who provided water samples for testing or who volunteered to have water meters installed in their homes. Interviews followed a questionnaire developed by the University of Alberta research team (Mah, Hnidan, Davies, and Ulrich) and Samson leadership that also encouraged interviewees to share their own concerns or present information the interviewers may not have anticipated. In this way, those we interviewed participated in the research beyond the data we sought. Their input led us to modify our research methodology to accommodate recommendations or concentrate on new concerns. These modifications were not significant in our technical methods but definitely influence how we think about, conduct, and discuss our research. By being receptive to community members, we opened the door for community members to more subtly direct our thinking than if we had little to no interaction with them. While we collected objective data for this research, we know the means through which we collected and observed had impacts for its reliability and validity. Interviews not only provide better data, more importantly they foreground individuals in the community. Plus, when assessing less technical components of water—the perception of water quality risk, for example—we abandon attempts for "objective" measurement. Further, interviews provide context and explanation for observations and these justifications of evidence are what make measurements useful. Further still, research is based on curiosity and passion. A curious researcher would be open to interview methodology and the insights interviewees provide on research topics. Direct human-to-human interaction emphasizes the importance of research and helps both participants engage more with the research process.

In addition to community members participating through interviews, we sought opportunities to provide information and knowledge to the community. Such efforts have included the delivery of workshops on water quality and quantity at the local high school, an elders consultation meeting, and the distribution of information through the community newsletter. This type of dissemination is important to the research process because as the subject of the research, the community should be able to access and be informed about the research. Ultimately, it is the members of Samson Cree Nation who have to live with the problems we researched and they should have knowledge of these problems as we studied them.

Finally, community-based research aims for social relevance (point 5). This research project offers the goals of both an improved water system for members of Samson Cree Nation and a demonstration of self-government through the management of local water resources. Taking steps to evaluate, analyze, and improve the overall water system (water quality and water quantity) serves the goals of social and cultural reproduction—the ability of a social organization to reproduce or perpetuate itself. Likewise, demonstrating the ability to manage water resources serves the goal of operating as a self-governing nation and demonstrating Indigenous nationhood.

Many municipalities, governments, or other "community representative" bodies have community engagement strategies that they use to inform community members and receive feedback for engineering and infrastructure projects. These strategies include town halls, open houses, mail-out surveys, and even interviews. What sets the community-based approach outlined above apart is that a community-based approach attempts to remove power structures from the process: that one person does not have more decision-making power on the topic at hand due to their position. Power is shared among those affected by decisions. Typically, governing bodies retain their power to make the final decision in regards to engineering and infrastructure projects, even when the community is engaged through various processes. For this reason, I have not included these strategies as examples of community-based approaches. They maintain the power structures present in governing bodies by operating through or with these same bodies, which is counter to the goals of community-based research.

Now that I have outlined how our research theoretically met the criteria for community-based research, I can describe how we practically conducted our research.

2.4 Methodology

Community-based research seemingly appeals to more socially-oriented disciplines, and much of the following is borrowed from the schools of Native Studies and Anthropology, but we hope that our description explains the appropriateness for engineering to utilize this approach.

Both Fraser and I completed coursework through the Faculty of Native Studies where we learned the five criteria for community-based research outlined previously (McCormack, 2014), a structure to guide research, and how to conduct research interviews.

Starting in May of 2013, Fraser and I spent most of the weekdays and weeknights during that summer living in Samson Cree Nation. Wolcott (2005) identifies long-term rapport building and physical presence in the community of study as necessary to understand a community effectively. As a complement to conducting interviews for data collection, participant observation allows the researcher to observe and inquire into behaviours outside the interview structure (Wolcott, 2005), opening data collection to more anecdotal information from those who may not be strictly participating in research. Participant observation is most simply participating in the community, observing those who do or do not participate, and taking notes on the process (Lassiter, 2005). We secured accommodation on-reserve (staying in tents in a resident's backyard) and were provided with space to work out of the band office in Maskwacîs. While we were only an hour's drive from home, we tried our best to immerse ourselves in community life. We participated in community and cultural events and ceremonies. We used as many opportunities as we could to discuss our research with folks in the community and to recruit volunteers to participate. We shadowed Maskwacîs Health Services staff and Samson Cree Nation Trades Centre staff as they worked in the community, trying to understand the administrative and political structures that guide water and housing issues. We read fiction and non-fiction works by and about Indigenous peoples in Canada. We tried—and are still trying—truly to understand and appreciate perspectives of Samson Cree Nation members. We attempted to align our research with the goals and values of Samson Cree Nation for the Nation's best use. The summer was transformative, to say the least. We cannot describe in detail everything that we experienced and learned over the summer and while we still cannot claim to understand Samson Cree Nation in its entirety, we are definitely more aware of how we can successfully work with Samson Cree Nation and represent community members' concerns.

Specifically, we know now that there is a strong desire for improving the water systems in Samson Cree Nation. The process moving forward must include the larger community and communication must improve between elected officials, community members, and other governing bodies. We have also learned that any solutions to water issues on-reserve must be actively supported by the community and must work for the best interests of the community. There is a desire among residents to improve water quality and access on-reserve and the community is welcoming to those who are willing to listen and learn as they work towards their goals.

Once the summer passed and we felt more comfortable with the community, we hosted an elder's consultation in October. We had spoken with elders throughout our time in Samson but this was the first time we deliberately included them in our research. Through the Elder's Department at the Band Office, we invited all of the elders to lunch at the Jim-O Community Hall. We described our research and answered questions from the elders. One of our primary questions for Samson elders was how best to engage the rest of the community in our water research. Their recommendation was that the entire community needs to be included in this type of meeting, that the invitation should not be restricted to elders alone. Chief and Council plan to host an open band meeting to discuss water broadly with Samson Cree Nation residents.

2.4.1 Interviews

Formal interviews comprise a significant portion of the data we have collected, and continue to collect. Volunteers for the interviews were selected based on their interest and whether their home had either a water sample collected for testing or a water meter installed. The interview questions were approved by the University's Research and Ethics Board.

Following cultural protocols of this community, we presented interview participants with tobacco, tea, and water, and thanked them for volunteering. Fraser and I conducted interviews separately but used the same questionnaire to guide the interview. Volunteers were able to steer the conversation to other topics if they so chose. Volunteers were also asked if the interview could be recorded; some consented.

The interviews lasted between twenty minutes and two hours, depending on the volunteers' interest in continuing the conversation. After the interview, we transcribed the results and provided the interview participants with a copy of the transcript and the Information and Consent Form which they could then verify for accuracy. Interview participants were provided with all of the data collected from their interview and their home. We also plan to keep them informed as data is published and what results come from the research.

Including the interview participants in the research in this way serves a few purposes. First, since they were kind enough to volunteer in the research project and give up their time to be interviewed, they deserve access to the results of their participation. We could not have collected the data otherwise and it is important for us as researchers to acknowledge that by giving control of the data to those who provided it. This control exists in the ability of volunteers to withdraw from the study, to edit the interview transcript, and to decide who can access the data (researchers, Samson Cree Nation staff, the public).

Second, we understand the value in demonstrating reciprocity through the research. Since we, as researchers, gain a lot from this study (publications, degrees, learning opportunities), we have a responsibility to ensure that participants receive something in return. This reciprocity is partly acknowledged by offering protocol before starting the interviews and the participant receiving the offering. Further, many residents were interested to know how much water they use or what the quality of their drinking water is. Sharing this data with residents, then, was not only easy but desired.

Last, soliciting the opinions and understanding of residents is necessary in effective resource management. Water systems are designed for end-users but it is difficult to evaluate the efficacy of any system without explicitly including users in the evaluation. Beyond including participants to collect more data, a successfully designed water system must account for how users actually interact with and perceive the system. Interviews provide an excellent opportunity to receive this information. The interviewers, however, must ask questions with an open mind. Interviewees will share what they think is important and true, regardless of the specific questions asked by the interviewer. The interviewer, then, must receive all the interview data as subjectively true, even if they conflict with their own truths. Obviously, the interviewer will rationalize these conflicts over time and accommodate them into their understanding of the world but in a collaborative process the interviewer must be open to and accepting of the views of interviewees.

An engineering preconception I had entering the research was that residents might not be interested in my research questions or answering my interview questions. My water provider has never interviewed me about my experiences and ideas on water quality and quantity in Edmonton; since I do not expect to be accommodated on that level by a water utility, why would members of Samson Cree Nation be any different? While some interviewees were not particularly interested in participating, happily deferring authority to leadership to manage water on-reserve, many stressed the importance of involving community members. The main message we received from consulting with elders in the community is that all community members need to be invited to participate in discussing Samson Cree Nation's water. So where I had previously expected apathy about water management or deferrals to elected authority figures—and certainly there were a few—I found instead interest and a desire for greater community engagement. Community members want the power to decide the level of their involvement. As an open researcher, I cannot presume anyone's interest in engagement; instead, I must ask.

The representation of Indigenous peoples in curricula, research, and scholarship that purport objectivity risk perpetuating racist and oppressive ideologies against those who do not share western, colonial thought (Absolon and Willet, 2005). As engineers conducting engineering research, we can—intentionally or unintentionally—dismiss relevant research information simply because it does fall within Western, colonial, academic thought. Stripped of the context of colonization and the ongoing struggles of Indigenous sovereignty, an objective interpretation of First Nations often leads to racist conclusions regarding the inherent ability and aptitudes of Indigenous communities. A western, colonial worldview—employed heavily in engineering—can destabilize collaborative relationships (Leydens et al., 2012) because it creates conflict with alternative ways of knowing. Adhering strictly to a set of principles can make working in other contexts very difficult. This is something we actively sought to avoid.

In the goal of translating interviews into scientific subject matter for quantitative, scientific analysis, we strive continually to evaluate the research process. Working reflexively with the community and interview participants in a dialogic process encourages a collaborative approach to the work, thereby ensuring reassessment of the goals, purposes, and audience of the research products (Lassiter, 2005). This collaboration is critical as it makes relationships more central to the research process and assists in knowledge creation through co-understanding (Lassiter, 2005). Making relationships a focus holds researchers accountable to the project and those affected by it. Also, it helps identify and address the "cause" of the problem because those most affected by it, can engage with it on some level. Continually, we find challenges about what we are researching, how we are researching it, and how we can communicate our research. This reevaluation is made possible by continually interacting with individuals in the community, and leads to a better research product: one that is reflective, to a degree, of the community we study. Ultimately, this creates more sustainable research and working relationships because we adapt to the unique research context.

The morals and ethics surrounding this relationship building between researchers and interlocutors is not only consistent with collaborative research (Lassiter, 2005) but is consistent with the *Rule of Conduct* for engineering outlined previously in holding 'paramount the […] welfare of the public' (APEGA, 2014). If engineers are indeed, interested in the public welfare, they must assess who that public is. The "public" who is considered can easily change from project to project and they have more interests and more at stake than simply risk management and safety.

Lastly, in the interest of reflexive research practice, we must ask, "For whom am I writing?" (Lassiter, 2005) Clearly, one of the audiences for the work is the community itself. As engineers trying to "solve a problem" of uncertain water quality and quantity we must address this community. Not only must academic writing be accessible for the non-engineer for approval, as per the Information and Consent Agreement, research findings must consider and be useful for the community so that work addressing the issues identified can be completed. Listening to and understanding the stakeholders' cultural practices and views is necessary for the successful implementation of engineered community projects (Leydens et al. 2012). Further, since the interview requires us to quote and interpret the voices of Indigenous peoples, we must help their messages to be heard beyond the data.

2.5 Conclusion

In first trying to locate our research as engineers, we defined some aspects of engineering and engineering philosophy. We explained some of its theoretical limitations which justify its critical evaluation. We also explained a theoretical framework for community-based research that met five criteria set out by McCormack (2014):

1. Research must have a perceived benefit to the community;
2. Research is either initiated by the researcher, the community, or both together;
3. Research concerns a defined community;
4. Research involves some level of community participation like training or interviews; and,
5. Research serves a socially-relevant goal.

We successfully completed this engineering research with Samson Cree Nation using a community-based research framework and incorporating some Indigenous research methodologies through practicing self-location and interviewing community members.

There is a lot of work yet to complete as part of this research and much more that will never be complete. This could have been done in ways that are even more respectful, more collaborative, and less colonial. It's staggering, sometimes, to consider how our expertise is necessary, in a way, for Samson Cree Nation's governance of their water resources to be considered legitimate. While we certainly do have technical knowledge and services to offer, it should in no way be considered more important than other forms of expertise or those informed by other ways of knowing. Because of this and the governance of engineering, none of this work can be considered "decolonization" although we do find "settler harm reduction" to be apt (Tuck & Yang, 2012). We cannot decolonize an institution that is inherently colonial but these settler institutions can still provide work that is beneficial, that reduces harm, while still being colonial projects. We acknowledge also that the opportunity to participate in this research was not available to any Indigenous (engineering) (non-) students. Certainly more can be done to ensure that work that seeks to improve life for Indigenous peoples is completed.

Engineering that purports to balance the triple bottom line – the social, the environmental, and the economic – but chooses not to examine any of the three in depth, risks failure through ignorance. How can one know that the work has been successful without explicitly examining the measurement of success? Being cognizant of both the contemporary "infrastructure crisis" in First Nations communities across Canada and a rude understanding that Indigenous cultures are in some way "different" from our own, one wonders if there exists a failure in how engineering has been deployed. At the very least from the perspective of, for example, a consulting engineer, one of the most important factors affecting design is producing what the client wants. Less specifically, on a social level, engineers are instructed to consider the public good although seldom must they measure their impacts on it directly; the social consequences of their work are rarely measured, evaluated, and related back to the design. Rather, appeals to public welfare serve more as rhetoric than calls to action. Regardless, how can "the public" be understood or cared for without social understanding?

I propose a community-based research methodology in engineering as an appropriate way to conduct research that is anti-oppressive while still meeting Western scientific academic standards. Our approach is by no means universal or singular. We acknowledge that as young students we are relatively unencumbered by constraints such as children, a mortgage, physical ability limitations, or the multiple projects often being juggled by typical engineering consultants. But consider this an invitation to critique, improve, and employ what we have discussed. For community researchers and collaborators (scholarly or otherwise), it opens new ways of thinking and more opportunity for collaboration. For Indigenous communities, it provides a mechanism to inform, deeply, community outsiders about what you want and what is at stake. Preparing for a sweat ceremony one weekend, Dale Saddleback (2014) explained his openness to receiving *moniyawak* (white folks) at his home for ceremonies:

> Since our ancestors did not enter into these ceremonial relationships and share their cultures, this responsibility is now ours.

When the researchers and community members engage in this reciprocal relationship, balancing rights and responsibilities in the exchange of information and action, could you create research that is anything but respectful? Maybe this question is more indicative of settlers' relationship with Indigenous peoples broadly than an acute critique of engineering, but shouldn't it matter to both?

CHAPTER THREE

Domestic water consumption in Samson Cree Nation: Water metering program, resident interviews, water use patterns, and residential end purposes

3.1 Samson Cree Nation and domestic water use

First Nations reserve communities in Alberta currently use water without water licences, which are issued by Alberta Environment. The provincial government requires water licences for bulk water withdrawals for industry and municipalities—private residences do not require licences. Water licences detail the volume of water available for withdrawal by the licencee and any return flows they must meet. Alberta's licence system comes from the 1894 *North-west Irrigation Act* that declared Crown ownership of water in the Northwest Territories—now Alberta, Saskatchewan, the Yukon, the Northwest Territories, and parts of Nunavut, Manitoba, Ontario, Quebec, and Labrador (Percy, 2012). The Act allowed government to grant water licences, giving licence holders rights to divert and consume water (Percy, 2012). With the 1930 Natural Resources Transfer Agreement passing ownership and control of water to the provinces, Alberta maintained the licensing procedures and priority system whereby licence seniority—the age of the licence issued—dictates the priority of licence fulfillment during water shortages (Percy, 2012). This system is typically called first-in-time, first-in-right (FITFIR) because senior licence holders have the highest priority to fulfill their licences.

Since Indigenous peoples have been using water on this land long before the FITFIR licence system was established, they were never subject to it. Further, if the Provincial Government applied the logic of the system—first in time, first in right—to Indigenous peoples, their water needs should be met before any other inhabitants on this land. But as the Government of Alberta begins closing water basins to future licence allocation, questions are being raised about what this means for Indigenous communities who have no licences in the first place and were they to apply for any now, their licences would be junior licences—that is, the lowest priority for meeting water needs.

Samson Cree Nation is located in the Battle River Basin, which the Government of Alberta is considering closing to future water allocations (Nelson, 2012). Despite alternatives to meet future First Nations water needs in the Battle River Basin, like a regional water line or a gross diversion from the Battle River through a junior licence or a crown reservation (Nelson, 2012), some concerns exist for First Nations communities. A regional water line through any of the surrounding counties would effectively remove control of source water from First Nations and there is uncertainty in relying on a junior licence to meet water needs, as dicussed above. Leonard (2012) explained that through crown reservations, First Nations in the South Saskatchewan River Basin will meet their water needs only six of every 69 years and that First Nations in the Battle River Basin will meet their water needs one of every three years.

While conventional water management practices may not have historically included Indigenous water governance, First Nations communities are now facing tremendous pressure to adopt these practices. Water scarcity and water pollution have made it necessary for Indigenous peoples to demonstrate and fight actively for their Indigenous right to manage their water resources, using whichever means they find appropriate. Recent legislation, Bill S-8 or the *Safe Drinking Water for First Nations Act*

(Senate of Canada, 2012), seeks to deny First Nations communities in Canada of this right on the premise of unsafe or insufficient water services. Regulations made under the Act may (Senate of Canada, 2012, pg 4):

> b. confer on any person or body any legislative, administrative, judicial or other power that the Governor in Council considers necessary to effectively regulate drinking water systems and waste water systems;
>
> c. confer on any person or body the power, exercisable in specified circumstances and subject to specified conditions,
>
>   i. to make orders to cease any work, comply with any provision of the regulations or remedy the consequences of a failure to comply with the regulations,
>
>   ii. to do any work that the person or body considers necessary and to recover the costs of that work, or
>
>   iii. to appoint a manager independent of the First Nation to operate a drinking water system or waste water system on its First Nation lands.

Despite assurances that "nothing in this Act or the regulations is to be construed so as to abrogate or derogate from any existing Aboriginal or treaty rights […] except to the extent necessary to ensure the safety of drinking water on First Nation lands" (Senate of Canada, 2012, pg. 3), the Canadian Bar Association found the Act's qualification "except to the extent necessary" "an explicit abrogation or derogation of existing Aboriginal or treaty rights" (Craft, 2013, pg. 2).

Samson Cree Nation, one of the four Cree First Nations near Maskwacîs, Alberta, partnered with researchers at the University of Alberta to collect water quality and water use data and conduct a water resources analysis to support effective management of water resources by band leadership. We conducted this work in the spirit of cooperation to assist Samson Cree Nation in assessing water quality and quantity on-reserve and addressing the real and very serious threats to the Indigenous rights of the people of Samson Cree Nation.

The status of water supply and quality is uneven between First Nations reserves and other communities in Canada: boil water advisories are 2.5 times more common in First Nations communities (Patrick, 2011). The *National Assessment of First Nations Water and Wastewater Systems* (Neegan Burnside, 2011a) estimates that $1 200 000 000 is needed to bring First Nations water and wastewater systems up to "safe" levels, as defined in the Department of Aboriginal Affairs and Northern Development Canada's (AANDC) protocols. Corbella and Pujol (2009) stated the need to understand water use patterns and the uneven geography of water consumption as concerns about adequate water quality and quantity grow. Households are the key site to analyze water consumers' behaviours that influence domestic water use (Corbella and Pujol, 2009). A deep understanding of these behaviours makes domestic water demand management possible (Dziegielewsky, 1999).

Corbella and Pujol (2009) summarized the advantages of domestic water demand management and conservation, which,

- reduce water deficits;
- improve water supply reliability;
- reduce the need to construct large infrastructure;
- reduce pressure on the environment;
- improve utility management; and,
- decrease economic costs.

Inman and Jeffrey (2006) describe the benefits of residential water savings through domestic water demand management, as,

1. reducing operation and maintenance costs;
2. downsizing infrastructure; and,
3. decreasing purchases from wholesale water suppliers.

For the purposes of this report, Samson Cree Nation is described as a community with two water systems:

1. a municipal water distribution system with a water treatment plant; and,
2. a rural water system consisting of private groundwater wells.

Table 3.1 provides a summary of each system.

Table 3.1 Details of Samson Cree Nation water systems

	MUNICIPAL SYSTEM	RURAL SYSTEM
Source	Groundwater	Groundwater
Distribution	Piped network	Private wells
Homes serviced	313[a]	926[a]
Population serviced	1 675	5 051
Treatment	Chlorine disinfection	Point-of-use (if any)
Uses	Residential Commercial Institutional	Residential Institutional Industrial Agricultural
Constructed	1978	1961–Present
Capacity (dam^3/year)[c]	379[b]	393[b]
Design capacity (m^3/day)	2 780	—
Metered water use	None	None
Cost to consumer	None	None
Owned by	Samson Cree Nation	Individual homeowners
Operated and maintained by	Samson Cree Nation	Trade Centre Individual homeowners

[a] Neegan Burnside (2010)

[b] Aquatic Resource Management (2011)

[c] decameters cubed per year, 1 dam = 1 000 000 litres

Neegan Burnside (2011b) ranked Samson Cree Nation's municipal water system as medium risk. Further, up to 20% of private wells in Samson Cree Nation —servicing approximately 1 000 people—are under boil water advisory at any given time due to total coliform or *Escherichia coli* contamination. Samson Cree Nation leadership fears that Senate of Canada Bill S-8 may cause control of their water system to be taken from them, by forcing Samson to 1) receive water from a regional water line or 2) permit a water utility to operate their water system. For these reasons, in the words of Samson Cree Nation councilor Mario Swampy (2013):

> The time has come for us as Indigenous peoples not just to talk about our Indigenous rights, we need to demonstrate them. We need to actually take control and start managing our resources.

Domestic water use comprises a significant amount of our total daily water use. So how much water do residents of Samson Cree Nation use domestically? And what do they use it for? I explore answers to these questions, among others, below. Where appropriate, I discuss the two water systems separately—although note that comparisons of water use behaviours between systems (rural versus municipal) are reserved for the following chapter titled "Factors that affect domestic water consumption in Samson Cree Nation: Water source, household demographics, and perceptions of drinking water health risk".

A combination of factors makes Samson Cree Nation a compelling community, from a water resources management and planning perspective:

- All water use is unmetered with no charge to the consumer;
- Water quality perception is generally poor, especially on the rural system;
- Purchasing of bottled water for drinking water is pervasive;
- The majority of residents live in rural areas;
- Housing construction and maintenance are funded by Samson Cree Nation but houses are owned by residents;
- All rural houses are serviced by private wells—there are no cisterns—which enhances the rural-municipal divide between water systems;
- Federal funding for water servicing has not been community-led and has not proven reliable for community planning;
- The unemployment rate is high;
- There is a larger average household size than the North American average, due to multiple factors including family structures and housing limitations;
- Water legislation and regulation is jurisdictionally contested by First Nations, the provinces, and the Federal Government, as discussed above;
- Political, cultural, social, and spiritual histories of Samson Cree Nation residents have long-standing connections with water in the Maskwacîs region;
- First-in-time, first-in-right policy does not yet apply to Indigenous communities;
- A large demand for water and wastewater engineering work in First Nations communities has been created to address an "infrastructure crisis", increasing demand for technical services in these communities;
- The Battle River Basin may be the next river basin closed to water allocations in Alberta (Nelson, 2012);
- First Nations residents still speak of times when they were proud of the water from their well and they could confidently use water from a slough.

This last point is of particular interest. People speak openly about the changes they have witnessed in water over their lifetime in Samson Cree Nation and community members share this information. The late Paul Chartrand (2013)—on the topics of water and his wife, the late Hazel Cutknife-Chartrand—explained:

> Hazel says there used to be a hand pump north of the house and that the whole community would use it for water. Before Hazel got sick, she noticed a change in the water, about ten years ago. She said the taste changed. Hazel used to take water samples for the Health Centre. She says six mile has the best water.

3.2 Domestic water use

3.2.1 Water use metering

Studies on water use are ubiquitous. Water utilities commonly analyze their customers' water meter data. Economic literature has been concerned with the characterization of residential water demand since the 1960s (Corbella & Pujol, 2009). Fundamental principles of water system design are well understood in engineering. Average annual flow, maximum daily demand, peaking factors, and other important design values have known, straightforward calculations. However, Worthington and Hoffman (2008) warned that the lack of data on household water demand is a fundamental limitation of water demand modeling, which has relied heavily on data re-use and decontextualized data. Incorrect estimates of water demand can lead to substantial and unanticipated costs for water providers (Billings & Agthe, 1998). Billings and Agthe (1998) explain how both overestimations and underestimations of water demand can be costly for water utilities: massive underestimation can cause water shortages and expensive responses to both water shortages and public outcry while severe overestimations will cause revenue shortfall. For a community that does not charge for water use, overestimating water demand can cause unnecessary infrastructure and treatment expenses. Water demand equations typically relate water consumption quantity with price, income, and other factors (Corbella & Pujol, 2009). The variables that are now included in these equations are extensive (Nauges & Thomas, 2002 as cited in Corbella and Pujol [2009]). I investigate these variables that influence water demand in chapter four.

For this project, since water use is measured in the home—as opposed to at the municipal treatment plant—all measured water use is domestic. Commercial, industrial, institutional, or agricultural uses are not considered in this study. Domestic water use does not represent a water user's entire consumption throughout the day although it often makes up more than 75% of total municipal water use (Buchberger & Wells, 1996). EPCOR (2010) reports that about 58% of total water produced for the City of Edmonton is used residentially, with the remaining 42% is consumed for commercial or industrial purposes. Water usage of individuals in this study who use water exclusively in their home is captured in its entirety although it is averaged across all residents in the household. Days with zero metered use are removed from the average daily water use per capita calculation.

Dziegielewski et al. (1999) described water use mathematically as shown in Equation 3.1. They explained how water use can be understood as time series data (vector of values) for a water use entity *i*, such as:

- an individual water user,
- a group of water users, or
- all water users within a defined geographical area,

$$Q_{it} = \text{water use} \qquad \text{[Equation 3.1]}$$

where:

i = constant
$t = 1, 2, \ldots m$
m = number of time periods in series

for time period t. All water use—either recorded or estimated—is taken at regular time intervals, hourly for example.

Further, Dziegielewski et al. (1999) describe water use for an individual user i mathematically as the sum of specific end uses in Equation 3.2:

$$Q_{it} = \sum_j q_{ijt} \qquad \text{[Equation 3.2]}$$

where

q_{ijt} = water used for specific purpose j
i = constant
$t = 1, 2, \ldots m$
m = number of time periods in time series

for time period t.

Average daily domestic water use per capita—also referred to as average daily demand or simply average water consumption—is the most important datum point calculated for each metered household in this research. Average daily water use is measured in litres per capita per day (Lpcd), and is used in the following chapters to compare groups of water users in this study and between this study and others. It is referred to as "daily per capita water consumption", "average daily water demand", or variants thereof; further, since the focus of this study is domestic, or residential, water use, the terms "domestic" or "residential" are occasionally omitted.

Section 3.3 "Methods used to measure domestic water use in Samson Cree Nation" details the water metering procedure used in this study. To calculate the average household water use from water meter data, the daily water use measured by the water meter is averaged over all of the metered days, as shown in Equation 3.3.

$$\text{Household daily average water use} = \frac{\sum_t Q_{it}}{m} \qquad \text{[Equation 3.3]}$$

The household daily average water use can then be divided by the household size—i.e. the number of residents in the household—to give the average daily water use per capita at that household, as shown in Equation 3.4.

$$\text{Average daily water use per capita} = \frac{\text{Household daily average water use}}{\text{Household size}} \quad \text{[Equation 3.4]}$$

Table 3.2 shows average water consumption values for various regions to provide a sense of daily municipal (i.e. total) and residential water use volumes.

Table 3.2 Domestic water consumption for neighbouring regions

CITATION	REGION	MUNICIPAL (Lpcd)	RESIDENTIAL (Lpcd)
Environment Canada (2011)	Canada	510	274
Environment Canada (2011)	Alberta	395	209
EPCOR (2010)	Edmonton	341	226
Aquatic Resource Management (2011)	Wetaskiwin	364	182
Aquatic Resource Management (2011)	Ponoka	298	179

Understanding the amount of water that residents consume is necessary to develop forecasts of how much they will consume in the future. House-Peters and Chang (2011) highlight the importance of accurate and reliable water demand forecast models and the need to determine peak demand. They describe two types of models:

1. short-term forecasts (for operation and management) and
2. long-term forecasts (for planning and infrastructure design).

Chapter five titled "Domestic water use and forecasts in Samson Cree Nation: A system dynamics approach" reviews literature on water demand forecasting models and methods, while the current chapter is devoted to detailing the information required to develop these forecasts, such as peak flow rates.

The design of many water distribution systems is based on peak flow rates (Burn et al., 2002). Average flow rates are defined as the total volume of water used divided by the length of time measured—as opposed to instantaneous flow rates which indicate flow at the moment of measurement (AWWA, 1999). The "peak hour flow rate", then, is the flow rate for the consecutive 60-minute period of the day during which demand is the highest, while the "peak day flow rate" is the flow rate for the consecutive 24-hour period of a year during which demand is the highest (Scheepers, 2012). AWWA (1989) recommends that pipe design be based on the maximum flow rate of the most limiting demand condition between the: maximum-day demand plus fire-flow demand, maximum storage-replenishment rate, and peak-hour demand. The most limiting condition for system storage should be the highest flow rate between: peak-hour demand and maximum-day demand plus fire-flow demand (AWWA, 1989). One method to estimate peak demand is called the Hunter curve, which provides from the number of fixtures, based on a high probability of using many fixtures at once. The AWWA developed the 1975 M22 curves to refine the fixture unit method, which has shown to provide a better estimate than the Hunter curve although the uptake was not necessarily strong (AWWA, 2004). The original Hunter Curves have been incorporated into the Uniform Plumbing Code (AWWA, 2004).

Lingireddy et al. (1998) recommend that pipe sizes be based on the peak demand diversity (PDD) relation instead of using fixed peak per capita demands, especially for rural households. A fixed peak per capita demand relation bases design on maximum domestic flow requirements for each domestic connection (Lingireddy et al., 1998). On the other hand, a PDD relation bases design on peak domestic flow in each pipe link (Lingireddy et al., 1998). Using a PDD relation, as the number of domestic connections on a pipe link increases, the peak flow requirements per domestic connection decreases; this is due to the fact that the probability of all users on a distribution line simultaneously requiring maximum flows decreases with increasing connections (Lingireddy et al., 1998). Design based on fixed peak per capita demands will overestimate overall flow requirements and can underestimate individual branch line flow requirements or distribution lines with few connections (Lingireddy, 1998). While peak flow rate data is significant in water distribution system design and data collection through this research allows for peak demand analysis, it is not a focus of this thesis.

Bulk domestic water usage can be disaggregated into more specific end-uses of water—recall that water use for an individual, Q_{it}, is the sum of specific end uses. Domestic water use is typically separated into indoor water use and outdoor water use. Indoor end uses of water are grouped by fixture:

- toilet
- clothes washer
- shower
- bath
- faucet
- dishwasher
- leaks

Outdoor water use includes activities like lawn watering, gardening, animal and livestock watering, car washing, and playing in the sprinkler.

Researchers have conducted many studies disaggregating domestic water use into its end-uses. Edwards and Martin (1995) installed an average of 14 water meters in 100 study households to measure flows at each appliance separately at 15 minute intervals.

DeOreo et al. (1996), Mayer et al. (1999), DeOreo et al. (2001), Loh and Coghlan (2003), Roberts (2005), Heinrich (2007), and Willis et al. (2009) all used flow trace analysis to disaggregate domestic water use. Flow trace analysis involves recording the water volume passing a user's meter at short time intervals, like 10 seconds, and then using software like Trace Wizard to assign flows to specific end-uses (Scheepers, 2012). The average water consumption measured in each study listed above is summarized in Table 3.3.

Table 3.3 Average water consumption from domestic end use studies on municipal systems

CITATION	LOCATION	AVERAGE WATER CONSUMPTION (Lpcd)
Edwards and Martin (1995)	East Anglia, UK	141
DeOreo et al. (1996)	Boulder, USA	223
Mayer et al. (1999)	North America	650
DeOreo et al. (2001)	North America	241
Loh and Coghlan (2003)	Perth, Australia	155
Mayer et al. (2003)	East Bay MD, USA	326
Roberts (2005)	Melbourne, Australia	178
Heinrich (2007)	Judgeford, New Zealand	184
Willis et al. (2009)	Gold Coast, Australia	157

Table 3.4 summarizes the sampling details of these studies.

Table 3.4 Water meter sampling details for domestic end use studies

CITATION	SAMPLE SIZE (HOMES)	SAMPLE INTERVAL (SECONDS)	SAMPLE PERIOD (DAYS)
Edwards and Martin (1995)	100	900	365
DeOreo et al. (1996)	16	10	21
Mayer et al. (1999)	1 188	10	28
DeOreo et al. (2001)	37	10	28
Loh and Coghlan (2003)	120	10	575
Mayer et al. (2003)	33	10	15
Roberts (2005)	100	5	28
Heinrich (2007)	12	10	73
Willis et al. (2009)	151	10	14

Mayer et al. (1999) disaggregated residential water use into its end purposes at twelve North American study sites. They used historic billing records, a detailed mail survey, and end use water meter data to quantify domestic water use as shown in Figure 3.1.

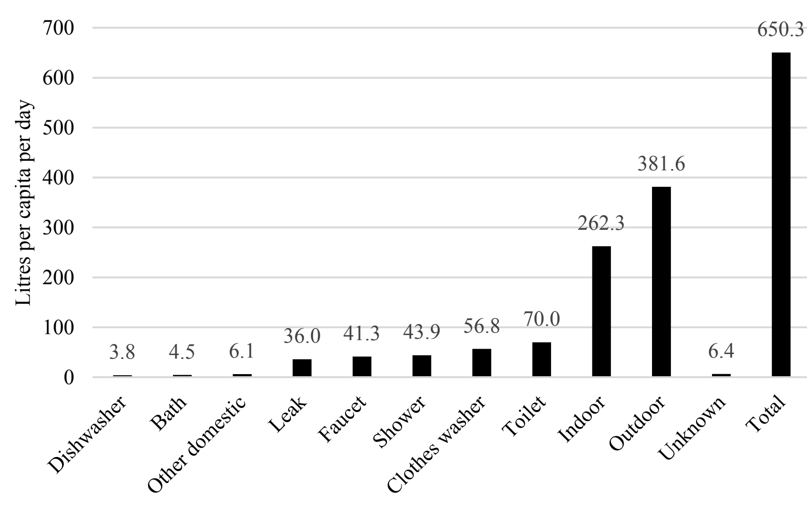

Figure 3.1 Mean daily per capita water use for 12 study sites (Mayer et al., 1999)

Note: “Indoor” is the sum of all indoor fixture usage and “Total” is the sum of “Indoor”, “Outdoor”, and “Unknown”.

Figure 3.2 shows indoor domestic water use—which represents the entirety of domestic water use during winter months in some regions—divided into percentage used by certain fixtures.

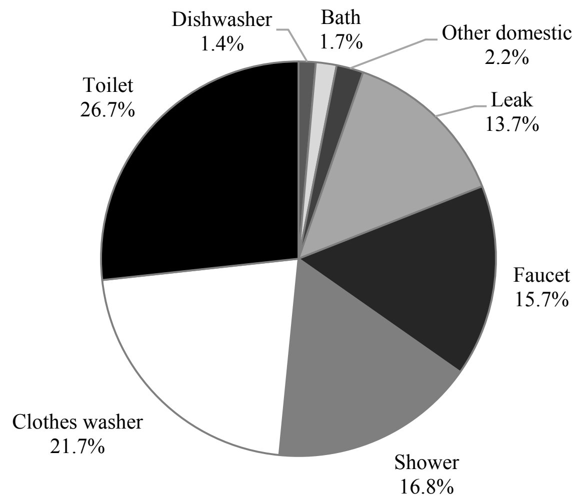

Figure 3.2 Indoor per capita use percentages by fixture at 12 study sites (Mayer et al., 1999)

Environment Canada (2013) has found a similar breakdown of indoor domestic water use by purpose, shown in Figure 3.3.

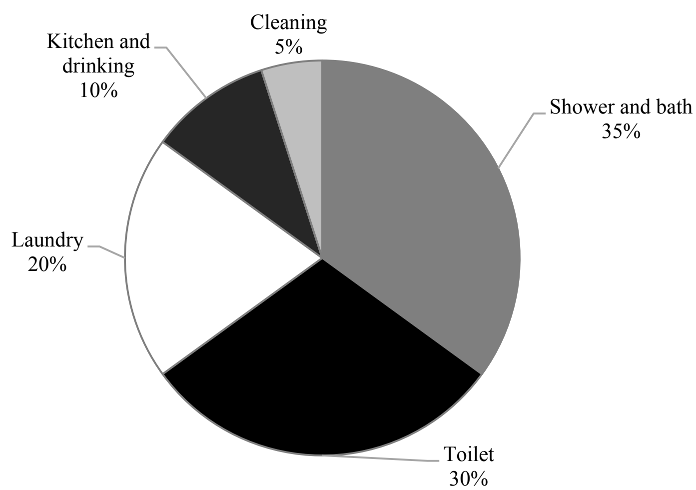

Figure 3.3 Indoor water uses in Canada (Environment Canada, 2013)

Table 3.5 summarizes end use volumes per event for a number of end use studies.

Table 3.5 Examples of reported end use volumes per event from domestic end use studies (Scheepers, 2012)

	AVERAGE VOLUME OF WATER PER END USE EVENT (L/EVENT)					
CITATION	TOILET	SHOWER	WASHING MACHINE	FAUCET	DISH WASHER	BATH
DeOreo et al. (1996)	16.0	61.0	—	—	—	—
Mayer et al. (1999)	13.4	66.3	157.6	—	—	—
DeOreo et al. (2001)	13.7	—	155.0	—	—	—
Loh and Coghlan (2003)	10.0	60.0	150.3	—	—	—
Mayer et al. (2003)	15.0	71.0	156.9	—	—	—
Roberts (2005)	7.6	67.5	143.0	1.3	23.9	123.0
Heinrich (2007)	6.2	82.0	134.0	1.6	—	—

Table 3.6 summarizes daily per capita water usage by end use.

