2019-07-17

Investigating Perceptions of Well Water Quality in Rural Alberta

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Investigating Perceptions of Well Water Quality in Rural Alberta

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILIOSOPHY

GRADUATE PROGRAM IN VETERINARY MEDICAL SCIENCES

CALGARY, ALBERTA

JULY, 2019

Abstract

Adequate access to safe drinking water is important in maintaining public health. Over 400,000 rural Albertans use well water for domestic purposes. The current policy on the management of private water wells requires well owners be responsible for their own water well management and well water quality. Therefore, the decision of when to test well water, what to test for, and what treatments to use to safeguard or improve water quality, lies with well owners.

The purpose of this thesis was to 1. Describe the perceptions, knowledge, and beliefs rural Albertan residents have of well water quality and whether they associate livestock farming with water well contamination. 2. Identify the barriers faced by water well owners with respect to implementing well water stewardship practices. 3. Identify factors associated with water well stewardship practices (i.e., testing and treatment). A mixed methods study was completed which included a systematic review, interviews with well owners, a questionnaire survey of well owners, and collection of well water samples to assess for microbiological indicators of drinking water contamination. Thematic analyses were used to understand factors shaping perceptions of well water quality and identify factors influencing water testing behaviour as viewed through the lens of the Health Belief Model. Descriptive statistics and logistic regression analyses were used to understand the characteristics of well owners, well use, well stewardship practices, as well as investigate associations between independent variables and well stewardship practices.

Barriers to treatment included a lack of awareness of what treatments to use. Increased education and awareness may be important to increase the adoption of well stewardship practices.

Several factors were found to influence perceptions of well water quality. Furthermore, well owners described issues such as low perceived susceptibility to water well contamination and logistical barriers when submitting water samples for testing.

Keywords: Mixed methods; Perceptions; Public Health; Risk; Well Water; Well Stewardship

Preface

Modified versions of chapters two and three have been published in the journals BMC Systematic Reviews and Canadian Water Resources Journal, respectively. Chapter four has been submitted for publication.

Chapter 2. This is a modified version of the published article Munene, A., & Hall, D. C. (2019). Factors influencing perceptions of private water quality in North America: a systematic review. Systematic Reviews, 8(1), 1-15. doi:10.1186/s13643-019-1013-9

Chapter 3. This is a modified version of the published article Munene, A., Lockyer, J., Checkley, S., & Hall, D. C. (2019). Perceptions of drinking water quality from private wells in Alberta: A qualitative study. Canadian Water Resources Journal / Revue Canadienne des Ressources Hydriques, 1-16. doi:10.1080/07011784.2019.1601599

As lead author in the manuscripts and chapters I was primarily responsible, for research conceptualization, data collection, data analysis, and reporting. The research contributions from each of the co-authors is stated in each chapter.

Acknowledgements

I am grateful for the opportunity to have conducted my research in Alberta and at the University of Calgary. This would not have been possible without the support of several people.

I thank my supervisor, Dr. David C. Hall, for providing me with the opportunity, the mentorship, and guidance throughout the study. Thank you for believing in me, supporting me, and providing the critical perspective that helped improve my thesis.

Thank you, Dr. Jocelyn Lockyer, for your eagerness, timeliness, enthusiasm for research, support, and invaluable expertise with the qualitative research components of this study throughout the program.

Thank you, Dr. Sylvia Checkley, for your support, guidance in epidemiology, and help in navigating through some of the complex issues faced by epidemiologists dealing with water public health. This research would not have been possible without your expertise and invaluable contribution.

Thank you, Dr. Alessandro Massolo, for your advice, introducing me to the One Health approach, and helping me think about the complexities of disease distribution from an ecological perspective.

I would like to thank the funders of the project, Alberta Innovates Energy and Environment Solutions, who provided the scholarship and operational research funds for the project. The Department of Ecosystem and Public Health and the University of Calgary Faculty of Veterinary Medicine for their Eyes High travel awards that provided funding support for conferences.

