A COMPARATIVE ANALYSIS OF COMMUNITY WATER SYSTEMS AND DRINKING WATER ADVISORIES ACTIVE IN SASKATCHEWAN COMMUNITIES FROM 2012-2016

A Thesis Submitted to the College of
Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements
For the Degree of Master of Public Health (Thesis Option)
In the School of Public Health
University of Saskatchewan
Saskatoon

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February 23, 2018

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ABSTRACT

This research aimed to describe temporal patterns in the number and duration of drinking water advisories in Saskatchewan communities on and off reserve from 2012 to 2016. The analyses included 445 communities – including cities, towns, villages, and reserves – in which 2036 advisories were in effect. The large sample test of proportion was used to compare the observed proportion of advisories issued which occurred on and off reserve to the expected proportion based upon the proportion of communities which experienced an advisory during the study period that were reserve or non-reserve. Comparisons were also conducted which took into account the size of non-reserve communities, the season advisories were issued, the year advisory were issued, and the community's geographic region. Descriptive statistics were utilized to describe reasons for issuing advisories. The duration of advisories was investigated using the same comparisons, as well as the reason for issuing advisories, using the Kruskal Wallis and Mann Whitney U Test.

Reserve drinking water systems were found to have fewer advisories than would be expected when compared to communities off reserve ($p<0.01$). Advisories on reserve were longer lasting than those off reserve, the median advisory lasted 14 days on reserve and 9 days for the smallest community type off reserve (villages) ($p<0.01$). Advisories occurred more often in summer for both reserve and non reserve communities. But while advisories were equivalent in duration across seasons off reserve, advisories issued for reserves were significantly longer if they were issued during the winter($p=<0.02$). Advisories were issued more often off reserve for depressurization and equipment issues, while power outages, disinfection failures, contamination, and operation deviation were more common on reserve.

The analyses included in this study highlight the acute problem of drinking water on reserve and shows that significant work remains to ensure that all Saskatchewan residents have access to safe, potable drinking water. The use of comparison between reserve and non-reserve

communities represents an important step forward towards understanding the extent and causes of drinking water disparities across Saskatchewan.

ACKNOWLEDGEMENTS

Thank you to Sam Ferris from the Water Security Agency of Saskatchewan and to Kevin McCloud of FSIN for their assistance in providing data sets.

DEDICATION

This thesis is dedicated to my mother:

Elizabeth Grace Knisely Daigle

For everything I know. For being my confidant and dear friend, shepherding us all through life, and for laying out the steps before us so that we could walk in them. I am so grateful to be your daughter and I am confident that this thesis would not have come to pass without your support, guidance, and love.

It is also dedicated to my grandmothers:

Doris Ann Connolly Daigle

For being the light in all of our lives, for elegant grace and delicate refinement along with deep grit and unswerving moxie. For joie de vivre and for your constant listening ear, tender care, and great love.

Joann Amelia Myers Knisely

For perseverance and grace amidst trials, sickness, and hardships. For showing me how to teach and teaching me to love the ocean, reflect on the great mysteries of life, and love well. I wish you were here.

It is also dedicated to my husband:

Josiah Elliott Sawatsky

For being my partner, confidant, and best friend. For adventuring with me across Canada and the world. There is no one else I would rather build my life with. I am so grateful for your support, encouragement, and love and there really are no words for how grateful I am for the great gift you are to me. I am so proud of all that you have accomplished as you have completed your studies and are so grateful for how well you provide for your girls.

Finally, it is dedicated to our unborn daughter:

Mariana Grace Sawatsky

Know, little one, that all of it was for you. May the work here and that of others help ensure that you grow up in a more just world. We love you forever.

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LIST OF ABBREVIATIONS

CWS	Community Water Systems
DWA	Drinking Water Advisory
EPO	Environmental protection officers
FN	First Nations
FSIN	Federation of Sovereign Indian Nations
GCDWQ	Guidelines for Canadian Drinking Water Quality
HR	Health Region
INAC	Indigenous and Northern Affairs Canada
L/P	Low pressure
MTA	Municipal Transfer Agreement
N	Number
NFN	Non First Nations
PDWA	Precautionary Drinking Water Advisories
Q	Quartile
WSA	Water Security Agency of Saskatchewan

CHAPTER 1: INTRODUCTION: THE CONTEXT OF THE DRINKING WATER CRISIS ON RESERVE

1.1 The Canadian Province of Saskatchewan

1.1.1 Water Resources in Saskatchewan

Canada is often known as a country of water – it contains approximately 7% of the world's renewable freshwater, the 3rd highest amount in the globe (Liu, 2015). Large scale threats to water quality in Canada include shale gas, fracking, and river development – especially mega-dams, and pipelines (Liu, 2015). However, lack of enforceable regulation causes difficulties in providing clean and safe drinking water from a regulatory perspective and local-scale problems with water treatment systems also post threats to community water supplies (Dunn, et al, 2014). Like Canada broadly, Saskatchewan is a land of water. Surface water resources in the province flow into 29 watersheds and flow into Hudson Bay, the Gulf of Mexico, or the Arctic Ocean (Saskatchewan Watershed Authority, 2010).

The second Saskatchewan State of the Watershed Report, published in 2010, investigated the health of the province's watersheds and ranked the province's watersheds: 6 watersheds were considered healthy, 19 were stressed, and 4 were impacted (Saskatchewan Watershed Authority, 2010). Stresses on the province's surface water include agricultural influences, human influences, industrial influences, natural resource extractions and water uses (Saskatchewan Watershed Authority, 2010).

In addition to its plentiful surface water features, Saskatchewan also includes rich sources of groundwater in aquifers (Pomeroy, et al, 2005). Groundwater may be affected by microbial contamination, agricultural runoff, and other man-made threats (Sketchell & Shaheen, 2000). However, naturally occurring mineral contaminants, such as arsenic, dissolved in groundwater supplies are an additional risk for the 43% of Saskatchewan residents who rely on groundwater drinking water sources (Thompson, et al, 1999). In 2011-2012, 60 samples from 26 drinking water treatment systems were received by the Water Security Agency of Saskatchewan (WSA) contaminated with Uranium (Thirunavukkarasu, et al, 2014).

1.1.2 Saskatchewan's Demographics

Saskatchewan is one of Canada's ten provinces and, as of 2016, was home to 1,098,350 individuals, or 3.12% of the 35,151,730 residents of Canada (Statistics Canada, 2017). 57.64% of Saskatchewan's residents reside in cities, while the remainder live in smaller communities (Statistics Canada, 2016). The median age of residents is 37.8 years, below the national median of 41.2 (Statistics Canada, 2017). In Saskatchewan, 2.62% of residents report that an Aboriginal language is their mother tongue, compared with 0.56% of Canadian residents (Statistics Canada, 2017). The median after-tax income in households of two or more people in 2015 was $81,696 in Saskatchewan, compared with $76,419 national (Statistics Canada, 2017).

1.1.3 First Nations Peoples in Saskatchewan

Saskatchewan's population is 15.7% Indigenous, which is the second highest among Canadian provinces, trailing only Manitoba (16.4%) (Aboriginal Affairs and Northern Development Canada, 2013 a). Saskatchewan's First Nations are part of five distinct cultural groups: Cree, Dene, Dakota, Nakota, and Salteaux (Aboriginal Affairs and Northern Development Canada, 2010 a). A Canadian person is Indigenous, as defined by the Canadian Constitution, if they are First Nations, Metis, or Inuit (Indigenous and Northern Affairs Canada, 2017 a). In the 2016 census, 2,130,520 Canadians reported having Aboriginal ancestry, of whom 71.6% reported having First Nations ancestry, 28.2% reported having Metis ancestry, and 3.7% reported having Inuit ancestry (Statistics Canada, 2018).

Seventy First Nations are located in Saskatchewan and most (63) are affiliated with a tribal council, of which there are 9 in the province (Aboriginal Affairs and Northern Development Canada, 2010 a). Each tribal council covers a different geographic area; for example, the Saskatoon Tribal Council covers the area surrounding the city of Saskatoon (Saskatchewan Indigenous Cultural Center, 2018). Tribal councils are political entities which seek the collective good of the member bands and work towards achieving mandates and priorities set by member bands (Saskatchewan Indigenous Cultural Center, 2018). Additionally, the Federation of Sovereign Indian Nations (FSIN) represents all First Nations in Saskatchewan with the mission of "Protecting Inherent and Treaty Rights" (Federation of Sovereign Indian Nations, 2018). Each First Nations band has a chief and council system which exercises governance over its members.

Saskatchewan is treaty land and includes parts of Treaties 2, 4, 5, 6, 8, and 10, contrasting with Southern Ontario and most of British Columbia, which are not covered by treaties (Aboriginal Affairs and Northern Development Canada, 2010 a). Reserves are defined by the Indian Act: "a tract of land, the legal title to which is vested in Her Majesty, that has been set apart by Her Majesty for the use and benefit of a band" (Indian Act, 1985). Reserves are located across the province but are concentrated in northern Saskatchewan.

1.2 Drinking Water Policies, Guidelines, and Regulations

1.2.1 The Saskatchewan Context

Drinking water regulation in Canada is considered one of the most decentralized among OECD countries as the regulatory matrix for all Canadian water systems is characterized by significant fragmentation: jurisdictional overlap, lack of clarity and coordination in decision making, and many competing interests (Bakker & Cook, 2011). Given these complicated regulatory relationships and devolution it is unsurprising that drinking water quality standards vary significantly across jurisdictions and may also be monitored at different levels of thoroughness (Dunn, et al, 2014).

Canadian water guidelines are provided in the Guidelines for Canadian Drinking Water Quality (GCDWQ) are published by Health Canada (Health Canada, 2017). These guidelines include 94 parameters (Health Canada, 2017). In contrast, Saskatchewan's guidelines include 65 parameters (Dunn, et al, 2014). Of Saskatchewan's 65 guidelines, 56 are as stringent as the GCDWQ, 6 are less stringent, and 3 are not included in the GCDWQ (Dunn, et al, 2014). Among the 32 parameters included in the GCDWQ but not included in Saskatchewan's guidelines are those regarding giardia, cryptosporidium, and enteric viruses (Dunn, et al, 2014).

The Environment and Protection Act of 2002 and The Water Regulations of 2002 legislatively control water governance in Saskatchewan (Dunn, et al, 2014). These regulations are legally binding, unlike five other provinces and territories and in concert with WHO suggestions (Dunn, et al, 2014). Oversight and governmental water management responsibilities in Saskatchewan are devolved to the Water Security Agency, which is tasked with managing the water supply, protecting water quality, ensuring drinking water safety and wastewater treatment, managing the province's 69 dams, protecting against damage from flooding and droughts, securing the safety of aquatic habitats, informing the public regarding water, and representing the province on transboundary water issues (Water Security Agency, 2017a). The WSA was formed in 2012 (Water Security Agency, 2017a). Other Saskatchewan government stakeholders in water regulation for the province include the Saskatchewan Ministry of Environment, the Saskatchewan Ministry of Government Relations, the Saskatchewan Ministry of Health and Health Regions, The Saskatchewan Ministry of Agriculture, and SaskWater (Water Security Agency, 2017 b).

Small systems often lack the resources, testing capacity, and highly trained personnel to provide water of the same quality as that distributed by larger centers. These issues are highlighted by Hrudey: "Providing consistently safe drinking water requires well-resourced treatment systems and highly trained personnel, yet we download this responsibility to local governments. Larger municipalities generally do well, but many smaller and more remote communities simply cannot cope with all the technical and managerial challenges… We are allowing a two-tier system of water supply, roughly split along the urban-rural divide" (Hrudey, 2008).

In addition to small water treatment systems, many rural water users rely completely on unregulated private wells or cisterns for household water: over 66,000 private wells were estimated to be operating in Saskatchewan in 2011 (Thompson, 2011). Approximately 15% of Saskatchewan's population uses private well water (Government of Saskatchewan, 2009). As each individual is responsible for the accessing and paying for their own water testing and there is no accepted schedule for testing, private water systems are only rarely evaluated. Those who rely on private wells or trucked to cistern water systems have no regulatory protection in the form of boil water or do not use advisories and therefore their level of risk in unknown (Charrois, 2010). Approximately two thirds of waterborne illness outbreaks in Canada from 1974-2001 occurred in private or semi-private systems (Schuster, et al, 2005). A review private Ontario wells located on farms found that 34% were contaminated with *E. coli* (Goss, et al, 1998). In Saskatchewan, 99.6% of 535 private wells which were tested exceeded an aesthetic or health-related guideline for drinking water and 35% violated a health guideline (Sketchell & Shaheen, 2000).

1.2.2 Federal Legislation for First Nations Drinking Water

The Canadian constitution sets the federal government as the jurisdictional body overseeing issues regarding First Nations peoples in Canada, even in areas where the provinces and territories oversee non-First Nations populations. *The Safe Drinking Water for First Nations Act* was passed in 2013, to provide federal regulations to increase the quality, safety, and reliability of drinking water on reserves (Safe Drinking Water for First Nations Act, 2013, c. 21). The act was the first federal legislation to protect the drinking water rights of First Nations people living on reserve in Canada and stipulates that the Governor in Council may institute regulations to ensure that these rights are met. To date, no such regulations have been passed.

The legislation stipulates that drinking water on reserves should follow the regulations associated with the province which the reserve is in. However, as has been previously noted, regulations vary significantly by province, which has the potential to cause significant variation in drinking water quality across provincial lines despite the fact that the federal government has jurisdiction over drinking water on reserve. For Saskatchewan, provincial regulations currently set for non-reserve communities are legally binding but lack many indicators included in the GCDWQ including indicators for microbiological hazards such as giardia and cryptosporidium and also have a maximum acceptable higher for Arsenic than is suggested by the GCDWQ (Dunn, et al, 2014). The Expert Panel described this method of regulation in 2006 but ranked it lowest among its suggestions, given the difficulties associated with ensuring access across provinces given varying regulations across provinces (Swain, et al, 2006). Furthermore, Bill S-8 does not appropriate any funding to meet the new regulations which could, hypothetically, be imposed. Therefore, the entire burden of shouldering the cost of increased testing would be upon the First Nations communities.

1.2.3 The First Nations Context

Oversight of drinking water on reserve is coordinated by Health Canada in collaboration with Indigenous and Northern Affairs Canada (INAC) (Health Canada, 2017). Both capital funding and planning for water treatment plants are under INAC’s purview along with daily operation of the plant (Health Canada, 2017). Standard, protocol, and guideline development is conducted by Environment Canada (Health Canada, 2017). Water quality programs for reserve communities are coordinated by Health Canada (Health Canada, 2017). Water treatment plant operation as well as additional funding for the day to day operation of the plant is to be managed by the Chief and Council (Health Canada, 2017). It is of note that, with the exception of the Chief and Council, federal agencies provide oversight of First Nations drinking water systems in Canada, while non-reserve communities receive oversight from provincial ministries. While some legislative protection of drinking water quality for First Nations reserve communities was provided by Bill S-8, additional legislation is required to ensure effective drinking water quality and quantity is available for all First Nations Canadians.

1.2.5 Federal Policy for First Nations Water Treatment on Reserve

In early 2000s a baseline assessment of water systems in Canadian reserves was conducted, which found that many reserves lack access to potable water. A number of government policies followed: The First Nations Water Management Strategy of 2003, an Expert Panel in 2006, The

Plan of Action for First Nations Drinking Water of 2007, and The First Nations Water and Waste Water Action Plan (Morrison, Bradford, & Bharadwaj, 2015). Each of these initiatives incorporated large amounts of funding but the efficacy of these programs has not been comprehensively assessed (Morrison , Bradford, & Bharadwaj, 2015). However, the continued high prevalence of boil water advisories in First Nations suggests that these programs have been ineffective.

1.3 Drinking Water Sources and Drinking Water Treatment

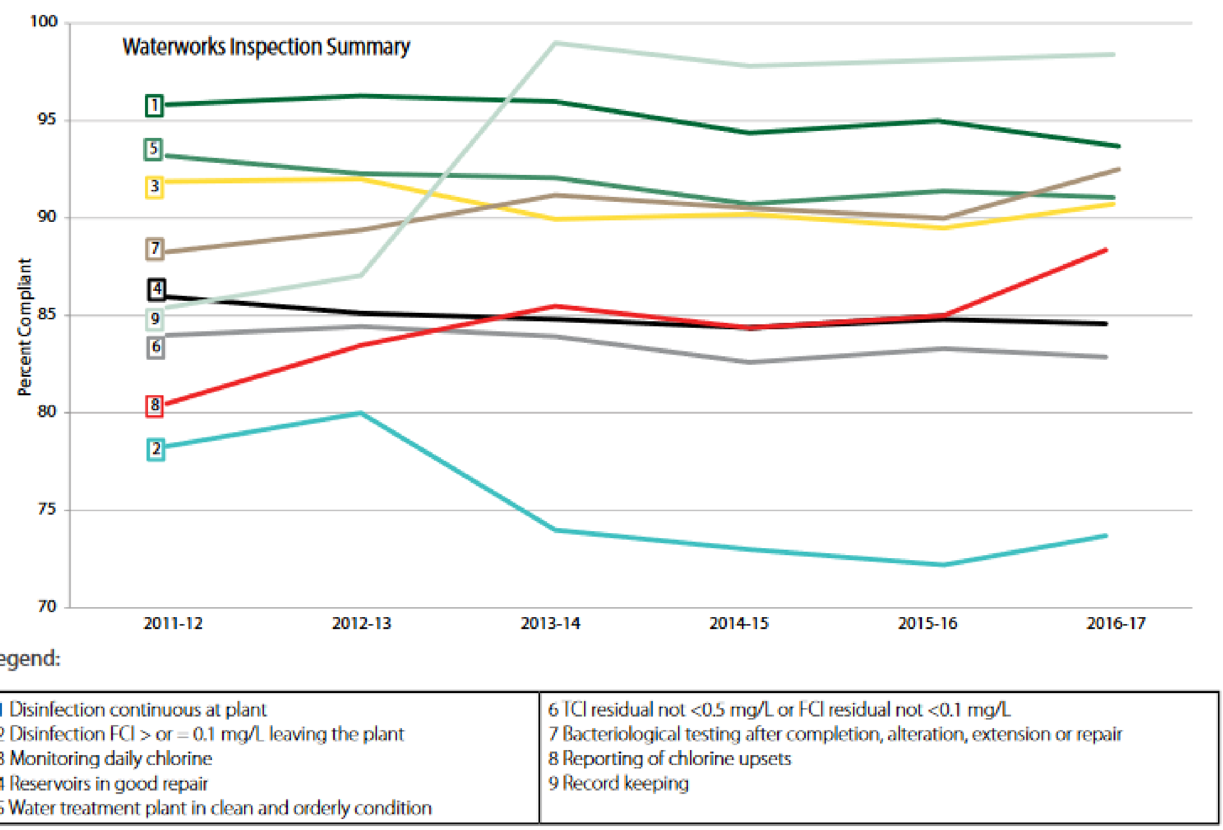
1.3.1 The Saskatchewan Context

The number of certified Water Treatment Plant Operators has increased from 1201 in 2012 to 1306 in 2016 (Water Security Agency, 2017 b). All water treatment systems overseen by the WSA in 2016 had a certified operator in place (Water Security Agency, 2017 b).