Table 3.6 Examples of reported end use volumes per capita from domestic end use studies (Scheepers, 2012)

	AVERAGE VOLUME OF WATER PER CAPITA PER DAY FOR SELECTED END USES (Lpcd)					
CITATION	TOILET	SHOWER	WASHING MACHINE	FAUCET	DISH WASHER	BATH
Edwards and Martin (1995)	47.9	5.8	30.5	36.3	1.5	18.9
DeOreo et al. (1996)	26.3	17.4	24.8	14.7	3.0	2.3
Mayer et al. (1999)	71.3	44.7	57.8	42.0	3.9	4.6
DeOreo et al. (2001)	71.2	34.1	56.0	34.8	5.3	14.0
Loh and Coghlan (2003)	33.0	51.0	42.0	24.0	—	—
Mayer et al. (2003)	76.7	46.2	53.6	40.5	3.9	11.6
Roberts (2005)	30.0	49.0	40.0	27.0	3.0	3.0
Heinrich (2007)	33.4	67.8	40.9	23.5	2.4	4.3
Willis et al. (2009)	21.1	49.7	30.0	27.0	2.2	6.5

Table 3.7 summarizes daily per capita end use frequencies.

Table 3.7 Examples of reported end use frequencies for domestic end use studies (Scheepers, 2012)

	AVERAGE END USE EVENT FREQUENCY (FREQUENCY PER CAPITA PER DAY)				
CITATION	TOILET	SHOWER	WASHING MACHINE	DISH WASHER	BATH
DeOreo et al. (1996)	3.8	0.7	0.3	—	0.2
Mayer et al. (1999)	5.1	0.8	0.4	—	0.1
DeOreo et al. (2001)	5.2	—	0.4	—	—
Mayer et al. (2003)	5.1	0.7	0.4	0.1	0.1
Roberts (2005)	4.2	0.8	—	—	—
Heinrich (2007)	4.7	—	0.3	—	—

Many studies have investigated household on-site leakage as a portion of total demand, as shown in Table 3.8.

Table 3.8 On-site leakage as a percentage of total demand for domestic end use studies

CITATION	LOCATION	LEAKAGE (% OF TOTAL DEMAND)
DeOreo et al. (1996)	Boulder, USA	2.3
Mayer et al. (1999)	North America	5.5
DeOreo et al. (2001)	North America	10.3
Loh and Coghlan (2003)	Perth, Australia	2.3
Roberts (2005)	Melbourne, Australia	5.7
Heinrich (2007)	Judgeford, New Zealand	3.7
Willis et al. (2009)	Gold Coast, Australia	1.0

Water-efficient, or "low-flow", appliances reduce water consumption. Grafton et al. (2011) found that 40% of Canadian households have low volume or dual-flush toilets and that 56% of Canadian households have low-flow showerheads; Statistics Canada (2009) gives similar figures: 39% for dual-flush toilets and 54% for low-flow showerheads.

Diurnal and weekly patterns strongly reflect residential lifestyles. Mayer et al. (1999) found that the same diurnal water use pattern existed for all 12 of their study sites across North America:

a. Lowest usage during the night (11 p.m. to 5 a.m.)

b. Highest usage in the morning (5 a.m. to 11 a.m.)
c. Moderate usage during the midday (11 a.m. to 6 p.m.)
d. High evening usage (6 p.m. to 11 p.m.)

Water use can also be analyzed weekly, monthly, and seasonally. Because chapter four discusses specific factors that influence water consumption, an analysis of seasonal variability of water consumption in Samson Cree Nation can be found there.

As part of their assessment, Neegan Burnside (2010) estimated an average day per capita water demand of 379 Lpcd and a maximum day per capita water demand of 951 Lpcd for Samson Cree Nation. They estimated these values based on water treatment plant flows. Since Samson Cree Nation reports many pipe breaks in the system, Neegan Burnside (2010) used an average daily use of 325 Lpcd and a maximum day factor of 2.5 for their water demand projection. Aquatic Resource Management (2011) estimated an average municipal per capita use of 401 Lpcd—of which 230 Lpcd is residential usage—based on water treatment plant flows and assuming five people per household. Since both studies only provide estimates and the data was not collected by Samson Cree Nation, band leadership hopes to collect information that is more accurate and is collected under their own initiative.

As mentioned previously, drinking bottled water instead of tap water in Samson Cree Nation is pervasive. Aquatic Resource Management (2011) conducted a bottled water survey of Montana First Nation—a neighbouring Nation to Samson. They found that 59% of residential homes use bottled water for drinking and cooking, averaging 183 litres of water per household per month from bottled water sources.

3.2.2 Water surveys and questionnaires

The use of surveys and questionnaires is common in water use studies. They provide household demographic data that is useful in disaggregating water use and in categorizing water consumers and their households. Edwards and Martin (1995), DeOreo et al. (1996), Mayer et al. (1999), DeOreo et al. (2001), Loh and Coghlan (2003), Mayer et al. (2003), Roberts (2005), Heinrich (2007), and Willis et al. (2009) all surveyed households for information, like: number of residents, age of residents, household income, level of education, water fixture use frequency, square footage, and garden size, to name a few.

Using data from Mayer et al. (1999) and Aquacraft (2005), the Alliance for Water Efficiency and The Field Museum developed the Water Calculator (Home Water Works, 2011). The Water Calculator estimates household water usage based on information entered by the user. As the user provides more information, the household water use estimate reflects more accurate information. The Water Calculator has been designed to estimate water use for homes in North America and is available to use free of charge. Some details of the calculations behind the Water Calculator are available on the Home Water Works (2011) website. Since Mayer et al. (1999) and Aquacraft (2004) combined flow trace analysis with survey results in their respective studies, the Water Calculator provides disaggregated water use estimates based solely on survey information.

3.2.3 Rural water use

Many tools and methods are available for studying water behaviours of households on municipal distribution systems; however, less is known about water use in areas without water utilities. Key questions, then, are, how could rural systems differ, and what insights might result from greater knowledge of rural water use behaviours? According to Thompson et al. (2001), piped households use about three times more water per capita than unpiped households in three East African countries: Kenya, Tanzania, and Uganda. Further, Thompson et al. (2001) found that urban households use more water than rural households for both piped and unpiped systems. Gazzinelli et al. (1998) also found that water source is significantly correlated with water use and that rural consumers use less water than urban consumers in Latin America. INAC (2007, Appendix A, pg. 2) (now AANDC) reflects these differences in water use based on delivery method in their *Level of Service Standards (LOSS)*:

> The minimum daily water quantities made available for design purposes, depending on the delivery method, shall be:
>
> a. 90 litres per person for piped water system with watering points;
>
> b. 90 litres per person for community truck haul water system to individual homes;
>
> c. 180 litres per person for community piped domestic water supply and distribution.

Importantly, these minimum volumes dictate water service funding for First Nations. Further, although water consumption quantities from individual or private wells are not provided, 14 479 First Nations households across the country (Neegan Burnside, 2011a), 31% of First Nations households in Alberta (Neegan Burnside, 2011b), and 75% of Samson Cree Nation households (*ibid*., 2011b) receive water from private wells. This is a significant number of water users for whom there is no water use data, and thus no method to properly manage their water resources in response to their water demand, or vice versa, and plan for future water use scenarios.

This situation is not unique to Indigenous communities in Canada, for Canadians "one third of rural and small town residents rely on private wells for their drinking water" (Hardie & Alasia, 2009, pg. 1). Further, we cannot assume consistent water use behaviour between municipal and rural water users: as Hardie and Alasia (2009) found, rural residents connected to a municipal water system use 60% more water than urban residents. They also found that of the Canadian households that drink tap water, urban residents are more likely to treat their water. "Between 23% and 31% of households primarily drink bottled water" (Hardie & Alasia, 2009, pg. 14).

Keshavarzi et al. (2006) studied rural domestic water consumption behaviour in Fars province, Iran. They compared domestic water use between different rural groups, as shown in Table 3.9, to highlight the relationship between water consumption and behavioral and cultural factors.

Table 3.9 Domestic water consumption in rural communities from different regions (Keshavarzi et al. 2006)

CITATION	LOCATION	AVERAGE WATER CONSUMPTION (Lpcd)
Hunnings et al. (1996)	Virginia, USA	284
Gazzinelli et al. (1998)	Latin America	40
	Rural Africa	1–25
Hartung (2001) as cited in Keshavarzi et al. (2006)	China	89
	Sri Lanka	36–54
	South India	14–42
	East Africa	5–23
Thompson et al. (2001)	East Africa	18–44
Lanka Rainwater Harvesting Forum (2001)	Kyenjojo, Uganda	11–23
FPRWWD (2004) as cited in Keshavarzi et al. (2006)	Fars Province, Iran	250
Keshavarzi et al. (2006)	Ramjed area, Iran	122

Gazzinelli et al. (1998) quantified domestic water use in Nova União village, Minas Gerais, Brazil. They studied factors affecting household water use from multiple water sources and found that total water use broke down into the following categories:

- 41% personal hygiene (bathing, washing hands, laundering)
- 33% cooking, drinking, washing utensils
- 24% environmental sanitation (washing floors, flushing toilets)

As stated before, water consumption depends on behavioural and cultural factors.

3.3 Methods used to measure domestic water use in Samson Cree Nation

For this project, Samson Cree Nation purchased 20 Neptune Technology Group Inc. E-Coder)R900*i* water meters and a CE5320X Handheld datalogger. Neptune also provided computer software (N_SIGHT™ R900®) for downloading water meter data from the datalogger. Accu-Flo Meter Service Ltd. provided training to the research group on the water meters, the datalogger, and the software purchased.

The E-Coder)R900*i* water meters are equipped with leak detection, tamper detection, and reverse flow detection (Neptune Technology Group, 2006). The meters stored daily and hourly water use data and, when activated, transmitted the data to the datalogger via radio frequency. Neptune software was then used to download data from the datalogger, convert data into the appropriate units, and export data into Microsoft Excel spreadsheets.

Samson Cree Nation provided a certified plumber to install the water meters in volunteers' homes. Installation required closing the water valve entering the home and draining the remaining water from the water lines inside the home. Then the plumber cut and removed a suitable portion of line above the valve and connected the water meter to the water line using appropriate fittings (as determined by the plumber). The valve was slowly opened and water was run through the taps to remove air. The plumber ensured the water meter was not leaking from any of its connections and I verified that it was indeed recording water flows through the water line. Figures 3.4, 3.5, and 3.6 show some of the installation process.

Figure 3.4 Water line section cut and removed above valve

Figure 3.5 Plumber attaching water meter to water line

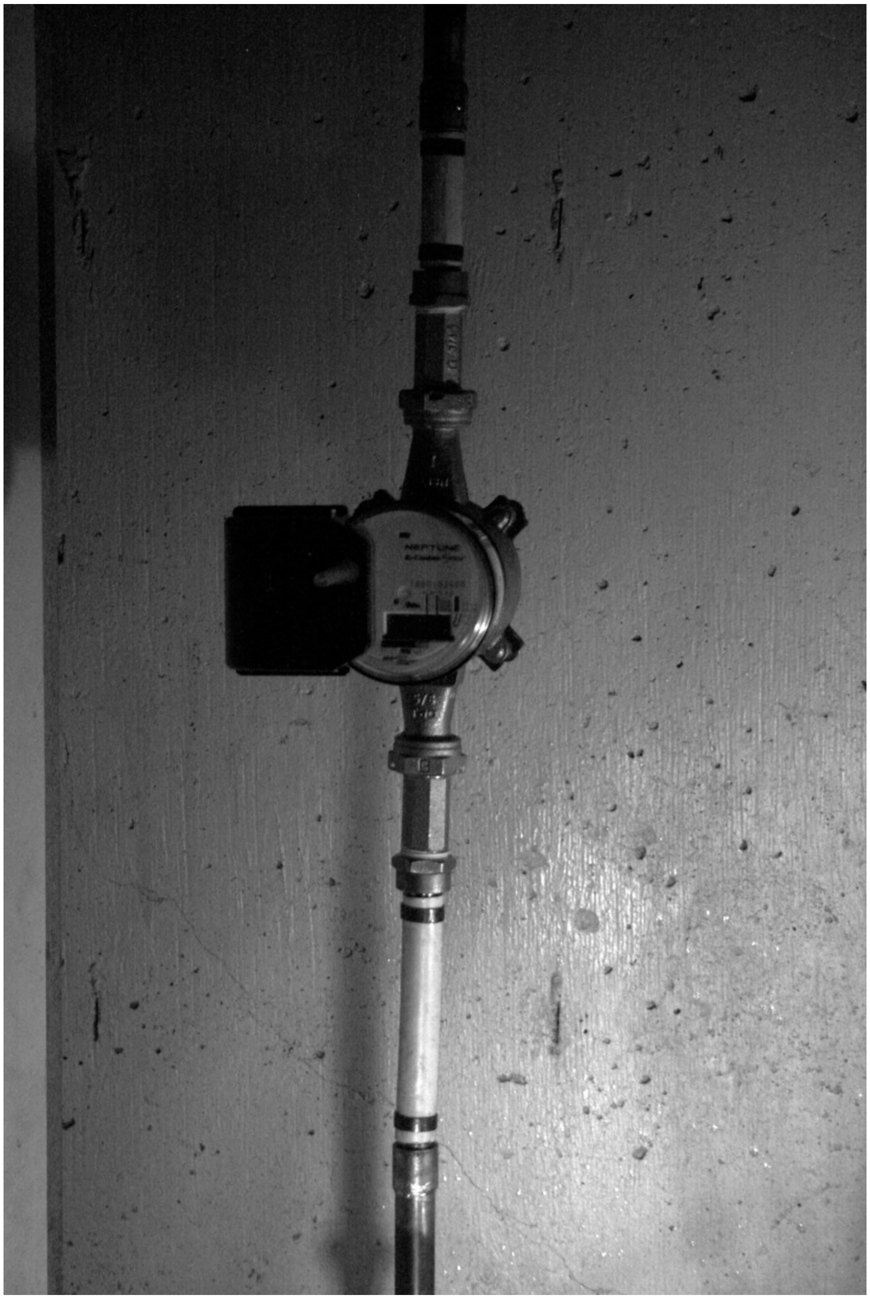

Figure 3.6 Installed and functioning water meter

Volunteers were recruited through existing connections—whether I had met them previously, Fraser had collected a water sample from their home, or I was referred to them—or by canvassing households door-to-door. Since the perceptions of water quality across Samson Cree Nation's water systems—rural and municipal—are a significant point of investigation for this project, volunteers were selected based primarily on the their water source:

- private groundwater well (rural, non-BWA);

- private groundwater well currently under a boil water advisory (rural, BWA); and,
- municipal distribution system (municipal).

We installed meters in batches of ten; Figure 3.7 shows the locations of metered households and Table 3.10 details the water metering program schedule.

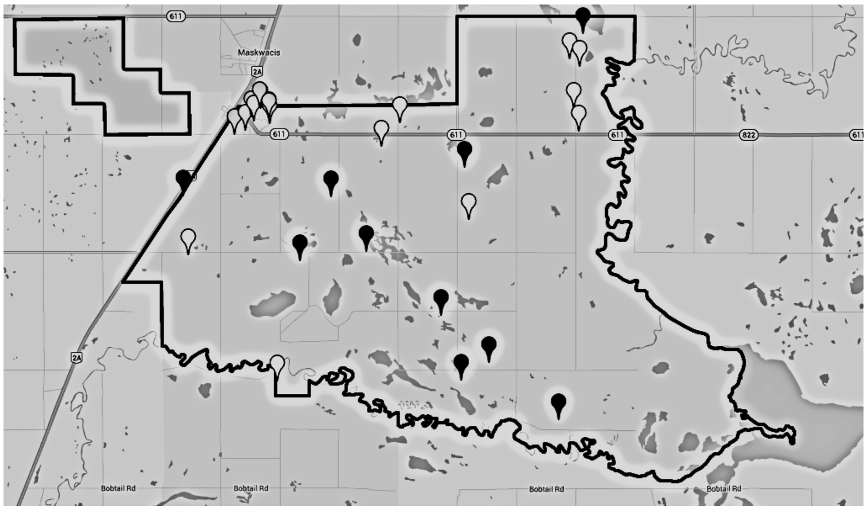

Figure 3.7 Water metering program for Samson Cree Nation, metered household locations. Black outline represents border of Samson Cree Nation lands. Black labels represent rural households under boil water advisory, white labels represent rural households not under boil water advisory, and grey labels represent municipal households (clustered in Maskwacîs townsite in the northwest corner of Samson Cree Nation)

Table 3.10 Water metering program for Samson Cree Nation

BATCH	SAMPLE PERIOD	SYSTEM SPLIT
1	Aug 2013–Jul 2014	4 Rural, non-BWA 3 Rural, BWA 3 Municipal
2	Sep 2013–Jan 2014	3 Rural, non-BWA 3 Rural, BWA 2 Municipal 1 Rural off-reserve 1 Municipal off-reserve
3	Mar 2014–Jul 2014	3 Rural, non-BWA 3 Rural, BWA 4 Municipal

Interviews were conducted with residents of 26 of the metered house-holds. Volunteers—usually homeowners—signed an Information and Consent Form (Appendix B) to give free, prior, and informed consent to participating in the research. The Information and Consent Form along with the interview questions were approved by the University of Alberta Research Ethics Office. During house visit to download water meter data, I asked residents if they would be willing to be interviewed. I interviewed most residents in their homes although on a few occasions, I interviewed residents at their place of work. I observed protocol before beginning the interview by offering participants tobacco, tea, and water and thanking them for their participation. The questionnaire (Appendix C) guided the interview questions, although interview participants were permitted to discuss topics not included in the questionnaire. The interviews lasted between 20 minutes and two hours, depending on the participant's interest in providing details.

Typically the interviews progressed with me asking a question directly from the questionnaire and the interviewee providing an answer that I could record in full. For lengthier responses, I was able to take notes to capture what the interviewee shared. Throughout many of the interviews, however, we would discuss topics not necessarily directly related to my research questions. I took notes of these conversations but in less detail. Some participants consented to a digital recording of the interview, pertinent results of which were transcribed, with copies provided to the participants. I asked participants to validate the information in the transcript for accuracy and inform me if they wished to make any changes. I also encouraged participants to keep me informed of any changes they may notice about their water supply or any other information that related to the interview questions. I explained how they could withdraw from the study if they wished. None of the interviewees requested changes to the transcription nor did anyone ask to withdraw. I did, however, receive periodic updates about water quality, housing problems, visitors staying at metered households, vacation plans, and deaths in the family.

Interview participants provided key demographic information about their households. Information—like the number of residents in the household and residents' ages in the household—permitted calculation of per capita water use and investigation of factors that affect water use. Further, residents provided sufficient detail to use the Water Calculator (Home Water Works, 2011), in combination with the metered water use for each household, to disaggregate measurements into each residential end-use category.

Calculations, charts, and figures were all processed through Microsoft Excel.

3.4 Discussion of average water consumption in Samson Cree Nation and other results

Overall, we collected a total of 143 969 hourly water flows, averaging 5 141 data points per household. In this section, I analyze and display the results of these measured flows along with interview results. Relevant values are calculated and shared. I analyze water use at hourly, weekly, and monthly scales. I also discuss the disaggregated domestic water use results, specifically: indoor use, outdoor use, and leakage. While an investigation of variables affecting water use is reserved for chapter four, I occasionally provide explanations or interpretations of data in the current chapter which address factors that impact water use. The factors that I draw on in the current analysis are for comparing water use in Samson Cree Nation to other groups of water users. These comparisons are not measured for statistical significance. In chapter four, I measure the variables affecting water use between groups in Samson Cree Nation.

Water meter data can be plotted as time series to show changes in water consumption over time. Figure 3.8, 3.9, 3.10, and 3.11 show raw data collected at four different residences for the same time period in hourly water consumption for the entire household.

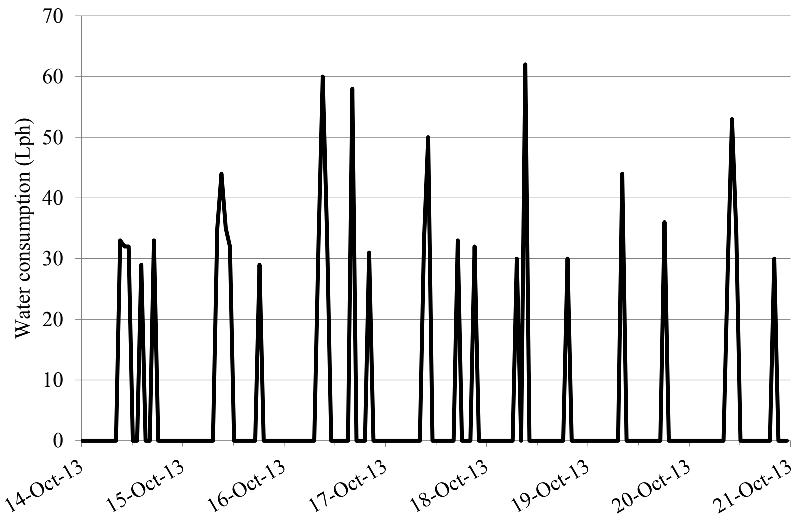

Figure 3.8 Water meter results for one week at the residence of Alphonse Nepoose

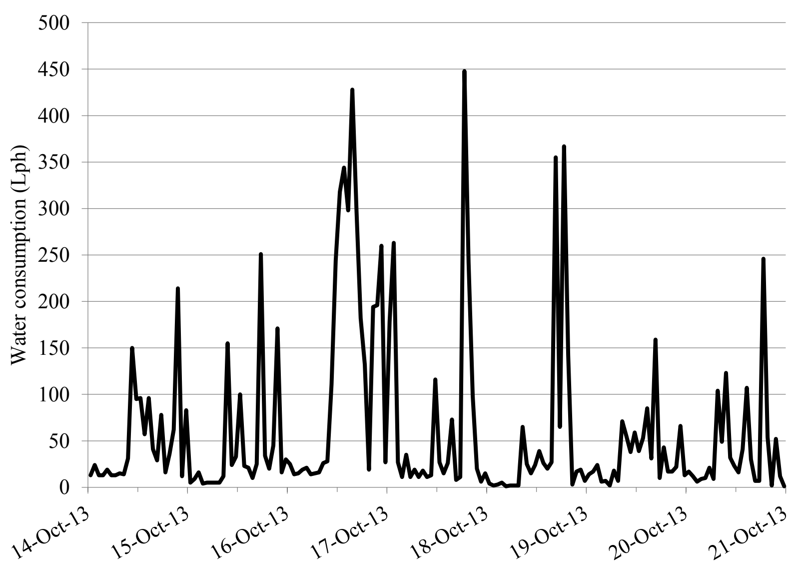

Figure 3.9 Water meter results for one week at the residence of Rita Saddleback

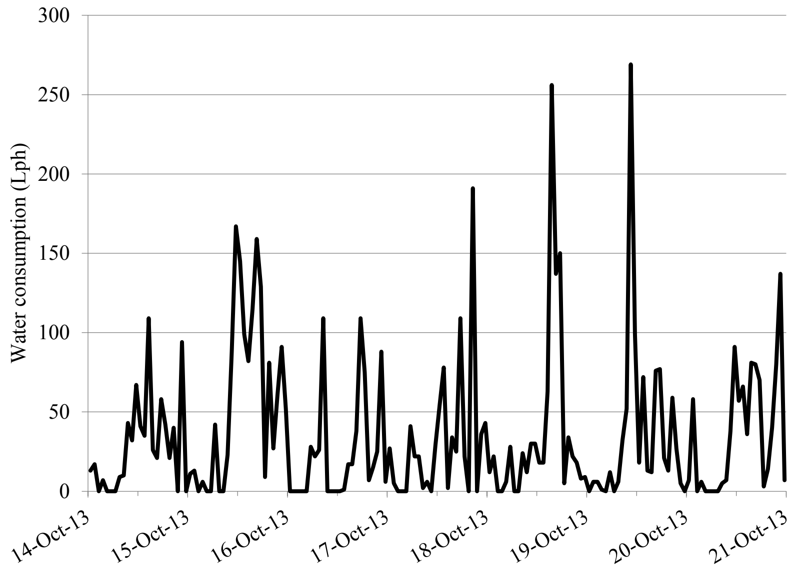

Figure 3.10 Water meter results for one week at the residence of Rita Cutknife

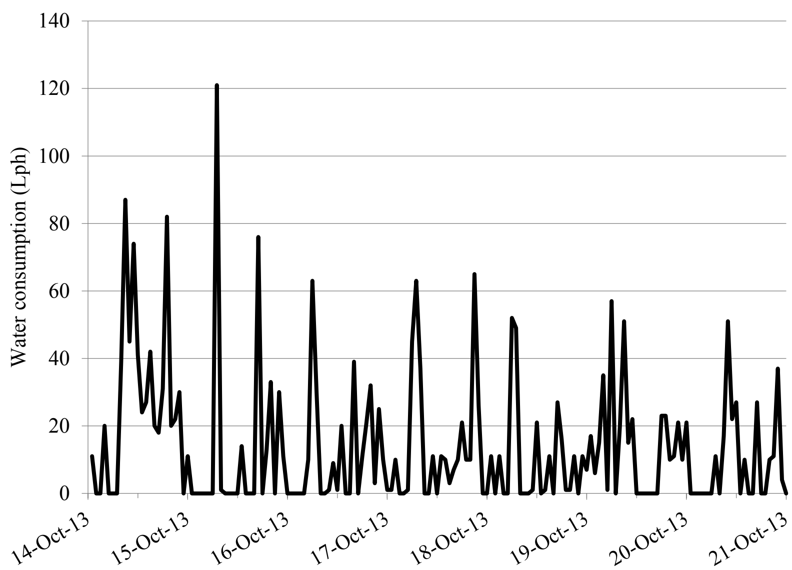

Figure 3.11 Water meter results for one week at the residence of Irene Omeasoo

Note how the pattern and scale of water consumption differ between the households, reflecting the distinct water use behaviours of each. Figure 3.8 shows one peak in hourly use just exceeding 60 litres whereas Figure 3.9 shows one peak reaching about 450 litres. These differences are reflective of household composition since Alphonse lives alone and seven people live in Rita Saddleback's home. Figures 3.8, 3.10, and 3.11 show the water meter reading zero litres of hourly water use periodically (usually during the night). Compare these to Figure 3.9 which appears to show water flows greater than zero even through the night, indicating potential leakage or that some residents are up during the night using water. These figures all show different patterns of water use with peaks or water use activities concentrated during varying times of day.

While these visualizations are useful for understanding the raw data collected and the unique characteristics of each metered household, the remainder of the results present data aggregated for groups of water users.

Table 3.11 summarizes some key results.

Table 3.11 Summary of Samson Cree Nation domestic water use

	MINIMUM	MAXIMUM	AVERAGE	STANDARD DEVIATION
Daily water use (Lpcd)	100	453	221	99
Daily use, Municipal Residents (Lpcd)	136	523	283	109
Daily use, Rural Residents (Lpcd)	100	344	195	84
Daily use, winter (Lpcd)	65	1378	234	80
Daily use, summer (Lpcd)	51	892	222	19
Household size	1	9	5.3	2.2
Household size, Municipal	1	9	5.9	2.4
Household size, Rural	1	8	4.9	2.1
Children per household (<6 years)	0	4	1.1	1.4
Elderly per household (>60 years)	0	2	0.4	0.7
Percentage of residents away from home during weekdays	0	100	62	34

When household flows are divided by the number of residents, we can analyze per capita water usage. Figure 3.12 shows the daily per capita water use frequency distribution of metered households.

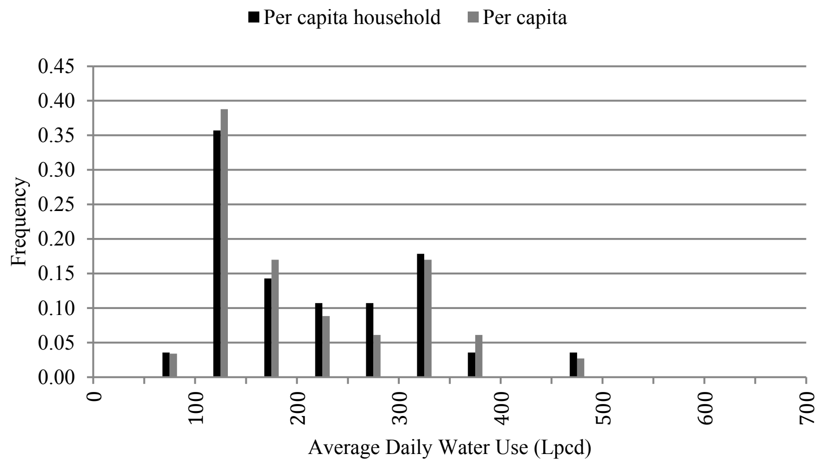

Figure 3.12 Daily average per capita consumption measurement frequencies

The units "per capita household" mean that the daily per capita water use values for each household are equally weighted (i.e., each household provides a single data point regardless of how many people live there). Thus, this study uses 28 data points for on-reserve per capita household water usage—one for each metered household. The units "per capita" mean that households with more than one resident provide that number of data points—weighing that water consumption value more heavily. This study uses 147 data points for on-reserve per capita water usage. Typically, I analyze data using "per capita household"—so as not to artificially increase the confidence of the data—and refer to such values as "per capita", except where explicitly stated otherwise, like above. While weighting the average water use based on household size would more accurately reflect the actual household composition (larger households accounting for more water users), it would increase the sample size above the actual measured amount (the number of metered households). Therefore, where it was necessary to weight households with more residents more heavily than households with fewer residents, I have made the appropriate distinction in units: "per capita household" versus "per capita". Otherwise, "per capita household" is referred to simply as "per capita". As seen above in Figure 3.5 these two approaches provide similar frequency distributions. While the distributions are not identical—and they would be in an idealized program where all households were metered—they provide a similar shape to each other. Therefore, the frequency distribution does not provide evidence that "per capita" water use will provide significantly different results as "per capita household".

Peak hourly water use is an important value in water distribution system design. To get a sense of peak hourly uses at the household level, the maximum hourly flow measured each day in each household is plotted as a frequency chart in Figure 3.13. The most frequent peak hourly usage for an entire day is between 200 and 250 litres for the entire household, or about 40 to 50 litres per person per hour.

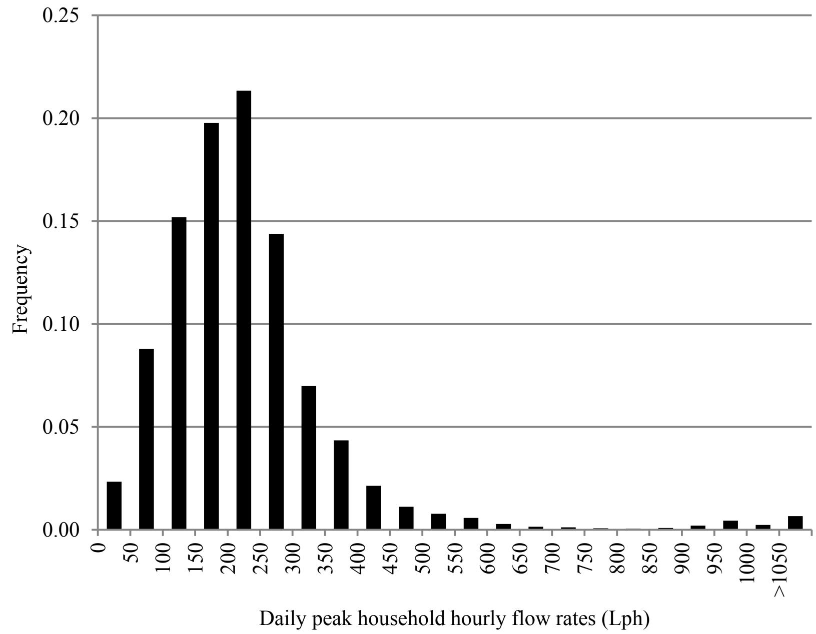

Figure 3.13 Daily peak hourly flow rates for the entire study period

The average total domestic water use for Samson Cree Nation is 221 Lpcd, a value significantly lower than the results of Mayer et al. (1999), who found an average total domestic water use of 650.3 Lpcd across their twelve North American study sites. This difference in water consumption is mostly a result of the differences in outdoor water use, as discussed below. However, domestic water use in Samson Cree Nation is comparable to nearby communities, as seen in Table 3.12.

Table 3.12 Average daily residential water use per capita in Samson Cree Nation and nearby communities

CITATION	REGION	RESIDENTIAL (Lpcd)
This study	Samson	221
Environment Canada (2011)	Canada	274
Environment Canada (2011)	Alberta	209
EPCOR (2010)	Edmonton	226
Aquatic Resource Management (2011)	Wetaskiwin	182
Aquatic Resource Management (2011)	Ponoka	179

This regional transferability of water consumption data is due—to a certain point—to the regional transferability of lifestyle. Despite a different standard of living, we find the same water using fixtures and appliances in Samson Cree Nation households as in other Albertan communities.

This means that, despite Samson Cree Nation's rural characteristics, water consumption behaviours are likely more similar to urban and rural communities in Alberta and the rest of Canada than to rural communities in other regions around the world. Comparison of rural water consumption in Samson Cree Nation with other rural communities' water use, provided in Table 3.9, only shows that rural domestic water use varies globally. Clearly the impact of dominant culture—that of Canadian, western society—that literally surrounds Samson Cree Nation plays a role in shaping the lifestyles, and thus the water use behaviours of those who call Samson home.

Oddly enough, average daily residential water use in Samson Cree Nation (221 Lpcd) is more similar to that in Edmonton (226 Lpcd) than to the two neighbouring urban centres: Wetaskiwin (182 Lpcd) and Ponoka (179 Lpcd). The rural residents in Samson Cree Nation use about 31% less water than municipal residents. This is counter to the findings of Hardie and Alasia (2009) who found that rural residents used 60% more water than their municipal counterparts; although Hardie and Alasia (2009) did only have data for rural household connected to municipal distribution systems. An explanation for why average water consumption in Samson Cree Nation is numerically closer to that in Edmonton than the physically closer municipalities of Wetaskiwin and Ponoka is that some other factor, leak prevalence for example, is increasing water consumption above the "expected" value of these proximate communities.

Since we only measured residential water use, we do not know what portion of total daily water use this 221 Lpcd represents. We cannot, therefore, verify Neegan Burnside's (2010) estimate of 379 Lpcd or Aquatic Resource Management's (2011) estimate of 401 Lpcd. However, the estimate of 230 Lpcd for residential use based on treatment plant flows (Aquatic Resource Management, 2011) is fairly accurate, although lower than the average municipal use of 283 Lpcd. Compared to the minimum water use requirements provided by INAC (2007) of 180 Lpcd for a piped delivery system, 283 Lpcd is much higher. One wonders, then, if the amount of funding for this delivery system was sufficient to meet this demand.

Combining hourly data from all households reveals the diurnal water use pattern, with clear distinctions between weekdays and weekends (Figure 3.14).

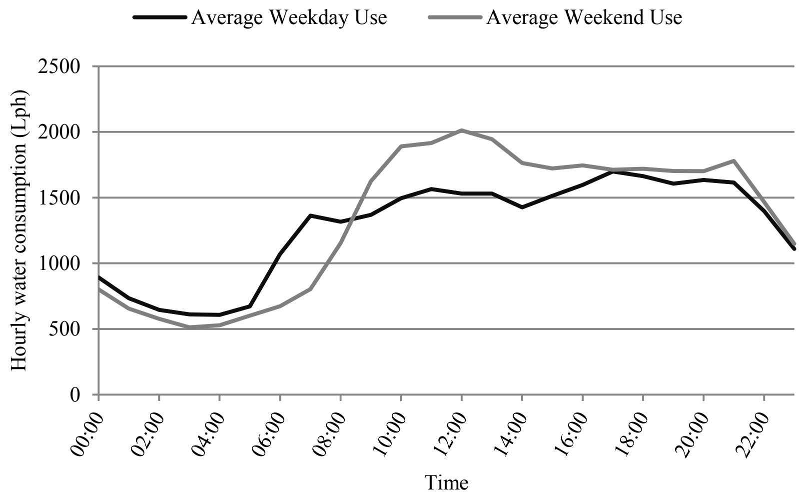

Figure 3.14 Average daily pattern of water use for metered households on weekdays and weekends

The impact of western lifestyles can also be seen in diurnal water use patterns. Figure 3.14, which shows Samson Cree Nation residents' daily pattern, shows an adoption of western modes of living. The weekday and weekend patterns are distinct, following the prevailing weekly schedules of schools, workplaces, and other institutions. The weekend pattern appears fairly consistent with:

a. Lowest usage during the night (from 11:00 p.m. to 8:00 a.m.)
b. Highest usage during the day (from 8:00 a.m. to 2:00 p.m.)
c. Moderate usage during afternoon and evening (from 2:00 p.m. to 11:00 p.m.).

The weekday pattern however, is less discernible, especially when compared to typical water consumption patterns. It appears that the weekday diurnal pattern is an overlay of two dominant water use patterns. The first is the weekend pattern described above. The second is:

a. Lowest usage during the night (from 11:00 p.m. to 5:00 a.m.)
b. Moderate usage during the morning (from 5:00 a.m. to 8:00 a.m.)
c. High usage during the day (from 8:00 a.m. to 4:00 p.m.)
d. Highest usage during the evening (from 4:00 p.m. to 11:00 p.m.).

Note how two of the weekday increases in water usage correspond to the two weekend increases in water usage, occurring around 11:00 a.m. and 9:00 p.m. each day. The remaining two peaks in weekday water usage—7:00 a.m. and 5:00 p.m.—correspond with "expected" water use patterns where peak water demand bookends residents leaving and returning home for the day for school or work. Although with a larger sample size, a very different pattern could emerge. Further investigation into changing diurnal patterns of water use can be found in chapter four.

Average daily water use per capita can be sorted by days of the week, as shown in Figure 3.15, below. The average domestic water use is relatively consistent throughout the week, staying between 200 and 240 litres per capita per day. Friday has the lowest water use (201 Lpcd) as most people are likely not doing water intensive activities, like washing clothes, at the end of the school or work week. Sunday has the highest water use (231 Lpcd) as people are likely preparing for the week and are at home to use water.

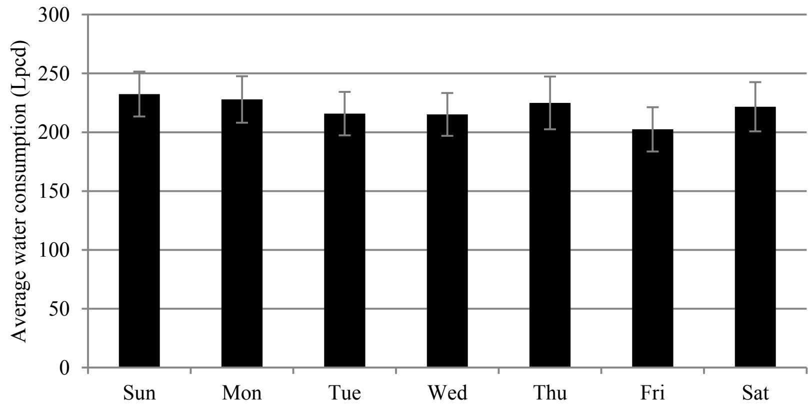

Figure 3.15 Average daily water use for metered households during the week over the entire sampling period. Error bars represent +/– one standard error, n=28.