I would also like to thank the people who helped make this research possible. Our liaisons with Alberta Environment and Parks, Ken Williamson (Working Well Program), Steve Clare, and Amanda Mitchell (Groundwater Information Centre) with their assistance in participant recruitment and providing access to the AWWID, respectively. The Watershed Planning and Advisory Council that assisted in the promotion of the research during the recruitment phase and community feedback sessions. Special thanks to Shannon Frank and Anna Garleff (Oldman River Watershed), Tim Romanow (Red Deer River Watershed Alliance), Marilou Montemayor, and Alyssa Roth (South East Alberta Watershed Alliance). I would also like to thank all the staff of AHS, the Public Health Laboratories (i.e., the ProvLab), and Public Health Inspectors who were responsible for water sample processing, conducting microbiological water testing, and informing participants of their well water quality results. I would also like to thank Dr. Karen Liljebjelke and Dr. Krishna Bhatt for their help in sample processing, microbiological testing, and use of their lab space.

For their friendship, social support, and advice while at the University of Calgary, I would like to thank my fellow graduate students: Sangay Rinchen, Ravi Holani, Krishna Bhatt, Matilde Tomaselli, Michelle North, Alejandra Santa, Tessa Baker, Pratap Kafle, Alejandro Oscar Aleuy, Jesse Invik, Ali Naqvi, Jeremiah Seni, Phil Rasmussen, Paul Burden, Fernando Guadardo. Postdocs: Stefano Liccioli, Omid Nekouei, Niamh Caffrey, Regina Krohn, Daniel Gomez, Fabien Mavrot. Faculty: Drs. Susan Cork, Frank Van Der Meer, Susan Kutz, John Gilleard. Staff and students: Abir Bachir, Karen Green, Robert Forsyth, and the VetMed soccer team.

For their friendship and support I would like to thank my family and close friends.

Most importantly, I would like to thank all the well owners who took the time and were dedicated to participating fully in this study given its various components. Thank you for prioritizing the protection of your well water sources.

Dedication

I dedicate this work to all the private well owners who participated. May you find this information useful and use it to enlighten others about the importance of well water stewardship.

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Abbreviation	Definition
ACFT	Alberta Centre for Toxicology
AEP	Alberta Environment and Parks
AEPHIN	Alberta Environmental Public Health Information Network
AER	Alberta Energy Regulator
AESRD	Alberta Environment and Sustainable Rural Development
AHS	Alberta Health Services
AWPQ	Alberta Perceptions of Water well Quality Questionnaire
AWWDA	Alberta Water well Drillers Association
AWWID	Alberta Water well Information Database
CDC	Centre for Disease Control
CDWQG	Canadian Drinking Water Quality Guidelines
HBM	Health Belief Model
MAC	Maximum Acceptable Concentration
NRCAN	Natural Resources Canada
OR	Odds Ratio
PHB	Preventive Health Behaviour
POE	Point of Entry
POU	Point of Use
ProvLab	Public Health Laboratories
SRB	Sick Role Behaviour
WPAC	Watershed Planning and Advisory Council
WWLG	Water Wells that Last Generations

WWRRP	Water Well Restoration and Replacement Program
WWP	Working Well Program
WSQ	Watershed Questionnaire
CFU	Coliform Forming Units

Epigraph

"… you have to study and learn so that you can make up your own mind about history and everything else, but you can't make up an empty mind. Stock your mind, stock your mind."

Frank McCourt

***

"Reality exists in the human mind, and nowhere else…"

George Orwell

***

"Inaction is a weapon of mass destruction…"