The number of systems which meet bacteriological guidelines at least 90% of the time remained relatively consistent throughout the study period, increasing from 98.5% in 2012-2013 to 99.1% in 2015-2016 (Water Security Agency, 2017 b). A smaller number of systems meet the disinfection requirements 90.0% of the time, with only 91.0% of systems meeting this requirement in 2012-2013 and 92.0% meeting them in 2015-2016 (Water Security Agency, 2017 b). Compliance with health and toxicity sample submissions, which include a number of heavy metals and other ions, has increased from 71.7% in 2012-2013 to 84.3% in 2015-2016 while compliance with parameters has decreased from 90.9% to 87.6% in the same period (Water Security Agency, 2017 b). The number of systems not meeting minimum treatment requirements increased from 9 in 2012-2013 to 14 in 2015-2016 (Water Security Agency, 2017 b).

As part of the WSA's 2017 annual report, results from yearly waterworks inspections by year are shown (reproduced in **Figure 1.1**). Increases across the study period were notably found for reporting chlorine upsets (8) and for record keeping (9) (Water Security Agency, 2017 b). The number of plants with an adequate chlorine residual has decreased over the course of the study period (2) (Water Security Agency, 2017 b). Other parameters measured remained relatively consistent between 2012 and 2016 (Water Security Agency, 2017 b).

Figure 1.1 Waterworks Inspection Trends 2011-2017 WSA



Reproduced from (WSA, 2016b):

1.3.2 The First Nations Context

Because of the variety in water source types and water supply infrastructure, the condition of drinking water varies on Canadian First Nations reserves and the specific challenges faced by a given reserve community may or may not be shared by others (Lebel & Reed, 2010). A water treatment system in a given community may also have multiple components – part of the population served may be piped while others use a trucked to cistern model. Lebel and Reed (2010) examined the Montreal Lake First Nation in Saskatchewan, and found that the quality and capacity of these components differed substantially.

A 2011 assessment of water and wastewater systems on reserves was completed by the private company Neegan Burnside, sponsored by the Department of Indian and Northern Affairs Canada. Called the Roll-Up Report, the initiative involved 571 First Nations (97% coverage) (Indigenous and Northern Affairs Canada, 2011 a). Water systems varied substantially across homes on reserves: water could be piped (72%), provided by individual wells (13%), trucked in (13.5%), or without water systems (1.5%) (Department of Indian and Northern Affairs Canada, 2011). Systems varied in their source of water: groundwater (52%), surface water (29%), and (19%) ground water under the direct influence of source water (Indigenous and Northern Affairs Canada, 2011 a).

In Saskatchewan, systems were listed less often as being high risk than the national average as part of the Neegan Burnside Report (High Risk [SK 26.21%, Canada 38.91%]; Medium Risk [SK 45.63%, Canada 34.45%]; Low Risk [SK 26.64%, Canada 26.64%]) (Indigenous and Northern Affairs Canada, 2011 a). Additionally, Saskatchewan plants were more likely to have a maintenance management plan when compared with the national weighted average (SK 7%, Canada 11%) and to have an emergency response plan (SK 40%, Canada 28%) (Indigenous and

Northern Affairs Canada, 2011 a). However, Saskatchewan plants were less likely to have a source water protection plan in place (SK 7%, Canada 11%) (Indigenous and Northern Affairs Canada, 2011 a).

The number of drinking water systems for First Nations rated as high risk has been steadily decreasing since 2001. However, there is not a transparent means by which water systems are moved through the risk levels – water treatment systems may be moved from high to medium risk without documentation, the publication of reports, or community consultation (Polaris Institute, 2008).

1.3.4 Traditional Forms of Knowledge among First Nations Canadians about Water

While it must always be acknowledged that Indigenous peoples are extremely diverse, there are nevertheless, areas of general agreement across traditions. Concerning water, these include an awareness of water and place in urban planning decisions, a recognition of a special connection between women and water related to pregnancy and birth, and respect for the spirit of the water (Lawless, et al, 2013). Water is also used medicinally in many First Nations' traditions (Longboat, 2014; McGregor, 2008).

Longboat, 2014, described the relationship between Indigenous Canadians and Water: "for First Nations, water is a sacred gift, the life blood of Mother Earth, and all water, not just water for human use, needs protection (Longboat, 2014). First Nations have exercised inherent responsibilities to fulfill obligations to the Creator to ensure clean water for all living things since time immemorial" p.7. Water is often described by Indigenous Canadians as the veins of Mother Earth (Longboat, 2014). Among Anishnaabe women, for example, women conduct monthly moon ceremonies to honor the water (McGregor, 2008). Thus, when westerners think of water security, it is generally in the interest of protecting human and ecosystem health, while when Indigenous Canadians describe water security, it is additionally to protect Mother Earth (Longboat, 2014).

An awareness of the local customs and ways of knowing is essential if plans to increase community drinking water capacity are to succeed. For example, as water is generally viewed as a spiritual, life-giving force by First Nations people, attempts to commodify water distribution may be opposed by community leaders (Longboat, 2014; Phare, 2011; McGregor, 2008). Additionally, some traditional water treatment methodologies may be deemed inappropriate and disrespectful by one First Nation and accepted by others (Lawless, et al, 2013). Cultural competency and sensitivity are required to develop regulatory policies that respect this diversity in beliefs.

1.4 Drinking Water Advisories

1.4.1 Water Advisories in General

When drinking water fails to meet regulatory guidelines, boil water advisories are given temporarily, until quality increases to the minimum level once again (Macintosh, 2009). The water system operators and primary agency trigger the advisory work alongside other stakeholders to determine the scale of the issue, identify the advisory's geographic boundaries, notify stakeholders, determine communication strategy, and distribute roles, and then issue the advisory to the public (Health Canada, 2015). However, these measures are not intended to be long term solutions, but rather, temporary stopgaps to prevent harmful effects on human health (Macintosh, 2009). Boil water advisories are not adhered to universally and, in general, if people heed the advisory they respond by drinking bottled water, not by using home chlorinators or boiling their water (Lindell, et al, 2015). The ability to deliver safe and high-quality drinking water is multidimensional and requires financial capacity, human resources capacity, institutional capacity, and technical capacity to facilitate success (Lebel & Reed, 2010).

1.4.2 The Saskatchewan Context

In Saskatchewan, if microbiological contamination of a drinking water supply is confirmed, an emergency boil water order (EBWO) is issued (Sun Country 2018; Health Canada, 2015). If the contamination is suspected or another concern regarding the water treatment system is present, a precautionary drinking water advisory (PDWA) is issued (Sun Country, 2018; Health Canada, 2015). If contamination by chemicals makes the water unsafe for human consumption, a rare class of advisories that makes up only 2% each year, a Do Not Use or Do Not Consume advisory is given (Environment and Natural Resources Canada, 2016). For the sake of this thesis, the three types of advisories have been merged together and are referred to as drinking water advisories (DWAs).

The Water Security Agency is a Treasury Board Crown corporation and is the body which collects advisory information for the province, though it is not the only issuing authority (Water Security Agency, 2017 a). While multiple agencies may issue a PDWA, EBWOs are always issued by the local Health Region in consultation with the WSA (Saskatchewan Auditor, 2013). Inspection and compliance services as well as the development and enforcement of standards and protocols are carried out in concert by the WSA, the Saskatchewan Ministry of Health, and the province's Health Regions (Water Security Agency, 2017 (b). Environmental protection officers (EPOs) employed by the WSA review reports from water testing done both in the plant and in laboratories (Saskatchewan Auditor, 2013). If there are areas of non-compliance with stated water safety testing frequency as per the plant's permit, the EPO is to refer to the water treatment plant operator and may, if water quality has become questionable, issue a PDWA (Saskatchewan Auditor, 2013). Communication regarding a PDWA or EBWO affecting the users of a water treatment plant with those users is the responsibility of the waterworks owner (Saskatchewan Auditor, 2013).

1.4.3 The First Nations Context

While typically drinking water advisories are temporary, remaining in place only until the offending issue was rectified, First Nations communities often experience long-term DWAs, some of which have lasted for decades (Polaris Insitute, 2008). In November 2015, seventy-seven advisories affecting community water systems which had been ongoing for at least one year were in effect on First Nations reserves (Indigenous Affairs and Northern Development Canada, 2017). This figure did not include users whose water is provided in cisterns or by wells. The longest lasting in Canada, at the Neskantaga reserve in Ontario, has been in effect since February 1, 1995, while Saskatchewan's longest lasting advisory has been in effect since April 24, 2006 in Clearwater River First Nation (Indigenous Affairs and Northern Development Canada, 2017). The risk that a given Canadian community will experience a DWA is two and a half times greater for reserves than non-reserve communities. This indicates that the systems to supply water on reserve have been less reliable or of poorer quality than their non-reserve counterparts (Patrick, 2011).

Drinking water advisories on reserve are issued by Chief and Council when water fails to meet regulatory requirements (Health Canada, 2007). Datasets provided by the Federation of Sovereign Indian Nations in Saskatchewan show that other regulatory agencies, including health regions and Health Canada also issue advisories; however, Health Canada technically is to have an advisory role in the issuing and rescinding of drinking water advisories (Health Canada, 2017).

Once an advisory has been issued, steps working toward the lifting of that advisory are to be followed (Health Canada, 2007). According to this framework, if the reason for the advisory is easily dealt with, Chief and Council are to take appropriate steps to address these issues and remove the advisory within 2-3 days (Health Canada, 2007). If this is not possible, Chief and Council are to develop an action plan and submit it to Health Canada and INAC for their review (Health Canada, 2007). If that action plan is deemed complete and appropriate, it is implemented, otherwise the Community-Based Water Team is activated to assist the Chief and Council in developing a new action plan, which is then implemented upon its completion (Health Canada, 2007).

No studies of DWAs on Saskatchewan reserves have been published to date. However, in 2016, Galway published an analysis of DWAs given on reserves in Ontario from 2004 to 2013. Of the 402 DWAs which were examined, more than fifty percent were caused by equipment malfunction (Galway, 2016). Listed in order of decreasing frequency, other causes of DWAs included inadequate disinfection residuals, turbidity, operation of the system would compromise public health, unacceptable microbiological quality, and deterioration of source water quality (Galway, 2016). As has been noted across North America, Galway found an increase in the number of advisories across the study period, with the largest number in 2013. The most advisories were noted during the summer and the fewest during the winter (Galway, 2016).

1.5 Surveillance of Drinking Water Systems

1.5.1 The Saskatchewan Context

There is no national surveillance plan for drinking water systems across Canada (Dunn, et al, 2014). However, records of current and past drinking water advisories are kept by the Water Security Agency of Saskatchewan, including the issuing authority, dates issued and rescinded, the reason for the advisory, and its scope. Additionally, an ad-based media company called Water Today maintains a database of current advisories across Canada and also publishes communications posted publicly to community members regarding advisories (Water Today, 2017).

1.5.2 The First Nations Context

Data regarding the water treatment systems on Saskatchewan reserves are collected by the Federation of Sovereign Indian Nations, excluding First Nations which form part of the Saskatoon Tribal Council as their data is not available. Data is also collected nationally by Health Canada and a national listing of advisories currently in effect across the country (excluding communities in the Saskatoon Tribal Council and in British Columbia) is available online (Health Canada, 2018).

1.5.3 Gaps in Current Knowledge

Little scholarly inquiry on the state of water treatment systems on Canadian reserves has been completed (McCullough & Farahbakhsh, 2012). To date, no comparative analysis has been conducted in Saskatchewan about water supplies in First Nations and non-First Nations communities. Differences between these communities in land use, regulatory landscape, culture, demographics, and other factors are substantial and it is likely that many of these factors influence the provision of water to First Nations communities. Investigating these differences could highlight areas that are integral to the difficulties faced by the government of Canada as it attempts to deliver potable water to communities on reserve. Additionally, only one longitudinal study of drinking water advisory trends in Canada has been published, and this investigation was limited to Ontario reserves (Galway, 2016).

1.6 Water Related Health

1.6.1 The Primacy of Water

Waterborne illness has been a major concern throughout the history of public health. It began to be systematically appreciated with the work of John Snow, who inferred that a cholera outbreak in London's Soho had been caused by a waterborne pathogen. Today, waterborne illnesses account for 2 million deaths per year, 50% of which occur in children under the age of five (WHO, 2018).

Outbreaks of waterborne illness in Canada from 1993-2008 were summarized in a report by Wilson, et al. in 2009. They found that among 47 outbreaks of waterborne illness identified, the most common causative agents were giardia (25%), cryptosporidium (19%), campylobacter (8%), and coliforms (8%) (Wilson, et al, 2009). After an outbreak was identified, DWAs were usually put in place (77%), however, no DWA was issued 19% of the time and an DWA had already been in effect in 5% of outbreaks (Wilson, et al, 2009). The source for communities affected by outbreaks was most commonly surface water (50%), followed by ground water (39%), and ground water under the direct influence of surface water (11%) (Wilson, et al, 2009). Water treatment was most commonly disinfection only (46%) or the system did not treat the water (40%) (Wilson, et al, 2009). The water treatment system served by supplies affected by outbreaks of waterborne illness ranged from 4 to 390,000 (mean 26,969; median 438) while the number of people sickened ranged from 0 to 15,000 (mean 654; median 20) (Wilson, et al, 2009). Factors identified as contributing to the outbreaks included contamination at the water source (precipitation, spring thaw, flooding, no source water protection, animals in the watershed), water treatment difficulties, cross contamination (broken pipes, post-treatment contamination), turbidity, and human error (Wilson, et al, 2009).

1.6.2 First Nations Specific Considerations to Waterborne Health

A coherent government policy on Indigenous health in Canada is currently lacking: significant regulatory gaps, overlapping interests, and confusion remain (Lavoie, 2013). These issues extend to waterborne illnesses. A recent scoping review of scholarship regarding drinking water quality in Canadian Indigenous communities found that conditions which have been linked with drinking water quality concerns were most commonly gastrointestinal, followed by birth defects/developmental issues and skin problems (Bradford, et al, 2016). Additionally, obesity, diabetes, cancers, mental health concerns, neurological problems, hypertension, heart disease, liver disease, kidney problems, immunopathy, and thyroid diseases have been reported when discussing reserve water supplies (Bradford, et al, 2016).

Fixing water supply issues, especially increasing the quantity of water provided to homes on reserve, has also been suggested as a remedy to reduce the burden of community-aquired MRSA on Canadian reserves (Irvine, 2012). Rates of waterborne illnesses have been reported to be greater on reserve than in the general population of Canada (Patrick, 2011; Basdeo & Bharadwaj, 2013;

Bradford, et al, 2016). This difference highlights the importance of ensuring safe drinking water for First Nations people living on reserves. Self-reported poor health outcomes from tap water, which were reported in 28% of households, were found to be associated with insufficient tap water (OR=3.0), paying for bottled water (OR=3.2), being concerned about environmental factors affecting water quality (OR=3.4), and avoiding the consumption of tap water (OR=2.9) (Waldner, et al, 2017).

1.7 Objectives of Current Research

1.7.1 Goals and Problem Statement

The current project endeavors to describe drinking water advisory outcomes from Saskatchewan using data sets shared by FSIN, SaskHealth, and the WSA of Saskatchewan and compare drinking water system outcomes on and off reserve. This quantitative approach complements the community based participatory research also being carried out as part of a large project, initiated in 2009, examining drinking water challenges in First Nations communities. Overall, this project seeks to achieve the integrated approach called for by Matsui in 2012 when he argued that compartmentalization in water systems knowledge contributes greatly to the problems faced by reserve communities across Canada.

While analyses of drinking water advisories have been completed by the Canadian government in the Neegan Burnside Report, this review only included advisories in effect when the data were collected (Indigenous Affairs and Northern Development Canada, 2011 a). Galway, in 2016, examined advisories in effect in Ontario from 2004-2013 but the report was almost exclusively descriptive in nature (Galway, 2016). No other studies have been identified examining the frequency or duration of advisories in affected communities in which statistical inference was utilized. Furthermore, no research has been reported comparing reserve and non-reserve drinking water system outcomes to determine whether and how much of a disparity exists in the relative number of advisories issued in affected communities on and off reserve or what factors may explain any differences identified.

The overall hypothesis of this project is that First Nations communities experiencing advisories face systematically more and longer advisories than communities experiencing advisories off reserve and that these advisories are issued for different reasons than those on reserve.

1.7.2 Investigate Differences in Drinking Water Advisory Frequency, Timing, and Duration on and off Reserve in Communities with Advisories from 2012-2016

The first research paper included in this thesis seeks to characterize factors associated with differences in the relative frequency of DWAs among communities that experienced at least one advisory during the study period. The specific objectives of this paper were to:

- Investigate differences in the proportions of total advisories issued on and off reserve during the study period compared to expected values based on the proportions of reserve and non-reserve communities experiencing at least one advisory. Investigations of differences in the duration of advisories across community types were also examined.
- Investigate differences between northern or southern Saskatchewan in the proportions of total advisories issued versus the expected values derived from the proportions of communities in each region which experienced at least one advisory. Differences in the duration of advisories was similarly compared across regions of the province.
- Investigate seasonal and temporal differences in the proportions of total advisories issued compared the expected values from the proportions of communities with at least one

advisory in each period for reserve and non-reserve communities. The duration of advisories was also compared across season and year the advisory was issued

The paper also describes the different challenges inherent in developing the data sets and issues with administrative data which were encountered during the cleaning process. Many variables which were available for reserve communities were not available off reserve, which limited the questions that could be considered.