Average daily water use per capita can also be sorted by month, as shown in Figure 3.16. The monthly averaged daily water consumption does not have an obvious pattern, although December is significantly higher than November or January. There are clear increases in hourly water use from many of the water meters between December 22, 2013 and January 2, 2014, which conforms to the scheduling of Canadian holiday periods, when people spend more time at home and therefore evidently use more water. Further, people visit family during this time, increasing the number of residents in some homes and decreasing it in others. With a fast growing young population, housing limitations, and older generations of people more likely to live on-reserve, people tend to visit Samson Cree Nation—and their families—during the holidays and increase water use.

Figure 3.16 also demonstrates how little water residents of Samson Cree Nation use outdoors. Typically water use increases during summer months with behaviours unique to warm weather: gardening, lawn watering, car washing, and playing in the sprinkler. However, in Samson Cree Nation we see the highest water use in December (309 Lpcd)—likely due to the holiday season when residents are off work and school and are visiting—followed by February (243 Lpcd), October (235 Lpcd), and then June (232 Lpcd). May (200 Lpcd) has the lowest average usage followed by April (205 Lpcd), January (209 Lpcd), and August (211 Lpcd).

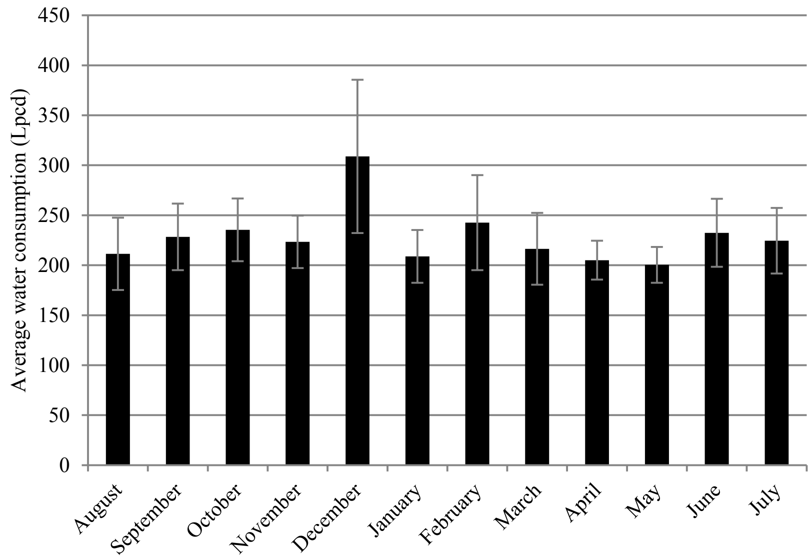

Figure 3.16 Average daily per capita consumption for metered households each month (August 2013 to July 2014). Error bars represent +/– one standard error.

Domestic water consumption can also be analyzed by how it is used in the home. Since not all metered households were interviewed, the average domestic water use for the disaggregated data is different than the 221 Lpcd reported earlier. The estimated average daily per capita water consumption for specific end uses in Samson Cree Nation was calculated using the Home Water Works (2011) Water Calculator and is shown in Figure 3.17.

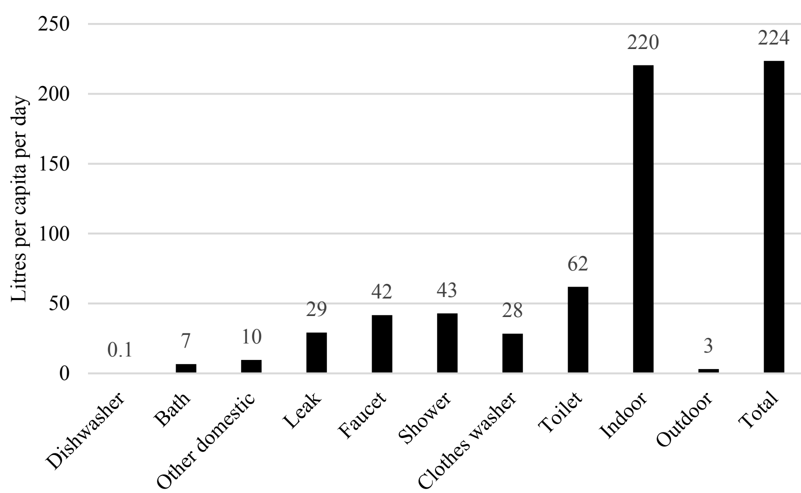

Figure 3.17 Mean daily per capita water use for metered households in Samson Cree Nation

Figure 3.18 shows the indoor end-uses isolated from outdoor consumption.

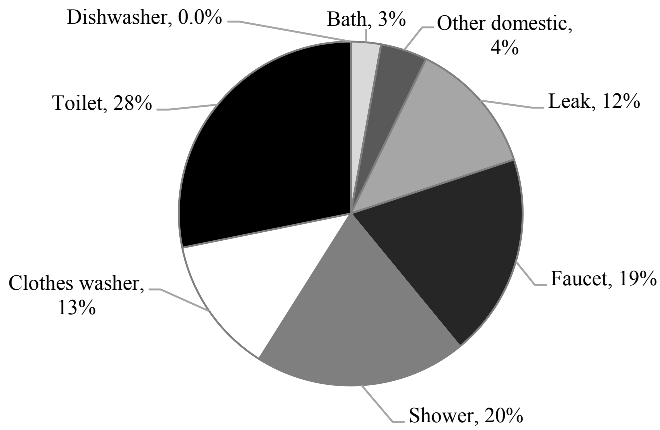

Figure 3.18 Average indoor domestic water end uses for metered households in Samson Cree Nation

Table 3.13 summarizes frequencies for specific purposes indoors.

Table 3.13 Reported residential end use frequencies in Samson Cree Nation

	AVERAGE END USE EVENT FREQUENCY (FREQUENCY PER CAPITA PER DAY)			
CITATION	SHOWER	WASHING MACHINE	DISH WASHER	BATH
This study	0.73	0.37	0.002	0.16

Despite regional similarities in water use, some clear distinctions in water use behaviours between individuals in Samson Cree Nation and other study groups exist. The results from the Home Water Works (2011) Water Calculator shown in Figure 3.18 confirm interview results. The most evident difference between the disaggregated results of Mayer et al. (1999)—or any other of the water end use studies—and Samson Cree Nation is that outdoor water use in Samson Cree Nation is practically non-existent. The average household in Samson Cree Nation uses about 3 Lpcd outdoors compared to the average household in Mayer et al. (1999) that uses 381.6 Lpcd outdoors. EPCOR (2010) reports that outdoor water use makes up 5% of total residential water use in Edmonton, Alberta: about 11.3 Lpcd. This is also significantly less than the values reported by Mayer et al. (1999) or other Canadian cities since Edmonton has relatively short summers (EPCOR, 2010).

Given the lack of lawns in Samson Cree Nation, it makes sense that outdoor water use is a small portion of total water use. Also, residential pools are very rare north of the Medicine Line (49^{th} parallel), as are outdoor spas or hot tubs—all of which are significant water consumers. Finally, a cooler climate and longer winters than any of the study sites in Mayer et al. (1999) means that Samson Cree Nation has very little need or time for lawn or garden irrigation. While Edmonton's average outdoor water use is also considerably lower than that of Mayer et al. (1999), it is over three times more than in Samson Cree Nation.

The reason may be cultural. When asked about lawn-watering, for example, Arlette Saddleback (2013) replied,

> No, that's a white person thing!

While her statement can immediately be taken as a joke, it hints at cultural factors. For example, whether caring for lawns is a sign of wealth, disposable income, disposable time, a cultural preference, a different relationship with the environment, or any combination of the above, landscaping—and the water use that accompanies it—is a rare occurrence in Samson Cree Nation. Further, most of the households in Samson Cree Nation are in the rural area where natural vegetation dominates around houses, requiring little care.

In terms of indoor water use, with an average value of 220 Lpcd from the Water Calculator, daily indoor domestic water use in Samson Cree Nation is lower than the 262.3 Lpcd measured by Mayer et al. (1999). Plus, Samson Cree Nation has some other notable distinctions—see Table 3.15, below.

Table 3.15 Summary of indoor water use in Samson Cree Nation

	AVERAGE
% households with dishwasher	3.33
% households reported leaks	30
% households with intermittent leak	100
% households with continuous leak	57
% households with continuous leaks, municipal	78
% households with continuous leak, rural	47

The majority of households in Samson Cree Nation do not have a dishwasher—but they do have a sense of humour. When asked if she has a dishwasher, Venus Redcrow (2014) responded:

> Yeah, my daughter.

Many interviewees would refer to a family member, usually one in the adjoining room, as the "dish washer" when I asked this question. Since houses are maintained by Samson Cree Nation and funding from the federal government is insufficient for housing costs, dishwashers are absent from households because, presumably, the band does not want to incur any unnecessary costs in dishwasher supply, maintenance, and repair. Some residents purchase dishwashers themselves but these sorts of voluntary expenditures on the part of residents are rare. One metered resident installed a low-flush toilet—the only low-flush toilet I encountered—during the study. A few households had purchased different (newer, more efficient) clothes washers from the standard models I saw in nearly every home. With such a low uptake of water saving devices, there is tremendous opportunity for water savings in Samson Cree Nation.

Leakage is another area worthy of investigation. The water meters registered intermittent and continuous leaks—although they measured only the occurrence of leaks, and not the flow rate. Leakage losses can be estimated using the low-metered flow rates—usually overnight usage—when a leak has been detected. Leaks are a significant concern for Samson Cree Nation, since the band is responsible for plumbing repairs in households. Further, about six households where we tried to install water meters—about 18% of households visited to install water meters—had plumbing concerns that made it impossible, or at least very difficult, to complete the installation. Corroded valves, buried curb cocks, weak or improperly assembled joints, and missing fixtures were common. Since we would have to shut off the water to install the water meter, houses with significant plumbing concerns were usually excluded from the study. So while the water meters detected leaks in the participating households, a selection bias may exist towards households with well-maintained plumbing infrastructure.

Neegan Burnside (2010, pg. 16) reported:

> Overall the pipe condition is considered poor. There are reported signs of cracking and the piping system experiences multiple failures every month, mainly in the older section in the main Townsite area. The community finds itself constantly fixing the breaks using their operations and maintenance budget.

3.5 Conclusions

From an interview with Flora Northwest (2013):

> 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?
>
> Hinder, if it's similar to federal. There is no consultation!

And later that same day from an interview with Arlette Saddleback (2013):

> 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?
>
> Data. It feels like we're at odds with the province. Data will be a point for us struggling against the province. Data will be useful for Samson.

Lastly, from an interview with Alphonse Nepoose (2013):

> What role do you see band leadership having in ensuring clean, safe drinking water?
>
> They need to listen to members and respond to concerns.

Each of these responses highlights frustration with some level government. And with jurisdictional complexities over water, resources, and territory between the Government of Canada, the Alberta Government, and Chief and Council plus a profound lack of listening to and response for those who struggle with safe or sufficient water supplies, is it any wonder?

Through a partnership with Samson Cree Nation, the research team at the University of Alberta collected data to address some of these concerns. I have calculated that the average domestic water use in Samson Cree Nation is 221 Lpcd. Average water use in Samson Cree Nation is different between residents serviced by the rural water system and residents serviced by the municipal water system. Municipal residents use on average 283 Lpcd. Rural residents use 31% less water, averaging 195 Lpcd. Ultimately these values have more in common with regional transferability of lifestyle from the surrounding communities—i.e. which water-using appliances are used in households—than they do with any other evident cultural factor.

That being said, Samson Cree Nation has some unique characteristics when it comes to water use. The daily water use pattern for metered homes in Samson Cree Nation has fewer obvious peaks than that of other (municipal) communities. This could be evidence of significantly different lifestyle from dominant Canadian society even though water-use volumes are similar. The average daily domestic water use in Samson Cree Nation is much higher for the month of December than for any other. This is mostly a result of the Christmas season when people are off work or school for weeks at a time and family and friends visit. Outdoor water use in Samson Cree Nation is notably lower than other communities, averaging 3.3 Lpcd. Dishwashers and water efficient appliances and fixtures are also rare in Samson Cree Nation.

The water meters detected intermittent leaks in every metered household and continuous leaks in 57% of metered households. Evidently, water could be easily saved in Samson Cree Nation by improving household-level plumbing maintenance and repair.

This study is limited in a few key ways.

1. I was not able to interview every metered household. This decreased the sample size for some calculations whose accuracy would be improved with more interview data.
2. I disaggregated the meter data using a Water Use Calculator which relied only on survey information. The equations behind the calculator presuppose a certain behaviour based on a few studies. It's very possible some consistent behaviour unique to Samson Cree Nation has been overlooked using the calculator to disaggregate data.
3. The metered household sample size on-reserve is 28. While it took considerable effort to manage collecting this data, a larger sample size would improve accuracy and ultimately, forecasting.
4. When the battery becomes disconnected from the Neptune water meters, the water meter deletes all stored hourly readings and sums them as a single hourly reading when the battery is reconnected. This occurred at three different households during the metering program, deleting a total of over three months of hourly data.

To address these limitations, I recommend:

- completing interviews with all metered households in Samson Cree Nation;
- collecting water-use data at 10 second intervals and using flow trace analysis to disaggregate the results;
- continuing the water metering program in Samson Cree Nation to increase the sample size and improve the accuracy of the data. Water demand on the municipal system could also be verified my measuring flows at the water treatment plant;
- expanding the study to include commercial, industrial, recreational, and institutional water use; and,
- using the tamper proofing features of the water meters to ensure the battery does not disconnect from the water meter due to a weak connection or someone tampering with the device.

But what of the complexity that introduced this chapter? And how to address the poor water servicing inside homes in Samson Cree Nation? To answer the latter first, collecting data on residential water use provides accurate values to ensure water service and housing funds can sufficiently provide safe, reliable water to consumers. To answer the former, I stress listening to those impacted by water policies and funding. To those in power, in the words of Trena Soosay (2014):

> Everyone needs to work together to make it work. It can't be one, it has to be many.

CHAPTER FOUR

Factors that affect domestic water consumption in Samson Cree Nation: Water source, household demographics, and perceptions of drinking water health risk

4.1 Water knowledge and resulting behaviours in Samson Cree Nation

Roy and Judy Louis hosted a water ceremony on May 10, 2014. Fraser, Sarah, and I stopped at the gas station in Maskwacîs to purchase some tobacco for protocol on the way to the ceremony. As we were about to leave I heard,

> Travis! My water changed again.

Alphonse Nepoose was now working at the gas station. He updated me once before, in December 2013, when his water started to smell odd. He continued,

> It's black now and I can't even shower in it anymore.

Alphonse's house was under a boil water advisory (BWA) and had been since August 2012. About a year after the boil water advisory was first issued, we installed a water meter in his house and I interviewed him about water use. Since that time his water quality had deteriorated.

A dramatic change in water quality—like the kind Alphonse experienced—has obvious impacts on domestic water use; he identified them himself. Because the water meter collected water use data during this time, I could quantify Alphonse's change in water use behaviour. Plus, I interviewed Alphonse and maintained contact so he continued to inform me of how he used water. Some questions remain, however, such as:

- Do changes in water quality or the perception of water quality—the implementation of a boil water advisory on a household, for example—influence water consumption behaviour?
- Do domestic water use behaviours respond to other "objective" measurements of water quality, like particular chemical concentrations?
- How might "subjective" factors influence water consumption, like users who question the safety of their water?
- Finally, do demographics affect consumption? For instance, does the presence of children impact household water consumption?

These are a few of the questions I address in this chapter.

Alphonse found employment during the time his home was metered—another source of quantifiable change in water use behavior—because it causes the emergence of a new daily water use pattern and a probable decrease in his water use at home. Further, he rarely hosted visitors as he feared exposing people to what he felt was an unsafe environment—he had concerns about water and air quality in his home. Specific household-level information like this was captured through interviewing and maintaining contact with residents. When data from numerous households are combined, I can investigate variables that effect domestic water consumption across Samson Cree Nation—an investigation that is the focus of this chapter.

The relationship between household perception of water quality and household practices of water use are not well understood (Hardie & Alasia, 2009). Some clear differences exist between water quality in First

Nations communities and water quality in non-First Nations communities as mentioned previously:

- Boil water advisories occur 2.5 times more frequently in First Nations communities than in non-First Nations communities (Patrick, 2011);
- 30 percent of First Nations community water systems are classified as "high risk" (Neegan Burnside, 2011a); and,
- Water borne infection rates in First Nations communities are 26 times higher than the national average (Patrick, 2011).

Samson Cree Nation seemingly fits this description of First Nations water systems:

- about 20% of the rural, private wells in Samson Cree Nation—which provide water for approximately 1 000 people—are under boil water advisory at any given time;
- Neegan Burnside (2011b) evaluated Samson Cree Nation's water system as "medium risk"; and,
- Samson Cree Nation has some unique health concerns, as explored below.

The Maskwacîs Cree Nations—Samson Cree Nation, Ermineskin Cree Nation, Montana First Nation, and Louis Bull Tribe—exhibit some strong health distinctions from other Indigenous communities in Canada. Data from the First Nations and Inuit Home and Community Care (FNIHCC) Program in Figure 4.1 show the primary reasons for seeking community care services in Maskwacîs Cree Nations, in Alberta, and across Canada.

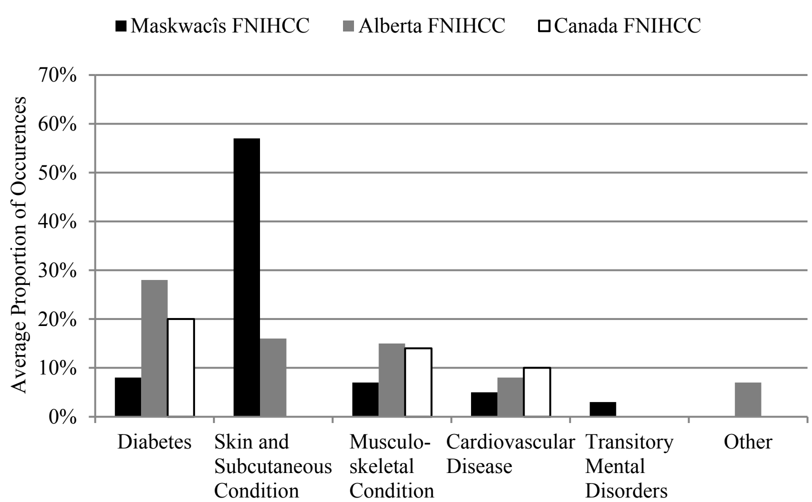

Figure 4.1 Primary reason for seeking FNIHCC services (Health Canada, 2014b)

Figure 4.2 shows that the type of care that Maskwacîs Cree people seek is also distinct from other Indigenous communities.

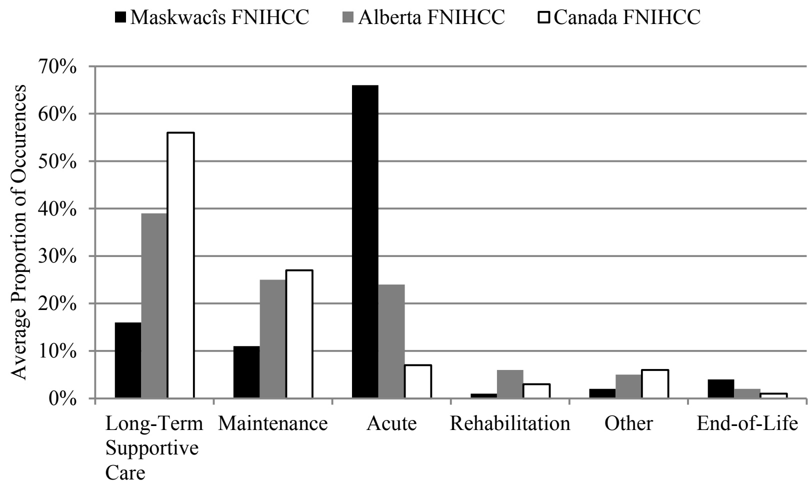

Figure 4.2 Average proportion of FNIHCC occurrences by type of care (Health Canada, 2014b)

The high rate of skin and subcutaneous conditions in the Maskwacîs Nations was also reported by residents: many people discussed alternative bathing practices—bathing at neighbours' households, for example—and expressed concern about bathing themselves and their children in unsafe water. Certainly Alphonse's behaviour demonstrates that concern for safety. Similarly, in an interview with Ian Saddleback (2013), I asked him about water quality and water use:

> TH: Have you had any problems with water quality here?
>
> IS: Oh yeah, since the house was built in 2002. We've been under boil water advisory before. We have brown water and the taste is not great. Our well was shock-chlorinated twice in one week in mid-September. Our kids have really dry skin from the water. They have eczema.
>
> TH: When on boil water advisory, do you still use well water for other purposes?
>
> IS: Yes.
>
> TH: Which purposes?
>
> IS: Everything except for drinking. I'm worried though because the kids still drink it in the tub and you can't really stop them.

So while this project analyzes data unique to Samson Cree Nation, some insights may be transferable to the other Maskwacîs Cree Nations, other Indigenous communities, and water consumers in general.

In this chapter, I will review the literature on variables affecting domestic water use and variables affecting perception of drinking water risk. Next, I will summarize the methodology I used in measuring and analyzing variables that impact domestic water use. Then, I will provide the analysis results along with a discussion of the most significant findings. Primarily, I will compare how variables affect domestic water use in the literature to how those same variables affect domestic water use in Samson Cree Nation. I will also investigate some variables of my choosing for their impact on domestic water use in Samson Cree Nation and I will report those with significant results. I will provide conclusions at the end of this chapter.

4.2 Variables affecting water use

4.2.1 Drivers of water consumption

Dziegielewski et al. (1999) describe water use as a generally linear function of its explanatory variables, in Equation 4.1, for water user *i* and time period *t*:

$$Q_t = a + \sum_i b_i X_i \qquad \text{[Equation 4.1]}$$

where

Q_t = water use
a, b = coefficients
i = constant
X_i = set of explanatory variables

This representation of water use can apply to any level of aggregation: individual, household, communal, etc. (Dziegielewski et al., 1999). But by disaggregating demand Q_t into its components and modeling each separately, we can develop more precise models of water demand (Dziegielewski et al., 1999). So for a particular sector—publicly-supplied residential, for example—sectoral water demand can be expressed by its unique variables. Since demand is not necessarily linear, the elasticities can be expressed as exponents. Dziegielewski et al. (1999) provide the following equation to show water usage rates of sector *k* (publicly-supplied residential, in this case) for geographical area *g* and time period *t*, as a function of explanatory variables:

$$q_{kgt} = \alpha I^{\beta_1} H^{\beta_2} L^{\beta_3} T^{\beta_4} R^{\beta_5} P^{\beta_6} e^{b_7 B} \qquad \text{[Equation 4.2]}$$

where

q_{kgt} = predicted average water demand
I = median household income
H = average household size (persons)
L = average household density (units per acre)
T = daily-maximum air temperature
R = rainfall
P = marginal price of water (including sewer)
B = fixed charge or rate premium of water/wastewater tariff
α = constant

β_i = constant elasticities of explanatory variables
b_7 = coefficient of rate premium
e = base of natural logarithm

They note that the number of users in each sector analyzed can also be expressed as a function of explanatory variables. Dziegielewski et al. (1999) provide a list of variables investigated in residential water use studies. Day and Howe (2003) provide a comprehensive list of factors influencing peak water demand. Again, while peak demand calculations and an understanding of factors affecting peak water demand are important, they are not a focus of this study.

Table 4.1 summarizes variables that have studied effects on water consumption.

Table 4.1 Summary of studies on variables affecting water use

VARIABLE	EFFECT (POSITIVE OR NEGATIVE) ON WATER USE	CITATION
Household size	Positive: increases household demand Negative: generally reduces per capita household demand	Linaweaver et al. (1966), Hamilton (1983), Gazzinelli et al. (1998), Arbués et al. (2003), Zhang and Brown (2004), Keshavarzi et al. (2006)
Household income	Positive: increases household and per capita household demand	Linaweaver et al. (1966), Gazzinelli et al. (1998), Domene and Saurí (2006), Grafton et al. (2011)
Lot size or house size	Positive: increases household and per capita household demand	Linaweaver et al. (1966), Gazzinelli et al. (1998), Keshavarzi et al. (2006), Coomes et al. (2010), Grafton et al. (2011)
Water meter prevalence	Negative: decreases household and per capita household demand (usually accompanies charges for water use)	Linaweaver et al. (1966), Hardie and Alasia (2009)
Climate	Positive: temperature, summer temperature, and drought index increase demand Negative: precipitation frequency and amount decrease demand	Linaweaver et al. (1966), Maidment et al. (1985), Miaou, (1990), Mayer et al. (1999), Zhou et al. (2000), Arbués et al. (2003), Gato et al. (2007), Coomes et al. (2010), Grafton et al. (2011)

Water source	Negative: distance to water source decreases demand as does the presence of alternative sources of water	Sandiford et al. (1990), Gazzinelli et al. (1998), Mayer et al. (1999), Coomes et al. (2010), Grafton et al. (2011)
Number of households	Positive: increases water demand for geographic region	Sandiford et al. (1990), Martin (1999)
House quality	Positive: increases household and per capita household demand	Gazzinelli et al. (1998)
Household employment rate	Negative: decreases household and per capita household demand	Gazzinelli et al. (1998), Mayer et al. (1999)
Education levels	Negative: generally decreases household and per capita household demand (although education and income are positively correlated which can invert this relationship)	Gazzinelli et al. (1998), Howarth and Butler (2004), Keshavarzi et al. (2006), Grafton et al. (2011)
Population	Positive: increases demand for a geographic region	Martin (1999), Hardie and Alasia (2009)
Age of house	Positive: increases household and per capita household demand	Mayer et al. (1999), Coomes et al. (2010)
Presence and number of water using/saving fixtures and appliances	Positive: water using appliances increase demand Negative: water saving appliances decrease demand	Mayer et al. (1999), Coomes et al. (2010), Grafton et al. (2011)
Outdoor water use	Varied effects. Generally, any outdoor water use behaviours increase household and per capita household demand.	Mayer et al. (1999), Domene and Saurí (2006), Keshavarzi et al. (2006)
Head of household or respondent age	Negative: decreases household and per capita household demand	Murdock et al. (1991), Keshavarzi et al. (2006), Grafton et al. (2011)
Rurality	Positive: increases household and per capita household demand	Hardie and Alasia (2009)
Household popula-	Positive: the number of children and the number of adults in-	Grafton et al. (2011)

tion	creases demand	
Environmental concerns	Negative: decrease household and per capita household demand	Gilg and Barr (2006), Grafton et al. (2011)

Similar to the list of variables above, Corbella and Pujol's (2009) reviewed literature on variables influencing domestic water consumption, they address the complexity of water consumption relationships and conclude that domestic water use can depend on:

- water price;
- household income;
- household size;
- household characteristics;
- household age distribution;
- gender;
- cultural variables;
- religious variables;
- household residents' nationalities;
- education levels;
- responsiveness to conservation campaigns;
- physical capital in the household;
- presence of water efficient technologies;
- population;
- population growth;
- urban form (density); and,
- climate.

Note that domestic water use is most commonly studied in relation to water price. Water utilities—which must plan for large-scale water consumption—use price to control demand and are interested in how price and water use are related. Since water is provided to Samson Cree Nation residents free-of-charge, water price is not a variable affecting current water consumption. The next chapter, "Domestic water use and forecasts in Samson Cree Nation", investigates Samson Cree Nation's water systems through a system dynamics model that considers the implications of price on water consumption. Since the chapter touches only on model structure rather than calibration or testing, I do not review literature on water pricing. Arbués et al. (2003), however, summarize literature on price elasticities of water.

Corbella and Pujol (2009) summarized the main findings from domestic water use literature: the relationships among water use and population, territorial, social, and cultural factors in urban environments. In the following paragraphs, I review these variables in more detail: income, household size, household demographics, age, religious practice, education, climate, low-flow appliances, rurality, and water source.

Corbella and Pujol (2009) highlighted the positive correlation between domestic water consumption and income—that income or affluence increases water consumption, since a higher living-standard increases the presence of water-using appliances and the presence of high-water demanding outdoor use, like lawns, gardens, and pools. Domene and Saurí

(2006) found that the effect income has on water consumption is more evident when there is outdoor water use. Garden watering strongly reflects household income and class (Domene et al., 2005).

Many studies investigated the effect of household size on water consumption (Linaweaver et al., 1966; Hamilton, 1983; Gazzinelli et al., 1998; Arbués et al., 2003; Zhang and Brown, 2004; Keshavarzi et al., 2006). They have found that the number of people living in a house has varied effects (Corbella and Pujol, 2009). For example, a greater number of residents in a household should cause a greater water demand for the entire household but should also decrease per capita usage through water saving opportunities provided by multiple residents (Corbella and Pujol, 2009); however, Arbués et al. (2003) argue that beyond an optimum household size threshold, economies of scale vanish.

Corbella and Pujol (2009) emphasize the role of household demographics in water consumption. Households reflect—but also shape—socio-demographic structures of human geography (Buzar et al., 2005), meaning that households are relevant sites for investigating larger groups of people. Household dynamics, therefore, are fundamental to understanding dynamic resource use and environmental impacts of social organizations (Liu et al., 2003). These points raise questions about how water use may compare between communities that are similar geographically or climatically but differ culturally and socially.

Murdock et al. (1991) found that householder age affects domestic water consumption. Older people tend to use less water per capita than younger people and households with children or teenagers are expected to use more water, especially outdoors (Corbella and Pujol, 2009). These behaviours are justified by arguments that older people use water more carefully and that older people are not accustomed to contemporary water-using comforts (Corbella and Pujol, 2009).

Smith and Ali (2006) linked differences in water use patterns directly with religious practices in ethnic minority communities in the United Kingdom. They found that the impact of specific cultural or religious practices can be seen in water demand patterns, changing when consumers use water on a large scale. They also concluded that this effect on water demand might be increased when cultural differences accompany larger households.

Howarth and Butler (2004) studied the influence of consumers' education on water use. They found that public awareness campaigns about water conservation can decrease water consumption; however, they stressed that relying on communication alone to engage water users is insufficient in achieving water conservation, and that users must be actively engaged in implementation. Gilg and Barr (2006) examined water conservation as it relates to consumers' attitudes and actions toward environmental issues and found that there are different levels of behavioural commitment: water and energy users apply a variety of conservation strategies to varying degrees. They recommended that conservation campaigns should thus target specific groups of users—based on their level of behavioural commitment—to achieve desired water or energy savings.

Climate heavily influences domestic water consumption—temperature and rainfall in particular (Gato et al., 2007)—although moisture and irradiation could be significant variables too (Corbella and Pujol, 2009). The main variables affecting residential water use can change seasonally (Agthe & Billings, 2002). Thus, season is a variable that affects water consumption, influencing not only outdoor use but also indoor use. Both rainfall event frequency and intensity have a psychological effect on water consumers, causing them to use less water, although the effect of frequency is stronger (Arbués et al., 2003). Climatic factors vary seasonally and can affect water demand immediately following rainfall or other stochastic weather events—like a heat wave (Maidment et al., 1985; Miaou, 1990; Zhou et al., 2000). This variability is due to humans responding to both actual and perceived environmental changes (House-Peters and Chang, 2011).

Coomes et al. (2010) investigated household water usage trends in North America over 30 years to identify factors that drive water usage. They found that low-flow appliances and household demographics—a decline in the number of residents per household and an increase in household income—account for a 16 percent reduction in average household water consumption from 1990 to 2007 across North America (Coomes et al., 2010).

If the urban model of development has an important effect on natural resource—i.e. water—consumption (Haase and Nuissl, 2007), what do we make then of rural development? If lower population densities afford particular outdoor water uses in North America, like pools (Corbella and Pujol, 2009), which water use behaviours might be afforded or limited by a rural or townsite life on-reserve? Since Samson Cree Nation has both a municipal and a rural water system, it is necessary to consider that rurality could impact resource use.

Analyzing data from the Municipal Water and Wastewater Survey (MWWS) database 2004, Hardie and Alasia (2009) found that while urban water consumers and rural and small town water consumers shared similar water use patterns, domestic water use is higher in rural and small town areas. They investigated total daily water use per capita and found that it averaged:

- below 500 litres in larger urban centres;
- about 600 litres in smaller urban centres and municipal influence zones; and,
- over 800 litres in more rural regions.

Hardie and Alasia (2009) further concluded that domestic water use—which is a portion of total water use—showed a similar pattern, with urban residents consuming about 300 litres per capita per day and consumption increasing with rurality. Contrary to the trend above, they found that residents of medium-sized urban centres consumed less water domestically than urban residents: about 250 litres per capita per day. So while rurality impacts water consumption, other water distribution characteristics can affect use too. For example, water pressure also influences water demand: lower supply system pressures reduce water use (Jacobs et al., 2006). So two different water distribution systems operating with different water pressures could show corresponding differences in water use.

Gazzinelli et al. (1998) found that source water selection depended on household activity: residents preferred stream water for laundry and well or spring water for cooking, drinking, and bathing. Clearly, given the variance among rural water users around the world (Table 3.9, chapter 3) and the observed differences between rural and urban water users, both culture and rurality are significant factors in water use. Samson Cree Nation, then—as a mix of both urban and rural settings and as a First Nations community—is a unique community when it comes to water consumption from both distribution and cultural perspectives.

4.2.2 Water quality and perceptions of water quality

Now I review literature on the relationship between water quality and water consumption. Perceived, or subjective, risk of drinking tap water influences subsequent consumption behaviour (Doria et al., 2005). Spence and Walters (2012) linked objective risk perception (measurable water contamination) and subjective risk perception (the risk one perceives): households that report seasonal contamination of their drinking water source and households that are uncertain about historical contamination of their drinking water source are both more likely to believe their drinking water is unsafe. The consumption of unhealthy beverages (soft drinks) and tap water substitutes (bottled water) is related to the perception of drinking water safety (Spence & Walters, 2012). How might the objective risk of drinking tap water—measured water quality—affect water consumption? How might the perception of water quality—or water quality risk—impact water consumption behaviours? How similar are perceptions of water quality and measured water quality in impacting water use? These are questions I will explore in the following section.

Hardie and Alasia (2009) found that water source—municipal distribution systems versus rural private wells—does not affect water consumers' perceptions of water quality. Similarly, Spence and Walters (2012) found that water source has no effect on the perception of drinking water risk.

EKOS Research Survey Associates (2009) conducted a survey of First Nations peoples on-reserve about the safety of their drinking water. Using a sample with 55% piped delivery, 19% cistern, 17% wells, and 9% unknown servicing, they found:

- First Nations peoples on-reserve have lower confidence in their drinking water quality compared to residents of other small communities—the general public;
- More than one quarter of on-reserve First Nations peoples consider their water quality "poor" and under half consider their water quality "good" compared to 63% of small community residents who consider their drinking water "good";
- Sixty-nine percent of on-reserve First Nations peoples consider their water somewhat or very safe compared to 89% of other small community residents. Thirty percent of First Nations peoples on-reserve consider their water very safe, about 40% of First Nations peoples on-reserve consider their water somewhat safe,

and 30% of First Nations peoples on-reserve consider their water very or somewhat unsafe;
- First Nations peoples on-reserve are more likely to blame unsafe water on perceivable water characteristics like pollution, chemicals or taste than residents of other small communities who are more likely to suspect treatment facilities and the water source, and;
- First Nations peoples on-reserve are less likely to use tap water for all indoor uses compared to residents of other small communities.

Spence and Walters (2012) summarized the literature on variables affecting the perception of water quality-related risk. These determinants include:

- degree of isolation;
- organoleptics (odour, flavour, colour);
- water chemicals;
- microbiological parameters;
- contextual indicators (household, community, or river condition);
- past negative health experiences;
- familiarity and prior experience with their water;
- impersonal and interpersonal information (acquaintances, friends, family, water companies, media);
- trust in water companies and other groups;
- perceived control;
- demographics;
- cultural background; and,
- worldviews.

A study by Flynn et al. (1995) shows how risk perception across a variety of issues—including the environment and health—differs among ethnic groups. For Spence and Walters (2012, pg. 2) this means that "an examination of First Nations on-reserve is particularly important in understanding risk perception as well as reducing inequalities." Media attention surrounding Attawapiskat First Nation, the *National Assessment of First Nations Water and Wastewater Systems*, and the debates surrounding Bill S-8 and Bill C-45, all emphasize water safety as a pressing social policy issue for First Nations. We may expect then, that the relationships between risk perception and its determinants "may operate quite differently than in cases where access to safe water is the norm" (Spence & Walters, 2012, pg. 3). "Undoubtedly, the history of colonialism, suffering, and shameful social conditions on many reserves, paired with the experience of the broader Canadian society and its formal institutions, would definitely figure into the process of risk perceptions" (Spence & Walters, 2012, pg. 6).

Women tend to exhibit stronger concern for societal issues than men, including drinking water (Park et al., 2001), and they perceive higher risks in drinking water than men (Anadu & Harding, 2000). Spence and Walters (2012) found that First Nations women reported a greater perception of risk for drinking water. Zwarteveen (1997) reviewed relationships between gender, water rights, and water access in developing countries. Van Koppen (2001) highlights the importance of gender roles—and the resultant gendered water use behaviours—for water policy development and implementation. The roles, responsibilities, and knowledge concerning water in Samson Cree Nation may have gendered aspects that I am not aware of and may not have access to. So it would be important not to discount the role gender may have in water management in Samson Cree Nation.

EKOS Research Associates Incorporated (2009) found that the number of children, seniors, or other vulnerable people in a home contributes to a sense of susceptibility, increasing concerns about water quality and safety. The presence of young children, seniors, and other vulnerable members, or the presence of a daycare in the home, likely causes household behavioural changes. Spence and Walters (2012) found that having children less than 15 years of age in a household increased respondents' perceptions of drinking water risk. Respondent age, however, had no effect on perceptions of drinking water risk (Spence and Walters, 2012; Doria, 2010).

People become used to certain characteristics of water quality, like organoleptics (hardness, taste, colour, and odour), which influence their perceptions of risk (Doria, 2010; Owen et al., 1999). This so-called "normalization of risk" occurs through increased contact and familiarity with hazards and accompanying issues (Halpern-Felsher et al., 2001; Lima et al., 2005). First Nations peoples who live on-reserve and have first-hand experience with certain hazards—like drinking water—can become desensitized to certain risks (Spence and Walters, 2012). Certainly those who live in Samson Cree Nation, with a boil water advisory frequency of 20% on private wells, have significant exposure to risk.

The local physical and social context similarly influences perceptions of safety (Spence & Walters, 2012). The water distribution system (Contu et al., 2005; Jones et al., 2007), the state of areas surrounding water bodies (House & Sangster, 1991), and community satisfaction (Syme & Williams, 1993) all reflect the localized context and affect safety perception. Health Canada (2014a) found that small, remote, and isolated communities are disproportionately likely to be "at risk" of unsafe water. Neegan Burnside (2011a) also found small, remote, and isolated water systems to be consistently "high risk". Regardless of whether isolation, remoteness, or smallness objectively increases risk, it can still affect perceptions of risk. Related to the local context, Spence and Walters (2012) found that water consumers living in a residence that required major repairs had greater perceptions of drinking water risk than those who lived in a residence in better condition.