Faithless

***

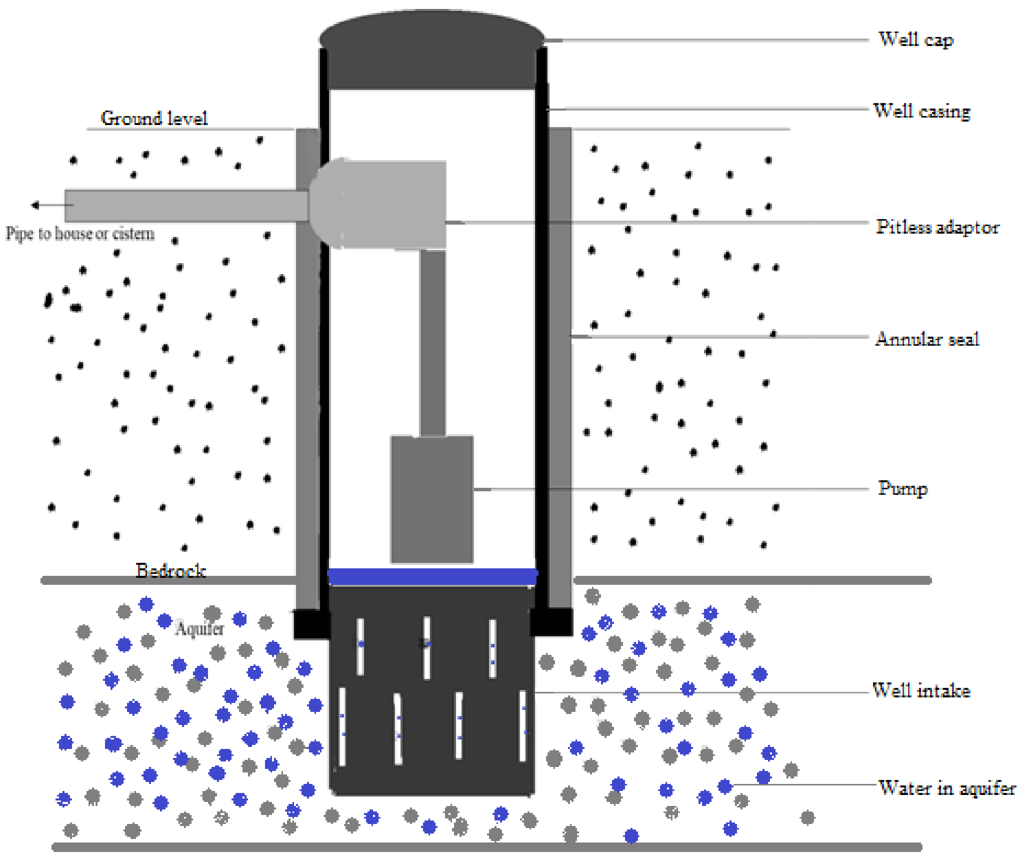
Chapter One: Introduction

1.1 Water well use in Alberta

Private water supplies serve over four million Canadians (Corkal *et al.*, 2004, Statistics Canada, 2019). Over 400,000 rural Albertan residents rely on private water wells for household use (Summers, 2010). Alberta has one of the highest well densities in Canada with over 500,000 drilled wells on record (Alberta Environment and Parks, 2015). Unlike municipal water supply systems which are regulated and may monitor water quality, the responsibility of well water stewardship is left to well owners to follow testing, treatment, and maintenance recommendations (Alberta Health Services, 2018; Health Canada, 2018).

To set the context for this research, a brief understanding of water wells and current initiatives supporting well stewardship within Alberta is required. Water wells are infrastructure that draw water from aquifers beneath the soil surface. Typically, a hole in the ground is either drilled, bored, or dug to access the aquifer. A shaft (i.e., casing or cribbing) is placed in the borehole. The shaft has three main purposes, to keep the borehole from collapsing in on itself, to store pumping equipment, and to prevent contamination from other aquifers or the soil substratum. Once the shaft is placed in the borehole an annular seal is placed in the space between the shaft and the borehole. The annular seal prevents contamination from the surface and contamination from other aquifers. A well intake with perforations is placed within the shaft. This allows groundwater from the aquifer into the well. To draw groundwater from the aquifer to the surface, a pump is placed within the shaft. A pitless adaptor then provides a sealed connection between the water distribution pipe that feeds the house and the pump. Pitless adaptors were introduced to replace the use of well pits. Well pits increased the potential for well contamination, made it difficult to service wells, and were also an on-farm safety hazard. A well cap is then usually placed on the top of the casing above the surface (Buchanan *et al.*, 2013). The main purpose of the well cap is to prevent contamination from the surface (e.g., run off). Figure 1.1 illustrates the important components of a modern well.