Because this investigation represents the first identified analysis of its kind, it will have significant implications for policy makers as they determine methods to mitigate any disparities found between reserve and non-reserve systems. To date, the scope of these disparities with regard to DWAs has been poorly described and analyses such as those included in this thesis are an important step if evidence based policy making is to be utilized.

1.7.3 A Comparison of Reported Reasons for Issuing Drinking Water Advisories For Community Water Systems On and Off Reserves

Advisories are issued for many different reasons. The second paper in this thesis describes the reasons for issuing advisories on and off reserve. The specific objectives of this work were to:

- Describe the reasons for issuing advisories on and off reserve among communities which experienced an advisory during the study period
- For each of the most common reasons for issuing advisories, investigate differences in the proportions of total advisories issued in towns, villages, and reserves compared with each other within each reason. The durations of advisories were also compared between reserve and non-reserve communities for each of the most commonly reported reasons.

- For each of the most common reasons for issuing advisories, investigate differences between northern or southern Saskatchewan in the proportion of total advisories issued as compared to the expected values based on the proportion of communities in each region experiencing at least one advisory. Differences in the duration of advisories were also compared across regions of the province .
- Seasonal and temporal differences were similarly investigated for each of the most commonly reported reasons for advisories.

As was the case with the first paper, no other comparisons have been identified to date regarding differences in advisory reason between reserve and non-reserve communities. Understanding the reasons for advisories being issued will assist in planning targeted interventions which could help mitigate the underlying issues which cause advisories to be issued.

CHAPTER 3: THE WATER IS ALWAYS BLUER ON THE OTHER SIDE: A COMPARATIVE ANALYSIS OF DRINKING WATER ADVISORIES IN COMMUNITY WATER SYSTEMS IN SASKATCHEWAN, ON AND OFF FIRST NATIONS RESERVES FROM 2012-2016

This chapter describes the relative number and duration of drinking water advisories in effect in incorporated cities, towns, villages, and reserves that had advisories issued in Saskatchewan from 2012 to 2016. The proportions of total advisories issued on and off reserve during the study period were compared to the expected values based on the proportions of reserve and non-reserve communities that experienced at least one advisory. Similar analyses were completed investigating differences across geographic region, as well as season and year issued. The duration of advisories was compared among community types, seasons issued, years issued, and geographic regions. This analysis represents a novel and important step in understanding the scope of the drinking water problem on reserve.

The Water is Always Bluer on the Other Side: A comparative analysis of drinking water advisories in community water systems in Saskatchewan, on and off First Nations reserves from 2012-2016

2.1 Introduction

First Nations communities across Canada face numerous barriers to safe and sustainable community water treatment systems. In Canada, there are over 600 First Nations Bands and 3100 reserves. The provision of safe and sustainable drinking water supplies for Indigenous communities faces continued challenges such as access to adequate source water, infrastructural limitations due to geography (i.e., permafrost, shield), and protection of water from contamination. Growing populations, remoteness, and poor economic conditions also cause difficulties (Lebel & Reed, 2010). Reserve communities are small, which precludes them from taking advantage of economies of scale (Dore, 2015). Policy, funding, and design hurdles compound the problems. Additionally, First Nations communities systematically lack source water protection programs (Simms, 2015).

Below 60 degrees of latitude, drinking water provision to First Nations communities is controlled by a variety of regulatory agencies, including Health Canada and Aboriginal Affairs Canada and Northern Development Canada, along with First Nation bands and Environment Canada (First Nations and Inuit Health Health Canada, 2016; Mcleod et al., 2014). This complicated structure contrasts with non-reserve communities, whose water is provided by the municipal and provincial governments. In Saskatchewan, a crown corporation, called the Water Security Agency (WSA) has overseen community water systems since 2012 (Water Security Agency, 2017a).

Boil water advisories are issued whenever drinking water fails to meet regulatory guidelines (Macintosh, 2009). Advisories are meant to be temporary, to protect public health, and are therefore not intended to be in place long term (Macintosh, 2009). Despite this, advisories may last months or, occasionally, years. Unfortunately, advisories are often not followed by communities and when they are followed, purchasing bottled water or boiling water has a negative economic impact (Lindell, et al, 2015).

Current federal policy states that drinking water systems on reserves should be equivalent to non-reserve communities of similar size and remoteness (MacIntosh, 2009). Nevertheless, disparities in access to safe drinking water in Canada have been identified between reserve and non-reserve communities: waterborne illness rates are higher on reserve than off reserve (Patrick, 2011; Basdeo & Bharadwaj, 2013; Bradford, et al, 2016). Recently, bacteriologic testing done in homes on reserve found waterborne coliforms even if the water had met regulatory requirements upon leaving the plant (Farenhorst, et al, 2017).

While these factors, combined with anecdotal evidence of First Nations communities with long term boil water advisories have been used convincingly to show that there is a drinking water disparity between reserve and non-reserve communities in Canada, no published quantitative comparative analysis has been identified. One study investigated factors which predicted having a drinking water advisory active in communities in interior BC in 2011 and found that governance type, water source, and treatment method were all important factors (Edwards, et al, 2012). Another study has been completed investigating factors predictive of having a drinking water advisory on reserve at a point in time using administrative data from the Neegan Burnside report (Murphy, et al, 2016). And finally, one study has described drinking water advisories affecting Ontario reserves from 2004 to 2013 (Galway, 2016). This study reviewed the prevalence of drinking water advisories during their study period and investigated temporal trends in advisory issuing as well as the issuing reason for advisories and the characteristics of plants at which advisories had been issued (Galway, 2016). Galway's analyses used descriptive statistics almost exclusively and did not compare to non-reserve communities of similar size.

Quantitative data about the prevalence, duration, and causes of drinking water advisories is currently lacking both in terms of reserve water systems themselves and comparisons of reserve water system outcomes to those off reserve among communities experiencing an advisory. This project was initiated to investigate patterns of drinking water advisories on First Nations reserves across Saskatchewan and to compare reserve and non-reserve communities in Saskatchewan regarding these factors. For example, analyses were conducted comparing the proportion of communities experiencing an advisory which were reserves to the proportion of advisories experienced by reserve communities.

2.2 Materials and Methods

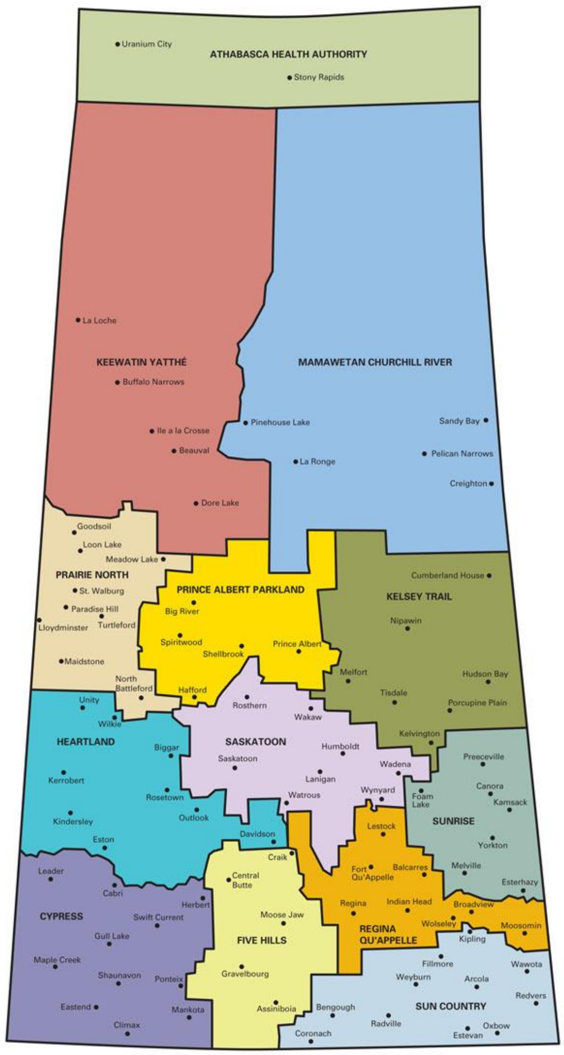
2.2.1 Study Area and Study Design

This cross-sectional investigation included all reserve and incorporated non-reserve communities in Saskatchewan that had an active drinking water advisory from 2012 through 2016. The analysis did not include First Nations which are a part of the Saskatoon tribal council as their data is not available. Communities which did not experience an advisory during the study period were also excluded from the analyses.

Saskatchewan is home to 3.1% of Canada's population (Statistics Canada, 2017). It has 70 First Nations reserves and the second largest percentage of First Nations people among the provinces. There are 16 cities in the province, defined as communities with more than 5000 residents, and many small communities: 147 towns and 256 villages (Statistics Canada, 2016). In 2011, 138,296 (13.38%) Saskatchewan residents lived in towns while 42,304 (4.09%) lived in villages (Statistics Canada, 2016). Over half of Saskatchewan's residents lived in cities in 2011, 595,678 (57.64%) (Statistics Canada, 2016).

Unlike Quebec, Ontario, Alberta, British Columbia, Prince Edward Island, New Brunswick, and Nova Scotia, Saskatchewan does not have counties and therefore such municipal barriers cannot be used as a regional marker in the province. However, the administrative boundaries forming the province's eleven health regions are often utilized similarly to county boundaries for research purposes. A map of the health regions is shown in **Figure 2.1**, reproduced from Sask Surgery, 2018. During the study period, health regions were an important stakeholder in issuing municipal boil water advisories, and for the purpose of this thesis, health region boundaries were utilized. However, all health regions were merged in December 2017 to create the Saskatchewan Health Authority and thus, these boundaries will therefore be outdated for future analyses (Saskatchewan Health Authority, 2018). Northern health regions were defined as the Athabasca Health Authority, Keewatin Yatthe Health Region, Mamewetan Churchill River Health Region, Prairie North Health Region, Prince Albert Parkland Health Region, and Kelsey Trail Health Regions while southern health regions were defined as the Heartland Health Region, Saskatoon Health Region, Sunrise Health Region, Cypress Health Region, Five Hills Health Region, Regina Qu'appelle Health Region, and Sun Country Health Region.

Figure 2.1: Health Regions in Saskatchewan



Reproduced from (Sask Surgery, 2018)

2.2.3 Data Sources

Administrative data from FSIN was obtained which included lists of drinking water advisories affecting community water systems on Saskatchewan's First Nations reserves, except for those in the Saskatoon Tribal Council, whether they were active or rescinded for each year 2012-2016. Each dataset listed the FN and provided information on the date the advisory was issued and rescinded and included the issuing authority which caused the advisory to be put in place as well as the reason(s) for the advisory's issuing. The scope of the advisory was also included, both in terms of the number of connections serviced by the water treatment system for which an advisory had been given and in terms of the approximate number of people whose homes it would affect. The date that the advisory was rescinded was included alongside the information regarding its issuing.

Similar administrative data was provided for non-reserve communities using data from the Water Security Administration (WSA) for each year from 2000 to 2016. These files contained lists of issuing orders, changes made to existing advisories, and orders to rescind an advisory. These datasets included all drinking water systems off reserve in Saskatchewan, excluding wells servicing a single home, and included the annual datasets for each year from 2000-2016. The scope of each advisory was not included as a separate variable. However, often it would be noted that the advisory affected only a given building or set of streets. This dataset included the same parameters as those described previously, except that it omitted information regarding the number of connections affected by the advisory and the population approximately affected by the advisory.

The two data sets were not always comparable. Fields available in datasets for reserve and non-reserve communities are shown in **Table 2.1**. Some seemingly simple variables of interest, such as the type of water source for all Saskatchewan water treatment systems, were not included in either data set.

Table 2.1: Advisory Information Available from Regulatory Agencies

Advisory Information	FSIN	WSA
Advisory type	X	X

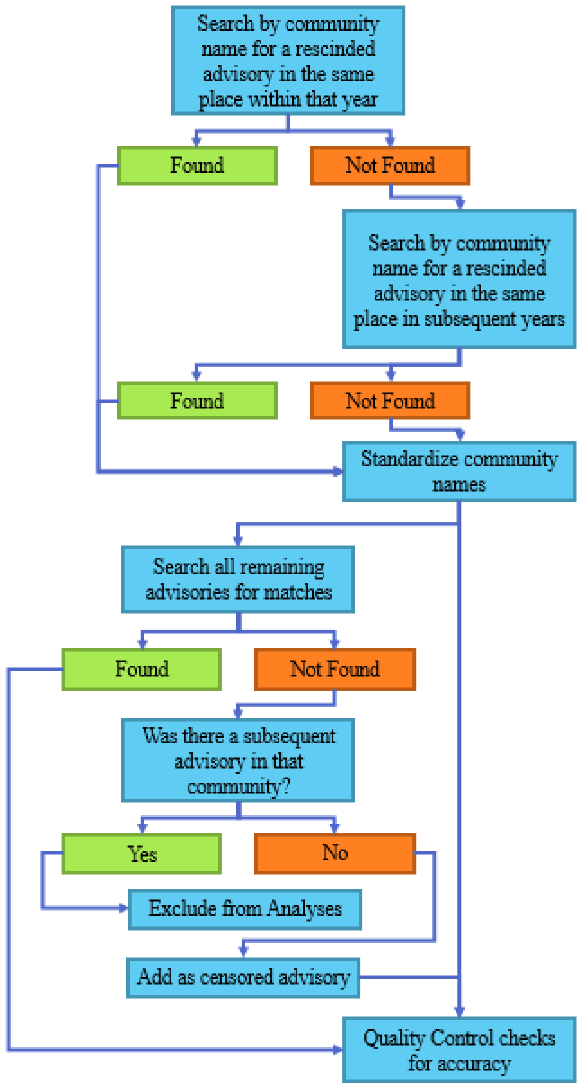
Ongoing advisories listed each year	X	
Scope of advisory	X	
End date listed alongside start date	X	
Reasons for advisory	X	X
Advisory issuing authority	X	X
Rescinding authority	Implied	X
Method of ending advisory	X	X
Date regulatory agency received advisory information		X

Covered population data was obtained from Saskatchewan Health, which included the population covered under the Saskatchewan provincial health plan across communities as of June 30, for each year from 2012 to 2016. These data were used to categorize the advisories listed in the WSA from cities [>5000 inhabitants], towns [>500, <5000], and villages [<500] within each Health Region. Community location were geolocated and dichotomized as northern or southern based upon the health region in which the community was situated, as described above.

A drinking water advisory was defined as any advisory or order relating to community drinking water. These include precautionary drinking water advisories, emergency boil water orders, and do not drink/consume orders. Given variation in issuing patterns between reserve and non-reserve communities, all types of advisory were used together as a single variable. An advisory was also considered to have ended if it switched types (from a PDWA to an EBWO, for example) as a new order was given to initiate the new type of advisory.

Records of an advisory's issuing with its rescinding were paired; a flow chart showing the scheme for matching the issuing of an advisory with its rescinding is shown in **Figure 2.2**

Figure 2.2: Flow Chart: Matching Advisory Issuing to Rescinding, Non-Reserve Communities



Duration for communities off reserve was calculated by subtracting the date issued (or censored) from the date rescinded (or censored) and then adding 1. When calculating the duration of advisories which were issued before 2012, the duration was calculated using January 1, 2012 as a start date. The duration of drinking water advisories was provided by FSIN, though the date issued was changed January 1, 2012, as previously described, for pre-existing advisories. The last date at risk was set at December 31, 2016 for both reserve and non-reserve communities, with the maximum possible duration as 1827 days. The date issued was used to derive a variable for year issued, with the possible range from 2000-2016, and a variable for season issued ("Spring": March, April, May; "Summer": June, July, August; "Fall": September, October, November; "Winter"; December, January February.)

The water system for which the advisory was given was classified as: park, industry, commercial, trailer park, campground, and subdivision for advisories occurring outside of community water systems. Water treatment systems which serviced provincial parks, industrial facilities such as mines, commercial single buildings such as rural restaurants, campgrounds, or RV parks were excluded from the analysis as they are not comparable with drinking water advisories affecting reserve communities. Water treatment systems active in hamlets, which are unincorporated communities of any size in Saskatchewan, were also excluded from the analysis as they were deemed non-comparable with reserve communities as they are not incorporated. If a system was only utilized seasonally (defined by seasonal start up as an issuing reason for the water treatment system), that system was excluded from the analysis.

Advisories were considered to have ended if they were rescinded by issuing authorities, switched type (for example, from a precautionary drinking water advisory to an emergency drinking water order), or if the system was decommissioned and deemed a hygienic system. Therefore, if the advisory switched types, the same event could lead to multiple advisories, which could be a source of bias. Additionally, right censored advisories were included in the data set, as described above.

2.2.4 Data Analysis

The first group of outcome variables utilized in the study included the proportion of total advisories with each characteristic of interest (observed value) compared with the proportion of communities with that characteristic that had experienced an advisory during the study period (expected value) (see **Table 2.2** for a full list). The second was the duration of advisories with each characteristic of interest. Factors of interest included comparisons of reserve and non-reserve communities, community type, geographic region, season issued, and year issued. Variables shown in the analyses are shown in **Table 2.2**.