Spence and Walters (2012) took national variations in well-being at provincial/territorial levels—education, housing, income, labour force activity—as indicators of institutional quality and social processes that affect resources, like water. They found that a greater perception of drinking water risk exists for those living in regions with lower well-being—the Arctic, Newfoundland/Labrador, Nova Scotia, New Brunswick, Quebec, Manitoba, Saskatchewan, Alberta, British Columbia, and the Northwest Territories—compared to Ontario.

Finally, Spence and Walters (2012) found that other factors that increase drinking water risk perception among First Nations water consumers include: being highly educated, being in poor health, having less attachment to Aboriginal culture (the ability to speak or understand an Aboriginal language), and reporting water contamination in the previous year or being uncertain of the contamination status of water.

Mah (2014), as part of this research project with Samson Cree Nation, investigated perceptions of water quality on-reserve. Mah (2014) found that lack of trust in water source was related to:

- increased use of bottled water;
- past or present boil water advisory;
- increased priority placed on Band leadership protecting water rights; and,
- increased willingness to pay for water servicing to cover infrastructure and maintenance.

Residents identified four main areas that impact poor water quality on-reserve or poor understanding of water quality issues on-reserve:

- communication problems about water quality testing and well management practices;
- oil and gas development on-reserve;
- problems resulting from contaminated well shock chlorination; and,
- resource mismanagement by the Federal Government and Band leadership (Mah, 2014).

Mah (2014) stressed communication as a key component for leadership moving forward to improve water quality and trust in the water systems.

4.3 Determining relationships between water use and variables

Using both metered household water usage and the calculated average daily per capita water consumption for each household—as discussed in the preceding chapter, "Domestic water consumption in Samson Cree Nation: Water metering program, resident interviews, water use patterns, and residential end purposes"—I can analyze differences in water consumption between different groups of water users, categorized by criteria like household demographics and perception of water quality. Interview participants provided the data for categorization through the interviews. Appendix C shows the questions asked during the interviews; also see chapter three for the water meter installation process and interview protocol. Mah (2014) collected water quality data, also used in this research, which are included in the investigation of variables affecting domestic water use.

I analyzed the significance of variables' effects on either the average daily household water consumption or the average daily water use per capita, depending on which made more sense for the investigated variable. These variables include:

- water system;
- boil water advisory status;
- water source trust;

- drinking water source;
- household demographics (infants, children, adults, elderly, vulnerable residents);
- household size (number of residents);
- daytime household occupancy;
- household leakage;
- resident reported end-use frequencies; and,
- climatic data (maximum daily temperature, degree warming days, and precipitation)

I reported results from one-way analysis of variance (ANOVA) and the Kruskal-Wallis test—using Microsoft Excel—to measure statistically significant differences between groups. ANOVA is a parametric test: it makes assumptions about the population distribution parameters and, consequently, is not the best analysis in identifying differences between groups of non-normally distributed data (Helsel & Hirsch, 2002). For non-normal data, the Kruskal-Wallis test is the equivalent non-parametric test (Helsel & Hirsch, 2002). Since I did not test the normality of data, I report P-values from each. An alpha (α) value of 0.1 is appropriate to measure statistical significance in these tests since there is no risk from errors. A P-value less than 0.1 means there is a statistically significant difference between the groups. A P-value greater than 0.1 means there is no statistically significant difference between the groups.

I also analyzed variables' impacts on water use patterns by plotting the average water consumption of different water user groups—household occupation during typical weekdays, specifically—at an hourly scale and making visual comparisons between the water use patterns. Water quality parameter concentrations—collected by Mah (2014)—and water consumption are plotted directly against one another to investigate potential relationships between objective water quality and water consumption. In instances where I tested relationships to no significant result, I report what I investigated.

Lastly, interview participants provided their own interpretations of factors that affected their water use and water-use behaviours, as we saw with Alphonse previously. I draw on these data and interpretations where necessary.

4.4 Analysis and results of variables affecting domestic water use

Hardie and Alasia (2009) characterized the effect of water metering on water usage. Municipalities with a high degree of water metering—more than 90% of serviced households metered—use on average 200 litres per capita per day less than comparable municipalities with a low degree of water metering—less than 10% of serviced households metered. Municipalities with some metering—between 10% and 90% of serviced households metered—use on average 70 litres per capita per day less than comparable municipalities with a low degree of water metering. In this study, installing a water meter was the most reliable method for measuring domestic water use and we assume that metering will have no effect on water use in Samson Cree Nation for a number of reasons:

- Water meter prevalence most likely impacts water use because it accompanies a payment structure for water use; and,
- We installed water meters for the sole purpose of conducting this research so metering did not accompany any payment for water servicing (further, we informed residents that water meter installation was temporary).

My first point of analysis is to assess whether the water system, rural or municipal, and the boil water advisory status of the household, non-BWA or BWA, affect per capita water consumption. The average daily water consumption per capita is shown for each grouping, with error bars showing one standard deviation above and below the average, in Figure 4.3. Table 4.2 summarizes the findings.

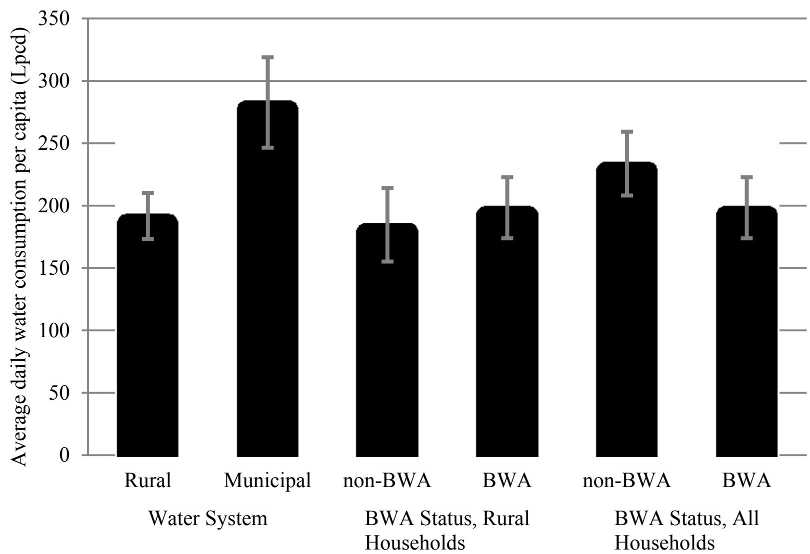

Figure 4.3 Average water consumption per person based on system type and boil water advisory status. Error bars represent +/– one standard error.

Table 4.2 Summary of statistical comparisons between water systems and boil water advisory status

	WATER SYSTEM		BWA STATUS, RURAL HOUSEHOLDS		BWA STATUS, ALL HOUSEHOLDS	
	RURAL	MUNICIPAL	NON-BWA	BWA	NON-BWA	BWA
Average (Lpcd)	192	283	185	198	234	198
Std error (Lpcd)	19	36	29	24	26	24
Sample Size	19	9	9	10	18	10
ANOVA P-value	0.02		0.73		0.37	
Kruskal-Wallis Test P-value	0.02		0.62		0.43	

There is a clear distinction between average daily water consumption per capita on the rural system and on the municipal system. Both tests show a statistically-significant difference—a P value less than 0.10—in water use between the two water systems in Samson Cree Nation: people using water from the municipal system use more water than those using water from the rural system.

This evidence runs counter to the findings of Hardie and Alasia (2009), which showed rural residents consuming more water than their urban counterparts, and suggests some of the drivers of domestic water use in Samson Cree Nation are different from the general Canadian population. This discrepancy justifies that we collect data and manage water at the community level. At the beginning of this study, the research team expected to find a difference in water use behaviour between municipal and rural residents and between households under boil water advisories and those households not under boil water advisories. Perceived or subjective risk of drinking tap water influences subsequent consumption behaviour (Doria et al., 2005). So, we expected that the uncertainty of water quality on the rural system—20% households currently under boil water advisory, historical and periodic contamination of wells throughout the rural area, and the absence of treatment technologies, to name a few—would affect water users' behaviour in general. We expected this perception of water quality to affect behaviour beyond drinking water behaviour, to a measurable extent. Further, we expected that rural lifestyles could be sufficiently different from urban ones to cause distinct water use behaviour.

We do not see, however, a significant difference between rural water users under boil water advisory and those not under boil water advisory. In fact, even when municipal residents are included in the "non-BWA" group, there is no significant difference in average daily water consumption per capita between "BWA" and "non-BWA". This may be due to drinking water composing a small percentage of total domestic water use. However another explanation for this result lies in boil water advisory communication between the Maskwacîs Health Services staff and rural residents. In the words of Odette Buffalo (2014):

> They tested the water but didn't tell us what it said.

As Mah (2014) explained, 18% of households reported that they were under boil water advisory when they were not, and 14% of households thought they were not under boil water advisory when they were. In general, people in Samson Cree Nation view the rural water system as unreliable, regardless of the boil water advisory status of specific households. Venus Redcrow (2014) lives in the townsite and describes how common it is for rural residents to be uncertain about water quality:

> When people come into town from the country they always ask "Is the water safe to drink?"

Trena Soosay (2014) echoes this division:

> People in the country need something. I don't think it's healthy for them, a lot of elders live out there.

So while the water system location—rural or municipal—might serve as an indicator for water quality or water risk, there could be other distinctions that influence water consumption significantly. For example, if the pressure tanks in rural households operate at lower pressures than the municipal system, this could contribute to the difference in measured water use (Jacobs et al., 2006). Also, there could be some other important differences between the two systems or between the two types of lifestyles that we haven't accounted for. Perhaps residents are responding to the water quality and using the clothes washer less frequently or using one elsewhere when the water at the their home stains their laundry. Residents could also be responding to the perception of water quality and limiting their exposure to potentially unsafe water by buying bottled water, taking shorter showers, and using bottled water for cooking. In any case, water consumption from Samson Cree Nation's municipal water system is significantly higher than that from rural private wells.

In the interviews, we asked residents if they trust their source water—whether a rural well or the municipal distribution system—and what their drinking water source is. The average daily water consumption per person for all users regardless of water system, grouped by their responses, are shown in Figure 4.4 and summarized in Table 4.3.

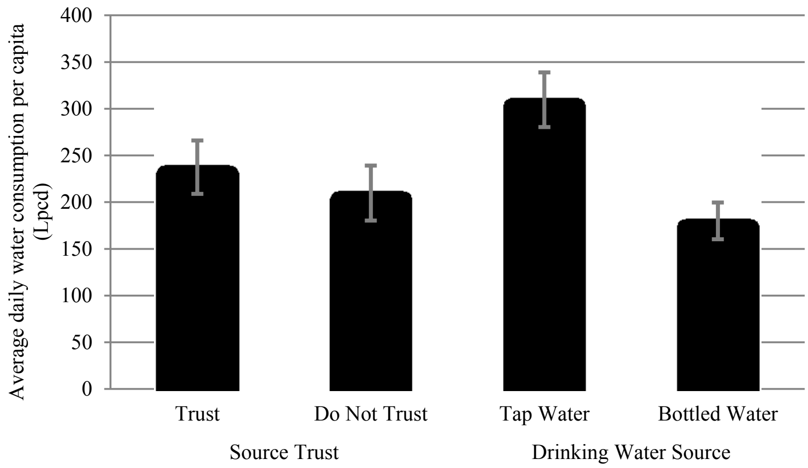

Figure 4.4 Average water consumption per person based on source water trust and drinking water source. Error bars represent +/– one standard error.

Table 4.3 Summary of statistical comparisons between trust in water source and drinking water source

	SOURCE TRUST		DRINKING WATER SOURCE	
	TRUST	DO NOT TRUST	TAP WATER	BOTTLED WATER
Average (Lpcd)	237	210	310	180
Std error (Lpcd)	29	29	29	20
Sample Size	10	14	8	16
ANOVA P-value	0.52		0.001	
Kruskal-Wallis Test P-value	0.28		0.002	

Contrary to indications—both measured and anecdotal—that the perception of water quality in Samson Cree Nation depends on the water system discussed above, there is not a clear distinction in water consumption based on interviewees' expression of trust in their water source. One explanation for this could be that the trust the respondent has in their water source does not necessarily reflect the trust of the entire household. Additionally, trust does not apply solely to water quality or to water quality risk. Trust could equally indicate that residents trust their water source to provide water, regardless of how "clean" or "safe" it may be. Further, it is quite possible not to trust one's water source but still rely on it if no alternatives exist.

Limiting the sample to rural households using wells, there is still no statistically significant difference in measured per capita water consumption between households that trust their well and households that do not trust their well. However, rural households that do trust their well use on average 223 Lpcd (n=6) and rural households that do not trust their well use on average 168 Lpcd (n=10)—a notable difference albeit not significant.

There is a significant difference, however, in average water consumption per person between households that drink their tap water and households that drink bottled water. Households where the interviewee identified tap water as the drinking water source use more water per person than households that drink bottled water. This response can more easily be applied to the entire household than that of trust because most of the households drinking bottled water use a water cooler. The presence of a water cooler in the home for drinking would more strongly influence residents' use of tap water than a single resident from the household expressing distrust in the tap water since the water cooler provides an immediate alternative. So while we do not see expressed trust in water source as a significant factor in domestic water consumption, a proximate indicator of water source trust—drinking bottled water instead of tap water—impacts household water use in Samson Cree Nation. This idea supports the justification for higher municipal water use: water users responding to water quality or perceived water quality.

Trena Soosay (2014) explained her motivation for using a water cooler:

> We first got it for baby formula. Now we use it for other stuff.

Trena describes her behaviour consistently with the EKOS Research Associates Incorporated (2009) study: that the presence of vulnerable people—infants and children—causes greater concern for drinking water supply and safety. However, an analysis of water consumption for households with vulnerable populations—infants, children, elderly, and combinations thereof—did not yield any statistically significant results in Samson Cree Nation. For that matter, analysis of household percentage composition of elderly, adults, teenagers, children, and infants yielded no significant results. We can interpret that to mean that these groups do not demonstrate any unique water behaviours that impact the household water consumption significantly.

Of course, household demographics can affect domestic water use in other ways. Primarily, the number of people in a household impacts the total household water use. Figure 4.5 below shows average daily water consumption per household, grouped by small and large households. Table 4.4 summarizes the results.

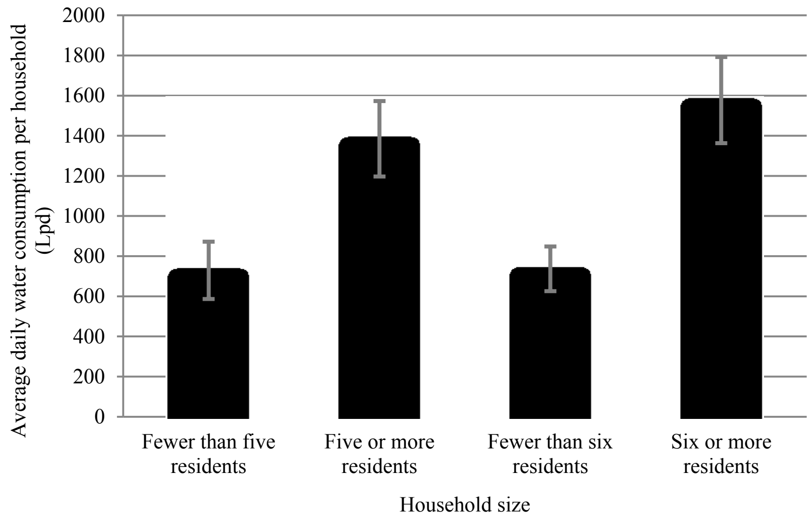

Figure 4.5 Average water consumption per household based on household size (number of residents). Error bars represent +/– one standard error.

Table 4.4 Summary of statistical comparisons between large and small households and household water consumption

	HOUSEHOLD SIZE (NUMBER OF RESIDENTS)			
	FEWER THAN FIVE	FIVE OR MORE	FEWER THAN SIX	SIX OR MORE
Average (Lpd)	729	1385	737	1578
Std error (Lpd)	143	188	111	215
Sample Size	11	17	15	13
ANOVA P-value	0.01		0.001	
Kruskal-Wallis Test P-value	0.009		0.001	

Defining a large household as having five or more residents or six or more residents both show statistically significant higher average daily water consumption per household than small households. While this result is expected—more water users in the household increases household water demand—it raises the question: how does household size affect per capita water use in Samson Cree Nation? Figure 4.6 and Table 4.5 answer this question below.

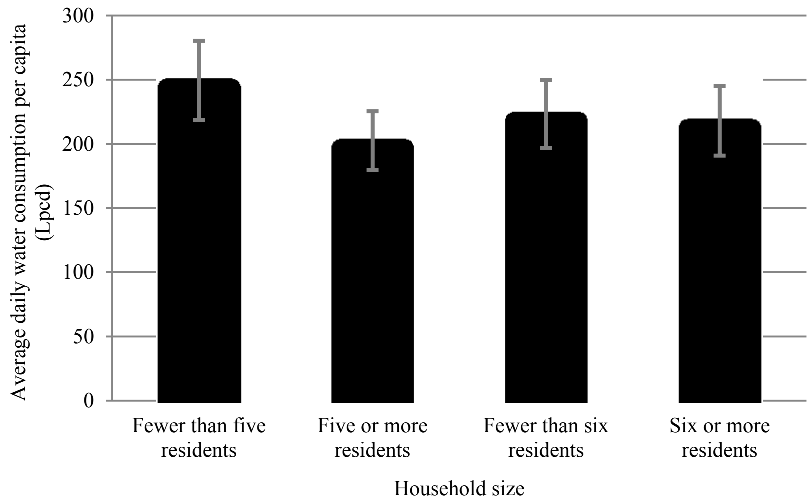

Figure 4.6 Average water consumption per person based on household size (number of residents). Error bars represent +/– one standard error.

Table 4.5 Summary of statistical comparisons between large and small households and per capita water consumption

	HOUSEHOLD SIZE (NUMBER OF RESIDENTS)			
	FEWER THAN FIVE	FIVE OR MORE	FEWER THAN SIX	SIX OR MORE
Average (Lpcd)	250	202	224	218
Std error (Lpcd)	31	23	26	27
Sample Size	11	17	15	13
ANOVA P-value	0.22		0.89	
Kruskal-Wallis Test P-value	0.27		0.93	

Here we see that larger households have lower per capita water use. This result is consistent with the literature, which explains that certain household activities do not change with the number of residents, causing higher per capita use in small households and lower per capita use in large households. Further, large households provide more opportunities for water sharing—sharing a load of laundry or reusing bath water, for example—than small households.

Whether large households are defined as five or more residents or six or more residents, there is not a significant difference in per capita water consumption between large and small households. Further, the average water use per person actually increases when the upper boundary for small households includes households with six residents compared to five. These results suggest that per capita water savings become less significant after an "optimum" household size (Arbués et al., 2003) and that this household size in Samson Cree Nation is about five people. Figure 4.7 shows how per capita water usage decreases and then increases as household size increases.

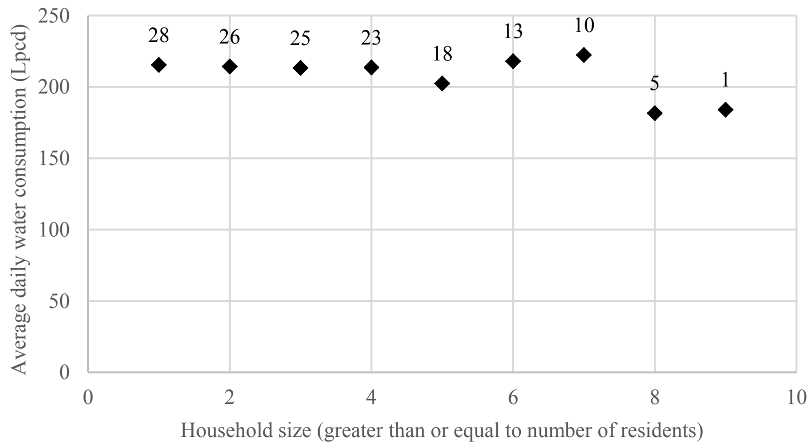

Figure 4.7 Average water consumption per capita and household size (measured as greater than or equal to the number of residents). Data labels denote the sample size for each range of household size.

Another demographic factor of note is the percentage of residents away from the home on a typical (week)day—whether for work, school, socializing, running errands, or any other routine activity. Figure 4.8 shows the diurnal patterns of water use on weekdays for households with:

- greater than 50% of the residents away during the day, and;
- 50% or fewer of the residents away during the day.

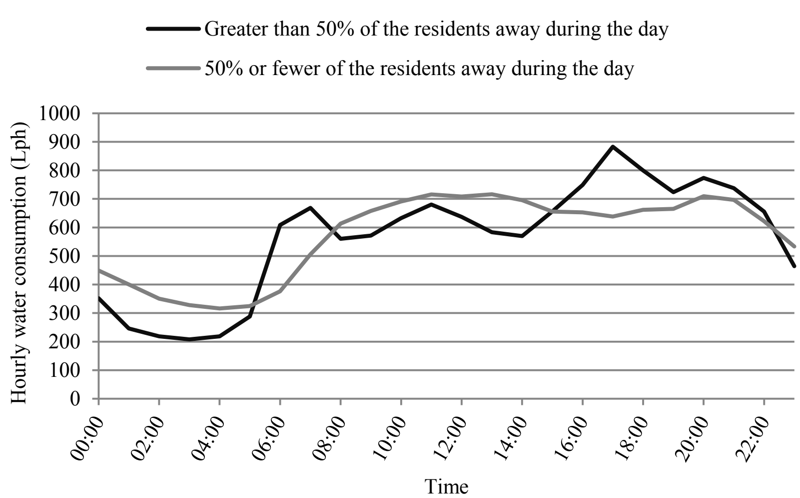

Figure 4.8 Diurnal weekday pattern of water use based on household occupation during the day

The immediate difference between these two groups are the peaks in water use at 06:00 and 17:00 in households where most of the residents are leaving for the day or returning home at these times. Households with most of the residents staying at home during the day have higher water use overnight and a peak in water use later in the morning at 10:00. Both groups share peaks in water use at 17:00 and then at 20:00 when people are running the dishwasher, preparing for bed, or drawing baths for themselves or their children.

Compared to the diurnal weekday water demand pattern for all metered water users in chapter three we can visually inspect how each group contributes to the overall pattern of water use in Figure 4.9.

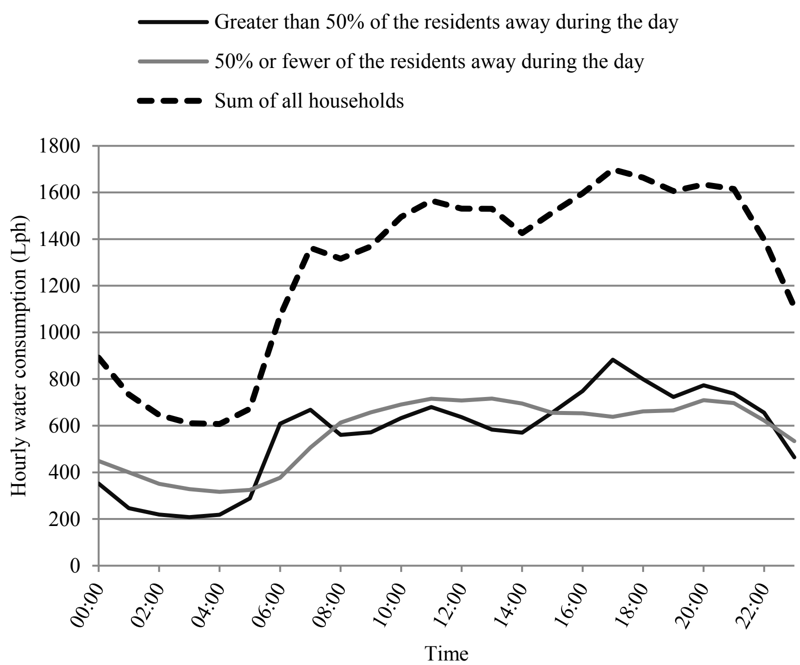

Figure 4.9 Diurnal weekday patterns of water use for households grouped by occupancy during the day contribute to overall diurnal water use pattern

How might these distinct patterns contribute to the per capita water consumption in those households? Figure 4.10 and Table 4.6 detail the results.

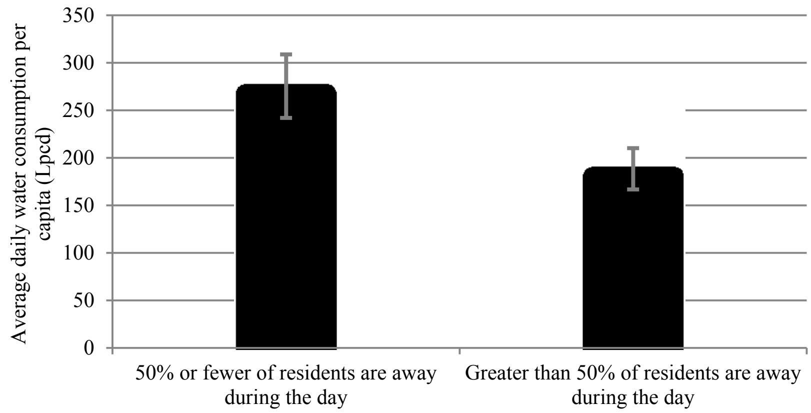

Figure 4.10 Daily water consumption per person based on household occupancy during weekdays. Error bars represent +/– one standard error.

Table 4.6 Summary of statistical comparison between households with varying occupancy rates during weekdays

	PERCENTAGE OF HOUSEHOLD RESIDENTS AWAY FROM THE HOME DURING A TYPICAL WEEKDAY	
	50% OR FEWER	GREATER THAN 50%
Average (Lpcd)	275	189
Std error (Lpcd)	33	22
Sample Size	9	16
ANOVA P-value	0.03	
Kruskal-Wallis Test P-value	0.02	

As expected, households with more residents at home during the day use more water than households with more residents away during the day. This difference is statistically significant with a confidence interval of 10%. Since this average consumption is measured per capita, we see that by averaging household water consumption among the residents, high water users in the home—those who stay at home throughout the day—increase the total water demand for that household.

While these results are anticipated, it is important to consider household occupancy for future water planning. If, for example, the employment rate in Samson Cree Nation increases, we can expect a decrease in domestic water use. A significant decrease in demand can cause distribution problems or can concentrate demand at specific times of the day—in the morning before work—stressing the distribution system. These sorts of considerations can be accommodated with household-level information.

Another important piece of household-level data is leakage. Leakage data was collected in two ways: residents reported household leaks in the interviews and the water meters could detect intermittent and continuous leaks based on flow rates. The water meters registered an intermittent leak when water has been used for at least 50 of the 96 15–minute intervals during a 24–hour period (Neptune Technology Group, 2006). The water meters registered a continuous leak when water use for all 96 15–minute intervals during a 24–hour period (Neptune Technology Group, 2006). Leak data for households from resident reported leaks and from the leak detection capabilities of the water meters were tested against household water use. During the interviews, residents were asked if they knew of any leaks in their home. If they described any, I have considered that a "reported leak". The water meters detected instances of intermittent leakage in every home. Continuous leak detection, then, was used to group households based on the water meter data. Figure 4.11 and Table 4.7 show the results of leakage reporting on domestic water consumption.

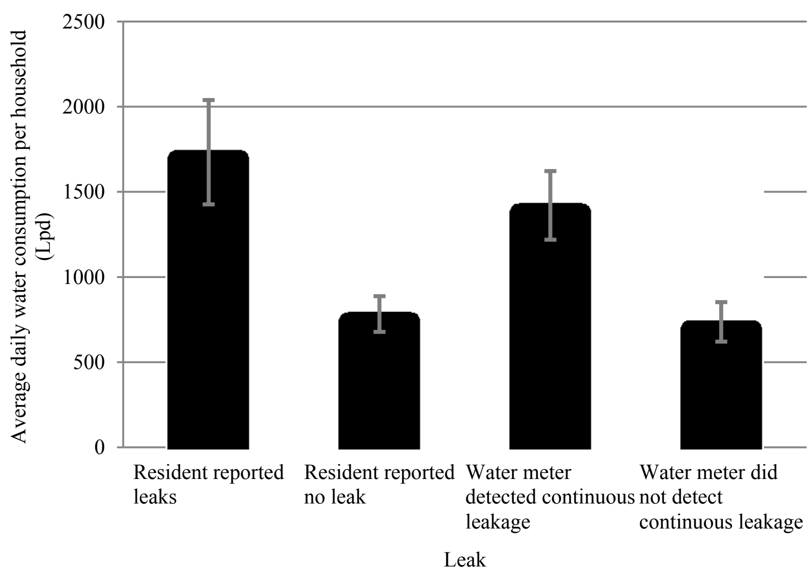

Figure 4.11 Daily water consumption per household based on leakage reporting and household clothes washer use frequency. Error bars represent +/– one standard error.

Table 4.7 Summary of statistical comparisons between household leakage reports

	LEAKAGE REPORTING			
	RESIDENT REPORTED LEAKS	RESIDENT REPORTED NO LEAKS	WATER METER DETECTED LEAKS	WATER METER DID NOT DETECT LEAKS
Average (Lpd)	1733	782	1421	737
Std error (Lpd)	306	105	201	116
Sample Size	9	16	16	12
ANOVA P-value	0.001		0.01	
Kruskal-Wallis Test P-value	0.007		0.01	

Note that the sample size is 25 for resident reported and 28 for meter detected since not all metered households were interviewed—so they were unable to report leaks—while all of the meters were equipped with leak detection. Both resident-reported leakage and meter-detected leakage significantly correspond to increased average daily water consumption per household. This suggests that a good portion of domestic water use in Samson Cree Nation among high water users relates to the presence of leaks. The problems with water leaks in Samson Cree Nation are not isolated only to the household. Water main leaks are an ongoing occurrence in the townsite.

Interestingly, when we consider per capita use in place of per household use, only resident-reported leakage maintains a statistically-significant effect on average water use. Figure 4.12 and Table 4.8 detail the results below.

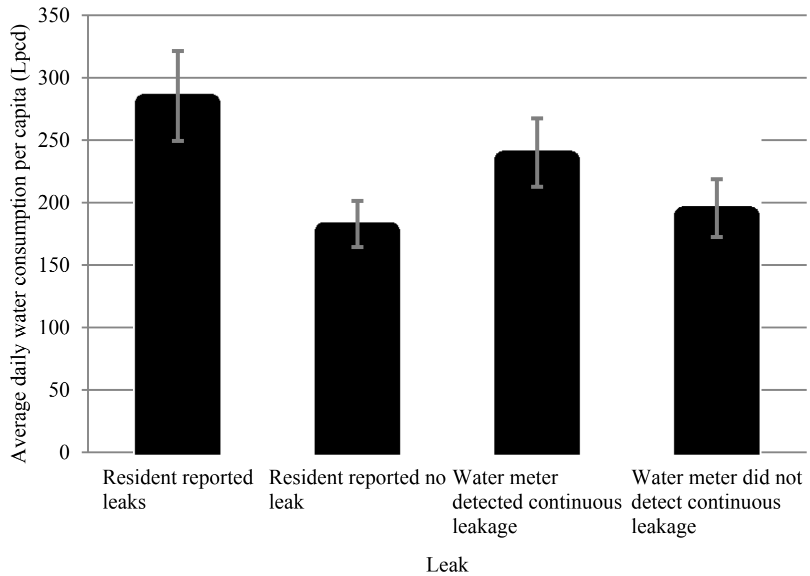

Figure 4.12 Average daily water consumption per person based on leakage reporting. Error bars represent +/– one standard error.

Table 4.8 Summary of statistical comparisons between leakage and per capita consumption

	LEAKAGE REPORTING			
	RESIDENT REPORTED LEAKS	RESIDENT REPORTED NO LEAKS	WATER METER DETECTED LEAKS	WATER METER DID NOT DETECT LEAKS
Average (Lpcd)	285	183	240	196
Std error (Lpcd)	36	19	27	23
Sample Size	9	16	16	12
ANOVA P-value	0.01		0.24	
Kruskal-Wallis Test P-value	0.009		0.24	

Since not all residents from households where continuous leakage was detected reported leakage, it is likely that only the most significant leaks would be noticed and then reported by residents. If a water meter detected a continuous leak at any time during the entire study, I classified the household as having a meter detected leak. So it makes sense that this grouping has a less measurable effect on average use per person because it includes households where leakage was continuous for even short periods of time. A more discrete analysis of leakage, like grouping households by frequent or infrequent continuous leaks or by inferring the size of leaks through overnight water use, could yield different results.

Other interview results like reported shower, bath, and clothes washer use frequency were also tested against average daily water consumption per capita. Reported shower and bath use frequency show no significant effect on average water use. Clothes washer use frequency, however, did, as shown in Figure 4.13 and Table 4.9.

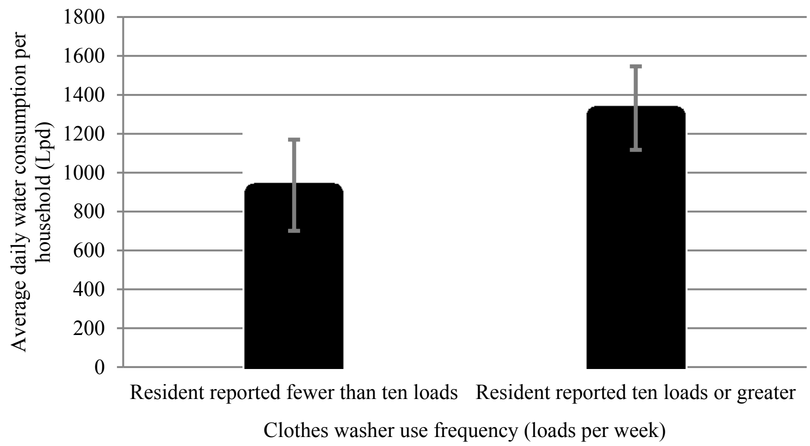

Figure 4.13 Average daily water consumption per household based on clothes washer use frequency. Error bars represent +/– one standard error.

Table 4.9 Summary of statistical comparisons between clothes washer use frequency

	RESIDENT REPORTED CLOTHES WASHER USE FREQUENCY (LOADS PER WEEK)	
	FEWER THAN TEN	TEN OR GREATER
Average (Lpd)	935	1332
Std error (Lpd)	235	215
Sample Size	11	13
ANOVA P-value	0.23	
Kruskal-Wallis Test P-value	0.09	

Since this data may not be distributed normally, the Kruskal-Wallis Test is the more reliable test for this data. Regardless, household water consumption is much higher for homes that report a higher frequency of clothes washer use. Clothes washers use significant volumes of water that can be seen on the household scale. In an interview with Trena Soosay (2014), I asked:

About how many loads of laundry are done in this house per week?

> Between 30 to 35 loads. We do lots of laundry because there are bed bug concerns on-reserve. Also a family who doesn't live here uses our washer.

I have also heard anecdotally among Samson Cree Nation residents that clothes washer sharing is not uncommon because some people do not have working machines or because water in some households will stain the laundry.

From the statistical tests of residential end uses, leakage is the most significant driver of domestic water use in Samson Cree Nation. Clothes-washer use frequency is the next most significant driver, while shower and bath use frequency have no measurable effect.

Mah (2014) collected water samples at 15 of the metered households. I plotted chemical concentrations against per capita water consumption at these households to investigate any relationships between water quality and water consumption. I discuss the most significant results below while all the remaining figures can be found in Appendix C.

The taste threshold concentration of sodium in room temperature water is about 200 mg/L or about 200 ppm (World Health Organization, 2011). All of the samples Mah (2014) collected exceeded 200 ppm in concentration which means sodium concentrations are within the range of taste perception. Figure 4.14 shows sodium concentration from tap water samples and per capita water consumption values for households. Water consumption trends toward higher values for higher concentrations of sodium although the correlation is weak.

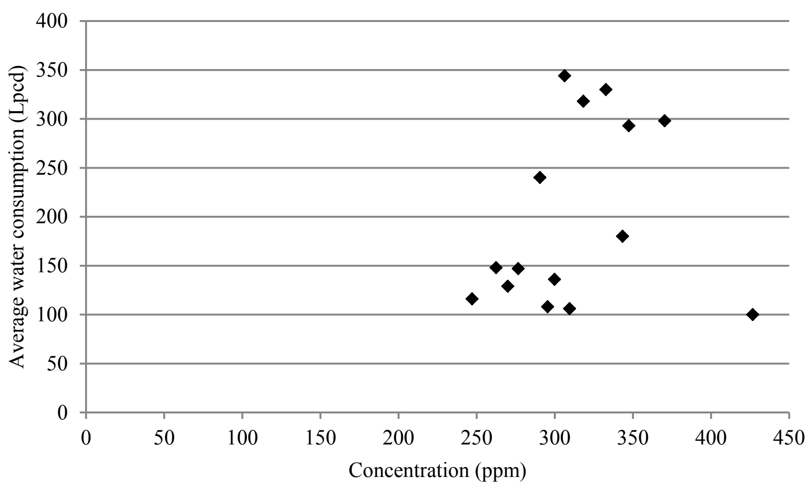

Figure 4.14 Per capita water consumption plotted against sodium concentration in tap water sample

Aluminum concentrations above 0.1–0.2 mg/L, about 0.1–0.2 ppm, can intensify water discolouration by iron (World Health Organization, 2011). Figure 4.15 shows aluminum concentration in tap water samples and the corresponding per capita water use in households.

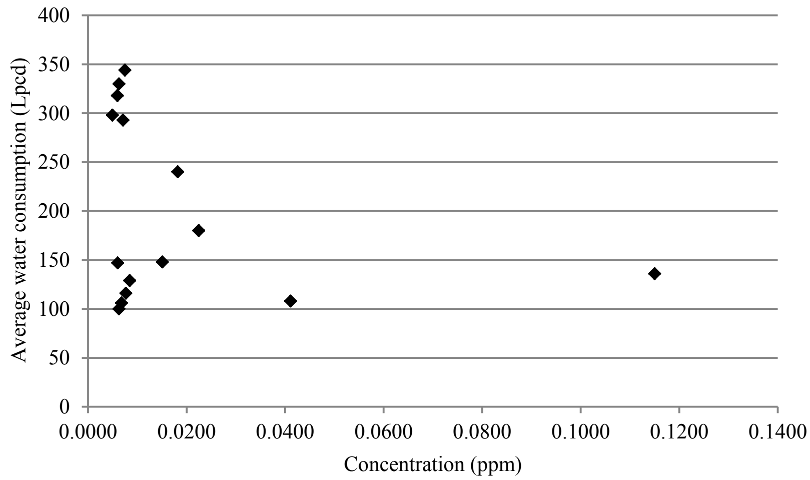

Figure 4.15 Per capita water consumption plotted against aluminum concentration in tap water sample

Here, water consumption trends toward lower values as aluminum concentrations increase but the correlation is weak. Only one data point exceeds the range where aluminum concentration has a visible effect on water, and then, only when iron is present. The water sample with this exceedance has an iron concentration of 0.149 ppm. At concentrations above 0.3 mg/L, or 0.3 ppm, iron can stain laundry and plumbing fixtures (World Health Organization, 2011). Below concentrations of 0.3 ppm, iron can contribute to water turbidity and colour but usually does not impact taste (World Health Organization, 2011). Water sample iron concentrations are plotted in Figure 4.16.

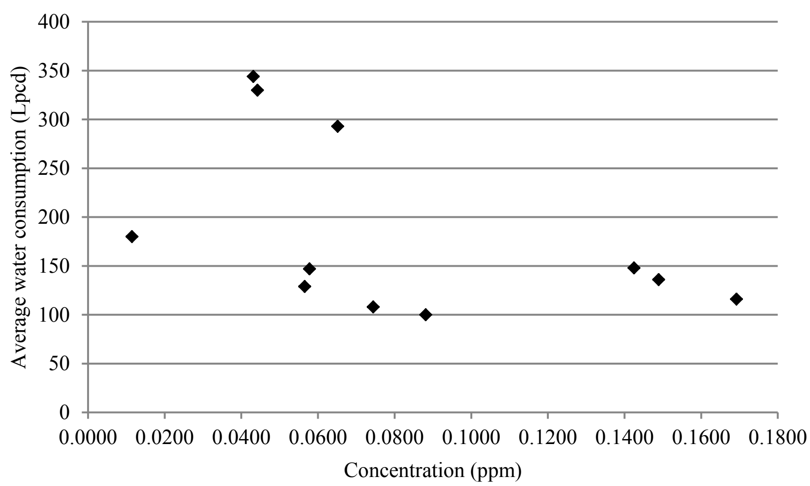

Figure 4.16 Per capita water consumption plotted against iron concentration in tap water sample

Similar to aluminum concentrations, water consumption per capita trends toward lower values as iron concentrations increase. This correlation is stronger than those of sodium and aluminum.

I investigated relationship between daily climatic data—maximum daily temperature, heating degree days, and precipitation amount—none of which yielded clearly visible relationships. I also averaged per capita water consumption for all metered houses for each day of the sampling period and plotted it against the same climatic data, again with no clear results. Since water users are not charged for water use, climatic data could have a more visible impact on domestic water use in Samson Cree Nation than in other communities. It would be interesting to investigate any climatic and water consumption relationships further, using different techniques. However, these relationship may indeed be very weak since outdoor water use in Samson Cree Nation is so low and outdoor water use would be the area most impacted by climatic variables.

4.5 Conclusions

Household water meter data reflects routine household behaviours. Samson Cree Nation, as a community with some unique characteristics, provides insight into how water use responds to drivers of domestic water demand. I investigated a number of variables' effects on domestic water use and found that water consumption can depend on:

- water system (rural or municipal);
- drinking water source (tap water or bottled water);
- household size (large or small);
- household occupancy during the day (percentage of residents away from the homes during the day);
- resident reported leakage;
- water meter detected leakage;
- clothes washer use frequency; and,
- maybe some water quality parameters (iron).

The best explanation for the difference in water consumption between rural and municipal residents is the perception of water quality: the rural water system is largely distrusted and rural residents use less water than municipal residents. This could also explain the significant difference in water consumption between household that drink bottled water and households that drink tap water: a reaction to water quality, both perceived or measurable, impacts water consumption. Certainly the anecdotal data point to this conclusion.

The most significant demographic features that drive domestic water use in Samson Cree Nation are household size and household daytime occupancy. Larger households use more water but a household size of five residents has the lowest per capita water consumption. Households with the majority of residents away from the home during the day use less water and also demonstrate a discernably distinct diurnal water use pattern.

Domestic water use in Samson Cree Nation, based on end purposes, is most significantly impacted by household leakage and clothes washer use frequency. Residents connect clothes washer use with water quality: many people have shared that the water stains their laundry. Perhaps this explains a decrease in water use in with increasing iron concentrations.

This study is limited in a few key ways.

5. I was not able to interview every metered household since some residents were consistently not available to complete an interview. This decreased the sample size for some calculations whose accuracy would be improved with more interview data.
6. The domestic water-use frequencies were reported by the residents. While this is sufficient to group households based on low or high reported frequency, flow trace analysis would objectively measure these frequencies.
7. The metered household sample size on-reserve is 28. While it took considerable effort to collect the data, a larger sample size would improve accuracy and, ultimately, forecasting.
8. Household leakage is significant but could be investigated further to determine actual leak volumes to see how they impact water demand.
9. I did not collect water pressure data. Water pressure could vary between rural households and the municipal system. Since water pressure impacts water consumption, it warrants investigation.

To address these limitations, I recommend:

- completing interviews with all metered households in Samson Cree Nation through more frequent site visits and more regular contact with residents;
- collecting water-use data at 10 second intervals and using flow trace analysis to disaggregate the results as done by DeOreo et al. (1996), Mayer et al. (1999), DeOreo et al. (2001), Loh and Coghlan (2003), Roberts (2005), Heinrich (2007), and Willis et al. (2009); and,
- continuing the water metering program in Samson Cree Nation to increase the sample size and improve the accuracy of the data. A larger samples size could reveal new variables that impact domestic water use.
- determining average leak volumes from the water meters by analyzing overnight water consumption.
- measuring water pressure at rural household and investigating its effect on domestic water use.

Williams & Florez (2002) argue that to mitigate environmental injustice, a strong link between citizen participation, institutional trust, and environmental issues is necessary. It is encouraging, then, to see Samson Cree Nation form their nipiy committee during this research project. The nipiy committee is a water-focused group under Chief and Council that is working to improve the state of water—infrastructure, housing, treatment, legislation, regulation, and the environment—in Samson Cree Nation in the best interests of the Nation. By collecting this data, conducting this analysis, and communicating with residents, we hope that we can understand the best ways to make improvements to the system for generations to come.

CHAPTER FIVE

Domestic water use and forecasting in Samson Cree Nation: A system dynamics approach

5.1 Domestic water demand forecasts, system dynamics modeling, and Samson Cree Nation's water systems

Why is it that water and wastewater systems in First Nations communities are so at risk, especially when compared to non-First Nation communities in Canada? And why is it that despite government initiatives, significant media attention, and the efforts of band leaders, First Nations water and wastewater systems have not only failed to improve but have actually become worse since 2003? The *National Assessment of Water and Wastewater Systems in First Nations Communities* (INAC, 2003) evaluated 740 community water systems and found that:

- 29% were high risk;
- 46% were medium risk, and;
- 25% were low or no risk.

The *National Assessment of First Nations Water and Wastewater Systems* (Neegan Burnside, 2011a) evaluated 807 community water systems and found that:

- 39% were high risk;
- 34% were medium risk, and;
- 27% were low risk.

Both assessments evaluated similar criteria. The 2003 assessment lists the following (INAC, 2003):

- water source;
- type and performance of the treatment systems;
- operational practices;
- reporting practices; and,
- the qualifications of operators.

The 2011 assessment lists the following (Neegan Burnside, 2011a):

- water source;
- design;
- operation;
- reporting; and,
- operators.

While the 2003 assessment does not describe how the risk categorization was numerically determined, the point remains that these large-scale evaluations are demonstrating increasing risk for water systems despite awareness of the concerns.

Water consumption and how it relates to demographics and population is complex and dynamic – in other words, not monocausal, linear, and static (Corbella & Pujol, 2009). Certainly the relationships uncovered in chapter 4 demonstrate some of the complexity of domestic water use and the variables that affect water use behaviours. But beyond these variables that have a measurable or observable impact on water consumption there are many institutional, social, and technical factors at play—some of which I explored in chapter 3. If we hope to understand why water systems in First Nations communities continue to be "risky", we must relate the variables that affect domestic water consumption to one another and to the more general determinants of domestic water use. For this I use a "system dynamics" approach.

While a system dynamics model will not answer the questions I posed above—and there is undoubtedly no single answer to either question—it will provide a greater, holistic understanding of how Samson Cree Nation's water system functions. Equipped with this understanding, Samson Cree Nation may avoid some pitfalls or identify barriers that impede Indigenous and rural communities from accessing reliable water quality and quantity. Further, I can investigate how the actions of other actors in the system—provincial and federal governments, for example—that attempt to "fix" the problems of uneven water access may actually exacerbate problems or cause unintended consequences.

The need for water demand forecasting cannot be overstated, as both water resources planning and management efforts among various levels of government and the quantity of academic literature on the topic indicate. Residents in Samson Cree Nation are not strangers to long-term planning: in fact, they talk about their ancestors seven generations ago who planned for their existence and how they must also plan for their descendants of the seventh generation. I wonder if a system dynamics approach can do as good a job.

In October 2013, Fraser and I hosted a consultation meeting with elders in Samson Cree Nation about water and our research. One elder, JT, said,

> It has been said long ago that our elders knew that we would be buying our water and that our water would be bad. Our reserve long ago used to be full of trees. You could drink the water and live off the land. The white man came and bulldozed our lands, destroying our ecosystems, even the rainforests. Trees cut down affect our air. Our trees are depleting, oxygen levels are affected. The white people with all their companies affect the ecosystem. The chemicals they use, even rain water is affected. Pollution, it always goes back to the white man, the almighty dollar. We have seen better days when we had clean water and it didn't affect our communities. We can talk and share ideas but what will it solve?

In chapter two I detailed the overall impetus and methodology for this research. How this research is positioned was deeply informed by Samson Cree Nation, both in my understanding of their physical water systems and processes and in how I have come to think about the institutional and political systems that affect the community. In chapter three I introduced some of the historical and contemporary political context—FITFIR water licences, Bill S-8—that affects access to safe water for Samson Cree Nation and Indigenous communities in Canada in general. I draw on this discussion and other information to create a causal loop diagram (CLD), explaining feedback loops that affect water systems on-reserve, which include water supply, water quality, regulation, and multiple levels of government. In chapter four I explored relationships that affect domestic water consumption in Samson Cree Nation. I used these relationships—along with anecdotal data and information from relevant literature—to build a CLD and a stock and flow diagram (SFD) of Samson Cree Nation's domestic water use system: a narrower scope than the political CLD described above. I describe the structure of both CLDs and the SFD in detail. Data from chapter three and the literature could then be used for the initial conditions of the SFD model and to calibrate the model. A completed model could then be used to project future water use scenarios in Samson Cree Nation and the impacts of specific water interventions.

5.2 Systems thinking and water resources engineering

What has been the response to the widely publicized water and wastewater conditions in First Nations? A mapping of how Aboriginal and Northern Development Canada (AANDC) might be approaching the situation could look like Figure 5.1, beginning as a reaction to the variable "media attention on First Nations quality of life/water".

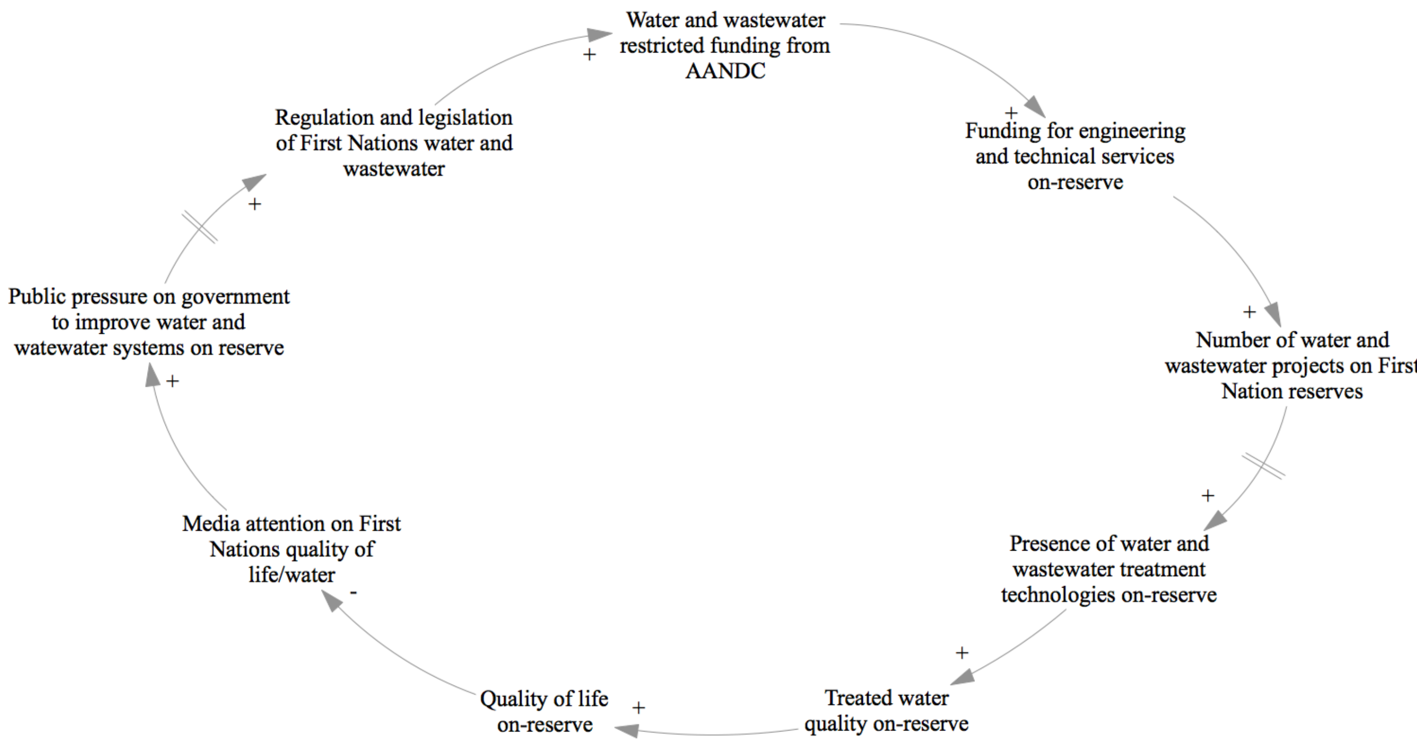

Figure 5.1 Problem-solving approach used by Aboriginal and Northern Development Canada to improve First Nations water and wastewater systems. Arrows demonstrate the direction of influence from cause to effect, or, from the independent variable to the dependent variable. The polarity shows the correlation: positive (+) means an increase in the independent variable causes an increase in the dependent variable or a decrease in the independent variable causes a decrease in the dependent variable; and, negative (–) means an increase (decrease) in the independent variable causes a decrease (increase) in the dependent variable. Double dashes (||) mean that there is a significant time delay between cause and effect.

The figure shows that the problem—high risk water and wastewater systems in First Nations communities that affect the quality of life on-reserve—is addressed with a straightforward response: invest in water and wastewater treatment technologies, infrastructure, training, and legislation. By taking action through different avenues, the hope is that the problem will be resolved quickly. The underlying logic here is that each component of the solution should directly address the problem. It follows, then, that once the solutions are implemented, we can expect full resolution of the problem.

One of the problems with using an approach like this—as it appears AANDC is doing—is that it fails to consider other effects the proposed "fixes" have, aside from improving water quality: in other words, their "side effects", or unintended consequences. If First Nations water and wastewater systems are to improve, a systems thinking approach can offer ways of identifying and addressing the root problems to safe drinking water. Linear causal thinking cannot adequately address complex problems (Forrester, 1961 as cited in Mirchi et al., 2012). This type of unidirectional thinking assumes that events are shaped by the collective effects of a series of ordered causes (Sterman, 2000 as cited in Mirchi et al., 2012), that there are no unintentional consequences. Isolating a problem from the surrounding environment in this way—removing the context of the problem—does not permit in-depth understanding of its root causes (Mirchi et al., 2012). Systems thinking, on the other hand, does.

By considering additional consequences to actions, analysts characterize the system's structure through feedback loops and interconnections (Richmond, 1993). Thinking of the system structure in this way is called closed-loop, non-linear causal, or systems thinking. It allows analysts to understand and shape complex systems (Richmond, 1993). This is not to say that proposed solutions through other ways of thinking cannot address problems. Certainly emergency response has neither the time nor the interest in long-term planning when problems need to be addressed immediately and unintended consequences can wait until after the emergency has subsided (Richmond, 1993; Simonovic, 2009 as cited in Mirchi et al., 2012). However, when insufficient attention is paid to the root causes of a problem, the typical linear, monocausal responses fail to address the problem appropriately and result in spatial or temporal shifts (Richmond, 1993; Simonovic, 2009 as cited in Mirchi et al., 2012). In other words, the problem is not resolved, but is simply delayed or moved to another area. Mascarenhas (2012) described how polluted water sources in Ontario disproportionately affect First Nations reserves because polluters—industrial and agricultural water users—do not have to live with the consequences of their activities as pollution moves downstream. The problem—pollution—is not managed, it's simply shifted to another time and place.

Because system dynamics models provide a deeper understanding of system structure and the relationships and interactions between system variables than other planning tools, they offer an alternative method for addressing dynamically complex problems (House-Peters & Chang, 2011). Compared to more conventional methods, system dynamics models take into account more components, feedback mechanisms, behavioural responses, and time lags (House-Peters & Chang, 2011). An understanding of system structure requires a holistic view – in other words, the perspective that the behaviour of the overall system as a whole is important. With holistic system understanding comes effective learning and management of complex systems, and a holistic view can help to build consensus among actors in the system (Winz et al., 2009). Despite these conditions, system dynamics' utility is not in predicting future system states, but rather in indicating how choices affect the tendency of the system to move toward certain conditions (Simonovic, 2002). Plus, they allow modelers to represent complex interrelationships between human behaviour and socio-biological-physical factors (Costanza & Ruth, 1998 as cited in Leal Neto et al., 2006). System dynamics permit interaction and consultation with those who participate in the system. To gain the system understanding necessary in constructing a system dynamics model, stakeholders familiar with the system—inhabitants of the area, public officials, etc.—can be engaged to identify the system variables and the complex relationships between them (Leal Neto et al., 2006).

Finally, although modelled systems may be complex, the reasoning is simple. Society is connected to the natural environment through a feedback loop: changes in the natural environment necessitate social adaptation and this adaptation will affect the natural environment in different ways (Davies & Simonovic, 2011). And while this explanation is still rooted in a human-nature dichotomy, when the appropriate variables are included, a systems thinking approach can avoid some of the problems that stem from ignoring the relationships between society and the natural environment.

5.2.1 System dynamics models and water resources

The underlying premise of system dynamics models is that the structure of a system brings about the system's observable and thus its predictable behavior (Forrester; 1968, 1987, as cited in Winz et al., 2009). Over the past five decades, system dynamics has become a well-established methodology for studies in ecology, economics, education, engineering, public health, and sociology (Sterman, 2000 as cited in Mirchi et al., 2012). Researchers have investigated a variety of water resources engineering problems using system dynamics, as summarized in Table 5.1.

Table 5.1 Summary of water resources studies using system dynamics modeling

CITATION	TOPIC OF INVESTIGATION
Ford (1996)	Decreased water flows in the Snake River in the western USA and declining water tables in the area: simulation of river flows and water appropriation to water users
Gao and Liu (1997)	Regional water resources decision making for the Plain Area of Hanzhong Basin, China; simulation of water withdrawals, water consumption, and wastewater return flows
Vezjak et al. (1998)	Freshwater eutrophication of Lake Bled, Slovenia; simulation of sewage and agricultural runoff nutrient discharge and its effects on plankton dynamics to support water qual-

	ity management
Simonovic and Fahmy (1999)	Water resources policy analysis and decision making in the Nile River Basin, Egypt; simulation of national-level socio-economic development plans and water availability
Ahmad and Simonovic (2000)	Reservoir operating rules to minimize flooding at the Shellmouth reservoir on the Assiniboine River, Canada; simulation of river flows, reservoir storage, and reservoir outflows
Guo et al. (2001)	Water quality and environmental degradation related to socio-economic growth in Lake Erhai Basin, China; simulation of regional physical and socio-economic subsystems and a water quality model
Saysel and Barlas (2001)	Salinization of irrigated lands in southeastern Turkey; simulation of socio-economic irrigation-based regional development, salinization, water availability, and crop yields
Li and Simonovic (2002)	Snowmelt runoff flooding of North American prairie rivers, the Red River specifically; simulation of snowpack accumulation, snowmelt, soil properties, and temperature change
Simonovic (2002)	Global water stressors for future supply based on the World3, or "Club of Rome", model; simulation of water supplies, water pollution, population, and the economy
Xu et al. (2002)	Sustainable water resources management in response to growing water demand in the Yellow River basin, China; simulation of water demand, water supply, population, and climate change
Simonovic and Li (2003)	Climate change impacts on flood protection system for the City of Winnipeg, Canada; simulation of temperature, precipitation, river flows, climate change, and flood control works
Stave (2003)	Public understanding of water management options in Las Vegas, USA; simulation of policy, water supply, and water use
Tangirala et al. (2003) as cited in Mirchi et al., 2012	Water quality management of pathogen contaminated streams in southeastern Kentucky, USA; simulation of pathogen fate and transport in river system
Ahmad and Simonovic (2004)	Flood damage estimation in the Red River basin, Canada; simulation of flood propagation linked with GIS mapping
Simonovic and Raja-	Water resources policy analysis and decision making in

sekaram (2004)	Canada; simulation of population, capital, agriculture, food, non-renewable resources, persistent pollution, energy, fresh water, and water quality
Tidwell et al. (2004)	Public participation in integrated water resources planning and management in the Middle Rio Grande Basin, USA; simulation of river flows, groundwater storage, and climate
Elshorbagy et al. (2005)	Reclamation of disturbed watersheds at Mildred Lake mine, Canada; simulation of precipitation and water storage
Sehlke and Jacobson (2005)	Water resources planning and management of the Bear River Basin in the western USA; simulation of river flows, aquifer storage, and water diversions
Simonovic and Ahmad (2005)	Flood crisis management in the Red River Basin, Canada; simulation of flooding conditions, evacuation policy, and evacuee behavior
Ahmad and Simonovic (2006)	Flood management in the Red River Basin, Canada; simulation of flooding conditions and flood control structures
Leal Neto et al. (2006)	Water quality and environmental deterioration due to socio-economic development in Sepetiba Bay watershed, Brazil; simulation of population, industry, infrastructure, agriculture, land use, commerce, and effluent flows
Leaver and Unsworth (2006)	Mass and thermal balance of a geothermal spring in New Zealand; simulation of rainwater, temperature, barometric pressure, and water level
Langsdale et al. (2007, 2009)	Climate change and integrated water resources planning and management for the Okanagan Basin, Canada; simulation of population, water levels, water use, and climate
Chung et al. (2008)	Urban water supply planning in southern Arizona, USA; simulation of domestic, agricultural, and industrial water demands and water and wastewater flows
Gastélum et al. (2009)	Water allocations among various groups in the Conchos basin, Mexico; simulation of hydrological, agricultural, economic, and institutional factors
Madani and Mariño (2009)	Water diversions in the water scarce area of the Zayandeh-Rud river basin, Iran; simulation of physical, socio-economic, and political systems
Graham et al. (2010)	Water accounting system for water management in the state of Victoria, Australia; simulation of water supply, water demand, infrastructure, and economic activity

Ahmad and Prashar (2010)	Water allocation among various groups and the effectiveness of municipal water conservation strategies in South Florida, USA; simulation of population, land use, and water levels
Bagheri et al. (2010)	Post-earthquake water resources management in Bam, Iran; simulation of population, crisis index, water demand, and infrastructure reconstruction
Li et al. (2010)	Climate change impacts on reservoir operation at the Shellmouth Dam, Canada; simulation of temperature, precipitation, and water flows
Davies and Simonovic (2011)	Global water scarcity; dynamic simulation of global climate, carbon cycle, economy, population, land use, agriculture, hydrological cycle, global water use, and water quality
Qaiser et al. (2011)	Sustainable water resources management in response to growing water demand in Las Vegas Valley, USA; simulation of conservation strategies like wastewater reuse
Vankatesan et al. (2011a, b)	Salinity load forecast and removal from wastewater return flows in Las Vegas Valley, USA; simulation of hydrology, water use, and water quality
Shrestha et al. (2011, 2012)	Energy and carbon requirements for water supply alternatives in Las Vegas Valley, USA; simulation of water supply, water use, energy use, carbon emissions, and unit price of water

Since system dynamics models incorporate both quantitative and qualitative information, their scope can increase beyond physical processes to include policy, human behavior, and other less "technical" components. In fact, since the aim of system dynamics models is to provide insights into system behavior over time, system dynamic models are not appropriate for forecasting or point prediction (House-Peters & Chang, 2011). Winz et al. (2009) highlight the advantages of the system dynamics model methodology over "traditional" methods:

1. System dynamics modelers use qualitative and quantitative variables;
2. System dynamics modelers can develop nested models to address a problem at multiples scales, and;
3. System dynamics modelers can continuously test assumptions and system sensitivity under multiple alternative futures.

These advantages make system dynamics a particularly useful method to analyze the water system of Samson Cree Nation. By applying a community-based research methodology in this project, it became very apparent that I would have to incorporate the political sphere into my understanding of "the water system". By political sphere, I mean certain legislation, regulation, policies, and actions by federal, provincial, and

First Nations governments. Further, anecdotal information and data from interviews are qualitative but have utility in a system dynamics model. Where I lack evidence from my data or experience, logic and examples from existing literature are sufficient to rationalize the model structure.

Dynamic models are integrative and multidisciplinary. They have been designed to understand how water consumption decision and behaviours relate to urban form and housing (Galán et al., 2009), changes in water price (Athanasiadis et al., 2005; Chu et al., 2009), conservation policies (Chu et al., 2009; Ahmad and Prashar, 2010), and climate change (Downing et al., 2003; House-Peters and Chang, 2011). The breadth of scope in studying these variables is not afforded in conventional static time series and econometric models (House-Peters and Chang, 2011).

Further, in a community that tells repeating stories about their relationships with government, settlers, "white folks", or *môniyâwak*, stories about how government continues to legislate life on reserve or stories about environmental racism (that polluters do not have to cope with their pollution and it most directly harms marginalized communities, First Nations reserves, in particular, in Canada) and continued environmental pollution, one wonders if current strategies simply defer problems rather than addressing them. Dynamic modelling, then, may provide some insight into how we can understand certain problems and address their root causes instead of repeating the same mistakes.

Aside from providing a representation of the structure under investigation and how the system may behave in the future, system dynamic modelers can introduce interventions into the model and observe the system's response over time (Ford, 1999 as cited in House-Peters and Chang, 2011). For a model focused on water consumption, interventions like water conservation campaigns, new water policies, or even the creation of a water utility can be incorporated.

House-Peters and Chang (2011) explained how water conservation could be encouraged through municipal-scale incentives in the household, like subsidies or assistance for low-flow appliances. Chung et al. (2008) investigated incentives for replacing faucets, showerheads, and toilets with more efficient fixtures and for purchasing front loading clothes washers to conserve water in a system dynamics model. They also considered a scenario in which newly constructed houses would have grey-water reuse systems, decreasing outdoor water demand. They found that the most significant conservation measures in both cost savings and fresh-water use reduction in their model were changing landscaping standards and regulations for existing homes and installing grey water reuse systems in new homes (Chung et al., 2008). Further, they estimated a decrease of 70% in water demand if all of their conservation strategies were implemented simultaneously. However, Chung et al. (2008) studied a hypothetical environment in Arizona where outdoor water use is significant, providing little insight into the potential characteristics of effective conservation strategies in Samson Cree Nation.

Ahmad and Prashar (2010) used a system dynamics model of South Florida to test the effectiveness of policies that introduced low-flow appliances, xeriscaping, and pricing in reducing municipal water demand. Specifically, Ahmad and Prashar (2010) targeted indoor and outdoor municipal uses for water conservation. By disaggregating indoor water use into its end uses—shower, toilet, faucet, laundry, leaks, and other—Ahmad and Prashar (2010) evaluated the effectiveness of certain low flow appliances on municipal water use. Vickers (2001 as cited in Ahmad and Prashar, 2010) estimated savings of up to 44% from low-flow appliances; however low-flow appliance savings are usually lower than rated due to consumers' behavioural responses (Davis, 2008; Mayer et al., 1999; Renwick and Green, 2000). Raising the price of municipal water can encourage water conservation. Ahmad and Prashar (2010) investigated water savings through price incentives using a municipal water price elasticity of –0.33 in their system dynamics model—note that elasticity has been found to range from –0.15 to –0.52. Last, xeriscaping—landscaping using appropriate, less water-intensive practices and plants—can result in water savings of 25% to 42% (Nelson, 1994 as cited in Ahmad and Prashar, 2010; Testa and Newton, 1993 as cited in Ahmad and Prashar, 2010; Sovocool, 2005; Vickers, 2006). Ahmad and Prashar (2010) estimated a 30% reduction in outdoor municipal water use for xeriscaping in their model. They found the largest municipal water conservation (13.2%) by using a combination of all three policy areas: low-flow appliances, water pricing, and xeriscaping. In isolation, low-flow appliances showed the most potential to save water followed by price increases. Finally, Ahmad and Prashsar (2010) recommended a tiered structure for water prices to avoid the inequity of charging various water users the same rate, advising that higher water consumers be charged more.

Qaiser et al. (2011) investigated the impacts of water conservation in the Las Vegas Valley. They found that given a future water use target, limiting outdoor water use yields the greatest water conservation (Qaiser et al., 2011). This is largely due to the arid climate of the Las Vegas Valley, the high proportion of outdoor water use, and because wastewater from indoor uses flows to water treatment plants, providing return flow credits—that is, additional water withdrawals in exchange for returning treated water to the environment—for an increased water supply (Qaiser et al., 2011). High outdoor water use does not permit wastewater return flow credits since the water is "consumed". So Qaiser et al. (2011) found outdoor water use as the most effective site of conservation because high indoor water use allows for more return flow credits.

Also in the Las Vegas Valley, Venkatesan (2011a) studied the impacts of indirect potable water reuse and direct potable water reuse on water conservation, pumping costs, and total dissolved solids in the receiving water body. Direct potable water reuse would save about 50% of water pumping costs, according the simulation. Further, Venkatesan (2011a) found that both indirect and direct potable water reuse systems would decrease total dissolved solids load to Lake Mead by over 50%, improving water quality.

Other system dynamics investigations of water resources have included water quality into their models. Guo et al. (2001) linked water quantity with water quality using a system dynamics model of the Lake Erhai Basin in China. Leal Neto et al. (2006) investigated the effects of industry, population, infrastructure, and land use on effluent, residues, and solid waste in the Sepetiba Bay Watershed in Brazil. However, these wastes or pollutants did not feed back to any other parts of the system. So while the results of pollutant discharge are important, how might water pollution affect other components of the model like available water stocks or population growth? Why do we see water quality as exogenous in many system dynamics models? Surely actual or perceived changes in water quality can and do impact how we use water—see chapter four—so how can water quality be incorporated as a feedback—incorporated endogenously in other words—to the water system?

5.2.2 System dynamics models and water quality

Rijsberman (2006) explained that as fresh water flows downstream it can become, in effect, unusable, so water quality should be included in assessments of water scarcity. Davies and Simonovic (2011) explained that while researchers have highlighted the importance of water quality on water scarcity, there is a lack of large scale modeling of its environmental and socio-economic effects. Some modelers have found ways to include water quality in this way in their system dynamics models.

Simonovic (2002) included pollution as a key stock in a dynamic global model of water resources and concluded that dilution requirements for water pollution will be the most important future water use issue globally. Simonovic (2002) described the use of the AQUA water submodel that considered domestic water supply, wastewater treatment options, fresh water quality, and the quality of aquatic ecosystems—including the ability for users to model the human response to water policies. The AQUA submodel, however, was not a dynamic model that considered relationships between the variables and any feedback loops to the system (Simonovic, 2002). Therefore, Simonovic (2002) developed the *WorldWater* model from the World3 model introducing two new sectors: water quantity and water quality. Significantly, *WorldWater* addresses freshwater needs for transport and dilution of polluted water—a consideration sorely lacking from other global water models (Simonovic, 2002). *WorldWater* links water quality with water supply: polluted water becomes unsuitable for water use (Simonovic, 2002). He also expresses population as a function of domestic water supply, domestic water use as a function of population, and life expectancy as a function of both total water quantity and water quality. Simonovic (2002) related life expectancy and domestic water supply as an exponential multiplier: life expectancy is zero for no water and at a maximum—one—for maximum supply. Simonovic (2002) used historical data from urban and rural populations not served by water supply and sanitation services to develop the relationship between life expectancy and water quality.

Using a similar model structure to *WorldWater*, Simonovic and Rajasekaram (2004) developed the *CanadaWater* model. One notable conclusion from their study is that an increase in the wastewater treatment standard allowed steadier population and gross domestic product growth (Simonovic & Rajasekaram, 2004). Further, improvements in water quality slightly increased water consumption but significantly reduced the water volume required for dilution (Simonovic & Rajasekaram, 2004).

Davies and Simonovic (2011) included water quality in their global system dynamics model of water resources. They also considered the dilution requirement for wastewater by fresh surface water: they assumed all domestic wastewater is polluted and must be diluted. The result was that a large volume of untreated wastewater yielded only a relatively small volume of clean water for other uses (Davies & Simonovic, 2011). Further, wastewater sources—domestic water use, manufacturing processes, irrigation, and rainfed cropland—were assumed to pollute receiving water bodies, making it unsuitable for other uses, and drinking water in particular (Davies & Simonovic, 2011). According to Shiklomanov (2000), each unit of contaminated wastewater renders eight to ten units of pure water in receiving water bodies unsuitable for further use. Clearly any model that attempts to manage water scarcity should include water quality as a key component.

5.3 Building system dynamics models

I developed three system dynamics models that are described in detail in this chapter. The first is a causal loop diagram (CLD) that reflects the current political, administrative, and technical variables that affect and are affected by water and wastewater systems on-reserve; it is not limited to Samson Cree Nation but could be reflective of many First Nations or Indigenous communities' water and wastewater systems, and the interactions of First Nations with government and other actors. The second is a CLD of Samson Cree Nation's domestic water system and its relevant variables; this model represents my understanding of how Samson Cree Nation's water and wastewater systems function and are managed by the Nation, based on my experience there. Last is a stock and flow diagram (SFD) of Samson Cree Nation's domestic water system that is based on the second causal loop diagram; this model was designed to use Samson Cree Nation's data.

5.3.1 Causal loop diagram of political water system

I developed this model in contrast, partly, to the CLD presented in Figure 5.1. The intent is to demonstrate that the political environment surrounding First Nations water and wastewater systems is far more complex than the simpler structure I suspect Aboriginal Affairs and Northern Development Canada employs. The federal government's actions and interventions that address problems on a certain level—e.g. increasing funding purely for water and wastewater treatment to First Nations—can have unintended consequences over the long term or through less direct routes—for example, increasing restricted funding to First Nations decreases First Nations sovereignty and opportunities for community-led projects. To be fair, at this point AANDC is likely more concerned with ensuring funds are spent in specific areas to improve deficient sectors for which they are blamed. Figure 5.2 shows the model structure.

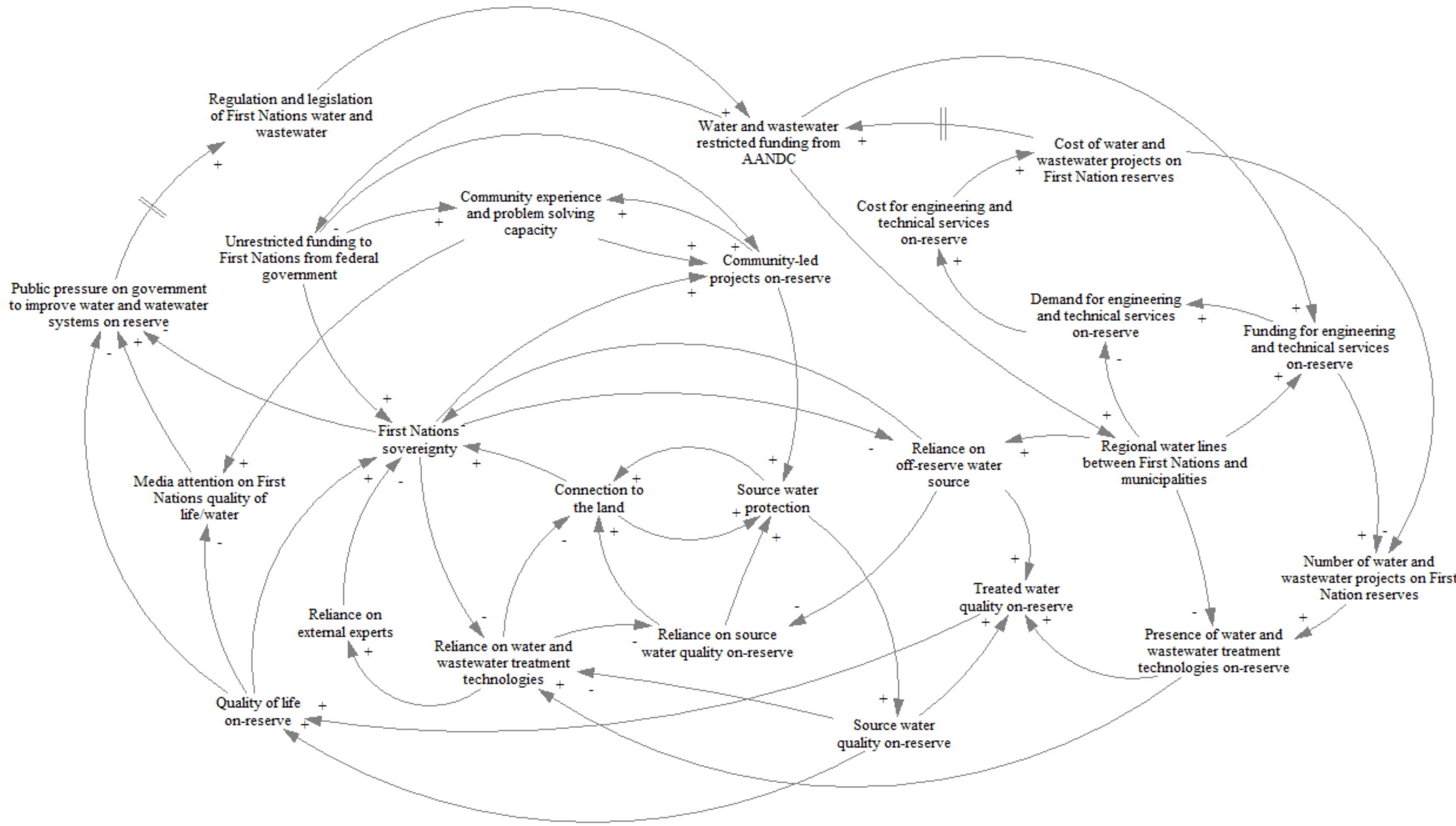

Figure 5.2 Causal loop diagram of political system surrounding First Nations water and wastewater

So what are the unintended consequences of AANDC's current approach? First, increasing dedicated funding for water and wastewater projects on-reserve decreases the funding available to Nations for projects of their own devising or for band leadership to direct the development of water and wastewater projects. The result is a diminution of First Nations sovereignty by limiting their ability to self-determine. Second, heavy investment in engineering and technical services on-reserve creates more demand for these services, causing First Nations communities to compete with each other and with external industries to procure or retain necessary staff, training, and services—water treatment plant operators, for example. Ultimately, this increased demand not only increases the costs of these services—further increasing restricted water and wastewater funding— but creates an entire industry that removes funding from the communities it assists through technical, expert work. To summarize, the funder (AANDC) dictates that provided funds be spent on a particular project (funding is restricted to water and wastewater projects) that must be delivered by agents external to First Nations (engineering and technical firms) who are paid for their work through the funder. The increase in demand for these services across First Nations, causes the services to become more costly and thus more inaccessible to First Nations communities.