Table 2.2: Factors of interest when comparing relative frequency and duration of drinking water advisories in communities with reported advisories

Variable	*Category*	*Description*
Community Type	City	Community off reserve with ≥5000 residents
	Town	Community off reserve with <5000 and ≥500 residents
	Village	Incorporated community off reserve with <500 residents
	Reserve	First Nations Reserve community, any size
Geographic Region	Northern HR	Any of the six northern HRs in SK, described above
	Southern HR	Any of the six southern HRs in SK, described above
Season Issued	Spring	March, April, May
	Summer	June, July, August
	Fall	September, October, November
	Winter	December, January, February
Year Issued	2000-2016	Year the advisory was issued

Tests of proportion were utilized to determine the significance of relative differences in the total reported advisory counts vs community type, geographic region, or the season/year in which the advisory was issued. The proportion of total advisories issued in a community type during the study period was compared to the proportion of communities that experienced at least one advisory that were of that same type. For example, the proportion of advisories that were experienced by reserve communities was compared to the proportion of communities which experienced an advisory that were reserves. A full list of comparisons used is shown in **Table 2.3**. Where more than two categories were utilized in the analyses, comparisons were done iteratively.

Table 2.3: Proportions Compared

	Observed proportion of total advisories	*Expected proportion based on relative frequency of communities*	*Categories Used*
Overall Comparison *Compared the proportions of*	Advisories experienced in communities	Communities which experienced an advisory	- First Nations - Non-First Nations
Community Type *Compared the proportions of*	Advisories experienced in communities	Communities which experienced an advisory	- Cities - Towns - Villages - Reserves
Season Issued – Reserve communities *Compared the proportions of*	Advisories experienced in communities in season B	Advisories experienced in communities in season A	- Spring - Summer - Fall - Winter
Season Issued – Non-Reserve communities *Compared the proportions of*	Advisories experienced in communities in season B	Advisories experienced in communities in season A	- Spring - Summer - Fall - Winter
Year Issued – Reserve communities *Compared the proportions of*	Advisories experienced in communities in year B	Advisories experienced in communities in year A	- 2012 - 2013 - 2014 - 2015 - 2016
Year Issued – Non-Reserve communities *Compared the proportions of*	Advisories experienced in communities in year B	Advisories experienced in communities in year A	- 2012 - 2013 - 2014 - 2015 - 2016
Geographic Region – Non Reserve communities *Compared the proportions of*	Advisories experienced in communities in geographic region B	Advisories experienced in communities in geographic region A	- Northern HRs - Southern HRs

The duration of a given advisory was investigated using Kaplan-Meyer survival analyses graphically and was analyzed using the Kruskal-Wallis one-way ANOVA followed by pairwise Mann Whitney U tests as the duration of advisories was not normally distributed. For the post-hoc, pairwise comparisons were completed iteratively to determine which comparisons showed statistically significant differences in median.

Cases with missing values were excluded from the analyses. However, if covered population data was missing or if the health region of a community could not be determined, that case was only excluded in tests using geographic region but was included in all other analyses. For example, Kiskaciwan's Health Region could not be geolocated and so that community was not included in tests regarding geographic region, but it was included in all other analyses.

Analyses were completed in STATA (versions 15.1) for the Kruskal Wallis ANOVA and Mann Whitney U test and in Microsoft Excel for tests of proportion (**Equation 2.1**).

$$z = \frac{\left(\frac{x_1}{n_1}\right) - \left(\frac{x_2}{n_2}\right)}{\left(\frac{x_1 + x_2}{n_1 + n_2}\right)\left(1 - \left[\frac{x_1 + x_2}{n_1 + n_2}\right]\right)\left(\frac{1}{n_I} + \frac{1}{n_2}\right)} \tag{2.1}$$

2.3 Results

2.3.1 Overall Data

On and off reserve, 2036 advisories were active during the study period (January 1, 2012-December 31, 2016), across 445 separate communities in Saskatchewan. The study period was 1827 days long, so that advisories could have a calculated duration of 1 day to 1827 days. A median duration of 8 days was observed.

2.3.2 Comparison of Proportion of Total Advisories Issued vs. Proportion of Communities of each Type with an Drinking Water Advisory

The proportion of advisories issued in cities (4.2%) was not significantly different than the proportion of cities among communities experiencing an advisory (2.7%, p=0.17) (**Table 2.4**). The proportion of total advisories issued in towns (36.9%) was larger than the proportion of towns among communities experiencing an advisory (27.7%, p<0.01). In contrast, the proportion of total advisories issued in villages (43.0%) and reserves (15.9%) were smaller than the proportions of villages and reserves among communities experiencing an advisory (49.8%, p<0.01 for villages; 19.8%, p=0.01 for reserves).

Table 2.4: Proportion of Total Advisories Issued Compared to Expected Values Based on Relative Frequency of Community Types with a Drinking Water Advisory

Community Type	*N (com.)*	*% (com.)*	*N (advisories)*	*%(advisories)*	*p-value*
	Expected relative frequency		Observed relative frequency		
City	12	2.7	86	4.2	0.17
Town	125	27.7	751	36.9	<0.01
Village	216	49.8	875	43.0	<0.01
Reserve	87	19.8	324	15.9	0.01
Total	*440*	-	*2036*	-	-

2.3.3 Comparison of Drinking Water Advisories between Geographic Regions

For communities outside of reserves, there was a significant overrepresentation of the total advisories issued in northern communities compared with the proportion of northern communities among communities experiencing advisories (p<0.01) (**Table 2.5)**. However, this difference was not significant for communities on reserve, though the direction was the same as that for non-reserve communities (p=0.11). The lack of significance may be due to a lack of power as the direction of the difference is the same as that identified for reserve communities.

Table 2.5: Proportion of Advisories by Geographic Region

Geographic Region	*N (geographic region)*	*% (geographic region)*	*N (advisories)*	*%(advisories)*	*2 tailed p-value*
Northern HR	144	33.4	775	39.0	0.03
Southern HR	287	66.6	1211	61.0	0.03
Total	435	-	1986	-	-
Northern FN	61	76.3	236	84.0	0.11
Southern FN	19	23.8	45	16.0	0.11
Total	80	-	281	-	-
Northern NFN	83	19.08	539	27.14	<0.01
Southern NFN	269	61.84	1166	58.71	<0.01
Total	351	-	1705	-	-

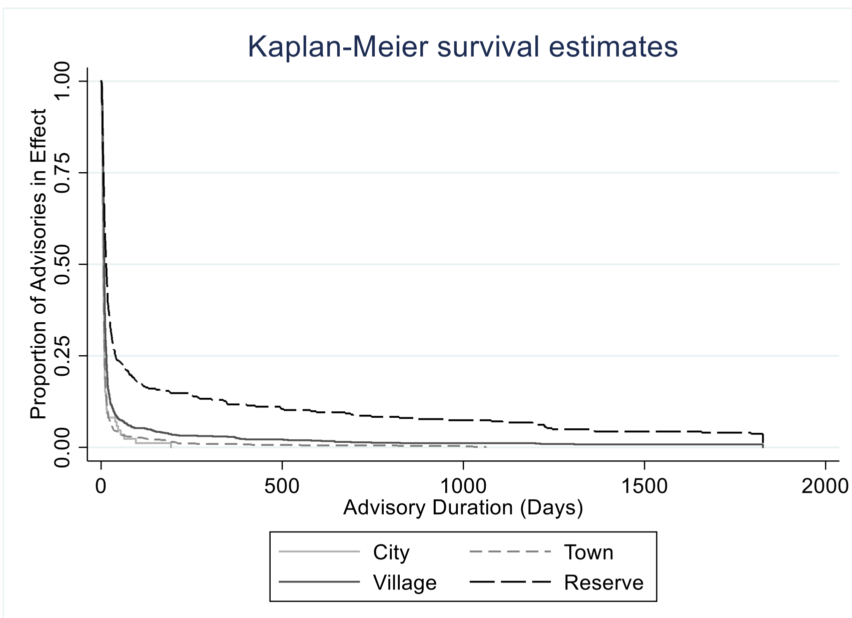
2.3.4 Advisory Duration by Community Type

The duration of advisories by community type was explored with the Kruskal-Wallis ANOVA given the right skew of the data (global p<0.01). Pairwise comparisons were all statistically significant (City-Town p=0.01 all other pairwise p<0.01). Kaplan Meyer survival curves of advisory duration are shown in **Figure 2.3** and descriptive statistics by community type are shown in **Table 2.6**.

Table 2.6: Advisory Duration (days) by Community Type

	N	*Minimum (days)*	*Q1 (days)*	*Median (days)*	*Q3 (days)*	*Maximum (days)*	*Mean (days)*	*Standard Deviation*
City	86	1	4	6	9	193	12.0	24.4
Town	751	1	5	7	10	1063	18.9	79.7
Village	875	1	6	9	15	1827	43.7	191.2
Reserve	324	1	7	14	39	1827	171.0	427.0
Overall	2036	1	5	8	14	1827	53.5	223.1

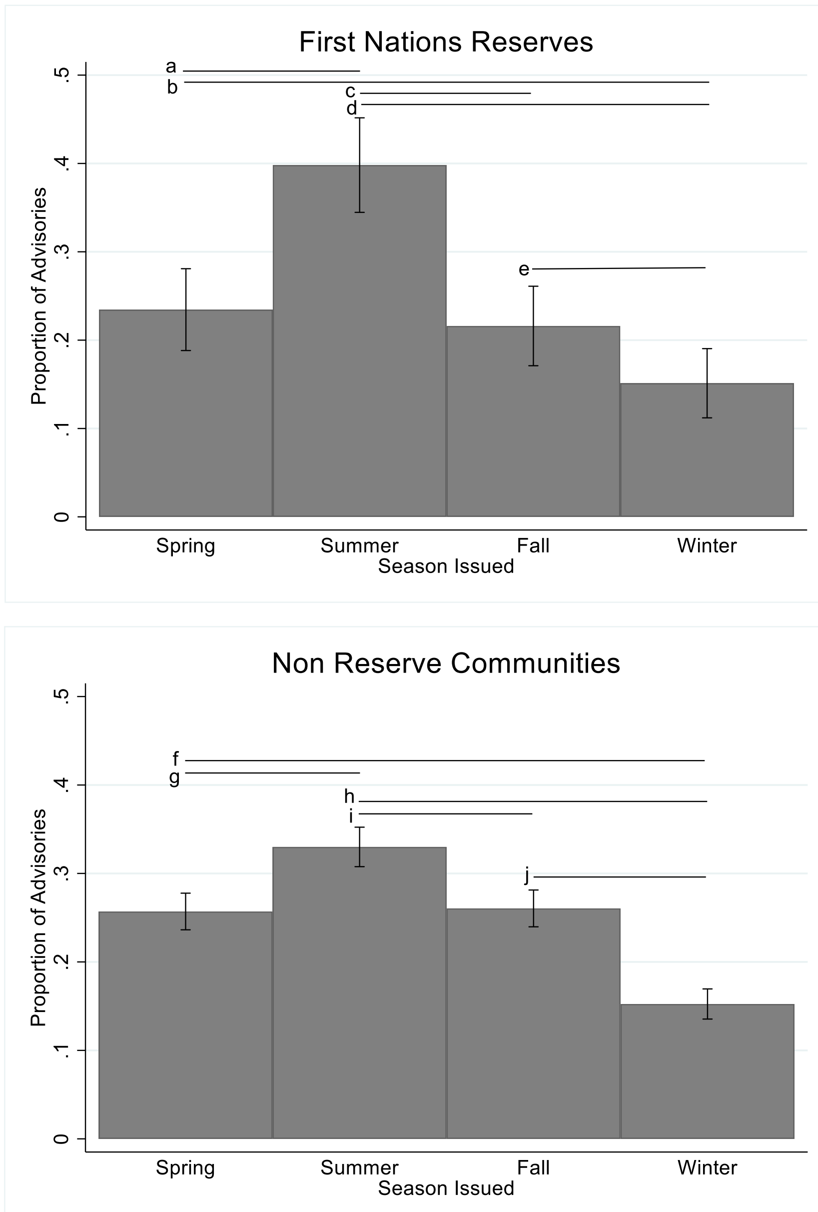
Figure 2.3: Survival Curve of Advisory Duration by Community Type



2.3.5 Advisory Seasonality

Drinking water advisories both on and off reserve were found to be most common in the summer months and least common in winter months (displayed in **Figure 2.4** with 95% confidence error bars). Pairwise comparison showed that for both reserve and non-reserve communities, advisory issuing was not statistically different in spring and fall (reserve p=0.57, non-reserve p=0.81). All other pairwise p-values were found to be <0.01, except for non-reserve Spring-Winter (p=0.01) and reserve Fall-Winter (p=0.03).

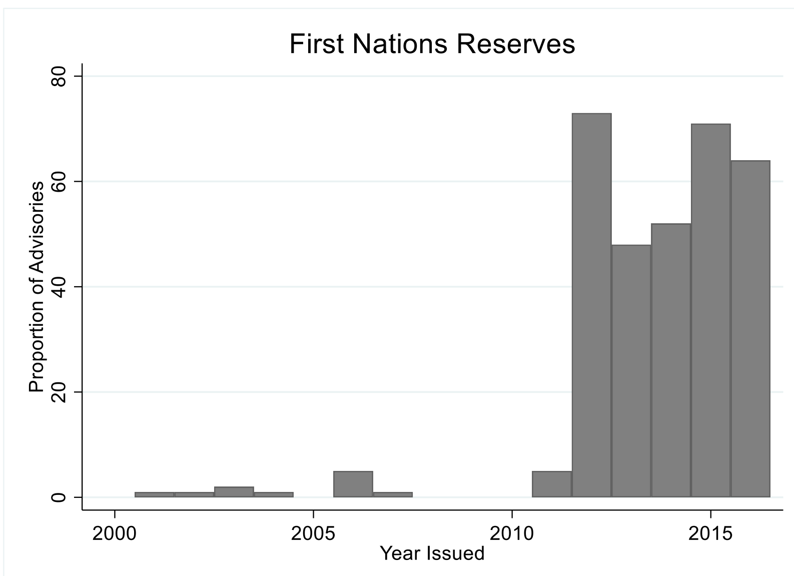
Figure 2.4: Proportion of Advisories on and off Reserve across Seasons

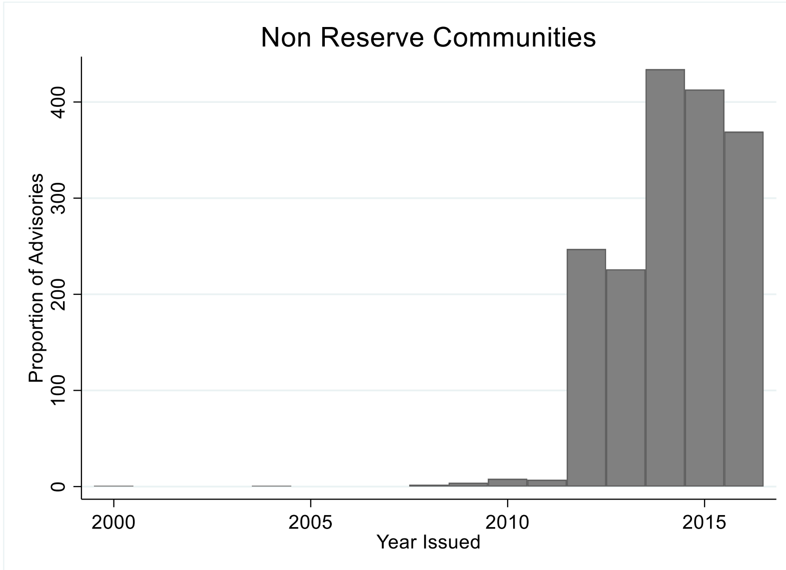


Legend: Significant differences are shown with black markers: (a) – (e) indicate comparison between reserve communities with (a) between spring and summer, (b) between spring and winter, (c) between summer and fall, (d) between summer and winter and winter, and (e) between fall and winter. (f) – (j) indicate comparison between non-reserve communities with (f) between spring and winter, (g) between spring and summer, and (h) between summer and winter (i) between summer and fall, and (j) between fall and winter.

The year of issuing for both prevalent and incident advisories by community type is shown in **Figure 2.5**. Prevalent advisories were issued as long ago as 2001 and 2000 on and off reserve, respectively. However, most advisories under study were issued between 2012 and 2016 (308 advisories on reserve and 1689 advisories off reserve). The years advisories were issued are shown in **Figure 2.5** for all advisories which were in effect during the study period, regardless of year issued and in **Figure 2.6** for advisories issued between 2012 and 2016 only, including 95% error bars based upon the proportion of advisories on or off reserve.

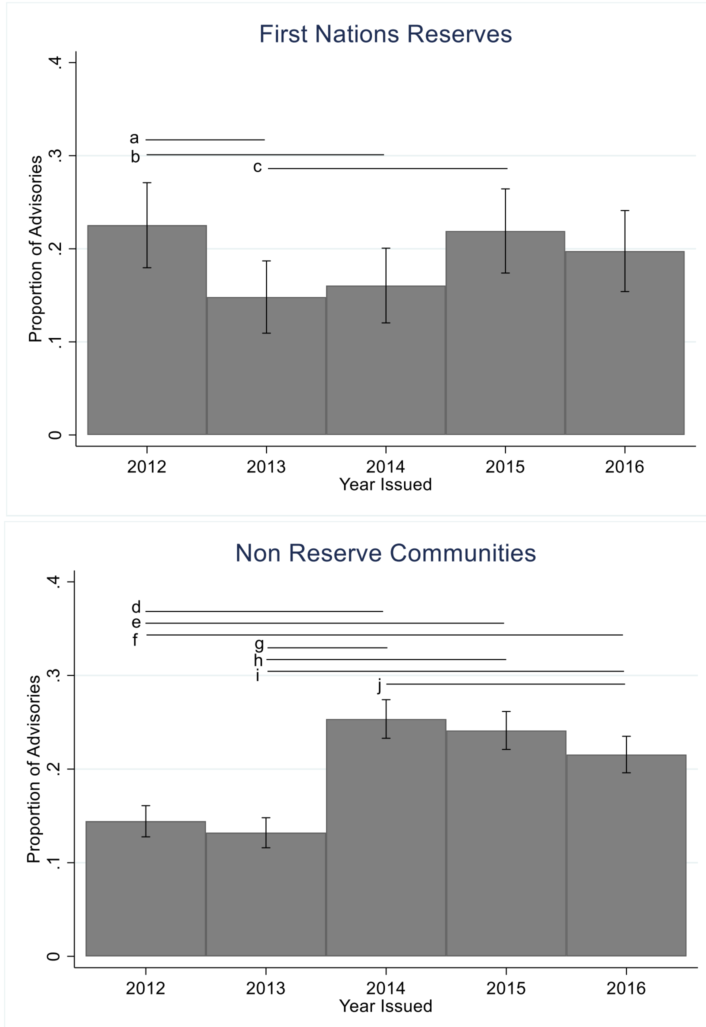
Figure 2.5: Proportion of Advisories on and off Reserve by Year Issued, 2000-2016





The proportion of advisories in a given year on or off reserve were compaired in pairwise fashion. Statistically significant differences are shown in **Figure 2.6** with black marker lines. Non-reserve communities experienced a spike in advisories in 2014 followed by small decreases in 2015 and 2016, while reserves had a decrease in advisories in 2013 folowed by an increase to approximately 2012 levels in 2015 and 2016.