Another effect of this approach is that an increase in the use of treatment technologies—both the number of treatment technologies and any technological advancements—increases the reliance on them. This is not uniquely true for Indigenous communities; certainly those living in large urban areas become reliant on daily engineering technologies. These water and wastewater treatment technologies improve the treated water quality on-reserve, but the increased reliance on them decreases people's reliance on source water quality and decreases their connection to the land/environment. In other words, without any water and wastewater treatment or distribution technologies, we would be entirely dependent on source water to provide safe and sufficient water supplies. This dependency promotes a connection to the land to ensure environmental and, consequently, human health. As source water improves in quality and quantity, we become less reliant on treatment technologies and invest more in source water protection, which further improves water quality. This type of resource management—investing in natural systems to ensure long term health—is not only a tenet of contemporary sustainability practices but has been practiced by Indigenous peoples since time immemorial.

Finally, dedicated water and wastewater funding has another unintended consequence, at least in Alberta: an increase in regional water lines shared between municipalities and First Nations. Again, the most evident impact of this increase is that the water supplied to First Nations improves in quality; however, there are other effects of these lines as well. Regional waterlines were, at least partly, funded by the Provincial Government through the Water for Life strategy but required a tri-party agreement. Many municipalities worked with First Nations communities to enter into these agreements and share responsibility for regional water systems. While this type of cooperation can be positive, there are questions about project funding. The First Nations financial contribution to this work largely—if not entirely—came from AANDC. The restricted funding provided to First Nations to participate in these tri-party agreements was therefore used to build, operate, and maintain infrastructure that is mostly off-reserve and that mostly serves an off-reserve population. This further diminishes First Nations sovereignty as it increases reliance on an off-reserve water supply and off-reserve treatment technologies, since the treatment plants for regional waterlines are often built in a municipality rather than in the First Nation. Some members of Samson Cree Nation had mentioned that this lack of source water control was a specific barrier for Samson Cree Nation to join a waterline. Further, the arrangement requires First Nations to pay for water entering their reserve and gives power to those who operate the distribution system off-reserve to restrict water supply to the reserve. While it is difficult to imagine that an entire community would be deprived of their water source, dependence on an off-reserve supply does not encourage First Nations self-sufficiency. One wonders how well a similar arrangement would be received by Canadians if, for the sake of argument, we received treated water from across the American border and that the valve that could stop flows into our nation was located on the other side of the border, in another jurisdiction.

The point here is not that the approach in Figure 5.1 is entirely wrong, but rather that it is shortsighted. So much concern has been placed on the need for improved water and wastewater servicing on First Nations reserves—see the *National Assessment of First Nations Water and Wastewater Systems* (Neegan Burnside, 2011a) or Bill S-8 (Senate of Canada, 2012)—that the Federal Government is pushing one particular, reactive "solution" above all others. However, the reality is that this particular solution has many unintended consequences, many of which end up diminishing, intentionally or unintentionally, First Nations' abilities to demonstrate self-governance. This infringement has felt especially true in my time working with Samson Cree Nation.

It may be idealistic to imagine a world in which First Nations have the funding and freedom substantially to govern their affairs—especially when the Federal Government fears being held accountable for the quality of life on-reserve or worse, for the inflated claims of corruption in band governments—but attempts to "fix the problem" or "help" that end up encroaching on First Nations sovereignty continue to be met with resistance. Perhaps the best—and most efficient—approach would be to give First Nations what they are due and provide assistance upon request, acting in a true Nation-to-Nation relationship.

5.3.2 CLD of Samson Cree Nation's water systems

A system dynamics model of Samson Cree Nation's water systems required both understanding and data. Chapter two explains how we achieved a degree of understanding through a community-based research approach. By living in Samson Cree Nation, working alongside staff, and speaking with residents, we were able to understand the inner workings of the system and gain insight that is informed by the community. Chapter three details the data collection methodology for both the water meters and the resident interviews. Quantitative data from the water meters, water quality testing, and the interviews and qualitative data from the interviews informed the diagram structure.

Once I understood the system, at least partially, I identified a set of variables and explored their potential connections. This exploration focused on water use as the dependent variable. Some of the relationships between water use—the measured data—and variables that influence water use behaviours from chapter four were included in the model. The existing literature on variables that drive water consumption informed other relationships in the model that we did not measure. Lastly, I have created some relationships through logical, anecdotal, or rhetorical arguments. I built the causal loop diagram using Vensim PLE developed by Ventana Systems, Incorporated.

The causal loop diagram representing Samson Cree Nation's water systems is more complicated than the "political" one described above, since it is composed of a number of subsystems described below. Subsystems—since they are smaller than the "whole" system and the relationships are usually more straightforward—are easier to describe and understand. The subsystems in this model are:

- rural domestic water use;
- municipal domestic water use;
- rural domestic wastewater production;
- municipal domestic wastewater production;
- rural housing and demographics (population);
- municipal housing and demographics (population);
- rural water and wastewater infrastructure condition;
- municipal water and wastewater infrastructure condition;
- water contamination;
- water quality; and,
- infrastructure and household maintenance.

The subsystems are related through system variables like frequency and duration of water use activities and leak repairs. Figure 5.3 provides the general relationships between these subsystems.

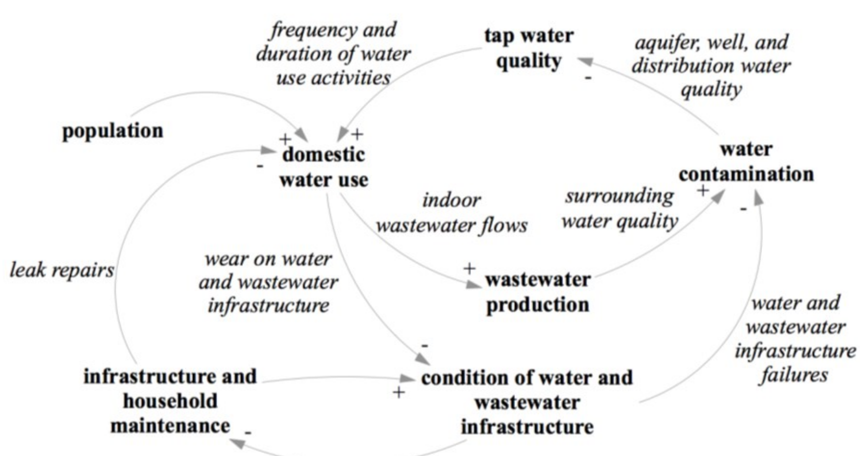

Figure 5.3 Causal loop diagram of subsystems in Samson Cree Nation domestic water use model.

I consider the system behavior at the household-level with a monthly time-step. Survey and interview methodologies are common tools for measuring human agency, household decision making, water use attitudes, and norms and behaviours (Syme et al., 2004; Miller and Buys, 2008; Randolph and Troy, 2008; Harlan et al., 2009; House-Peters and Chang, 2011). Three hypothetical scenarios are included in the model: a water conservation campaign, a water and wastewater pay-per-use servicing utility, and a subsidy program for water-efficient appliances. Figure 5.4 shows how these interventions interact with some of the subsystems.

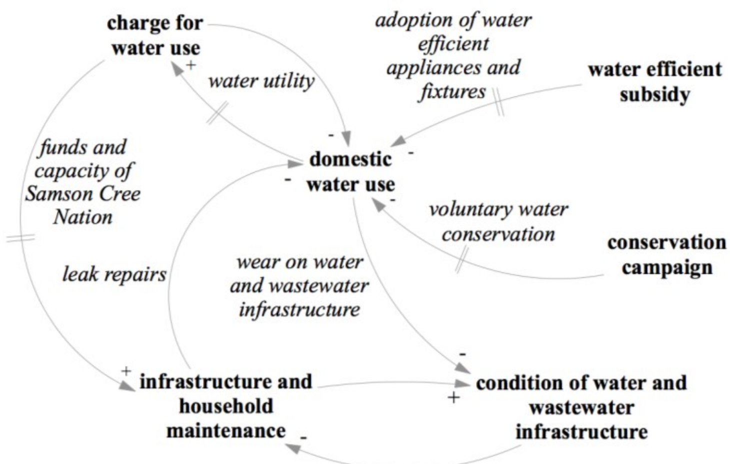

Figure 5.4 Causal loop diagram of policy interventions and subsystems

The rural and municipal domestic water-use subsystems have nearly identical structures. Daily domestic water use per household is the average residential use per household for either the municipal or the rural system. It is calculated by summing the average end use volumes for specific purposes: toilets, showers, clothes washers, faucets, baths, dishwashers, and outdoor uses. These average end-use volumes are calculated by multiplying the frequency or amount of time spent using a fixture and the volume per use or flow rate of the fixture. For example, daily toilet use volume is the toilet flush volume multiplied by the daily household toilet flushing frequency. Daily shower use volume, in contrast, is the daily minutes of shower usage multiplied by the shower flow rate.

Values like the toilet flush volume or the shower flow rate are calculated by accounting for the percentage of households that have water-saving devices like low-flush toilets or low-flow showerheads. These percentages change in response to a hypothetical intervention, where Samson Cree Nation subsidizes water efficient appliances, thus decreasing average flow rates and volumes per use across the Nation.

Frequency values for specific end purposes are driven by average household size: as household size increases (more residents per house), frequencies increase. In other words, more people use water fixtures more frequently. Another hypothetical intervention affects end use frequencies in this model: a water conservation campaign. A public campaign educating residents on ways to conserve water domestically may reduce frequency values in households. Finally, tap water quality affects certain end use frequencies—minutes in the shower, clothes-washing frequency, and minutes of faucet use, for example—but not others—toilet flush frequency and outdoor use, for example—since certain household activities are less desirable with poor water quality and can expose residents to contaminated water. Figure 5.5 summarizes this subsystem in a causal loop diagram.

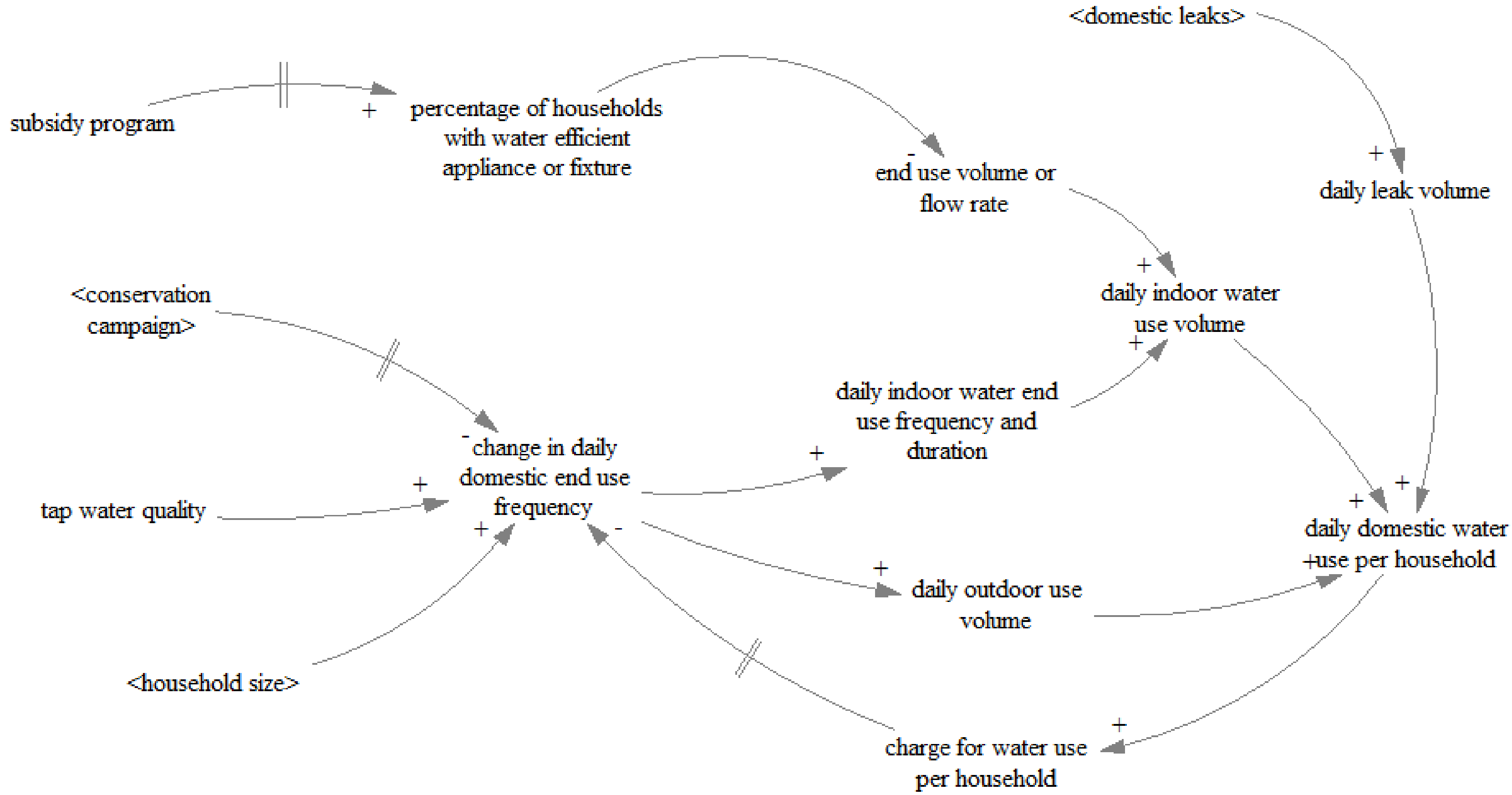

Figure 5.5 Causal loop diagram of domestic water use subsystem, with interventions. Shadow variables are shown inside angle brackets, like <household size>. The inputs for shadow variables are shown in another view. <domestic leaks> for example is calculated in the water and wastewater infrastructure condition subsystems (Figures 5.7).

The aggregated average daily water use per household can be used to calculate average water use per capita and the total water demand for each water system—either rural or municipal. This affects the amount of water withdrawn by the water treatment plant or from rural wells and, consequently, the amount of groundwater removed from aquifers. These variables are not shown in the figures but would be useful to assess aquifer health.

The wastewater production subsystems for the rural and municipal systems are quite different. Municipal domestic wastewater volumes are calculated by summing indoor end uses, since indoor water uses, for the most part, become wastewater after use. Samson Cree Nation's municipal sewage flows through two lagoons for treatment before discharge into the Battle River. Municipal domestic wastewater production ultimately affects the Battle River water quality downstream from Samson Cree Nation, which is also affected by river water quality upstream of Samson Cree Nation.

Rural domestic wastewater production is similar to the municipal system, since the wastewater volume is the sum of indoor end uses; however, rural wastewater flows from the house to household septic tanks or onto the land through "shoot-outs". As a household produces more wastewater, it places more stress on the septic system, increasing the likelihood of a septic tank failure. Septic tank failures are mitigated by maintenance, which depends on the Trades Centre capacity to maintain septic systems regularly. Septic tank failure can require a temporary shoot-out for the household, or can result in wastewater infiltration into the surrounding soil. Either a shoot-out or a septic tank leak can impair groundwater quality around the house by increasing the risk of groundwater contamination. This contamination can occur through pathways that require surface water infiltration into the groundwater source through cracked wellheads or improperly abandoned wells. Such processes eventually impair the tap water quality in the house. Figure 5.6 shows the rural wastewater production subsystem along with parts of the water contamination and household maintenance subsystems. It shares much in structure with the municipal subsystem, except for its inclusion of lagoons.

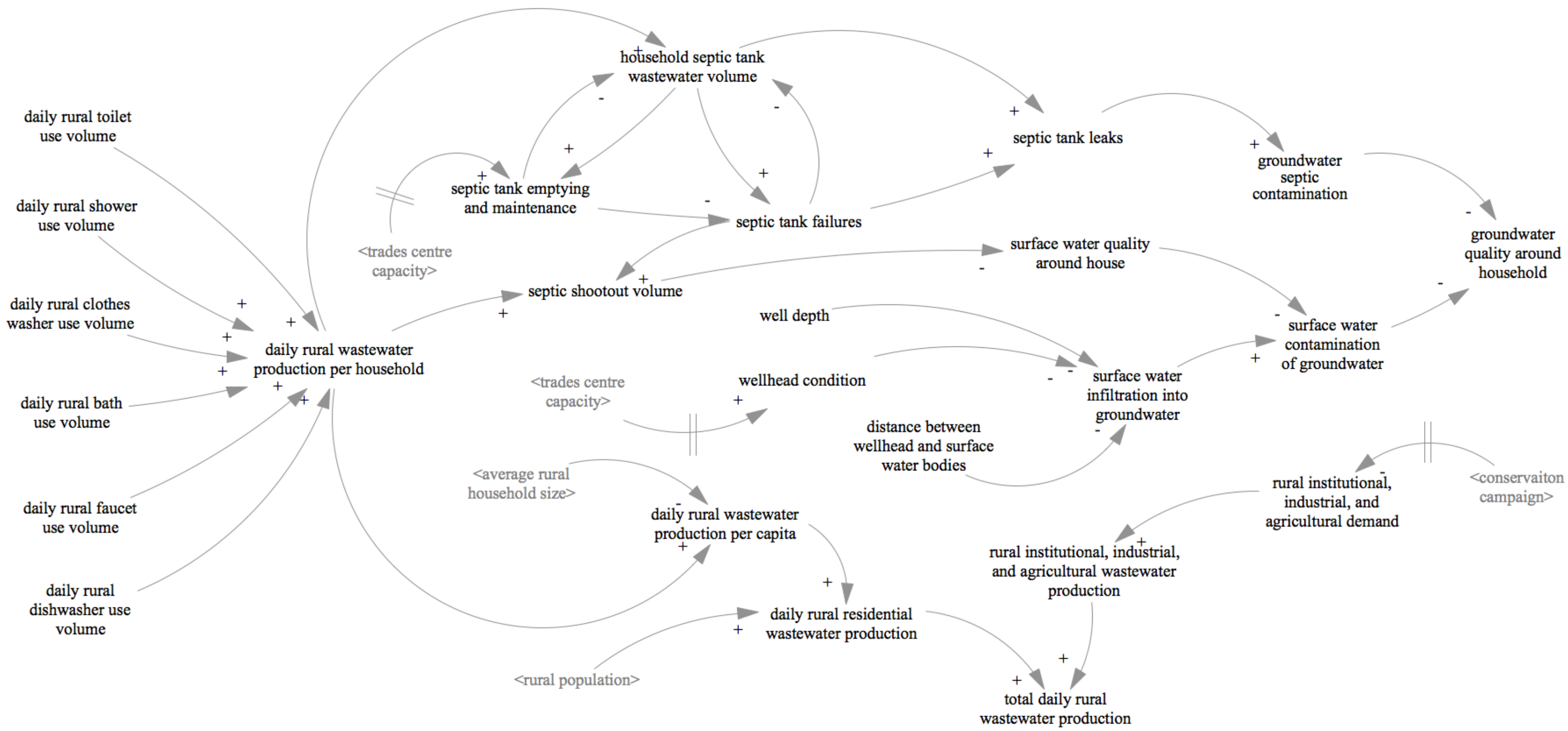

Figure 5.6 Causal loop diagram of rural wastewater production subsystem with parts of rural water contamination and rural household maintenance subsystems

The rural and municipal housing and demographics subsystems share similar structures. First, the population of both the municipal and rural systems is affected by deaths, births, emigration, and immigration. An increase in population increases the average household size. As household size increases, the available housing decreases, which decreases immigration and increases emigration. A decrease in available housing also increases demand for housing, eventually increasing housing construction and the number of houses—and households—on each system. An increase in the number of households increases available housing, decreases average household size, and decreases the average house age (since increasing the number of houses means building new, "younger" houses). Average household size positively affects the domestic water end use frequencies—more residents use more water—and the wear on domestic fixtures in the house.

Again, the rural and municipal leaks subsystems share much the same structure. Average household size and average house age both mean increased wear on domestic fixtures. Further, an increase in average house age also suggests increased wear on domestic pipes or pipes that are located in the house. Wear on domestic water using fixtures and on pipes inside the home both increase domestic leaks. Leaks are mitigated through household maintenance, which decreases wear on domestic fixtures and pipes through repairs. In this model, the Samson Cree Nation Trades Centre provides household maintenance.

The maintenance subsystem consists largely of the Trades Centre's activities. First, as the Trades Centre's capacity increases, household maintenance increases. This decreases leaks, as discussed above, but also decreases the likelihood that water quality deteriorates as it flows through pipes in the house. For example, while visiting homes and installing water meters with Cameron Saddleback, a plumber and contractor from Samson, he pointed out consistent maintenance problems with filters, softeners, pressure tanks, and hot water heaters which could be impacting water quality at the tap.

In the rural system, tap water quality is tested by Maskwacîs Health Services. When rural tap water quality decreases, the percentage of households under boil water advisory increases, which increases the need to shock-chlorinate wells. The shock chlorination rate of wells depends on the Trades Centre capacity to shock-chlorinate. Shock chlorination initially improves rural tap water quality and requires further Maskwacîs Health Services testing to remove a boil water advisory. Successful shock chlorinations result in fewer households under boil water advisories. The municipal system can also be placed under boil water advisory, but water quality is tested at the treatment plant and a boil water advisory would affect all households on the municipal system. Figure 5.7 shows the rural housing and demographics subsystem along with parts of the rural condition of water and wastewater infrastructure, water contamination, water quality, and housing maintenance subsystems. The municipal subsystems are similar in structure except that there is neither testing of municipal tap water quality nor subsequent shock chlorination.

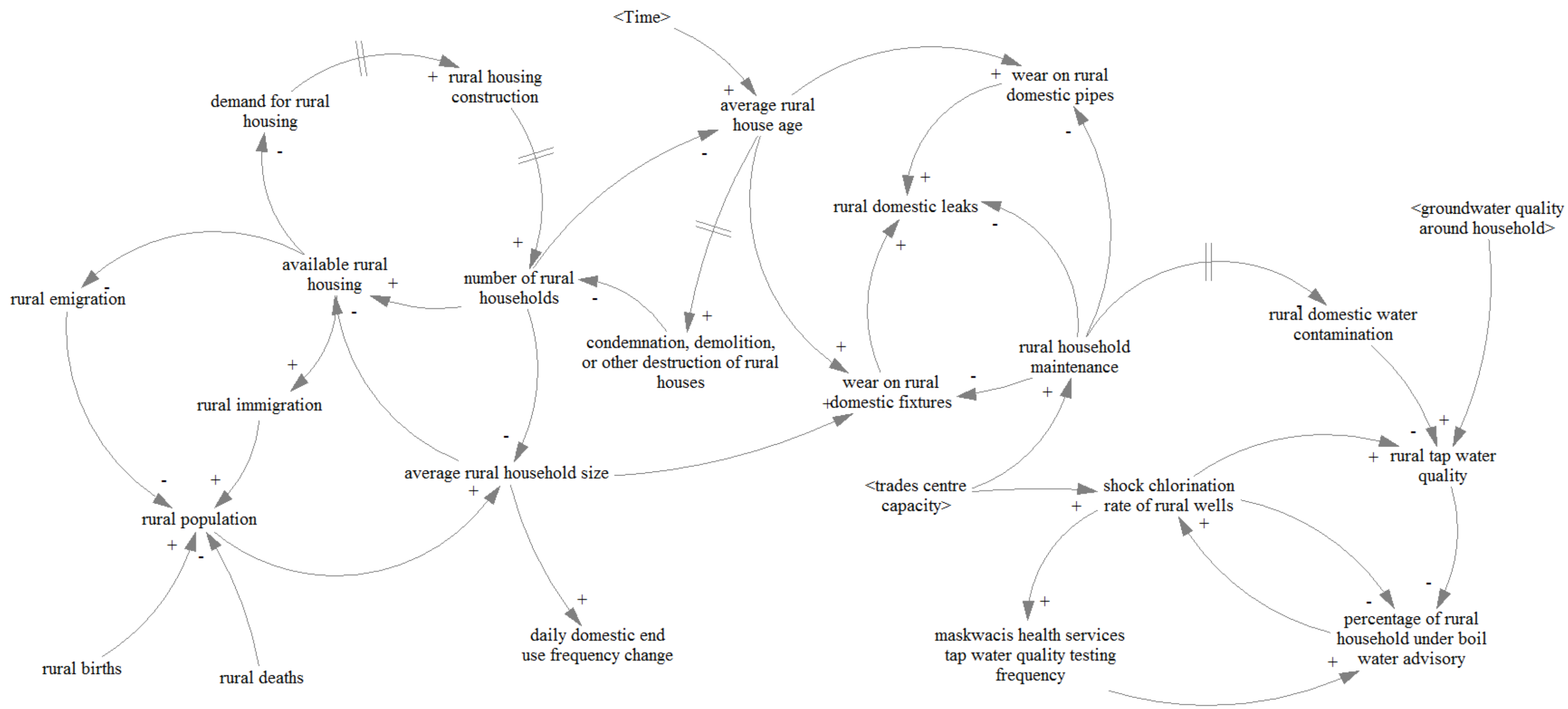

Figure 5.7 Causal loop diagram of rural housing and demographics subsystem with parts of rural condition of water and wastewater infrastructure, water contamination, water quality, and housing maintenance subsystems

In Figure 5.7 and the other subsystems I described, the Trades Centre is responsible for household maintenance and repairs through the “trades centre capacity” variable. However, in these figures I only show it as a shadow variable; its inputs are shown in the maintenance subsystem. Central to the maintenance subsystem are maintenance/repair calls to the Trades Centre. The number of repair calls increases when households report leaks or septic tank problems, and also increases with the number of households; more calls to the Trades Centre decreases their capacity to respond to calls. An increased Trades Centre capacity increases their expenditures, since they can respond to more calls and conduct more maintenance and repair work. Increasing Trades Centre expenditures then decreases the Trades Centre’s available funds. A decrease in the Trades Centre’s funds then decreases their capacity.

The interventions I created also affect this subsystem. The hypothetical household water conservation campaign would also increase leak detection and reporting which would further increase calls to the Trades Centre. The hypothetical water utility that charges households for water and wastewater servicing provides additional funds to the Trades Centre from charging for water use. Figure 5.8 shows the maintenance subsystem.

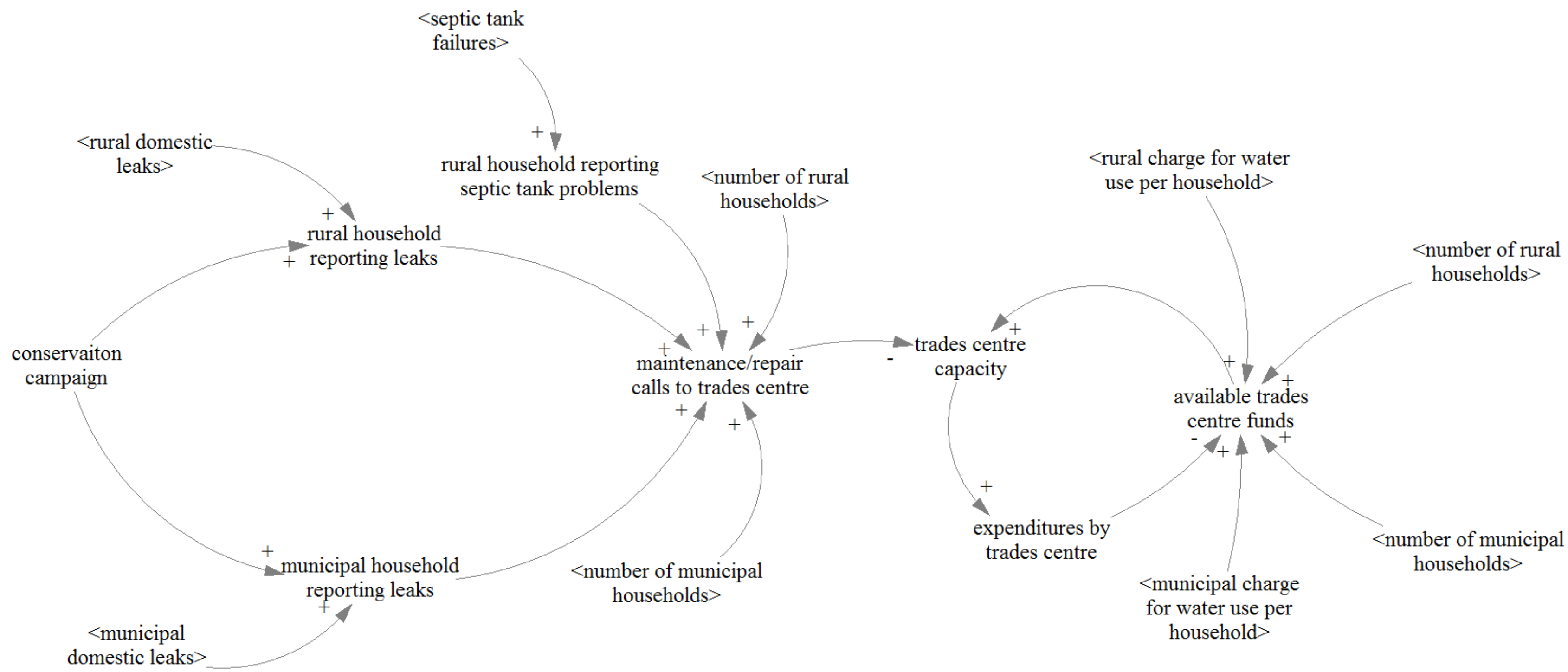

Figure 5.8 Causal loop diagram of maintenance subsystem

5.3.2 Building a stock and flow diagram of Samson Cree Nation's water systems

I can adapt the causal loop diagrams introduced above and their structures into stock and flow diagrams. The value of a stock and flow diagram is that it shows material flows and distinguishes between physical and informational details. In a stock and flow diagram, stocks are variables with memory. They can increase or decrease in value over time as a result of their inflows and outflows, and are affected also by their value in previous time steps. The variables I selected as stocks are summarized in Table 5.2.

Table 5.2 Stock variables in the stock flow diagram of Samson Cree Nation's water systems

SUBSYSTEM	STOCK VARIABLES
Rural domestic water use	Daily rural bathing frequency Daily rural clothes-washing frequency Daily rural dishwasher use frequency Daily rural household toilet flushing frequency Daily rural minutes of faucet use per household Daily rural outdoor use volume Daily rural showering minutes per household Percentage of rural households with dishwasher Percentage of rural households with low-flow showerheads Percentage of rural households with low-flow toilets Percentage of rural households with water-efficient clothes washers
Municipal domestic water use	Daily municipal bathing frequency Daily municipal clothes-washing frequency Daily municipal dishwasher use frequency Daily municipal household toilet flushing frequency Daily municipal minutes of faucet use per household Daily municipal outdoor use volume Daily municipal showering minutes per household Percentage of municipal households with dishwasher Percentage of municipal households with low-flow showerheads Percentage of municipal households with low-flow toilets Percentage of municipal households with water-efficient clothes washers
Rural domestic wastewater production	Average septic tank wastewater volume
Municipal domestic wastewater production	Lagoon 1 wastewater volume Lagoon 2 wastewater volume
Rural housing and de-	Number of rural households

mographics	Rural population
Municipal housing and demographics	Municipal population Number of municipal households
Rural condition of water and wastewater infrastructure	Rural domestic plumbing condition Rural domestic fixture and appliance condition Septic tank condition Well condition
Municipal condition of water and wastewater infrastructure	Municipal distribution system condition Municipal domestic fixture and appliance condition Municipal domestic plumbing condition
Water quality	Aquifer water quality
Infrastructure and household maintenance	Available Trades Centre funds

In addition to the stocks and flows, the other variables in the stock and flow diagram are recalculated at each time step or represent constants. Figures 5.9 through 5.17 show the stock and flow diagrams for the entire model. Since the structure and the relationships between variables follow the same arguments as the causal loop diagrams above, I do not provide explanations of each stock and flow diagram. I do, however, discuss some of the diagram's weaknesses.

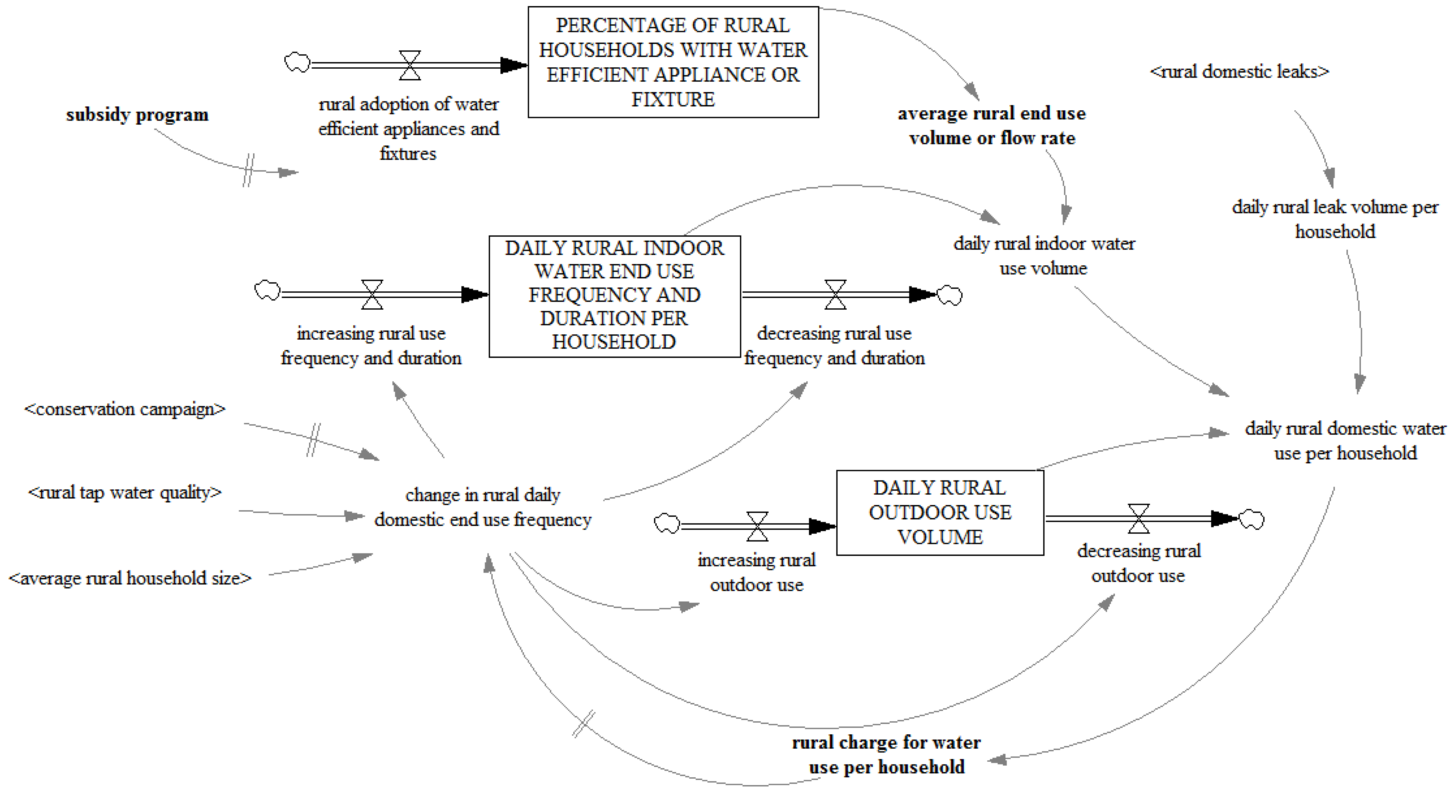

Figure 5.9 Stock and flow diagram of rural domestic water use subsystem. Bolded stocks and variables signify their use as a shadow variable in another view.

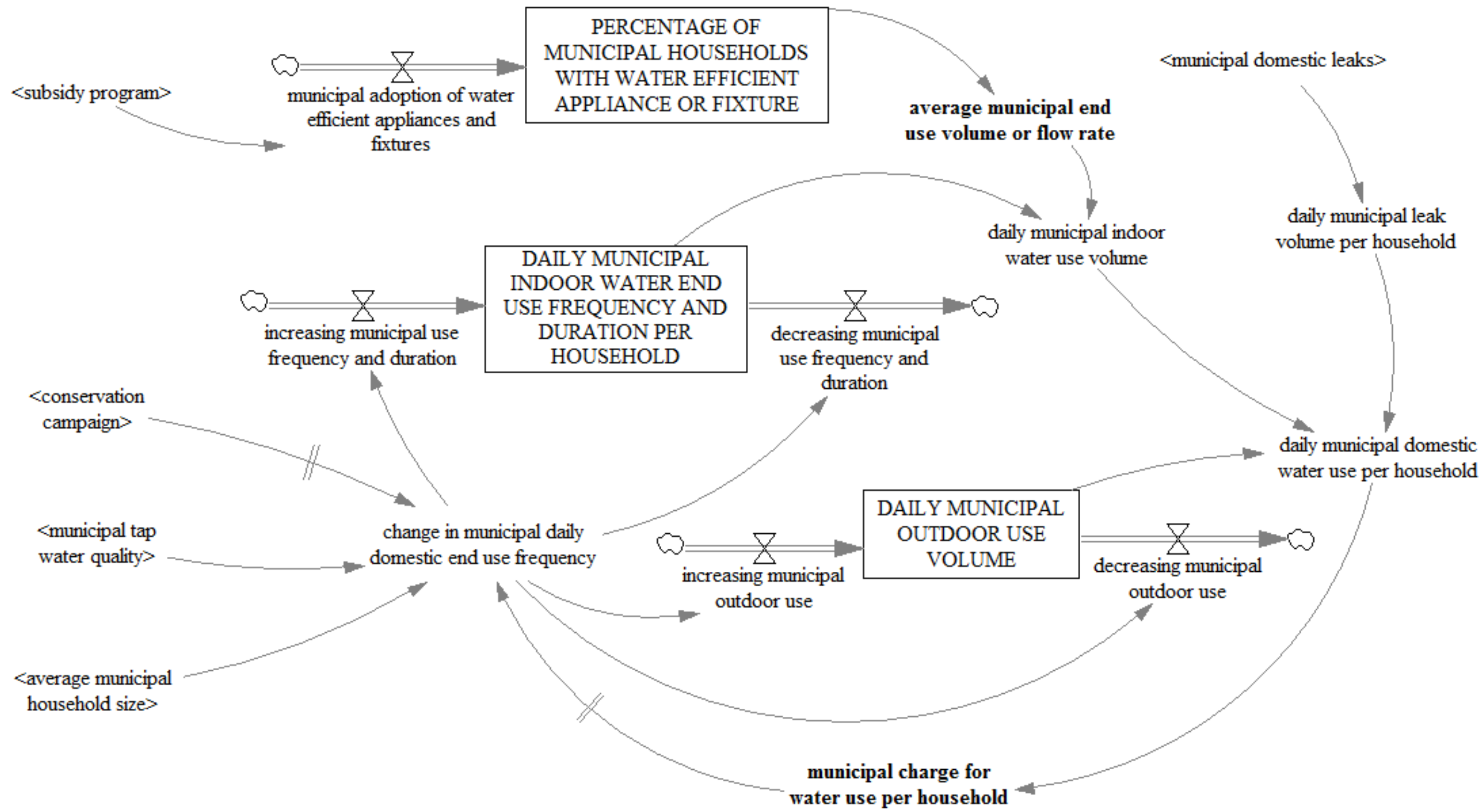

Figure 5.10 Stock and flow diagram of municipal domestic water use subsystem

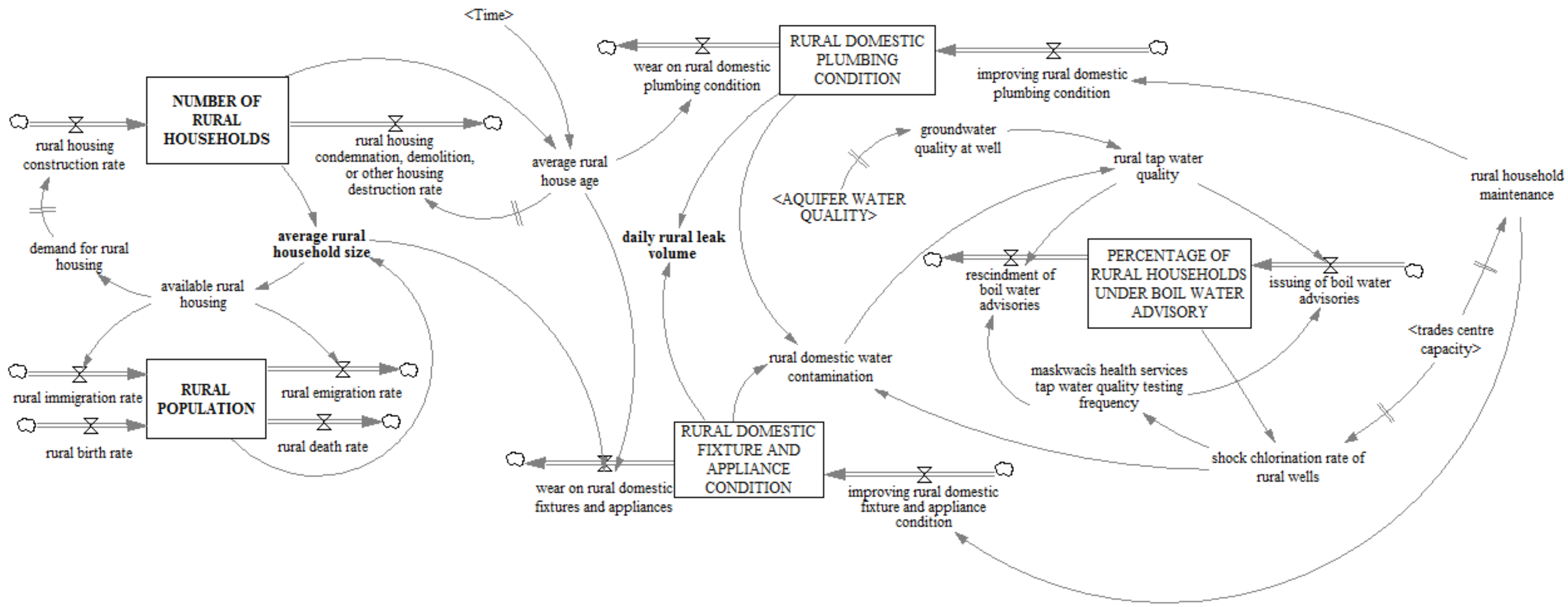

Figure 5.11 Stock and flow diagram of rural housing and demographics subsystem, with parts of rural condition of water and wastewater infrastructure, water contamination, and water quality subsystems

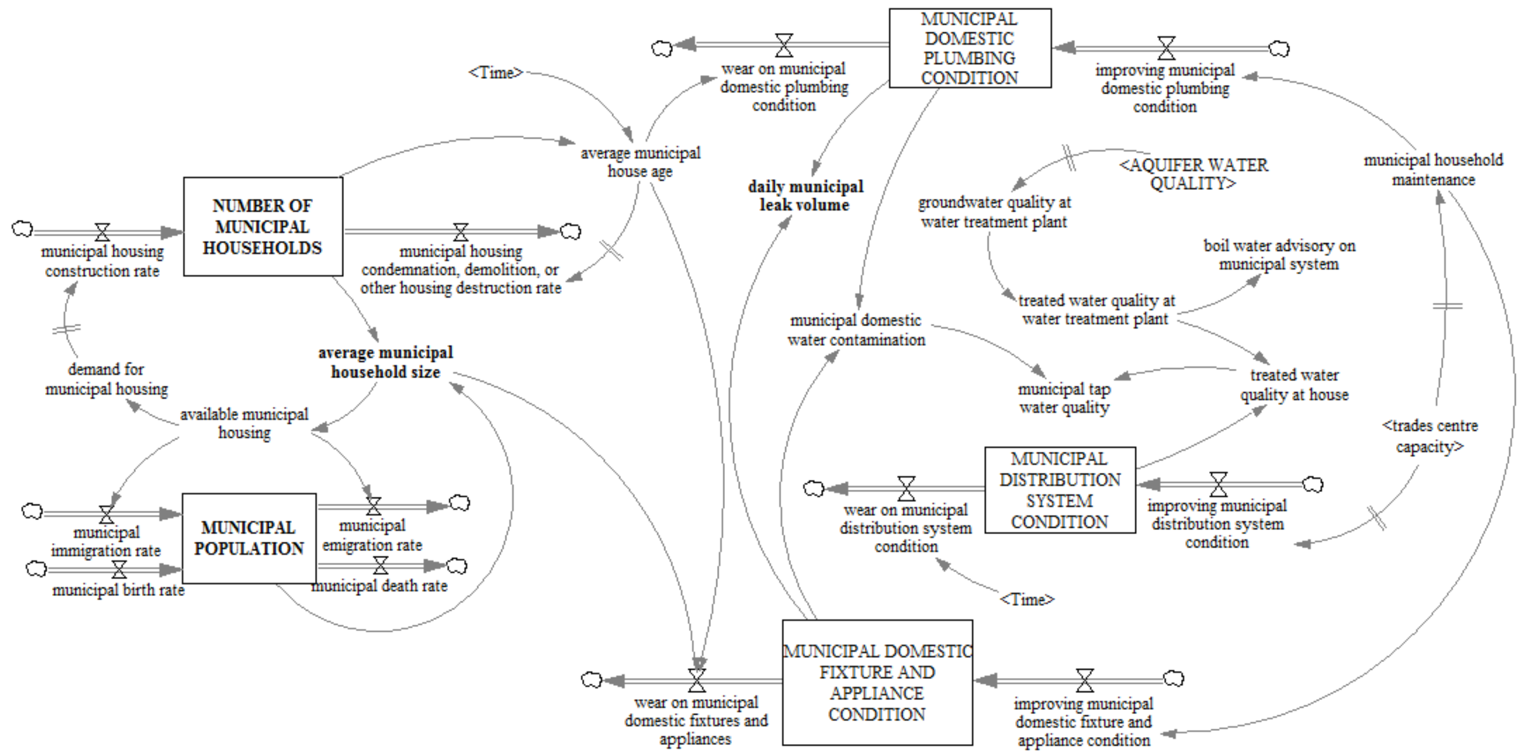

Figure 5.12 Stock and flow diagram of municipal housing and demographics subsystem, with parts of municipal conditions of water and wastewater infrastructure and water quality subsystems

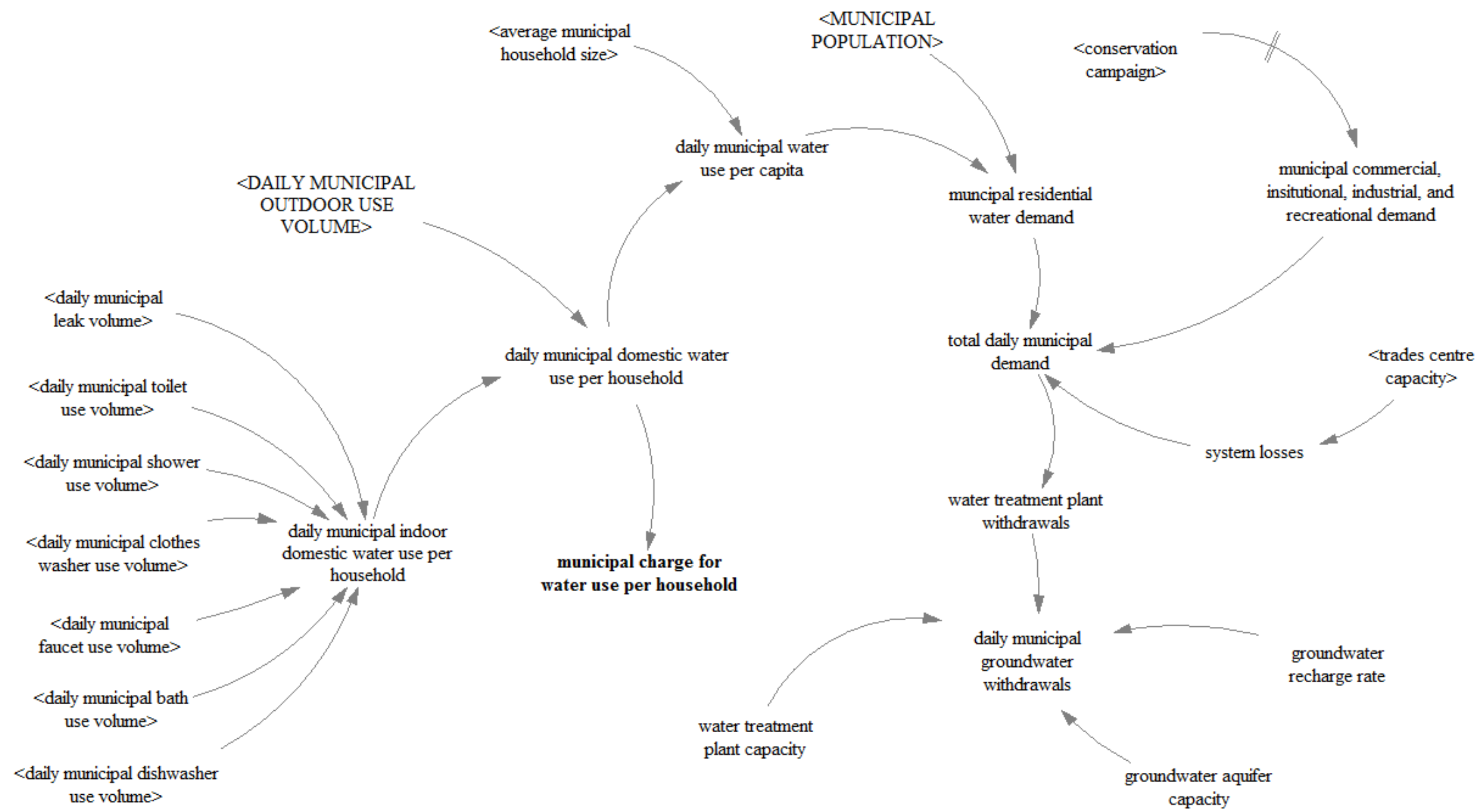

Figure 5.13 Stock and flow diagram of municipal water demand

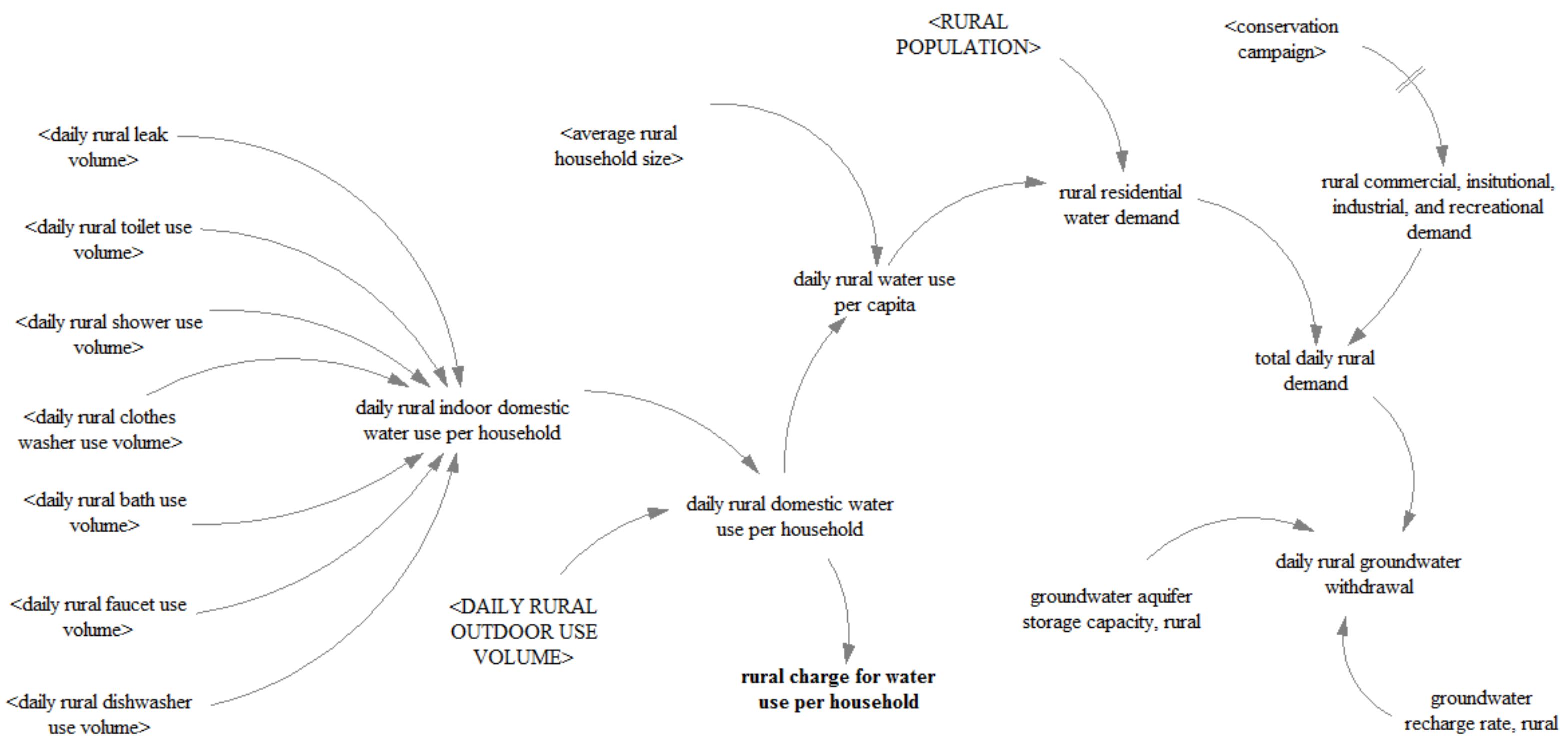

Figure 5.14 Stock and flow diagram of rural water demand

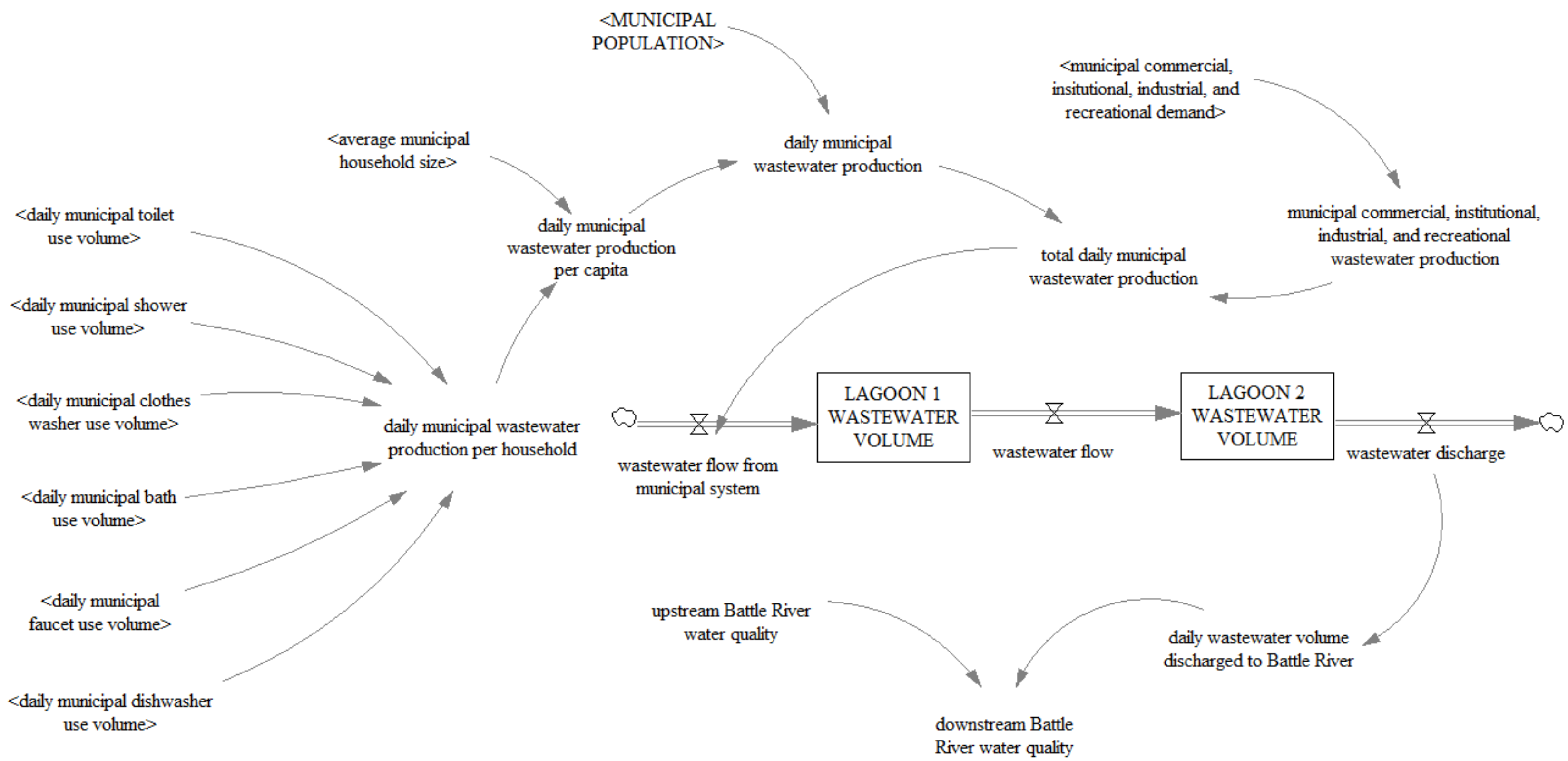

Figure 5.15 Stock and flow diagram of municipal wastewater production subsystem

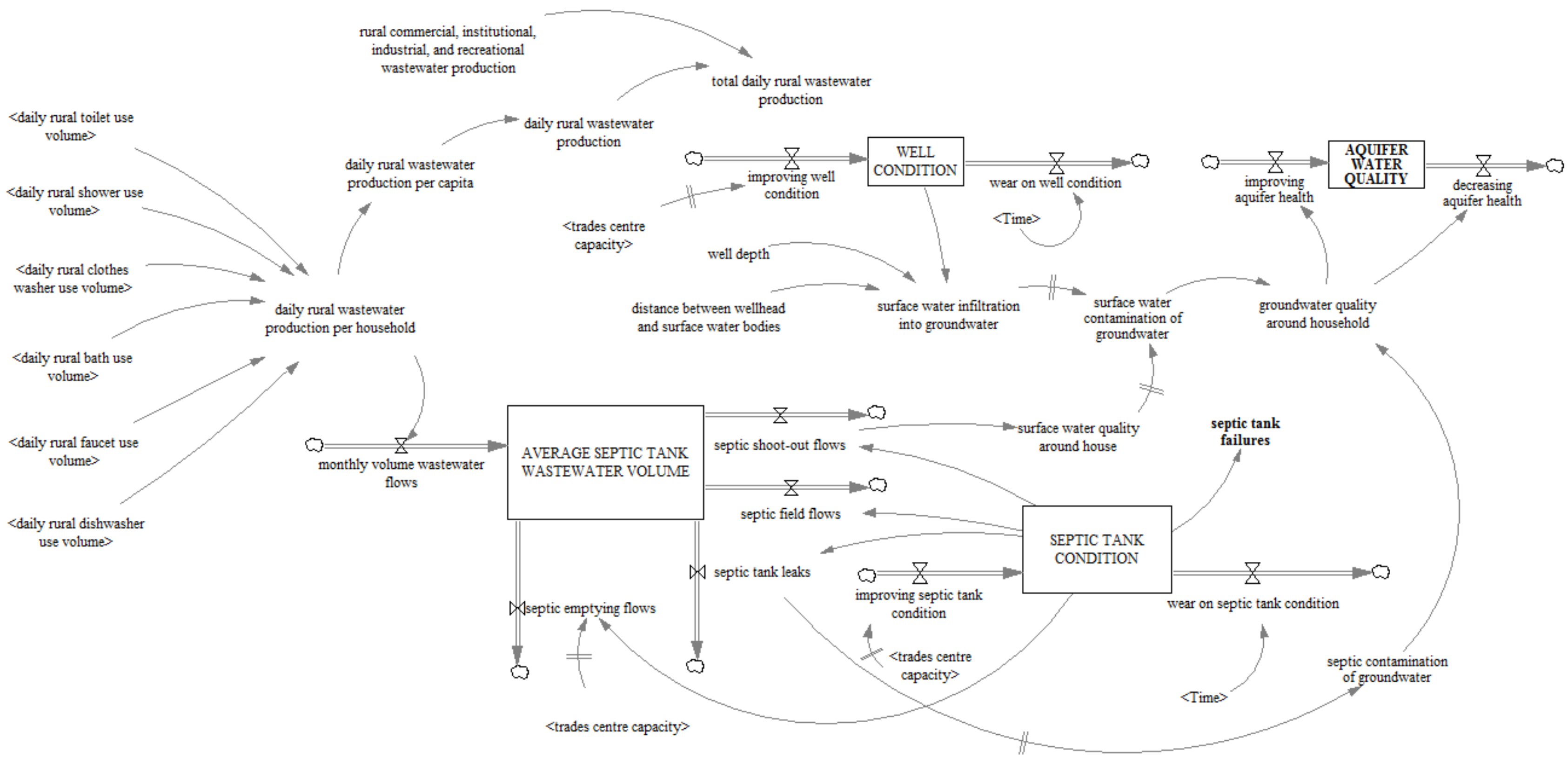

Figure 5.16 Stock and flow diagram of rural wastewater production, with parts of rural conditions of water and wastewater infrastructure, water contamination, and water quality subsystems

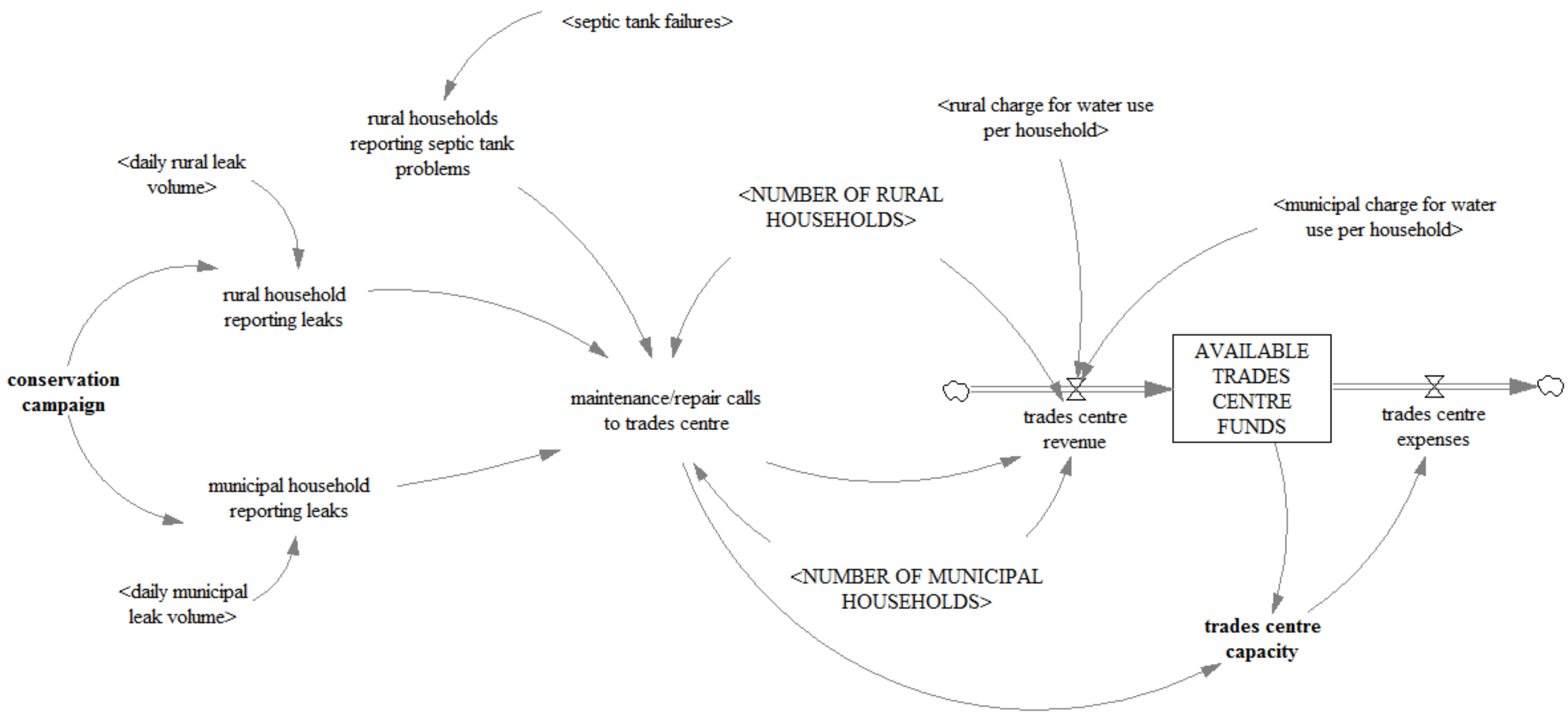

Figure 5.17 Stock and flow diagram of maintenance subsystem

5.4 Discussion of causal loop and stock and flow diagrams of Samson Cree Nation's water systems

The system dynamics structures created to represent Samson Cree Nation's water systems above address the scope and scale as I understood them. The first, Figure 5.2, is purely rhetorical. By spending time in Samson Cree Nation, interviewing residents, and working with Chief and Council, I realized that the political climate around the water systems is very significant. The diagram is my attempt to describe the contemporary reality of water and wastewater servicing in Samson Cree Nation—some of which is applicable to other First Nations—and the implications, both intentional and unintentional, of the current approach to water funding, legislation, and engineering. This structure cannot be quantified, tested, or calibrated easily, or verified, but I believe it has merit in demonstrating the complexity of the current system and problems that arise unintentionally.

The causal loop diagrams I described in detail—representing the actual water systems (rural and municipal)—and the resultant stock and flow diagrams however, are designed for modeling purposes. While I have not entered data into the model or run any simulations due to time constraints, there are some structural limitations I would like to identify. Since the causal loop diagram and the stock and flow diagram share essentially the same structure, this critique applies to both. The major limitations are:

1. The water quality feedback loop is based primarily on anecdotal information about the source of water contamination and how it affects water use behaviour.
2. The hypothetical water utility is linked directly to the Trades Centre.
3. Groundwater and aquifer water quality are grossly simplified.
4. Geography and the distribution of houses are not considered.
5. The structure relies on "averages" of households.
6. The interventions—the conservation campaign, the water utility, and the subsidy program—have no specific structure or target.
7. Climate does not play a role in the structure.
8. Water quality perceptions are omitted.

One of the feedback loops in this structure shows septic water as somehow contaminating groundwater. I provide several possible mechanisms—septic shootouts that contaminate surface water, wells in poor condition that allow surface water to infiltrate to groundwater, septic tanks or septic field flows that infiltrate to groundwater—but none of these pathways has been verified with water testing. Mah (2014) concluded that newer, deeper wells were less likely to show historical contamination in Samson Cree Nation. Shallower wells were more likely to show signs from surface water infiltration and bacteriological contamination (Mah, 2014). These results suggest that surface water and well condition could be playing roles in drinking well water contamination in Samson Cree Nation but they do not confirm the pathways for contamination.

Further, septic contamination related mostly to the presence of *E. coli* and total coliforms in well water (the parameters tested by Maskwacîs

Health Services) whereas the water quality characteristics that concerned most residents were organoleptics (taste, colour, smell). I explained in chapter four that residents may change their domestic water use behaviours in response to the implementation of a boil water advisory. If they do, this behaviour change is being practiced by all residents on the rural system since, on average, households under boil water advisory and households not under boil water advisory use the same amount of water—see chapter four. So, well water contamination due to septic flows and the resulting boil water advisories could be causing rural residents to generally reduce their exposure to water and consume less water. This argument, however, does not address other contaminants that can cause an immediate response in water use like iron, sulfur, organoleptics, and sediments. While these chemicals could enter drinking water systems through poor well conditions, poor infrastructure condition, or poor plumbing conditions, I imagine they affect behaviour in a fundamentally different way than *E. coli* or total coliform bacteria. A stronger model would more specifically separate water quality parameters and their potential effects on water use.

In creating a water utility in Samson Cree Nation, I linked its operation directly to the Trades Centre. While this connection might make sense if the water utility is created as a source of revenue for infrastructure upgrades and maintenance, I may have neglected other potential administrative components. The model relies on a feedback loop that represents the dependence of the Trades Centre on operating funds that are partially generated by the utility. Further, I did not discuss a pay structure. A flat rate would not be successful in reducing water use, while a pay-per-use approach would unfairly charge customers who have unrepaired leaks. A calibrated model could indicate the best utility structure for Samson Cree Nation but implementing it would require deliberate action. This could also be modeled but would require further research into utility structures.

Groundwater mapping is very complicated. I reduced the groundwater sources in Samson Cree Nation simply to “Aquifer Water Quality”. This stock affects the water quality of both the municipal and rural systems although its contamination by wastewater only occurs from the rural system. We have no evidence to suggest that the municipal system is affected by rural wastewater. However, by virtue of proximity, it is likely that both systems are connected to the same source and thus share the same water quality. The direction and speed of flow between the two systems is not considered. A more accurate representation would include aquifer depth as a variable affecting water quality along with flow and recharge rates. Including these variables would also help in assessing the long-term health of Samson Cree Nation’s groundwater supply.

System dynamics models cannot simulate the effect of neighbours on behaviour nor the agency of individuals acting autonomously, unlike agent-based modeling (House-Peters and Chang, 2011). They can, however, accommodate “cohorts”, which could be used to group households geographically, by well depth, by water quality, or a host of other factors. Similar to how water users were divided by water system—rural versus municipal—they could be further grouped to reflect households’ unique behaviours more accurately. Creating more household cohorts with unique characteristics would represent reality more accurately and would allow for new investigation into how neighbouring house proximity may contribute to water quality or even the perception of water quality.

On the subject of housing cohorts, a major limitation of this structure is the process of "averaging" household behaviour or data. For example, how do a few instances of poor water quality in some homes contribute to the numerical measurement of "rural tap water quality"? How specifically does a decrease in water quality increase the percentage of households under boil water advisory? Programming this model with numerical values would require addressing this limitation. Again, using cohorts could provide a workable structure, grouping households by water quality: poor water quality, variable water quality, and good water quality.

There are three interventions in this model: a water conservation campaign, a water utility, and a subsidy program. I did not quantify any of these interventions and, thus, their characteristics remain vague. In the model development phase, it is necessary to define the functions of these concepts explicitly. Further, a functioning system dynamics model would help to develop their specifics and to select the most effective policies.

In chapter four I did not identify any seasonal variations in water use or relationships between water use and climatic data. There are two aspects of seasonal variation that are relevant. First, outdoor use is a seasonal behaviour, albeit an uncommon one in Samson Cree Nation. Even though outdoor use is low, an accurate model would have outdoor use vary seasonally—zero outdoor use during the winter, and some outdoor water use during the other seasons. Second, Mah (2014) found a lag phase between peaks in rainfall and peaks in positive test results for *E. coli* and total coliform contamination. This impact of climate on water quality should be included in the system dynamics model.

Finally, despite the fact that I discussed the perception of water quality thoroughly in chapter four, I have not explicitly included it in this model. The issuing of boil water advisories in the model is connected to the perception of rural water quality, but it would be worthwhile to treat perception and its effects separately from an objective assessment of water quality.

5.5 Conclusions

Water quantity and quality in Samson Cree Nation make up parts of a complex system, both politically and technically. The message of the need for safe, reliable drinking water on-reserve is seemingly lost amid confounding factors. In my time studying and reflecting on the water systems in Samson Cree Nation, one solution is immediately evident: enabling community-driven, community-based management. Regulations, protocols, and standards prescribed at a distance cannot account for the community-specific context. Unless a great deal of trust exists between the parties involved, the action at a distance solutions of the Federal Government will yield little success and be met with great resistance. Further, the dispersed rural water system in Samson Cree Nation can only benefit from residents' engagement in and ownership over their water source. The restrictions imposed on First Nations—without the adequate resources to address problems like water quality—not only make community-focused solutions impossible, but doom other "solutions" to failure.

This conclusion is not unique among system dynamics modelers. Winz et al., (2009, pg. 1317) concluded that:

> Prospects for success are maximized when the group itself constrains the definition of the problems to be addressed, and participatory procedures are applied in scoping, development and testing of the model. Involvement underpins ownership, providing the platform for management applications that are not only responsive to group concerns, but also have greater prospects for effective implementation and uptake.

This study is limited in a few key ways:

1. The system dynamics mental models have not been programmed with mathematical equations, calibrated with data, or used to run any simulations.
2. The model structure was informed by community members but has not been verified or adapted by them, or by government ministries like AANDC.
3. Some of the necessary feedback loops in the structure have weak evidence to support their effects.

To address these limitations, I recommend:

- Producing a numerical simulation model and calibrating it. Running simulations of future water use scenarios. Using these simulations to develop the structures of the water conservation campaign, the water utility, and the subsidy program. Once the structures are determined, the best way of combining the interventions for maximum water savings can be analyzed.
- Creating a forum to discuss the model with community members, Band leadership, and government agencies. Allow residents and other stakeholders to recommend changes to the model and to interact with the model to understand how it functions. This sort of "participatory modelling" could be done in conjunction with the conservation campaign as part of its rollout, if Samson Cree Nation pursued such a strategy.
- Collecting more data on model variables to provide evidence for the model structure and to improve calibration and validation of the model. More information about periphery variables would also improve the model's structure and behaviour.

Fortunately, group decisions take time so there is plenty of opportunity to improve this model and apply it as a decision-support tool for residents and leadership in Samson Cree Nation. The water issues Samson Cree Nation is currently facing will not be resolved by individuals. How to proceed in this area is ultimately up to the community since they will be living with the consequences. For those who seek to improve the situation, we must remember that the community ultimately holds the power.

CHAPTER SIX

Domestic water use in Samson Cree Nation: Results discussion and conclusions

6.1 Research life

When I reflect on how much my perspective has changed since I started graduate school, or since I spent my first night in Samson, or since I spent my last night in Samson even, it always feels significant. And while this project has fundamentally affected the way I view my research and my role as a researcher, it has equally impacted my life outside of this project. Initially, it took quite a bit of effort and energy to first actually *listen* to perspectives very different from my own and then try to understand them—there are a lot of "alternative" histories and contexts to reconcile. But my outlook is no longer deliberately attempting to reconcile my previous understanding of the world or that of dominant society with the perspectives of some people in this community. Now, it seems, that instead of making an effort to think in a certain way or deliberately adopting a different perspective for analysis, my approach is inherently informed by everyone I have met through this research. And these people are not limited to those I interviewed: casual conversations with folks in Samson Cree Nation or in the faculty of Native Studies have been eye-opening as have those with other researchers and engineers. As important as it is for me to push myself and my thinking, I must also try to be aware of the barriers that make cross-cultural understanding in what we now call Canada so seemingly difficult. Of course, a community-based approach provides some assistance.

In this chapter, I summarize the key results of the previous chapters and provide questions for further research.

In chapter two, "Just add water: Engineering, Indigenous, and community-based research methodologies in Samson Cree Nation", I outlined a theoretical framework for community-based research. Community-based research meets five criteria:

6. Research must have a perceived benefit to the community;
7. Research is either initiated by the researcher, the community, or both together;
8. Research concerns a defined community;
9. Research involves some level of community participation like training or interviews; and,
10. Research serves a socially relevant goal.

I propose a community-based research methodology in engineering as an appropriate way to conduct research that is anti-oppressive while still meeting western scientific academic standards. Certainly these are not the only guidelines available for conducting "community-based research", we simply offer it as one methodology that we followed. But consider this an invitation to critique, improve, and employ what we have discussed. For community researchers and collaborators (scholarly or otherwise), it opens new ways of thinking and more opportunity for collaboration. Much of what we learned came from applying this methodology rather than the stricter, formal methodology of data collection. This is to say that it improved the research and the research findings dramatically by emphasizing context and those affected by the research over "objective" measurements. For communities—Indigenous or otherwise—it provides a mechanism to inform, deeply, community outsiders about what you want and what is at stake.

Relationships should be central to research that involves communities or people in general. Using an approach like the one I described encourages more interaction between researchers and community members, improving the research products and holding the researchers accountable to community members and community goals.

In chapter three, "Domestic water consumption in Samson Cree Nation: Water metering program, resident interviews, water use patterns, and residential end purposes", I outlined the scientific methodology for data collection that we used in this research and provided some general characteristics of Samson Cree Nations water systems and water users.

We installed water meters in 28 volunteer homes in Samson Cree Nation and measured hourly household water consumption from July 2013 through July 2014. I interviewed household residents about water use and we collected and tested tap water samples at some of the households. The average domestic water use in Samson Cree Nation is 221 Lpcd. Average water use in Samson Cree Nation is different between residents serviced by the rural water system and residents serviced by the municipal water system. Municipal residents use on average 283 Lpcd. Rural residents use 31% less water, averaging 195 Lpcd. Ultimately these values have more in common with regional transferability of lifestyle from the surrounding communities—i.e. which water-using appliances are used in households—than they do with any other evident cultural factor.