Figure 2.6: Proportion of Advisories on and off Reserve by Year Issued, 2012-2016



Legend: Significant differences are shown with black markers: (a) – (c) indicate comparison between reserve communities with (a) between 2012 and 2013, (b) between 2012 and 2014, and (c) between 2013 and 2015. (d) – (j) indicate comparison between non-reserve communities with (d) between 2012 and 2014, (e) between 2012 and 2015, (f) between 2012 and 2016, (g) between 2013 and 2014, and (h) between 2013 and 2015 (i) between 2013 and 2016, and (j) between 2014 and 2016.

The duration of advisories on and off reserve by season issued is shown in **Table 2.7**. Kaplan Meyer survival curves are displayed in **Figure 2.7** and **Figure 2.8**. Off reserve, seasonality did not have an effect on advisory duration, with the median remaining at 8 days and a global

Kruskal Wallis one way ANOVA p-value of 0.28. On reserve, however, seasonality did have an effect ($p<0.01$). Pairwise comparison using the Mann Whitney U test showed that advisories given in winter were universally longer in duration than those given in other months (Winter-Spring $p=0.02$, Winter-Summer & Winter-Fall $p<0.01$). All other pairwise comparisons were not statistically significant.

Table 2.7: Advisory Duration by Season

	N	*Minimum (days)*	*Q1 (days)*	*Median (days)*	*Q3 (days)*	*Maximum (days)*	*Mean (days)*	*StDev*
Reserve	324	1	7	14	40	1827	171.1	427.0
Spring	76	2	8	15	53.5	1827	154.0	411.4
Summer	129	2	5	13	30	1827	122.6	335.6
Fall	70	1	6	12	21	1827	117.1	355.5
Winter	49	4	10	41	402	1827	402.2	644.1
Non Reserve	1712	1	5	8	12	1827	31.3	147.2
Spring	440	1	5	8	11	1827	26.0	121.3
Summer	565	1	5	8	13	1827	34.5	173.4
Fall	446	1	5	8	12	1827	33.7	159.0
Winter	261	1	5	8	12	819	29.0	95.5

Figure 2.7: Kaplan-Meier Advisory Survival Estimates by Season Off Reserve

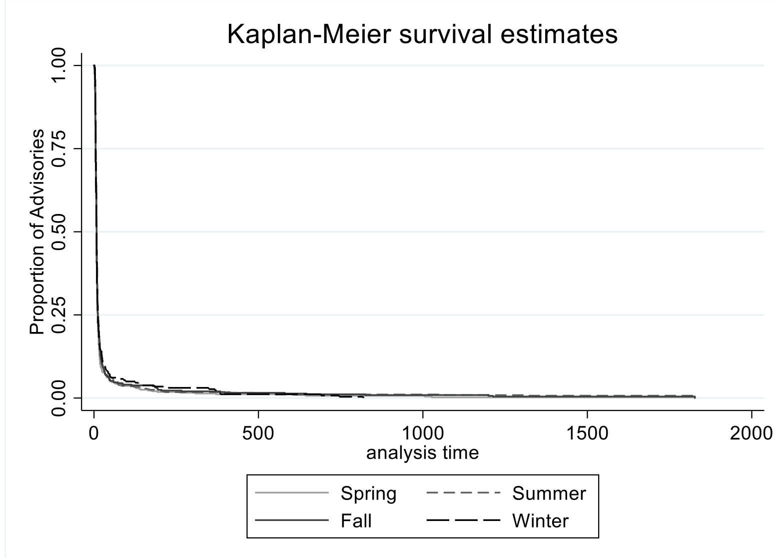
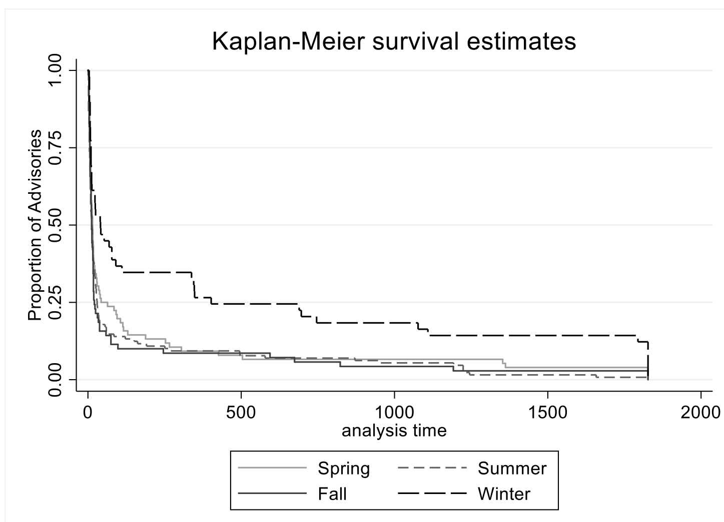


Figure 2.8: Kaplan-Meier Advisory Survival Estimates by Season On Reserve



2.4 Discussion

The proportion of total drinking water advisories which occurred on reserve was smaller than the proportion of reserves among communities experiencing an advisory, indicating that reserves experienced relatively fewer advisories than other community types. The same trend was found for villages, the smallest community type off reserve considered in this analysis. However, advisories on reserve lasted longer than those off reserve. While off reserve advisories were relatively equivalent from season to season, reserves experienced a spike in advisory length during the winter months. This may be due to difficulties in access for reserve communities in winter, as they tend to be in remote areas and may face challenges in obtaining the necessary parts and services to repair water treatment plant issues promptly during an advisory. These findings highlight the difficulties faced by reserve communities in resolving DWAs and highlight the importance of evidence for informed policy making directed at drinking water access and safety for reserve communities. Given how little research exists investigating differences in drinking water treatment system outcomes between reserve and non-reserve communities, this research is particularly important as it provides empirical results on which evidence based policy can be based. However, it also means it is impossible to place these results in the context of other research in the Canadian context.

The longer duration of reserve advisories is further evidence of disparities in the availability of safe drinking water for First Nations people living on Canadian reserve lands. This disparity may be due to differences in the quality of water treatment plants on reserve compared to non-reserve communities. Unfortunately, no data on drinking water plant capacity is available for non-reserve communities, but investigations of the role of water treatment plant characteristics and their effect on drinking water advisories is an important future aim of this research. This longer duration could also be due to differences in issuing reason for advisories on and off reserve, that is, if more serious issues at a plant are more likely to cause an advisory on reserve, it is logical that these advisories would be longer lasting. Another explanation for this longer duration of reserve advisories is potential differences with the issuing patterns and communication roles and responsibilities on and off reserve, given that reserve communities are regulated by the Canadian federal government and non-reserve communities are regulated by the provincial government. Additionally, on reserve, if an advisory is to last longer than 2-3 days, chief and council must submit a plan to ameliorate the problems underlying the advisory to Health Canada and INAC for review and, if not deemed sufficient, a plan is developed by the community based water team which was to have been previously established by chief and council (Health Canada, 2007). This system may perhaps cause undue delays in planning and implementing the necessary steps to remove the advisory. Finally, reserve communities tend to be very remote and may find it difficult to obtain the necessary parts or expertise to fix issues with water treatment plants in a timely manner, especially in the winter. Regardless of the contributions of each of these potential issuing reasons to the longer duration of reserve advisories, this lack of basic health and human services fails to meet the goals of the latest development goals from the UN, an experience not expected in a country such as Canada.

Over the course of time, the number of advisories in Saskatchewan communities (both on and off reserve) has increased. On reserve, advisories rose within the study period, with a significant jump between 2013 and 2014. The prevalence of advisories was also noted to increase across the most recent decade in Ontario reserves by Galway, 2016, a trend which was understandably also seen in Saskatchewan, as risks posed to community members by unsafe drinking water are approached with great caution in the wake of the Walkerton tragedy. While this caution is advised to prevent water borne illnesses, the economic effects of boil water advisories are only beginning to be quantified and understood. Boil water advisories are costly, both in terms of productivity and in terms of financial losses (Raucher, et al, 2014).

Smaller communities off reserve faced a smaller proportion of drinking water advisories, a trend which contrasts with what has been found in interior British Columbia in non-reserve communities (Edwards, et al, 2012). This research found that smaller communities and residential water systems serving smaller numbers of connections were associated with higher odds of experiencing a drinking water advisory in the year 2011 in a logistic model, however, these relationships lost statistical significance when other factors were added to the model (Edwards, et al, 2012). However, this research included small water systems, which served from 0-50 people, but communities of similar size in Saskatchewan were excluded due to concerns about data quality and the communities' lack of incorporation. Among these factors was government type, with systems overseen by a local government faring much better both in terms of having fewer advisories and in having advisories of shorter duration (Edwards, et al, 2012). It seems, therefore, that considerations of political capital should be included in intervention planning to mitigate the issues of advisories on reserve and in small communities off reserve. That towns experienced proportionally more advisories and villages experienced proportionately fewer may be due, at least in part, to the increased testing required of towns. For example, bacteriological testing for villages using groundwater as a source is required twice a month, while towns using groundwater must test weekly (Water Security Agency, 2012).

Advisories were found to be less common but longer on reserves in the winter. This is likely due to a lack of advisories due problems such as turbidity, which is caused by spring run off, and also by the lower risk of surface water quality problems than in summer months, which are caused by higher temperatures and lower water levels (Galway, 2016). Additionally, as discussed above, obtaining the parts required to fix an equipment malfunction is more difficult in winter, when road conditions are worse, especially for rural and remote communities, such as many First Nations reserves.

Off reserve, communities in the northern part of the province were subject to significantly more advisories and slightly longer advisory duration. This is likely due to their being, generally, smaller and more remote than southern communities, with understandably less capacity internal to the community to provide high quality drinking water as well as being characterized by more difficulty when trying to optain parts and expertise to repair breaks in water treatment plants. Such communities generally have large Indigenous populations and speak to challenges in obtaining clean and reliable sources of drinking water for Indigenous people in Saskatchewan. Additionally, advisories lasted longer off reserve based on the community type, with Cities having the shortest advisories, followed by Towns and, finally, Villages (the smallest community type). This is logical, as more sophisticated water treatment systems and plants are in place in larger communities alongside larger tax bases, larger social networks, stronger communication infrastructure, and increased political clout. Population movement also means that smaller centers are shrinking, further eroding the political, social, and economic capacity of these communities and making it harder for them to provide safe, clean water to their residents.

Given that Bill S-8 requires that reserves hold to the same drinking water standards as the province in which they are situated, despite drinking water on reserve being overseen by federal agencies, not provincial entities, it is important to compare reserves in Saskatchewan with non-reserve communities in the province. Additionally, the prevalence of drinking water advisories has been shown to vary by region, as Raucher et al showed in 2012 when comparing rates of advisories across US states. The use of a reference group of non-reserve communities for comparison has not been identified in published research prior to this project.

The study was limited by the nature of the data sets used, especially the WSA dataset. Because the WSA dataset lacks information alongside an order that had been issued about whether it had been rescinded or is ongoing, pairs had to be made between the issuing and rescinding of a given advisory, which created opportunity for bias. Long term advisories are also subject to significant error as it is possible that some advisories which are listed as ongoing were rescinded without the WSA having been contacted. The FSIN dataset also lists the scope of each advisory and the number of houses affected. Both advisory sets would have been assisted by information being included regarding the type of water treatment system used in each community. Such data is available from FSIN for reserves but is not available for non-reserve communities.

The large sample test of proportions has an assumption of independent proportions being used, which was violated for the analyses considered in this chapter which compared expected numbers of advisories based on the number of communities of each type which experienced an advisory to the observed number of advisories in that community type. The same violation of an assumption occurred when comparing across geographic regions. This problem creates questions regarding the validity of the findings and limits the weight that can be given to the conclusions included in this thesis. Adding communities which did not experience an advisory to the dataset and using a poisson or negative binomial regression would have facilitated stronger conclusions and would also have taken into consideration the effects of censoring that were included in the dataset. Multiple comparisons were utilized in tests of proportion without a global test statistic, causing a greatly increased risk of a type 1 error in the analyses. Use of the Bernouli correction for multiple comparison would have given a conservative estimate for the statistical significance of the findings when multiple comparison was used.

Censored data was utilized when calculating the duration of an advisory, however, no method was utilized to correct for potential biases which were introduced by utilizing censored data. The use of a test for the difference in survivor function using a cox correction would have been more appropriate and would have corrected for the use of censored data in the analyses.

Administrative data regarding water treatment systems in Canada could do much to inform public policy regarding water treatment both provincially and federally. As the new regulatory landscape since the passage of federal Bill S-8, (The Safe Drinking Water for First Nations Act, 2013), is developed, an increased commitment to easy access for researchers to administrative data is imperative to facilitate effective decision making and governmental planning.

2.5 Conclusions

Despite much political interest, many government funding programs, and a largescale project investigating reserve water treatment systems, no comparison has been made of drinking water advisories issued to communities on and off reserve to date. This research is therefore the first of its kind as advisories were examined over a five-year period among reserve and non-reserve communities. These investigations showed that advisories happened less often on reserve among communities experiencing an advisory and also showed that advisories on reserve are more severe than those off reserve as the median advisory on reserve lasted significantly longer than those on reserve, with the median advisory lasting 14 days on reserve, compared with 9 days in villages, the smallest community type off reserve. Seasonal trends were found in both community types, but were more pronounced on reserve. Off reserve, smaller communities experienced more and longer advisories, however, when these smaller communities were compared to reserves, reserves still experienced more and longer advisories than the small non-reserve communities. These results show the important differences in drinking water outcomes on and off reserve.

CHAPTER 4: WHY WE BOIL: A COMPARATIVE ANALYSIS OF DRINKING WATER ADVISORY ISSUING REASONS IN COMMUNITY WATER SYSTEMS IN SASKATCHEWAN, ON AND OF CANADA FIRST NATIONS RESERVES FROM 2012-2016

This chapter describes the reasons for issuing drinking water advisories in effect in Saskatchewan's incorporated cities, towns, villages, and reserves that had advisories which were active from 2012-2016. The proportion of advisories issued for each reason identified was described for reserve and non-reserve communities that experienced at least one advisory. Similarly, the proportions of advisories which were long and short term were also described for reserve and non-reserve communities for each reason. The duration of advisories was compared between reserve and non-reserve communities for each of the most common reasons for issuing advisories. Understanding differences in why advisories are issued is a critical step toward identifying the interventions that will bridge the gaps between reserve and non-reserve drinking water advisory outcomes.

Why We Boil: A comparative analysis of reasons for issuing drinking water advisories in community water systems in Saskatchewan, on and off Canada First Nations reserves active from 2012-2016

3.1 Introduction

Canadian water systems are regulated in a fragmented fashion that is characterized by a large amount of devolution, which includes jurisdictional overlap, lack of clarity and coordination in decision making, and competing interests among stakeholders (Bakker & Cook, 2011). Therefore, it is unsurprising that drinking water quality standards vary across Canadian jurisdictions with regard to what standards are enforced, whether or not they are legally binding, and the thoroughness with which they are monitored (Dunn, et al, 2015). Reserve communities across Canada face even more complex drinking water regulatory matrices, including many branches of the Canadian federal government, the provincial government in which the reserve lies, tribal councils, reserve communities, and other stakeholders.

Provision of safe drinking water for Indigenous communities is fraught with challenges such as access to adequate source water, infrastructural limitations due to geography and the threat of contamination (Boyd, 2011). Population growth, remoteness, and poor economic conditions also cause difficulties (Lebel & Reed, 2010). Reserve communities are generally small, which precludes them from utilizing economies of scale (Dore, 2015). Policy, funding, and design hurdles compound these problems. Additionally, First Nations communities systematically lack source water protection programs, which are considered an integral part of the modern multi-barrier approach to water treatment (Patrick, 2011). These issues have resulted in poor drinking water treatment systems across Canadian reserves with long term boil water advisories being common and rates of waterborne illness which were higher that in the general population (Patrick, 2011; Basdeo & Bharadwaj, 2013; Bradford, et al, 2016).

Similarly, small communities off reserve also face threats to their water security which put public health at risk. The same economies of scale are at work in these small communities and population shifts toward urban centers only exacerbate these difficulties. Challenges in meeting regulatory requirements on small budgets causes poor water outcomes, operator stress, and friction between community members and those tasked with keeping their water safe (Kot, et al, 2011). The costs of keeping up even simply with the educational requirements for operator certification can be prohibitive for small communities even as operators are under increased pressure to stand in the gap between their community members and waterborne hazards, which often leads to poor rates of operator retention and more risks to public health (Kot, et al, 2011).

If, for any reason, drinking water fails to meet the regulatory guidelines in place in a province, a drinking water advisory is issued. Drinking water advisories are temporary measures put in place to protect community members from waterborne hazards until water can be assured to be of at least minimum quality once again (Macintosh, 2009). If water is unsafe for human consumption unless boiled for any reason other than confirmed contamination, a precautionary drinking water advisory is issued, otherwise an emergency boil water order is distributed (Sun Country 2018; Health Canada 2015). For the sake of this paper, both types of advisories are referred to as drinking water advisories or advisories and are merged together in analyses.

Reasons for an advisory being issued include contamination by microbes, metals, or other toxins, loss of pressure in the distribution system, failure to meet treatment requirements, operator error, scheduled maintenance to the plant, emergency repairs, and many more (Health Canada, 2015). Understanding the reasons for issuing advisories could illuminate the factors associated with different advisory outcomes across community types. Despite this, very little research has been done to date on this topic. The only identified study investigated the most common reasons for drinking water advisories on First Nations lands in Canada and included a longitudinal review of advisory outcomes in Ontario (Galway, 2016). Despite the limited scholarly inquiry into this topic, it is important. Investigating the reasons for issuing drinking water advisories allows threats to public health to be identified and quantified.

This investigation seeks to characterize the reasons for issuing advisories on and off reserve and to assess differences between reserve and non-reserve communities in the length of advisories issued for the most common reasons.

3.2 Materials and Methods

3.2.1 Study Area and Study Design

A cross sectional study design was utilized to describe reserve and incorporated non-reserve communities with drinking water advisories which were in-effect between 2012 and 2016. Communities which did not experience an advisory during the study period, communities which were not incorporated, and reserves which are part of the Saskatoon tribal council were not available for analyses.

Saskatchewan is one of Canada's prairie provinces and is home to 3.12% of Canada's population (Statistics Canada, 2017). It also has the second largest percentage of First Nations people among Canadian provinces, with 34 First Nations reserves. Many of these are organized into the 10 tribal councils in the province. Reserves are located across the province but are concentrated in northern Saskatchewan. Off reserve, Saskatchewan has 16 cities, 147 towns, and 246 villages (Statistics Canada, 2011). In 2011, 595,678 people lived in Saskatchewan's cities, 138, 296 lived in towns, and 42,304 lived in villages (Statistics Canada, 2011).

3.2.3 Data Sources and Variables

A list of existing, new, and completed DWAS in Saskatchewan reserve communities for each year from 2012-2016 was obtained from the Federation of Sovereign Indigenous Nations (FSIN) and utilized for this study. All reserve communities with a DWA were included in the data set obtained from FSIN with the exception of reserve communities affiliated with the Saskatoon Tribal Council. This data set also included information regarding the reasons for issuing an advisory, the issuing authority, the scope of the advisory, and the type of advisory (precautionary drinking water advisory, emergency boil water order, do not use/consume order), and the type of water system (community, small system).

An administrative data set obtained from the Saskatchewan Water Security Agency (WSA) which included all drinking water advisories which have been given, rescinded, or were ongoing in SK non-reserve communities each year from 2012-2016 was utilized. A similar dataset was obtained from the Federation of Sovereign Indian Nations (FSIN) was also included in analyses, which included new, ongoing, and ended advisories for Saskatchewan reserves from 2012-2016. Both the WSA and FSIN datasets included the reasons for issuing an advisory.

Covered population data, obtained from Saskatchewan Health, which included the SK population covered under the provincial health plan across communities, was utilized in this study for the purpose of investigating the relationship between community size and drinking water outcomes. This data set provided information on community type (City [>5000 inhabitants], Town [>500, <5000], Village [<500], Hamlet [unincorporated, any size], and reserve) and the Health Region in which the community is located. Covered population data excludes population measures of many First Nations persons, as they are not covered by the provinces' health plan, as well as incarcerated persons and those who are a part of the RCMP or Canadian Armed Forces. To geographically describe the distribution of advisories across Saskatchewan, the health region in which each community is located was recorded, where available. Non-First Nation community location within health regions was determined using the covered population dataset and communities were dichotomized as northern (7 HRs) or southern (7 HRs) health regions.

Reasons for issuing a drinking water advisory were provided in free text form in both the FSIN and WSA datasets. The reasons for issuing a DWA were coded into dichotomous yes-no answers for each of possible reason, which were created inductively during a review of the dataset (Table 3.1). More than one reason could be coded for a single DWA. This occurred at times because codes varied in their specificity: known contamination with giardia would be coded with "known contamination", "microbes", and "giardia". A power outage causing depressurization would be coded "power outage" and "depressurization."

Repair work was provided as a reason for issuing a DWA in both the WSA and FSIN data sets. Given the difficulty of determining whether repair work was due to scheduled and routine maintenance, a planned construction/upgrades, or an emergency repair, all such activities were grouped into the category of "equipment failure/maintenance". Where possible, the specific areas of focus of equipment malfunction or repair work were also coded, be they water main, water line, reservoir, etc. Some misclassification error is suspected equipment repair or malfunction was noted in water pipes between reserve and non-reserve communities. Reserves more commonly reference water line failure while non-reserves note issues with the water main. Therefore, a water line/main variable was created and analyzed instead of the separate variables.

Table 3.1: Reasons for Advisory Issuing Categorical Variables

Issuing Reason	*Highlighted*
Break In	No
Depressurization	**Yes**
Discoloration	No
Disinfection Failure	**Yes**
- High Chlorine	No
- Low Chlorine	No
Equipment	**Yes**
- Breaker	No
- Construction	No
- Curb Stop	No
- Equipment Failure	No
- Hydrant	No
- Pump Failure	No
- Scheduled Maintenance	No
- Sewer Main/Line Failure	No
- Valve Failure	No
- Water Main Break	No
- **Water Main/Line Failure**	**Yes**
- Water Line	No
- Well Failure/Contamination	No
Filtration Failure	No
Firefighting	No
Flushing	No
Known Contamination	**Yes**
- Arsenic	No
- **Microbes**	**Yes**
○ Copepoedia	No
○ Cryptosporidium	No
○ E. coli/Coliform	No
○ Giardia	No
- Nitrate	No
- Potassium Permanganate	No

- Uranium	No
Lack of Treatment	**Yes**
Lack of Water	No
Not Compliant	No
Not in Use	No
Oil Spill	No
Operator Error	**Yes**
- No Samples	No
Possible Contamination	No
Poor Source Water	No
Power Outage	**Yes**
Raw water mixing with treated	No
Reservoir Failure	No
Sewage into Treatment System	No
Start Up*	No
- Start Up (New System)*	No
- Start Up (Seasonal)*	No
System Shutdown	No
Turbidity	**Yes**
Unknown	No
Upset Condition	No
Weather	No
- Flooding	No
- Freezing Water Mains	No
- Runoff	No
- Wildfire	No

The duration of a drinking water advisory in each reserve community listed in the FSIN data set was provided. The duration of a drinking water advisory for non-reserve communities listed in the WSA dataset was generated by subtracting the date an advisory was issued or January 1, 2012 (if the advisory was issued before the beginning of the study period) from the date it was rescinded or December 31, 2016 (if the advisory was in effect at the end of the study period) and adding 1, to include the day on which the advisory was issued into the count. The maximum duration of an advisory for the sake of the analyses included here was, therefore 1827 days, if an advisory was issued prior to January 1, 2012 and was in effect at the end of the study period. Advisories were coded as being short term in duration if they were 35 days or fewer and were coded as being long term in duration if they were longer than 35 days. The date the advisory was issued was coded based on season ("Spring": advisories issued in March, April, or May; "Summer": advisories issued in June, July, or August; "Fall": advisories issued in September, October, or November; "Winter"; advisories issued in December, January, or February.)

3.2.4 Data Analysis

Variables utilized in the comparative analysis of reasons for issuing a DWA in non-reserve and reserve communities in SK and the outcomes used to assess these reasons are shown in **Table 3.2**.

Table 3.2: Advisory Characteristics Categorical Variables

Variable	*Category*	*Description*
Community Type	City	Community off reserve with ≥5000 residents
	Town	Community off reserve with <5000 and ≥500 residents
	Village	Community off reserve with <500 residents (not classified as a hamlet)
	Reserve	First Nations Reserve community, any size
Geographic Region	Northern HR	Any of the six northern HRs in SK, described above
	Southern HR	Any of the six southern HRs in SK, described above
Season Issued	Spring	March, April, May
	Summer	June, July, August
	Fall	September, October, November
	Winter	December, January, February
Year Issued	2000-2016	Year the advisory was issued

The statistical analysis focussed on the duration of some of the most common reasons for issuing advisories: depressurization, equipment, water main/line, power outage, turbidity, disinfection failure, known contamination, lack of treatment, operator error, and microbes (**Table 3.1**). These reasons were highlighted because they were common or considered very important, and the coding was straightforward. The proportion of all advisories issued for each reason of interest was described for reserve and off reserve communities and for community types based on size. Season issued and geographic region were described for communities on and off reserve.

Differences in advisory duration for each reason across potential risk factors of interest was investigated using the Kruskal-Wallis one-way ANOVA followed by pairwise Mann Whitney U tests and was implemented because the duration of advisories was not normally distributed (STATA ver 15.1 College Station, Texas). Missing values for risk factors of interest were handled using listwise deletion of observations in each analysis. An example of this is the community of Kiskaciwan, whose health region could not be geolocated and, therefore, it was excluded from analyses of geographic region. However, advisories issued in Kiskaciwan were included in all other analyses.

3.3 Results

3.3.1 General Description of DWAs

2036 advisories were included in the analysis, across 445 separate communities (FN/non-FN). The median advisory duration was 8 days, with a minimum of 1 day, and a maximum of 1827 days (length of study period).

3.3.2 Proportion of Advisory by Reasons on and off Reserve

The proportion of advisories were determined by reason on and off reserve (**Table 3.3**).

Table 3.3: Proportion of All Advisories by Reason on and off Reserve

Issuing Reason	*N*	*NFN*	*%NFN*	*FN*	*%FN*
Break In	3	2	0.1	1	0.3
Depressurization	1460	1271	74.2	189	58.3
Discoloration	3	0	0	3	0.9
Disinfection Failure	74	35	2.0	39	12.0

- Low Chlorine	61	26	1.5	35	10.8
Equipment	1134	1050	61.3	84	25.9
- Construction	45	44	2.6	1	0.3
- Curb Stop	1	1	0.1	0	0
- Filtration Failure	2	2	0.1	0	0
- Hydrant	67	66	3.9	1	0.3
- Pump Failure	30	24	1.4	6	1.9
- Reservoir Failure	23	22	1.3	1	0.3
- Sewer Main/Line Failure	4	4	0.2	0	0
- Valve Failure	53	53	3.1	0	0
- Water Main/Line Failure	639	593	34.6	46	13.2
- Well Failure	3	3	0.2	0	0
Known Contamination	37	24	1.4	13	4.0
- Arsenic	4	3	0.1	1	0.9
- Microbes	18	9	0.5	9	2.8
o Cryptosporidium	2	1	0.1	1	0.3
o E. coli/Coliform	10	8	0.5	2	0.6
o Giardia	1	1	0.1	0	0
- Potassium Permanganate	5	4	0.2	1	0.3
Lack of Treatment	20	16	0.9	3	0.93
Lack of Water	19	12	0.7	7	2.2
Not Compliant	5	2	0.1	3	0.9
Not in Use					
Oil Spill	9	8	0.5	1	0.3
Operator Error	40	15	0.8	25	7.7
- No Samples	6	1	0.1	5	1.5
Possible Contamination	90	85	5.0	5	1.5
Poor Source Water	16	15	0.9	1	0.3
Power Outage	306	205	12.0	101	31.2
Raw water mixing with treated	7	6	0.4	1	0.3
Sewage into Treatment System	2	0	0	2	0.6
Start Up (New System)	29	29	1.7	0	0
System Shutdown	28	21	1.2	7	2.2
Turbidity	130	92	5.4	38	11.7
Unknown	8	8	0.5	0	0
Upset Condition	2	2	0.1	0	0
Weather	16	13	0.8	3	0.9
- Flooding	12	9	0.5	3	0.9
- Runoff	1	1	0.1	0	0
- Wildfire	2	0	0	2	0.6
Total Advisories	**2036**	**1712**	**-**	**324**	**-**

Depressurization (74.2% off reserve vs 58.3% on reserve) and equipment failure/maintenance (61.3% off reserve vs 25.9% on reserve) were among the most common reasons for issuing an advisory both on and off reserve; however, both made up a larger share of advisories issued off reserve. Water main or line issues also made up a larger share of reasons for issuing advisories off reserve (34.6% off reserve vs 13.20% on reserve). In contrast, power outages were more common reasons for issuing DWAs on reserve (12.0% off reserve vs 31.2% on reserve). Turbidity issues were also more common issuing reasons on reserve than off reserve (5.4% off reserve vs 11.7% on reserve) as were disinfection failures (2.0% off reserve vs 12.0% on reserve). Operator issues also made up a larger share of reasons for advisory issuing on reserve (0.9% off reserve vs 7.7% on reserve). Known contamination, which was defined as contamination of any type be it microbial or chemical, was more often a reason for issuing advisories on reserve (1.4% off reserve vs 4.0% on reserve) with contamination due to microbes showing the same trend (0.5% off reserve vs 2.8% on reserve). Lack of water – that is, a drinking water system not being able to draw water from the source, not a lack of pressure in the distribution system – was also a more common reason for advisory issuing on reserve (0.7% off reserve vs 2.8% on reserve).

3.3.3 Duration of Advisory by Reason

The proportion of non-reserve (**Table 3.4**) and reserve (**Table 3.5**) advisories by duration (short term vs long term) were compared. The percent of total short term and long term advisories are shown and, given that not all advisory issuing reasons were highlighted, the columns do not sum to 100%.

Table 3.4: Proportion of Long and Short-Term Advisories by Advisory Reason off Reserve

Off Reserve		Short Term		Long Term	
	N	N	%	N	%
Depressurization	1271	1230	77.6	41	32.3
Equipment	1050	1009	63.7	41	32.3
Water Main/Line	593	569	35.9	24	18.9

Power Outage	205	199	12.6	6	4.7
Turbidity	92	58	3.7	34	26.8
Disinfection Failure	35	16	1.0	19	15.0
Known contamination	24	19	1.2	5	3.9
Lack of Treatment	17	10	0.6	6	4.7
Operator error	15	10	0.6	5	3.9
Microbes	9	6	0.4	3	2.4
Total	1712	1585		127	

A larger share of reasons for issuing advisories off reserve that were short term was observed for a number of reasons, when compared to long term advisories off reserve, including depressurization (77.6% short term, 32.3% long term), equipment issues (63.7% short term, 32.3% long term), water main/line breaks (35.9% short term, 18.9% long term), and power outages (12.6% short term, 4.7% long term). Turbidity (3.7% short term, 26.8% long term), disinfection failure (1.0% short term, 15.0% long term), lack of treatment (0.6% short term, 4.7% long term), and operator error (0.6% short term, 3.9% long term), by contrast, made up a larger share of issuing reasons for issuing long term advisories than short term advisories off reserve.

Table 3.5: Proportion of Long and Short-Term Advisories by Advisory Reason on Reserve

On Reserve		Short Term		Long Term	
	N	N	%	N	%
Depressurization	189	165	69.3	24	27.9
Power Outage	101	94	39.5	7	8.1
Equipment	84	64	26.9	20	23.3
Water Main/Line	46	39	16.4	7	8.1
Disinfection Failure	39	17	7.1	22	25.6
Turbidity	38	19	8.0	19	22.1
Operator error	25	10	4.2	15	17.4
Known contamination	13	3	1.3	10	11.6
Microbes	9	2	0.8	7	8.1
Lack of Treatment	3	0	0	3	3.5
Total	324	238		86	

Among reserve communities, depressurization (69.3% short term, 27.9% long term), power outages (39.5% short term, 8.1% long term), and water main/line issues (16.4% short term, 8.1% long term), made up a larger share of reasons for issuing a short-term advisory than long term advisory. A nearly equivalent proportion of long and short-term advisories on reserve were issued because of equipment problems (26.9% short term, 23.3% long term). Disinfection failure (7.1% short term, 25.6% long term), known contamination (1.3% short term, 11.6% long term), lack of treatment (0% short term, 3.5% long term), and operator error (4.2% short term, 17.4% long term) were more found to make up a larger proportion of reasons for issuing long term advisories than short term advisories.

Table 3.6: Differences in Median Advisory Duration on and off Reserve

	N	*Q1 (days)*	*Median (days)*	*Q3 (days)*	*P*
Depressurization					**<0.01**
- Reserve	189	5	9	19	
- Non-Reserve	1271	5	7	10	
Power Outage					0.39
- Reserve	101	5	8	17	
- Non-Reserve	205	5	7	11	
Equipment					**<0.01**
- Reserve	84	6	12.5	30	
- Non-Reserve	1050	5	8	10	
Water Main Line					**<0.01**
- Reserve	46	6	11	24	
- Non-Reserve	593	5	7	10	
Disinfection Failure					0.12
- Reserve	35	9	40	193	
- Non-Reserve	39	15	49	871	
Turbidity					0.08
- Reserve	38	17	36.5	92	

- Non-Reserve	92	10.5	18.5	82.5	
Operator error					0.06
- Reserve	25	20	75	1109	
- Non-Reserve	15	7	18	60	
Lack of Treatment					**0.02**
- Reserve	3	305	1827	1827	
- Non-Reserve	16	10	14	120	
Microbes					0.08
- Reserve	9	151	495	1827	
- Non-Reserve	9	8	13	96	
Known contamination					**<0.01**
- Reserve	13	151	495	1794	
- Non-Reserve	24	3	8	14.5	
Overall					

Advisories on reserve lasted longer than non-reserve advisories for the same reason among advisories given for depressurization ($p<0.01$), equipment ($p<0.01$), water main/line break ($p<0.01$), lack of treatment ($p=0.02$) and known contamination ($p<0.01$) (**Table 3.6**). No statistically significant difference was observed among power outages ($p=0.39$), disinfection failure ($p=0.12$), turbidity ($p=0.08$), operator error ($p=0.06$), and microbes ($p=0.08$).

3.3.4 Community Type and Advisory Reason

Reserve communities were compared with non-reserve communities split by size into towns (between 500 and 5000 residents) and villages (incorporated communities of less than 500 residents) (**Table 3.7**). Given the small number of cities in Saskatchewan and the difference in size between cities and reserves, cities were excluded from the analysis. Because the percentages shown are the percent of total advisories within a community type and not all advisory issuing reasons were highlighted, the totals do not sum to 100%.