Samson Cree Nation has some unique characteristics when it comes to water use. The daily water use pattern for metered homes in Samson Cree Nation has fewer obvious peaks than that of other (municipal) communities. This could be evidence of significantly different lifestyles from dominant Canadian society even though water-use volumes are similar. The average daily domestic water use in Samson Cree Nation is much higher for the month of December than for any other. This is mostly a result of the Christmas season when people are off work or school for weeks at a time and family and friends visit. Outdoor water use in Samson Cree Nation is notably lower than other communities, averaging 3.3 Lpcd. Dishwashers and water efficient appliances and fixtures are also rare in Samson Cree Nation.

The water meters detected intermittent leaks in every metered household and continuous leaks in 57% of metered households. Evidently, water could be easily saved in Samson Cree Nation by improving household-level plumbing maintenance and repair.

To improve the results in chapter three, I recommended

- completing interviews with all metered households in Samson Cree Nation;
- collecting water-use data at 10 second intervals and using flow trace analysis to disaggregate the results;
- continuing the water metering program in Samson Cree Nation to increase the sample size and improve the accuracy of the data. Water demand on the municipal system could also be verified my measuring flows at the water treatment plant;
- expanding the study to include commercial, industrial, recreational, and institutional water use; and,

- using the tamper detection features of the water meters to ensure the battery does not disconnect from the water meter.

In chapter four, “Factors that affect domestic water consumption in Samson Cree Nation: Water source, household demographics, and perception of drinking water health risk”, I use water meter, water quality, and interview data from chapter three to determine the drivers of domestic water use in Samson Cree Nation. Household water meter data reflects routine household behaviours. I investigated a number of variables’ effects on domestic water use and found that water consumption can depend on:

- water system (rural or municipal)—municipal residents use more water on average than rural residents;
- drinking water source (tap water or bottled water)—tap water drinkers have higher metered water use on average than those who say they drink bottled water;
- household size (large or small)—larger households use more water but typically residents of larger households have lower per capita water use;
- household occupancy during the day (percentage of residents away from the homes during the day)—households with the majority of residents at home during a typical weekday use more water;
- resident reported leakage—residents who reported leaks in their home use more water on average than those who did not;
- water meter detected leakage—households where water meters detected continuous leaks use more water on average;
- clothes washer use frequency—households that report using the clothes washer more than ten times a week use more water on average; and,
- maybe some water quality parameters (iron)—there is a weak correlation between increasing iron concentration in tap water and household residents using less water.

The best explanation for the difference in water consumption between rural and municipal residents is the perception of water quality: the rural water system is largely distrusted and rural residents use less water than municipal residents. This could also explain the significant difference in water consumption between household that drink bottled water and households that drink tap water: a reaction to water quality, both perceived or measurable, impacts water consumption. Certainly the anecdotal data point to this conclusion.

The most significant demographic features that drive domestic water use in Samson Cree Nation are household size and household daytime occupancy. Larger households use more water but a household size of five residents has the lowest per capita water consumption. Households with the majority of residents away from the home during the day use less water and also demonstrate a discernably distinct diurnal water use pattern.

Domestic water use in Samson Cree Nation, based on end purposes, is most significantly impacted by household leakage and clothes washer use frequency. Residents connect clothes washer use with water quality:

many people have shared that the water stains their laundry. Perhaps this explains a decrease in water use with increasing iron concentrations.

To improve the results in chapter four, I recommended:

- referring to the first three recommendations for chapter three regarding completing interviews, collecting data at smaller time intervals, and continuing the water metering program;
- determining average leak volumes from the water meters by analyzing overnight water consumption; and,
- measuring water pressure at rural household and investigating its effect on domestic water use.

In chapter five, “Domestic water use and forecasts in Samson Cree Nation: A system dynamics approach”, I described the design of two causal loop diagrams and one stock flow diagram that represent the water systems in Samson Cree Nation using a systems thinking approach. I use the first causal loop diagram to argue that Aboriginal Affairs and Northern Development Canada’s approach to improving water and wastewater systems on First Nations reserves has many unintended consequences that exacerbate the problem. The second causal loop diagram describes domestic water use in Samson Cree Nation, influenced by my findings from chapter four. Domestic water use in this diagram is affected by the water system (rural versus municipal), household size, water quality, and the conditions of water and wastewater infrastructure. I also introduced policy interventions—a water conservation campaign, a water utility, and a water efficient appliance subsidy program—to improve the water systems and show where they would interact with the current structure of Samson Cree Nation’s water systems. Last, the stock flow diagram of Samson Cree Nation’s domestic water systems reflects the structure of the causal loop diagram but allows for numerical analysis and simulation.

Although I have not tested the model, I draw some important conclusions: namely, the importance of community-based decision making. Regulations, protocols, and standards prescribed at a distance cannot account for the community-specific context. Further, the dispersed rural water system in Samson Cree Nation can only benefit from residents’ engagement in and ownership over their water source. The restrictions imposed on First Nations—without the adequate resources to address problems like water quality—not only makes community-focused solutions impossible, but dooms other “solutions” to failure.

To improve the results of chapter five, I recommended:

- inputting data into the model and calibrating it. Run simulations of future water use scenarios. Use these simulations to develop the structures of the water conservation campaign, the water utility, and the subsidy program. Once the structures are determined, the best way of combining the interventions for maximum water savings can be analyzed;
- creating a forum to discuss the model with community members and Band leadership. Allow residents to recommend changes to the model and to interact with the model to understand how it functions. This could be done in conjunction with the conserva-

tion campaign as part of its rollout, if Samson Cree Nation pursued such a strategy; and,

- collecting more data on model variables to provide evidence for the model structure and to improve calibration and validation of the model. More information about periphery variables would also improve the model's structure and behaviour.

6.2 Moving forward

Addressing the recommendations for improving this research, a clear benefit would be to continue collecting data from households in Samson Cree Nation and to expand the study to other water users: commercial, industrial, institutional, and recreational. This expanded data collection will ensure that Samson Cree Nation has the necessary measurements to secure adequate water supply for its people. This includes completing interviews with metered households and continuing to interview residents about water in general. Further, Samson Cree Nation could invest in flow trace analysis water meters and software to get more accurate data on residential end uses of water. Collecting measured data on specific end use frequencies will help evaluate how targeted a water efficient appliance subsidy program would need to be and how effective it can be.

Continuing to interview and involve residents in further water research is also extremely important. The system dynamics model requires calibration and Samson Cree Nation leadership and residents can be involved in this process. Appropriately calibrating this model with more accurate data and input from those who participate in the water systems, can make the model a useful decision support tool for Samson Cree Nation. Not only can the model assess the short-term and long-term impact of water policies or other changes to the system, it can help connect water users to their water source and encourage them to think about how they use water. This would no doubt help the Nation implement any of the changes they find necessary, be it a water conservation campaign, a water utility, a subsidy program, or any other policies of their choosing. A model like this, focused on rural water systems with uncertain water quality will not only be useful for Samson Cree Nation, but could have transferability to other Indigenous or rural communities with rural water systems.

More specifically, to address the imminent water treatment plant capacity concerns, implementing a water conservation campaign for municipal users could extend the design life beyond the year 2015. I would like to work with Samson Cree Nation leadership and members in developing a water conservation strategy. Any successful conservation campaign requires buy-in from membership so the community should be involved in developing household conservation strategies. Leadership can disseminate conservation information through the band newsletter, website, and an open band meeting on water. Further, Samson Cree Nation can involve students by giving water conservation presentations to classrooms and encouraging students to hold their families accountable for water use. Overall, a water conservation campaign is a low cost, low input strategy to addressing the very real need to extend Samson Cree Nation's water treatment plant's capacity and improving the water system long-term.

Since household leakage is correlated with domestic water use and that system leaks in the municipal distribution pipes are significant, combatting leakage will also extend the water treatment plant capacity in Samson Cree Nation while improving infrastructure. Performing a leak survey of the municipal distribution system will allow Samson Cree Nation to identify the location and size of water main leaks. Reducing these system losses through repairs could yield significant water savings for the water treatment plant, extending its operating life. Plus, Samson Cree Nation can improve leaks inside homes by providing maintenance information to residents on how to identify, mitigate, and report household leakage. In this way, members can not only be engaged in improving water on-reserve, but they can see the steps leadership is taking in water management and planning.

The nipiy committee continues to work to improve the water systems in Samson Cree Nation and I look forward to my continued involvement, putting this research to good use.

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APPENDIX A

Raw data

Samson Cree Nation owns the raw data used in this research. Access to the raw data is granted at the discretion of Samson Cree Nation Chief & Council. If you would like access to the raw data used in this research, please contact Travis Hnidan at hnidan@ualberta.ca.

APPENDIX B

Information letter and consent form

INFORMATION LETTER and CONSENT FORM

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

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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.

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:

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:

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:

Research Investigators:
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Supervisors:
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Edmonton, AB, T6G 2W2
evan.davies@ualberta.ca, aulrich@ualberta.ca
780-492-5134, 780-492-8293

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 form

INTERVIEW FORM

UNIVERSITY OF ALBERTA

Developing a Strategy for Ensuring Confidence in Drinking Water Quality and Quantity for 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 during the day or week 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 ______ Rainbarrel ______

Stream ______ Sprinkler system ______

Cistern ______

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?

APPENDIX D

Tap water chemical test results plotted against per capita water consumption

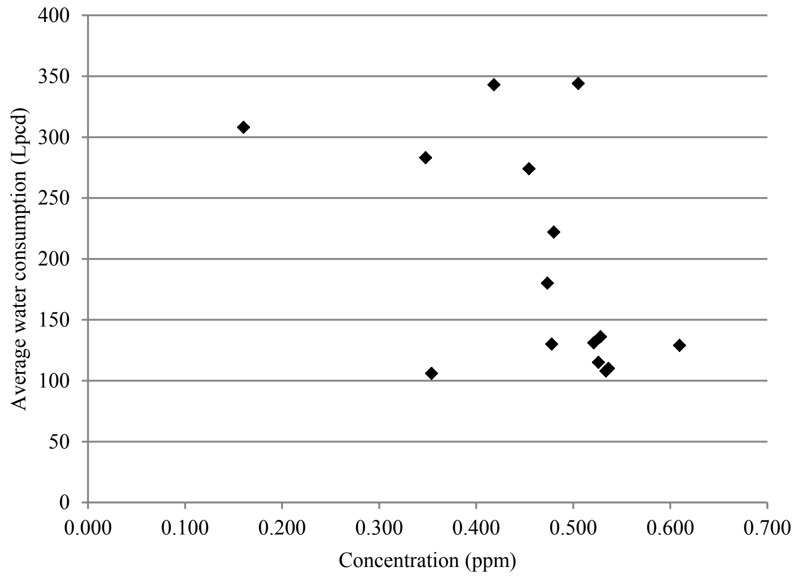

Figure D1 Per capita water consumption plotted against boron concentration in tap water sample

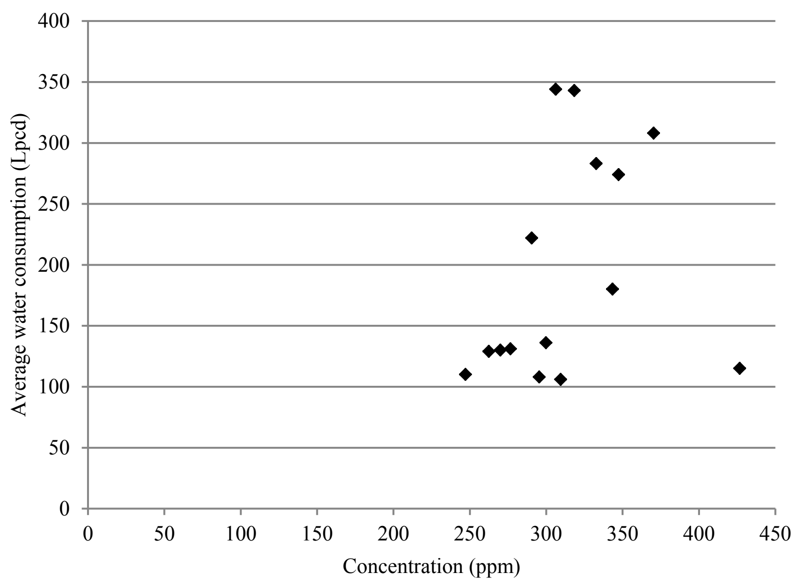

Figure D2 Per capita water consumption plotted against sodium concentration in tap water sample

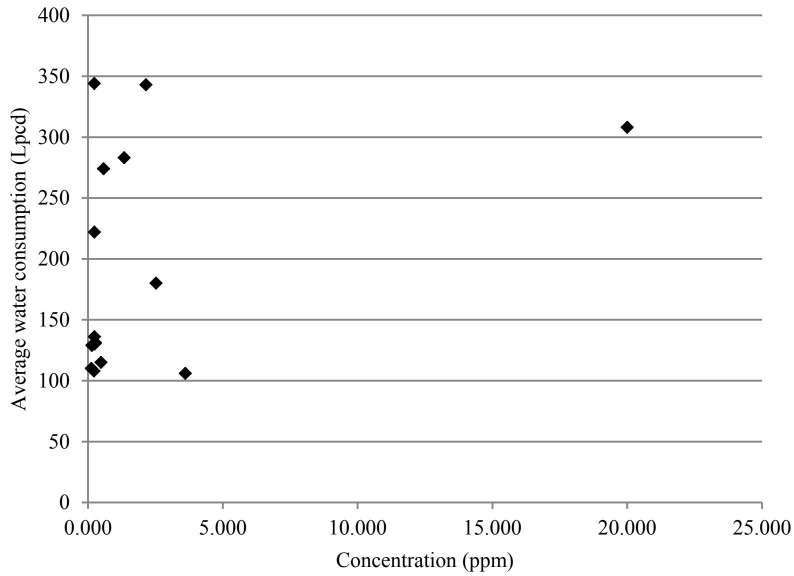

Figure D3 Per capita water consumption plotted against magnesium concentration in tap water sample

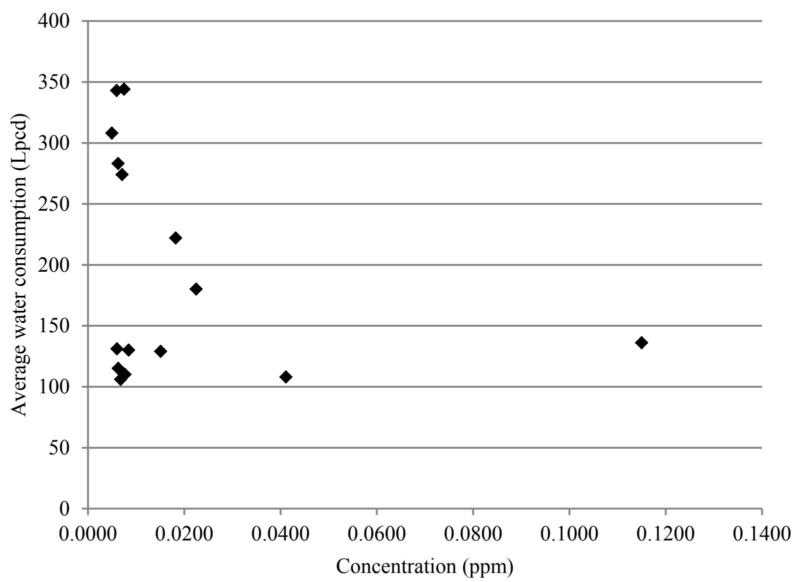

Figure D4 Per capita water consumption plotted against aluminum concentration in tap water sample

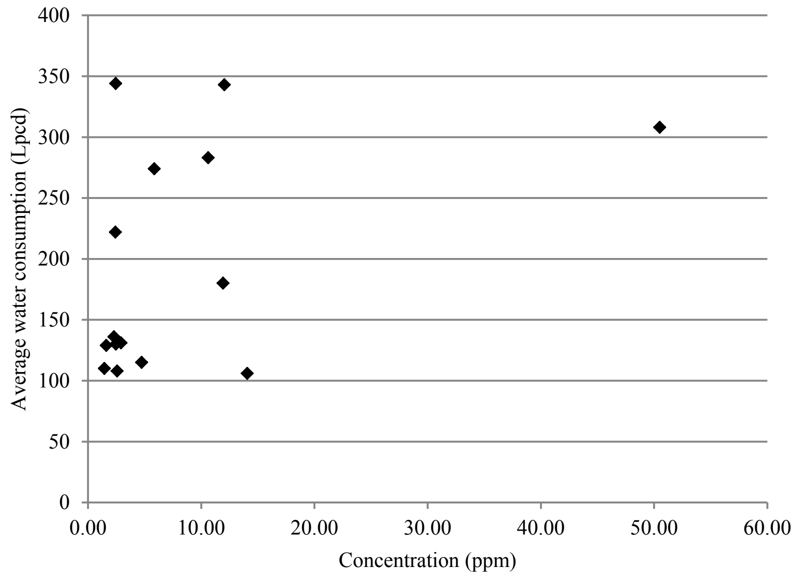

Figure D5 Per capita water consumption plotted against calcium concentration in tap water sample

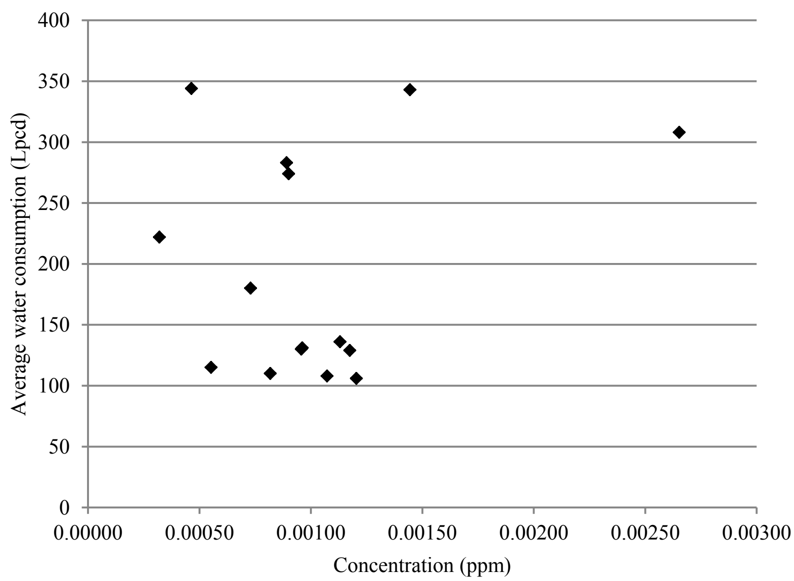

Figure D6 Per capita water consumption plotted against chromium concentration in tap water sample

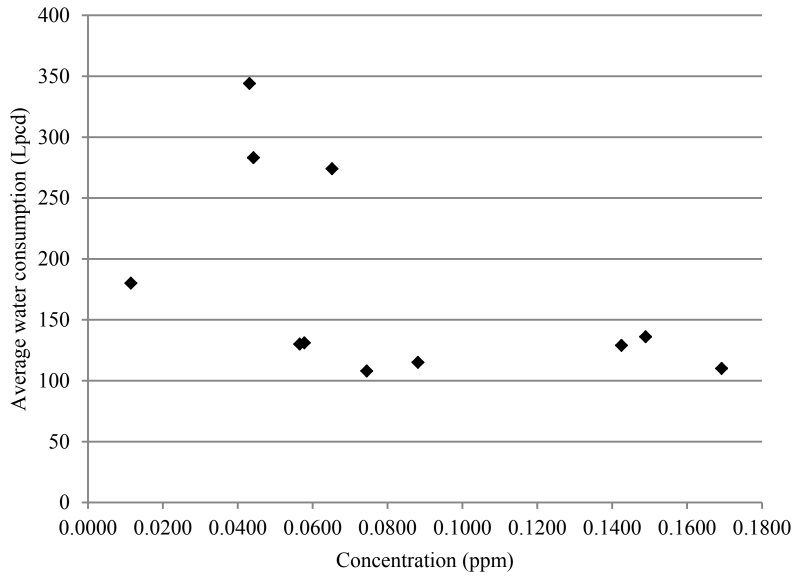

Figure D7 Per capita water consumption plotted against iron concentration in tap water sample

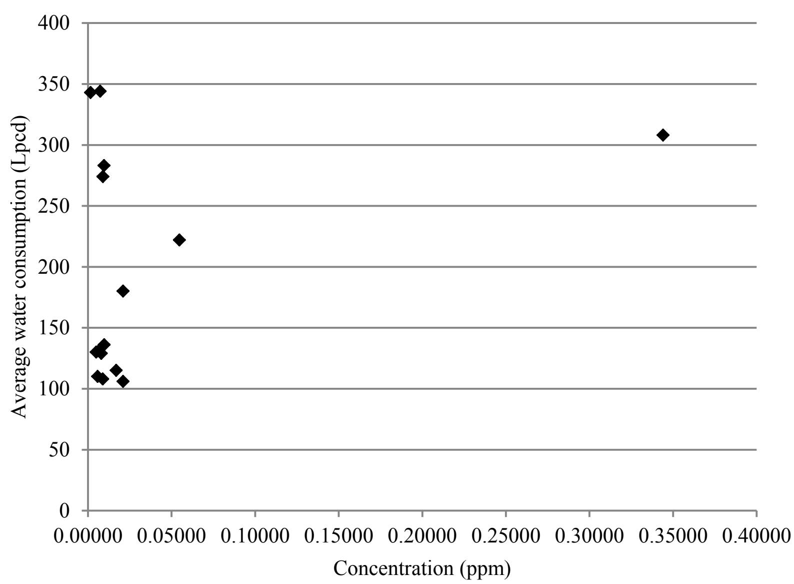

Figure D8 Per capita water consumption plotted against manganese concentration in tap water sample

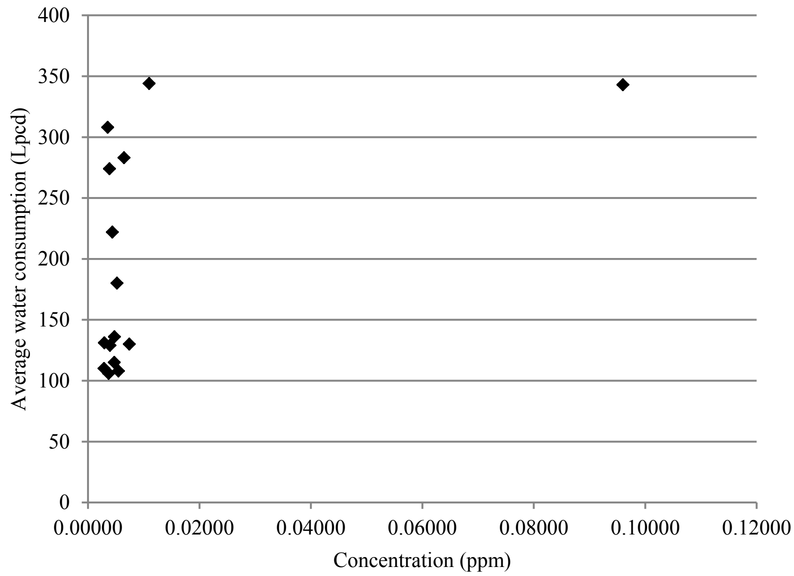

Figure D9 Per capita water consumption plotted against copper concentration in tap water sample

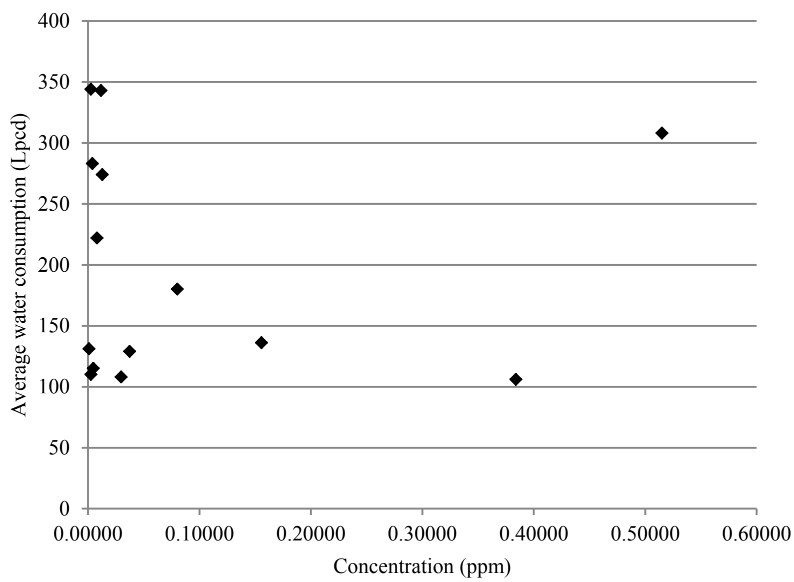

Figure D10 Per capita water consumption plotted against zinc concentration in tap water sample

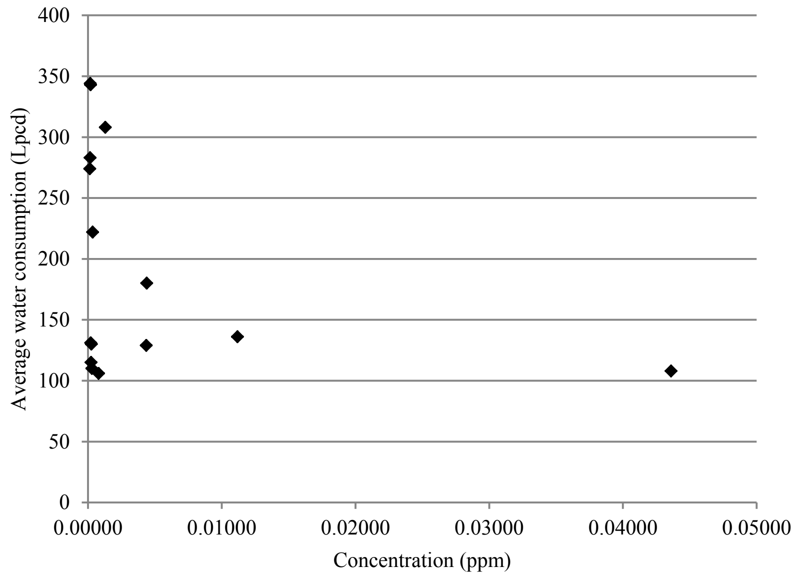

Figure D11 Per capita water consumption plotted against arsenic concentration in tap water sample

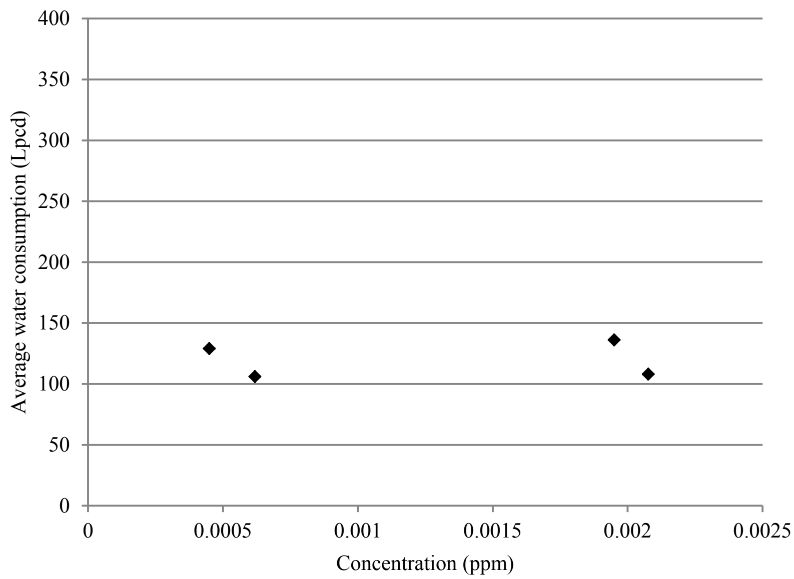

Figure D12 Per capita water consumption plotted against antimony concentration in tap water sample

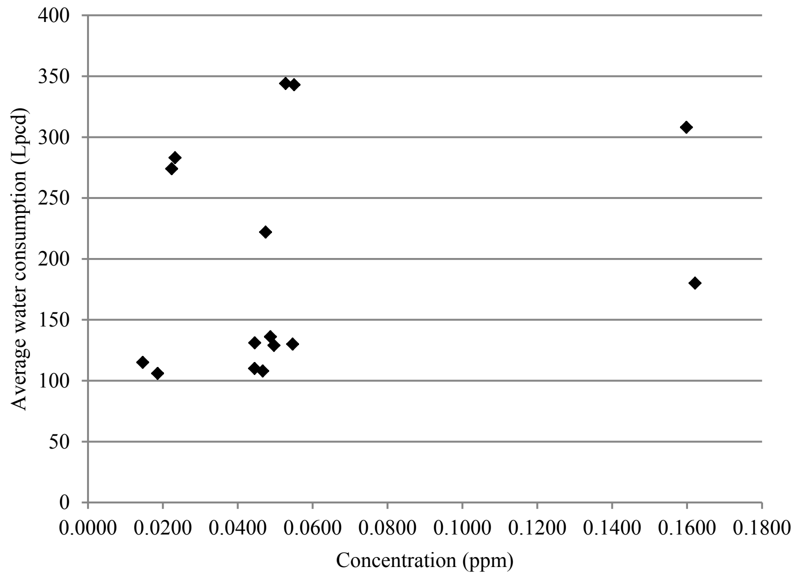

Figure D13 Per capita water consumption plotted against barium concentration in tap water sample

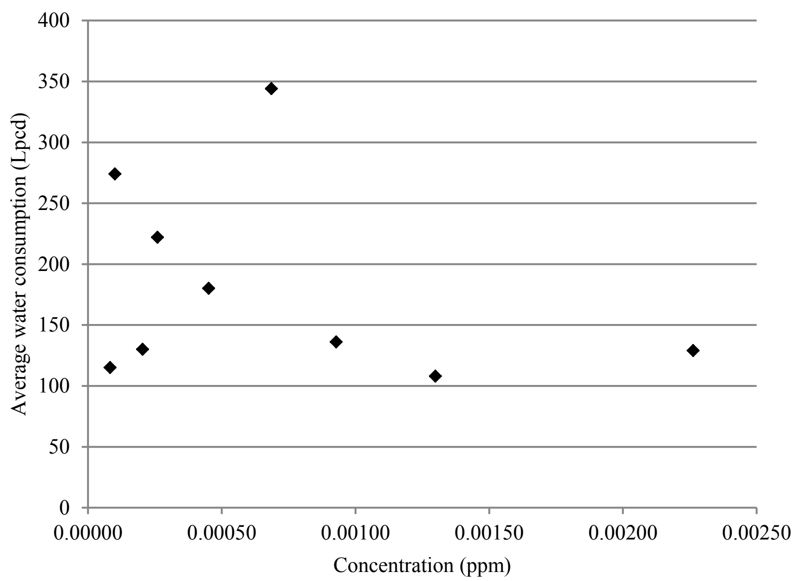

Figure D14 Per capita water consumption plotted against lead concentration in tap water sample

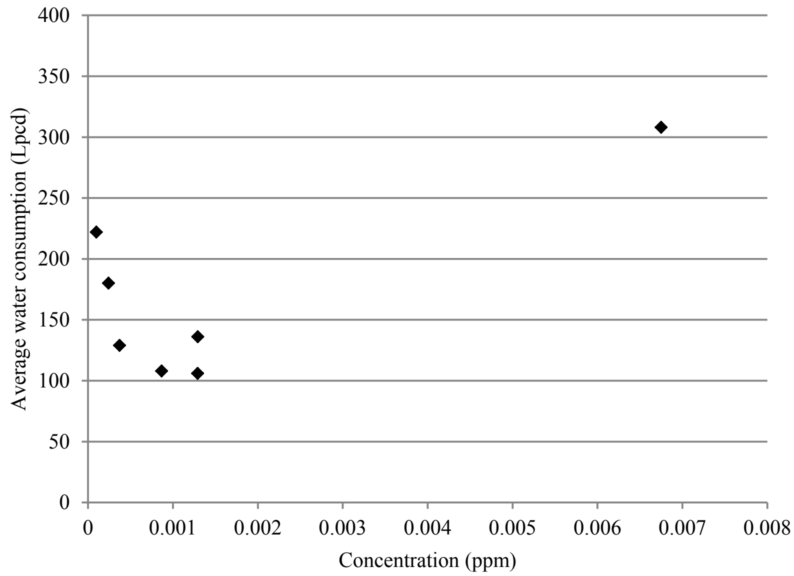

Figure D15 Per capita water consumption plotted against uranium concentration in tap water sample

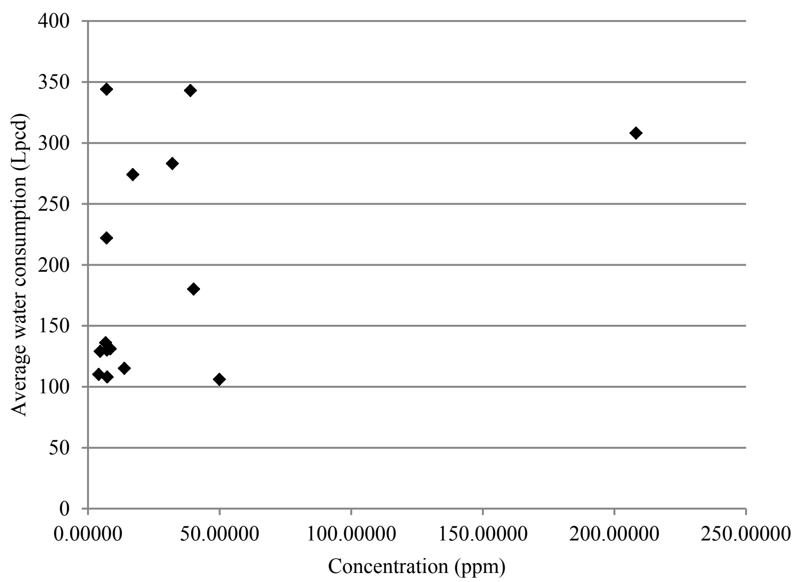

Figure D16 Per capita water consumption plotted against hardness concentration in tap water sample

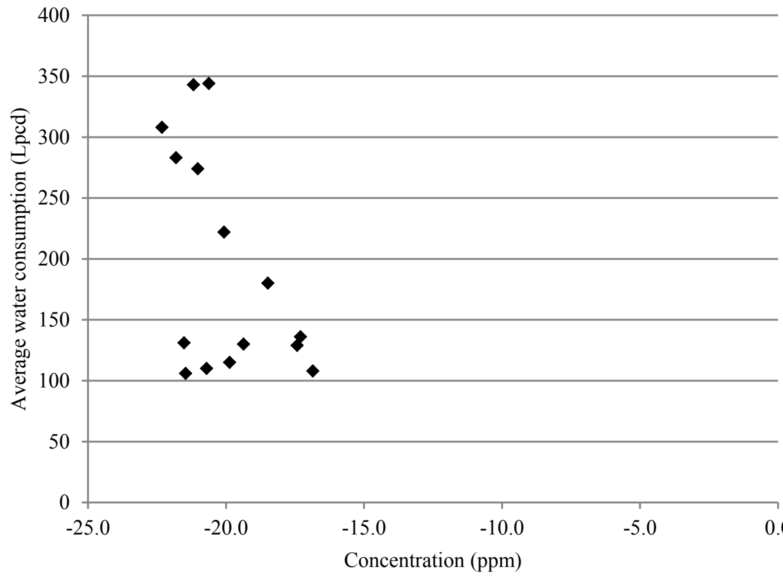

Figure D17 Per capita water consumption plotted against $\delta^{18}O_{water}$ concentration in tap water sample

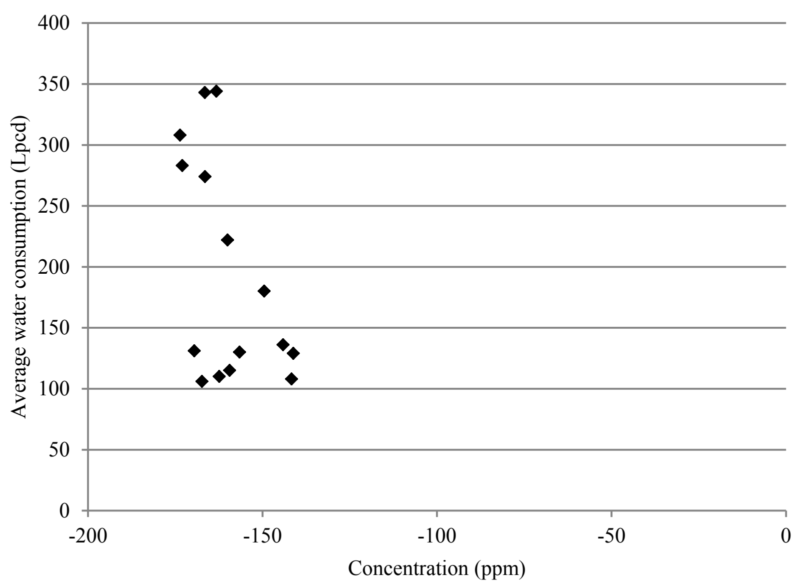

Figure D18 Per capita water consumption plotted against $\delta^{2}H_{water}$ concentration in tap water sample

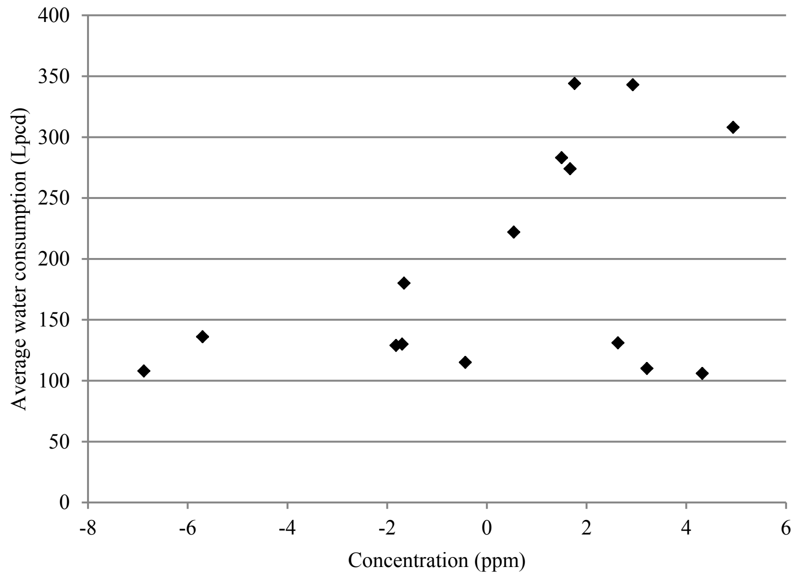

Figure D19 Per capita water consumption plotted against δ-excess concentration in tap water sample