Table 3.7: Proportion of Advisories by Community Type and Advisory Reason

		Town		Village		Reserve	
	N	N	%	N	%	N	%
Depressurization	1394	574	76.4	631	72.1	189	58.3
Equipment	1070	568	75.6	421	48.1	84	25.9
Water Main/Line	603	341	45.4	216	24.7	46	14.2
Power Outage	297	44	5.9	152	17.4	101	31.2
Turbidity	128	25	3.3	65	7.4	38	11.7
Disinfect. Failure	73	11	1.5	23	2.6	39	12.0
Operator error	39	5	0.7	9	1.0	25	7.7
Known contamination	31	7	0.9	11	1.3	13	4.0
Lack of Treatment	17	8	1.1	6	0.7	3	0.9
Microbes	16	1	0.1	6	6.8	9	2.8
Total	1950	751	-	875	-	324	-

Depressurization made up a smaller share of advisory issuing reasons in towns versus villages (town 76.4%, village 72.1%). Reserves experienced a smaller proportion of depressurizations than other community types (58.3%). The same pattern held for equipment problems (town 75.6%, village 48.1%, reserve 25.9%) and for water main or line issues (town 45.4%, village 24.7%, reserve 14.2%).

Reserves had a larger share of advisories issued because of power outages (31.2%), followed by villages (17.4%), and finally towns (5.9%). The same pattern was observed for turbidity issues (reserve 10.8%, village 7.7%, town 3.4%), disinfection failure (reserve 12.0%, village 2.6%, town 1.5%), operator error (reserve 7.7%, village 1.0%, town 0.7%), known contamination (reserve 4.0%, village 1.3%, town 0.9%), and microbes (reserve 2.8%, village 0.7%, town 0.1%).

Table 3.8: Differences in Advisory Duration Across Community Types by Reason for Advisory

	N	*Q1 (days)*	*Median (days)*	*Q3 (days)*	*P(Town vs. Village)*	*P(Town vs. Reserve)*	*P(Village vs. Reserve)*
Depressurization	<0.01				<0.01	<0.01	0.03
- Town	574	5	7	9			
- Village	631	6	8	12			
- Reserve	189	5	9	19			
Power Outage	<0.01				<0.01	<0.01	0.77
- Town	44	4	5.5	8			
- Village	152	6	8	13			
- Reserve	101	5	8	17			
Equipment	<0.01				<0.01	<0.01	<0.01
- Town	568	5	7	10			
- Village	421	6	8	12			
- Reserve	84	6	13.5	30			
Water Main Line	<0.01				<0.01	<0.01	0.01
- Town	341	5	7	10			
- Village	216	6	8	12			
- Reserve	46	6	11	24			
Disinfection Failure	0.12						
- Town	11	15	71	192			

-	Village	23	7	18	195			
-	Reserve	39	15	49	871			
Turbidity		0.01				0.02	<0.01	0.42
-	Town	25	9	15	25			
-	Village	65	13	24	128			
-	Reserve	38	17	36.5	92			
Microbes		0.13						
-	Town	1	6	6	6			
-	Village	6	8	10.5	825			
-	Reserve	9	151	495	1827			
Lack of Treatment		0.05						
-	Town	8	10	12	19			
-	Village	6	10	205	746			
-	Reserve	3	305	1827	1827			
Operator error		0.19						
-	Town	5	7	18	26			
-	Village	9	8	18	120			
-	Reserve	25	20	75	1109			
Known contamination		0.02				0.29	<0.01	0.15
-	Town	7	3	6	12			
-	Village	11	3	8	825			
-	Reserve	13	151	495	1794			

Differences in the duration of a DWA by community type were calculated within advisory reasons were investigated (**Table 3.8**). No statistically significant difference in advisory duration by community type was observed for disinfection failure (p=0.12), microbes (p=0.13), lack of treatment (p=0.05) or operator error (p=0.19). It is likely that the lack of statistically significant difference for microbes and lack of treatment were due to the small number of advisories being issued for those reasons.

Advisories issued because of depressurization (global p-value <0.01) were found to be longest on reserves (median 9 days), followed by villages (median 8 days), and finally, by towns (median 7 days, pairwise p-values <0.01, except village vs. reserve, where p=0.03). The same pattern held for equipment failure (global p-value <0.01, all pairwise p-values <0.01) and water main/line issues (global p-value<0.01, pairwise p-values =<0.01).

Advisories issued due to turbidity (global p-value=0.01) were found to be shorter in towns when compared to villages (p=0.02) or reserves (p<0.01) but no statistically significant difference was found between villages and reserves (p=0.53). The same trend was seen for power outages (global p<0.01, pairwise p-values including town<0.01 while village vs reserve p=0.77), Differences in advisory duration were only found to be statistically significant for known contamination when villages were compared to reserves (p<0.01). However, only 7 advisories were issued because of known contamination in towns during the study period and so it is likely that the analysis lacked power.

3.3.5 Geography and Reason for Advisory

As described above, non-reserve communities were coded as being in either northern or southern health regions to enable the comparison of patterns of reasons for issuing an advisory across Saskatchewan (**Table 3.9** and **Table 3.10**).

Table 3.9: Proportion of Advisory Reason off Reserve by Geographic Region

Off Reserve		Southern		Northern	
	N	N	%	N	%
Depressurization	1268	849	72.9	419	77.7
Equipment	1043	729	62.6	314	58.3

Water Main Line	590	405	34.8	185	34.3
Power Outage	205	112	9.6	93	17.3
Turbidity	92	65	5.6	27	5.0
Disinfection Failure	35	31	2.7	4	0.7
Known contamination	24	13	1.1	11	2.0
Lack of Treatment	17	14	1.2	3	0.5
Operator error	15	6	0.5	9	1.7
Microbes	9	8	0.7	1	0.2
Total	1704	1165	-	539	-

Differences between communities in northern and southern communities were observed for depressurization (72.71% Southern, 77.74% Northern) and power outage (9.61% Southern, 17.25% Northern), and operator error (0.51% Southern, 1.67% Northern).

Table 3.10: Duration of Advisory by Geographic Region and Advisory Reason

	N	*Q1 (days)*	*Median (days)*	*Q3 (days)*	*P*
Depressurization					**<0.01**
- Southern	849	5	7	10	
- Northern	419	6	8	11	
Power Outage					**0.01**
- Southern	112	5	7	10	
- Northern	93	6	8	12	
Equipment					**<0.01**
- Southern	729	5	7	10	
- Northern	314	6	8	12	
Water Main Line					**<0.01**
- Southern	405	5	7	10	
- Northern	185	6	8	12	
Disinfection Failure					0.60
- Southern	31	9	46	195	
- Northern	4	12.5	17	69.5	

Turbidity						**0.02**
-	Southern	65	14	25	125	
-	Northern	27	9	15	25	
Microbes						>0.99
-	Southern	8	8	12	460.5	
-	Northern	1	13	13	13	
Lack of Treatment						0.84
-	Southern	13	10	12	120	
-	Northern	3	4	39	43	
Operator error						0.26
-	Southern	6	18	43	60	
-	Northern	9	7	8	18	
Known contamination						**<0.01**
-	Southern	13	8	12	96	
-	Northern	11	3	3	3	

Communities in Southern Health Regions showed longer median duration of advisories for depressurization ($p<0.01$), power outages ($p=0.01$), equipment ($p<0.01$), water main/line ($p<0.01$); while Northern HR communities had longer advisories for turbidity issues ($p=0.02$) and known contamination ($p<0.01$).

3.3.6 Season of Issuing and Advisory Reason

Table 3.11: Proportion of Advisories off Reserve by Season Issued

		Spring		Summer		Fall		Winter	
NFN	N	N	%	N	%	N	%	N	%
Depressurization	1271	335	76.1	421	74.5	320	71.7	195	74.7
Equipment	1050	265	60.1	320	56.6	310	69.5	155	59.4
Water Main/Line	593	176	40.0	176	31.2	133	29.8	108	41.4
Power Outage	205	56	12.7	84	14.9	38	8.5	27	10.3

Turbidity	92	28	6.4	34	6.0	18	4.0	12	4.6
Disinfection Failure	35	8	1.8	8	1.4	17	3.8	2	0.8
Known contamination	24	2	0.5	15	2.7	4	0.9	3	1.1
Lack of Treatment	16	5	1.1	3	0.5	3	0.7	5	1.9
Operator error	15	4	0.9	7	1.2	4	0.9	0	0.0
Microbes	9	1	0.2	3	0.5	3	0.7	2	0.8
Total		440		565		446		261	

Off reserve, no differences in the proportion of advisories for depressurization, turbidity, or lack of treatment were observed based on the season the DWA was issued (**Table 3.11**). Equipment issues made up a greater proportion of advisories in the fall when compared to all other seasons (69.5% for fall). Water main or line issues were more common among advisories issued in the spring (40.0%) or winter (41.4%), when compared to advisories issued in the summer (31.2%) or fall (29.8%). Power outages made up a larger proportion of advisories issued in the spring (12.7%) or summer (14.9%) when compared to the fall (8.5%). Disinfection failure made up a larger proportion of advisories issued in the fall (3.8%) than in the summer (1.4%).

Table 3.12: Proportion of Advisories on Reserve by Season Issued

		Spring		Summer		Fall		Winter	
FN	N	N	%	N	%	N	%	N	%
Depressurization	189	40	52.6	85	65.9	42	60.0	22	44.9
Power Outage	101	10	13.2	72	55.8	12	17.1	7	14.3
Equipment	84	28	36.8	18	14.0	21	30.0	17	34.7
Water Main/Line	46	19	25.0	7	5.4	11	15.7	9	18.4
Disinfection Failure	39	9	11.8	10	7.8	9	12.9	11	22.4
Turbidity	38	12	15.8	9	7.0	10	14.3	7	14.3
Operator error	25	4	5.3	11	8.5	5	7.1	5	10.2
Known contamination	13	1	1.3	5	3.9	3	4.2	4	8.2

Lack of Treatment	3	3	3.9	0	0	0	0	0	0
Microbes	9	0	0	4	3.1	1	1.4	4	8.2
Total	324	76		129		70		49	

Among reserve communities, a larger proportion of advisories due to depressurization occurred in summer (65.9%) when compared to the winter (44.9) (**Table 3.12**). Power outages were more common among advisories issued in the summer (55.8%) when compared to all other seasons (spring 13.2%, fall 17.1%, winter 14.3%). In contrast, equipment issues made up a smaller proportion of advisories given in the summer (14.0%) when compared to all other seasons (spring 36.8%, fall 30.0%, winter 34.7%). Water main or line issues followed the same pattern as equipment issues of any kind (summer 5.4%, spring 25.0%, fall 15.7%, winter 18.4%). Disinfection failure made up a higher proportion of advisories issued in the winter (12.9%) when compared to the summer (7.8%). Turbidity issues were more common in the spring than in the summer (15.8% vs 7.0%).

3.4 Discussion

This analysis was completed to determine whether there were differences in the reasons for issuing advisories between reserve and non-reserve communities in Saskatchewan from 2012 to 2016 and, if so, to characterize these differences. The analyses here found that depressurization was the leading cause of reserve advisories (58.3%), followed by power outages (31.2%), equipment failure (25.9%), water main/line issues (25.9%), disinfection failure (12.0%), turbidity (11.73%), and operator error (7.7%). An investigation of DWAs on Ontario reserves between 2004 and 2013 included 402 DWAs found that over half were caused by equipment malfunction (Galway, 2016). Other causes, in decreasing frequency were inadequate disinfection residuals, turbidity, operation of the system would compromise public health, unacceptable microbiological quality, and deterioration of source water quality (Galway, 2016). Galway's findings and the results in this thesis chapter are similar, though the categorization of advisories was likely different between the two analyses, and this agreement highlights the importance of turbidity and disinfection residuals to the functioning of water treatment plants on reserve.

Off reserve, however, the highest incidence reasons for drinking water advisories were depressurization (74.2% overall; 76.4% for towns and 72.1% for villages), equipment issues (61.3% overall; 75.6% for towns and 48.1% for villages), water main or line problems (34.6% overall; 45.4% for towns and 24.7% for villages), power outages (12.0% overall; 5.9% for towns and 17.4% for villages), and turbidity (5.6% overall; 3.3% for towns and 7.4% for villages). While the most common reason for both on and off reserve communities to call for an advisory was because of a loss of pressure in the system, equipment issues were a more frequent reason for advisories off reserve, even when comparing villages to reserves. In contrast, reserve systems face issues caused by power outages, turbidity, and issues with disinfection. While the percent of advisories in villages for these reasons was less than that for reserves, it was larger in villages than in towns, indicating that at least some of the disparity between reserve and non-reserve communities is due to factors which affect small communities more broadly, not reserve-specific concerns. The turbidity issues may be due to treatment practices but may also be caused by lower source water quality. Funding requirements for backup generators may not be available for reserve communities, meaning that each time an outage occurs, an advisory must be issued. Small communities often struggle to meet both safety and aesthetic guidelines due to smaller budgets and the difficulties associated with adequately treating water to meet the same regulatory requirements as large well-funded systems (Kot, et al, 2011).

While differences in advisory duration by community type (with non-reserve communities stratified by whether they were towns or villages) were observed for depressurization, power outages equipment problems, water main/line issues, turbidity, and known contamination, other highlighted reasons for issuing advisories were not statistically significant (disinfection failure, turbidity, microbial contamination, lack of treatment, and operator error). Pairwise comparisons showed statistically significant differences between reserves and villages for depressurization, power outages, equipment, and water main or line problems. Additionally, within the statistically significant reasons for issuing advisories, the size of the difference was diminished when reserves were compared with villages. For example, the median duration of advisories issued due to water main or line problems was 10 days in towns (communities off reserve with between 500 and 5000 residents), 12 days in villages, and 24 days on reserve. Similar trends were observed for advisories which were issued due to depressurization, equipment issues, water main/line problems, microbial contamination, lack of treatment, and known contamination. These results indicate that comparative analyses of reserve and non-reserve communities ought to consider community size when studies are designed. These smaller communities share difficulties associated with operator retention, small budgets, and shrinking populations (Kot, et al, 2011; Murphy, et al, 2015). An important area for future comparative work would be to focus on the issue of remoteness, to determine how drinking water advisory duration varies on and off reserve based upon distance from large city centers.

Power outages occurred as a much larger share of reserve advisories than non-reserve advisories and were also more clustered temporally in the summer. Off reserve, more power issues occurred in smaller communities, however, they remained at nearly half the proportion of advisories when compared to reserve communities. Reserve systems often lack generators to provide power to the water treatment plant in the event of a loss of power and may also face difficulties in returning power due to issues of remoteness when power is lost. Such issues cause depressurizations and significant burdens on communities. These problems are highlighted by the fact that 34% of unplanned power outages in the last 5 years were due to infrastructure problems or had unknown reasons, compared with 31% due to weather and 31% due to nature (Sask Power, 2017). As smaller communities across the province shrink, whether they are on or off reserve, investment in aging infrastructure becomes less of a priority as these communities lack the political capital to advocate for themselves. An unplanned power outage in any community is unpleasant, but if the water treatment plant lacks a backup generator, a boil water advisory will need to be placed in the event of a power outage, which causes economic losses in real terms for the community affected and may also, if not adhered to or communicated properly, create risk of waterborne illness.

Off reserve, northern communities faced more power outages and depressurization. This finding may be explained by remoteness: communities across northern Saskatchewan are often far from the major centers of Saskatoon and Regina, which may make it more difficult for repair parts and services to be obtained in the event of an outage. Additionally, these communities tend to be small and may lack the economies of scale. Further research on advisory outcomes using GIS data to investigate the effects of remoteness on drinking water outcomes would be of great assistance in describing the unique challenges faced by small remote communities, reserve and non-reserve alike, in providing safe drinking water to their residents.

Differences in how data is recorded among various jurisdictions are an important limitation of this study. Depressurization, for example, was only included as a reason for the advisory being issued if it was explicitly stated in an administrative data set, for example. It may be that many other advisories included depressurization which were not coded as such. Similar categorization issues are likely for other issuing reasons. Incorporating expert opinions when coding advisory issuing reasons would have helped to prevent biases due to misclassifications. Additionally, it was often very difficult to elucidate whether an equipment issue was due to a break requiring immediate repair, a longstanding malfunction, or routine and preventative maintenance. This caused all equipment issues to be collapsed into a single variable. Water main issues and water line issues faced similar difficulties and were therefore merged together.

In addition, no records of how often testing was completed as part of the analysis, which would have allowed analysis of the rate of advisory issuing per rate of testing, which would have proved extremely helpful in characterizing the state of drinking water systems both on and off reserve.

Hamlets, small unincorporated communities off reserve, were excluded from the analyses. This may be a source of bias as some very small reserve systems were included in the analyses while very small communities off reserve were excluded. Each advisory was also only included as a single data point, even if multiple communities were affected, which could have caused bias if the same advisory affected both a town and a village, as was the case for Air Ronge and LaRonge at times.

While censored data was used throughout the analyses, no method was used to control for censoring nor was any statistical methodology utilized to control for repeated measures within communities. Analyzing advisory duration by using tests of the equivalence of survivor functions which included a Cox model with a shared frailty term or clustered robust adjustment to the variance would have provided more confidence to be placed in the validity of the statistical findings.

No statistical inference was utilized when comparing the number of advisories issued in different community types for the same issuing reason. A more robust method would have been to use a negative binomial or Poisson regression to investigate differences in the count of advisories issued throughout the study period for a given reason. This would have allowed the effects of important covariates, such as community size, to be investigated.

An important area for future research is to investigate differences among reserves based upon the presence of generators for use in the case of a power outage. Additionally, research should focus on reasons for the higher rate of contamination and operator issues on reserves. Differences in waterborne illness rate not only between reserve and non-reserve communities should also be investigated – which has previously been completed and which showed a higher rate of illness on reserve – but ought to compare reserve communities with communities off reserve of similar size and remoteness (Patrick, 2011; Basdeo & Bharadwaj, 2013; Bradford, et al, 2017).

3.5 Conclusions

Drinking water advisories on and off Saskatchewan reserves that were in effect between January 1, 2012 and December 31, 2016 were examined and the reasons for issuing advisories was compared. Non-reserve communities more often had advisories because of issues related to depressurization and equipment failure, while reserves faced advisories due to power outages, turbidity, disinfection failure, operator issues, and contamination. However, the differences in contamination may be, in fact, due to more microbiological hazards, as evidenced by the relative abundance of disinfection failure, but may also be because of differences in testing rates.

Many advisory reasons did not show differences in duration between reserve and non-reserve communities. However, for reasons for which there were statistically significant differences within a given issuing reason, the effects sizes were found to be decreased if reserve communities were compared to smaller non-reserve communities. This highlights the importance of comparing communities of similar size when making policy inferences about water treatment systems on reserve.

First Nations Canadians living on Saskatchewan reserves not only face longer duration drinking water advisories than those who live off reserve, but they also face them for a different set of issues. These systematic differences between advisories on and off reserve highlight the importance of increased capacity within reserve water treatment systems to deal with contamination and operator difficulties and suggest the need for additional funding to address the issue.

CHAPTER 4: CONCLUSIONS

CHAPTER 4: CONCLUSIONS

4.1 Overall Conclusions

This investigation sought to describe the relative numbers of drinking water advisories issued on and off Saskatchewan reserves, the duration of the advisories and the reasons for issuing advisories. The project hypothesized that reserves would experience more and longer advisories for systematically different reasons than communities off reserve. These analyses were completed using administrative datasets which were provided by the Water Security Agency of Saskatchewan and the Federation of Sovereign Indian Nations. These investigations used the test of proportions (large sample) to compare the observed proportion of advisories in reserve and non-reserve communities with the expected number, which was based upon the proportion of reserve and non-reserve communities among communities which experienced an advisory. The duration of advisories was also investigated using the Kruskal Wallis and Mann Whitney U tests. No statistical inference was used in investigations of advisory issuing reason, except that the Kruskal Wallis and Mann Whitney U tests was used to investigate difference in advisory duration within common issuing reasons.

Drinking water systems with advisories which were active from January 1, 2012 to December 31, 2016 were included in the analyses. When comparisons between reserve and non-reserve communities were performed for Saskatchewan communities with advisories, fewer drinking water advisories were found on reserve. However, advisories which were issued for reserves were of longer duration than non-reserve communities. Reserves experienced a spike in advisory length during the winter months. This is a pattern which was notably absent from off-reserve communities, where no statistical difference in advisory duration was observed from season to season. Possible reasons for these differences include the remoteness of many reserves, difficulties in training and retaining skilled operators, and insufficient water treatment plant quality causing increased chances for contamination for reserve communities.

Reserves more often faced advisories due to power outages, turbidity, disinfection failure, operator issues, and contamination, while non-reserve communities more often had advisories because of issues related to depressurization and equipment failure. Reserve communities were also found to be more likely to experience advisories due to contamination, however, it is unknown whether these differences were due to an increase in microbiological hazards in drinking water, as evidenced by the relative surplus of disinfection failure on reserve or if it may also be due to differences in testing rates between community types. The effects size of statistically significant associations, such as increased advisory duration within issuing reasons (depressurization,power outage, equipment issues, and water main/line problems, all others not statistically significant between villages and reserves), were reduced in magnitude if reserve communities were compared to villages, the smallest incorporated communities off reserve, and not to all non-reserve communities. These findings highlight the differences in drinking water advisory issuing patterns on and off reserve and point towards areas where targeted funding could help to address the inequities that exist currently, such as increasing operator capacity or funding generators for use at plants during power outages. That the effects sizes of statistically significant differences were smaller when reserves were compared to villages indicates that features specific to smaller centers, such as measures of remoteness, should be included in future research, as should factors which are uniquely faced by communities in Northern Saskatchewan.

The analyses included in this thesis represent an important step towards characterizing drinking water advisory outcomes evidence-based policy making to be possible for drinking water systems for reserve communities. The importance of comparing reserve communities with communities off reserve of similar size and remoteness has been highlighted by the results included in this thesis and is a crucial consideration for future work. Such research points toward areas where interventions can be targeted so that disparities in advisory duration between reserve and non-reserve communities can be eliminated.

4.2 Strengths of the Research

This research study was novel in its use of administrative data sets to compare reserve and non-reserve water advisory outcomes. The statistical inference utilized in this research was largely limited to nonparametric comparisons advisory length and the large sample test of proportions. Nevertheless, it is the first use identified of a comparison between reserve and non-reserve communities in studies examining drinking water advisory outcomes on Canadian reserves and is the most extensive use of statistical inference to date in identified research. Investigating trends over a five-year period, not at a point in time, allowed the duration of advisories to be taken into consideration, which has only been previously done by Galway in 2016.

While many limitations were associated with the administrative data sets used in this study, the use of such data sets permits the strength of routine data collection programs to be evaluated and compared across community types in communities across the province.

4.3 Limitations of the Research

Shortcomings inherent in the administrative data sets which were utilized to form the basis for the analyses limited the study. The data sets for communities off reserve required extensive cleaning to create a database of advisories which were active between 2012 and 2016 in Saskatchewan. Each year's dataset for communities off reserve included separate entries for when an advisory was issued and was rescinded. Both the datasets for reserve and non-reserve communities included data from a number of issuing authorities. It is unclear how thorough each authority was in recording advisories and it is likely that some advisories were missed as part of the reporting process.

Because the WSA dataset does not have information about an advisory's ending alongside the issuing order, a current list of the advisories currently ongoing off reserve could not be compiled. Error is also suspected with long term advisories as it is possible that some advisories which are listed as ongoing were, in fact, rescinded, but the WSA was not contacted. The reserve dataset, obtained from FSIN, includes data about the scope of each advisory and the number of residences which it affected – no such data is available for communities off reserve.

Data recording across different jurisdictions was not uniform, which caused significant difficulties for data analysis. Depressurization, for example, was only coded when explicitly stated as a part of the issuing reason, not when it was suspected but not stated outright. Determining the lines between certain categories was also difficult, for example, whether an equipment issue was due to a break requiring immediate repair, a longstanding malfunction, or routine maintenance. To prevent misclassification, all three issues were merged into a single variable for this study. Similar merging was conducted for other advisory reasons. When pairing data, caution was utilized to prevent misclassification bias, however, this meant that certainly some data points were excluded from the analyses, hampering statistical power, and also possibly that some mismatches were allowed into the datasets, which could cause bias. This is especially true for longer advisories for which the end date was unclear.

Records of testing frequency did not form part of the administrative data sets. Analyses of these rates paired with DWA outcomes and water quality data would have facilitated an interesting line of inquiry in describing the frequency and duration of drinking water systems on and off reserves.

The statistical methodologies utilized had significant limitations. The large sample test of proportion's assumption of independent observations was violated as it did not account for repeated measures in individual communities. The validity of the results included in this thesis is therefore questionable and the weight given to the conclusions of this work need to account for this. Similarly, the Kruskal Wallis test assumes observations are independent. They were not as more than one advisory originated from the same community in some cases. This failure to adjust for clustering typically has the effect of underestimating variance and inflating the potential for identifying significant differences.

Additionally, multiple comparisons were conducted iteratively across categories, which causes a high probability of a type 1 error. Using the Bonferroni correction for multiple comparisons would have given a conservative estimate for the statistical significance of such multiple comparisons. No statistical inference was used to compare the proportion of advisories issued for a given reason across community types. An analysis plan which included statistical inference would have been much stronger and would have allowed the conclusions to be much more substantive.

Including communities which did not experience an advisory during the study period to the dataset and investigating advisory issuing using a poisson or negative binomial regression would not only have prevented the problems noted due to the independence assumption of the large sample test of proportion due to repeated measures which occurred in each community. It would also have allowed us to comment on the difference in the likelihood or probability of advisories in different types of communities rather than restricting conclusions to communities experiencing advisories as was the case here. Investigating advisory duration using a test for the difference in survival function which incorporated a robust variance correction or a shared frailty term would have adjusted for the violation of the independence assumption for the duration data associated with repeated measures within communities and would have also accounted for the right censored data. Both of these approaches would have allowed for building multivariable models to simultaneously consider geography, community size, season and year of issue and adjust for the potential impact of confounding in the results.

Investigations did not include comparisons by water source, system construction year, system capacity, treatment class, disinfection class, distribution class, and water treatment methodologies. Such an analysis would have allowed important comparisons between community types to be investigated: such as how trends in advisory issuing vary between reserve and non-reserve communities with the same water source type. This analysis was precluded because the WSA database lacked a listing of community water systems currently reporting to it. Such data would be extremely helpful in permitting analyses of water treatment outcomes across the province and would facilitate evidence-based policy.

4.4 Future Research

While this study investigated temporal trends in advisories being issued, it was retrospective in nature. Future prospective and longitudinal research would be able to mitigate the issues associated with retrospective research and would also facilitate direct linking of cause and effect. Incorporating testing schedules and water quality data into prospective analyses of water treatment systems would help contamination issues to be better understood both on reserve and in small communities off reserve. A prospective study would also facilitate studies of what protocols are followed in practice when water fails to meet regulatory environments and the speed and methodology by which community residents are advised of the advisory.

Future research ought to investigate differences between communities experiencing an advisory in a given period and those not experiencing an advisory. Deepening scholarly understanding protective factors which prevent advisories from being issued represents an important next step for this research. Comparing reserve and non-reserve water treatment systems by the water source, system construction year, and system capability measurements, would put the differences in advisory outcomes and issuing reasons detailed in Chapters 2 and 3 into context. Such work may be best completed in a prospective study because these variables are not available from the WSA and also so that recent construction and upgrades are reflected in the analysis.

4.5 Summary

Drinking water advisory prevalence, issuing reason, and temporality were examined on and off reserves from 2012-2016 in Saskatchewan. These analyses highlighted the disparities between reserve and non-reserve communities: reserves experience fewer advisories but have advisories which last for more time and experience advisories for more often for reasons such as operator error and microbial contamination. These investigations are novel among identified research and represent an important step forward for evidence-based policy making to be utilized as the issue of drinking water on reserve is to be effectively dealt with.

APPENDIX 1: CODING ALGORITHMS FOR ISSUING REASON

This appendix is included to show the algorithms which were used when coding the reasons for issuing an advisory, which were used in the analyses described in Chapter 3.

Break In

Break in was coded as a reason for issuing an advisory if issues with break ins or vandalism at the plant were noted.

Depressurization

Depressurization was coded as a reason for issuing an advisory if a depressurization event was explicitly stated. If a depressurization event was only suspected, such as when a power outage caused an advisory to be issued, it was not coded.

Discoloration

Discoloration was coded as a reason for issuing an advisory if the advisory was issued due to discoloration in the treated water.

Disinfection Failure

Disinfection failure was coded was coded as a reason for issuing an advisory if disinfection failure or an equivalent was noted in the issuing order. Additionally, high chlorine and low chlorine (both of which were also coded as advisory issuing reasons in their own rights only if explicitly stated in the issuing order) were also coded as disinfection failure.

Equipment

Equipment was coded as a reason for issuing an advisory if any issue with equipment was noted in the advisory issuing order. This included construction, scheduled maintenance, or emergency equipment failure, regardless of which type and whether or not the specific reason for the equipment issue was noted. Additionally, the advisory issuing reasons for various reasons for issuing an advisory which were coded only if stated verbatim in the issuing order were also coded as “equipment”. These included: breaker, construction, curb stop, filtration failure, hydrant, pump failure, reservoir failure, sewer main/line failure, valve failure, water line break, water main break, and well failure. Because water line break and water main break were coded differently between reserve and non-reserve communities and it was often unclear whether the water line effected was in fact a water main, the two were merged together into a single variable.

Firefighting

If the activities of firefighting caused an advisory to be issued, such as if water used while firefighting caused a depressurization event at a treatment plant, firefighting was coded as a reason for issuing an advisory.

Flushing

If an advisory was given due to flushing of the water treatment system, it was coded as flushing.

Known Contamination

Known contamination was coded if an advisory was issued because of confirmed contamination of treated water. It was not coded if, for example, raw water and treated water mixed in the treatment system as there was not a positive test for microbial hazards in the treated water.

If this contamination was microbial in nature, the advisory was also coded as “microbes” and the specific infectious agent was also coded, if noted. Infectious agents included in the dataset were: copepoedia, cryptosporidium, e. coli/coliform, and giardia.

Chemical contamination of treated water was also included in known contamination. These included arsenic, nitrate, potassium permanganate, and uranium. Advisories issued due to oil spills contaminating the water supply were also coded as known contamination.

Lack of Treatment

If the water treatment system was unable to meet the requirements for treating water for any reason, lack of treatment was coded. This included overloading of the system with organic matter, deterioration of source water quality, insufficient treatment, failing to meet minimum treatment processes, interruption of treatment process, and no treatment.

Lack of Water

Lack of water was coded as a reason for issuing an advisory if the drinking water treatment system ran out of source water due to high utilization.

Not in Use

If a water treatment system was not operating and had a drinking water advisory issued because of this, it was coded as not in use. This did not include short term system shutdowns or power outages which caused advisories, which were coded as separate variables.

Oil Spill

An oil spill on the North Saskatchewan river caused a variety of water treatment plants to divert to alternate water treatment sources. While these new sources were tested, drinking water advisories were issued, for which the reason for issuing the advisory was coded as “oil spill.”

Operational Problems

An advisory was coded as issued due to operational problems if it the issuing order included any of the following reason: a deviation from normal operation, no operator, no certified operator, process error, operational issues/problems, or no samples being submitted.

Possible Contamination

While ostensibly advisories not issued due to known contamination are always issued due concerns that the water is possibly contaminated, possible contamination was only coded if the issuing order specifically noted concerns about possible contamination of the water treatment system.

Poor Source Water

Deterioration of source water quality was coded as poor source water. It was coded regardless of the reason for source water deterioration and included advisories issued due to the oil spill on the North Saskatchewan River. A groundwater source was believed to be under the direct influence of surface water but there was insufficient treatment to deal with the direct influence of surface water, poor source water was coded. Silt being drawn into the treatment system by wells and changing the source water to a non-regulated water source were also coded as poor source water.

Power Outage

Losses of power at water treatment plants which caused a drinking water advisory to be issued were coded as “power outage.” They were not coded as “system shutdown” or “not in use.”

Raw Water Mixing with Treated Water

Backflow of water, unchlorinated/untreated water entering reservoirs or distribution systems, and possible sewage cross-contamination were coded as “raw water mixing with treated water.”

Sewage into Treatment System

Sewage entering the intake of treated water system or backflowing into the treatment system was coded as sewage into treatment system.

Start Up

Advisories were issued as part of the start up procedure of plants. This is standard regardless of whether the system is new or is a seasonal system which was being started up at the start of its use. However, seasonal water systems were excluded from the analyses in this thesis and therefore advisories issued due to seasonal start up were not included in analyses.

System Shutdown

System shutdown was coded as a reason for issuing an advisory if the system was shutdown temporarily. This was not coded in the case of a power outage causing the plant to shutdown or for longer term shutdowns during periods in which the system was not in use.

Turbidity

Turbidity was coded as a reason for issuing an advisory if turbidity problems were noted as part of the order issuing the advisory.

Unknown

If no reason for issuing an advisory was included in the issuing order it was coded as unknown.

Upset Condition

Upset condition was coded as a reason for issuing an advisory if a system upset occurred in the water treatment system.

Weather

Weather events which caused advisories to be issued were coded as “weather”. These included spring runoff, flooding, storms causing power outages, wildfires and freezing water mains. Flooding, runoff, freezing water mains, and wildfires were also included as reasons for issuing advisories. Power outages which were not explicitly stated to be due to rainfall or other inclement weather were not coded with weather.

APPENDIX 2: FORMULA EXAMPLE FOR MICROSOFT EXCEL

This Appendix is included to show a sample calculation completed in Microsoft Excel for the large sample test of proportions, which was utilized in the analyses discussed in Chapter 2.

Figure A.1: Sample Calculation – Large Sample Test of Proportion

Total | N Short Term | % Short Term | N Long Term | % Long Term | Total Short Term Advisories (Any issuing Reason) | Total Long Term Advisories (Any issuing Reason) | Test Statistic | P-value

	A	B	C	D	E	F	K	L	O	P
106	FN	N	ST		LT		TST	TLT		
107	Depressurization	189	165	69.328	24	27.907	238	86	6.678	0.0000
108	Power Outage	101	94	39.496	7	8.140	238	86	5.380	0.0000
109	Equipment	84	64	26.891	20	23.256	238	86	0.659	0.5097
110	Disinfection Failure	39	17	7.143	22	25.581	238	86	4.504	0.0000
111	Turbidity	38	19	7.983	19	22.093	238	86	3.485	0.0005
112	Water Line	36	29	12.185	7	8.140	238	86	1.023	0.3063
113	Operation Deviation	25	10	4.202	15	17.442	238	86	3.944	0.0001
114	Known contamination	13	3	1.261	10	11.628	238	86	4.199	0.0000
115	Water Main Break	10	10	4.202	0	0.000	238	86	1.931	0.0535
116	Microbes	9	2	0.840	7	8.140	238	86	3.530	0.0004
117	Lack of Treatment	3	0	0.000	3	3.488	238	86	2.895	0.004
118	Water Main Line	46	39	16.3866	7	8.1395	238	86	1.878	0.0604

=100*C107/K107

=E107*100/L107

=2*(1-NORM.S.DIST(O107, TRUE))

=ABS((C107/K107-E107/L107)/SQRT(((C107+E107)/(K107+L107))*(1-(C107+E107)/(K107+L107))*(1/K107+1/L107)))

APPENDIX 3: DATA LOSS TABLE

This Appendix is intended to show how data was lost due to exclusions based upon community type, system type, and the inability to identify health region. It affects analyses in both chapters 2 and 3.

Table A.1: Data Loss Table

Reason for Data Loss	*All*	*% Lost*	*NFN*	*% Lost*	*FN*	*% Lost*
Original Total	2575	100.00	2251	100.00	324	100.00
Start up (seasonal system)	2548	98.95	2224	98.80	324	100.00
Pipeline	2348	91.18	2024	89.92	324	100.00
Hamlet	2082	80.85	1758	78.10	324	100.00
Rural Municipality	2059	79.96	1735	77.08	324	100.00
Community Type Unknown	2036	79.07	1712	76.06	324	100.00
HR Unknown*	1985	77.09	1704	75.70	281	86.73

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