Figure 1.1. Simplified diagram of the components of a well



Water wells may be drilled for several purposes including domestic, agricultural, industrial, and as test wells to determine the quality and quantity of water an aquifer is producing. Depending on the depth, the lithology of substrate being dug into, the materials used to design the well, and the well's use, the cost of installing a water well may range from CDN $6,000 to $45,000 (Alberta Water Well Drilling Association, personal communication, January 30, 2018). Well installation in Alberta may only be done by a licensed journeyman.

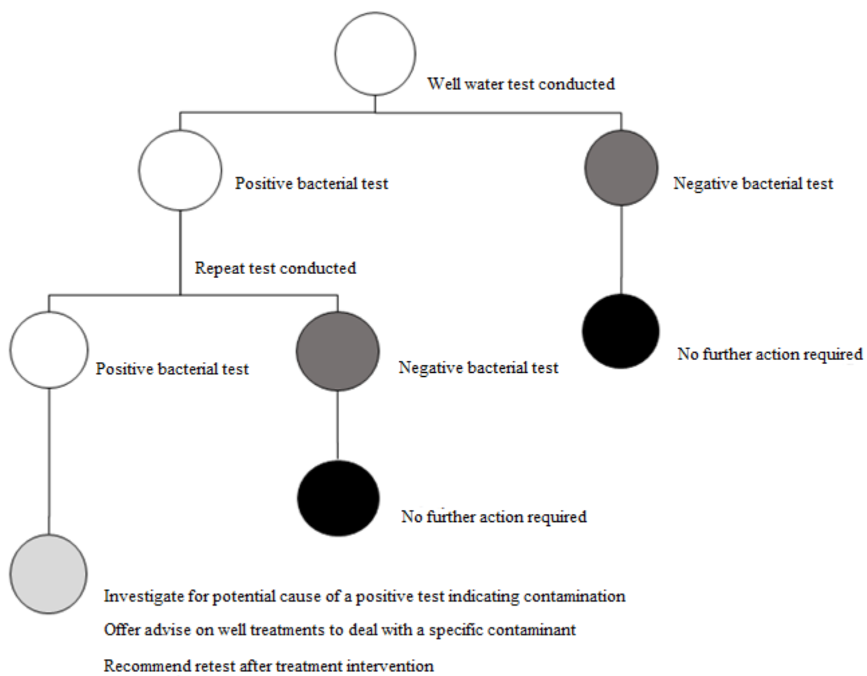
1.1.1 *Overview of well stewardship initiatives in Alberta*

Once a well has been installed, it is the responsibility of the well owner to manage their well. This involves deciding when to test their well water quality, what tests to conduct (microbiological or chemical), what treatments to use, and when to carry out well maintenance (e.g., shock chlorination). To help water well owners in their decision-making process on well stewardship practices, the Water Wells that Last Generations (WWLG) handbook (Buchanan *et al.*, 2013) was drafted and is a publicly available educational resource.

In addition to the WWLG, the government of Alberta has also invested in the Working Well Program (WWP). Since its inception in 2008, the WWP has run several workshops across the province to educate well owners on well stewardship practices (AEP, 2017). The workshops are run through the collaborative effort of several agencies and various rural communities across the province. The well workshops are held annually in the fall, winter, and spring with workshop sessions running for approximately three hours. Workshop sessions cover topics such as understanding how aquifers work, the drilling and design of water wells, ways a well owner can maintain their wells to ensure both their water quality and quantity are sufficient for their needs, and finally the risks to well water quality (AEP, 2018).

To increase compliance towards well water testing, AHS offer no charge well testing services for both microbiological and chemical contaminants. Well owners can pick up water sampling bottles at health centres. Water samples are then delivered to the Public Health Laboratories (i.e., the ProvLab) for testing where they are processed. Water samples for microbiological analysis (i.e., total coliform and *Escherichia coli*) must arrive in the ProvLab within 24 hours of sample collection. Water samples for chemical analysis can be received up to 72 hours after sample collection and are processed by the Alberta Centre for Toxicology (ACFT). Water test results are usually delivered by mail to well owners within one to eight weeks of sample submission depending on whether water samples were submitted for microbiological or chemical tests. In the event of microbiological contamination (i.e., exceedances in the Maximum Acceptable Concentration (MAC) of total coliform and/or *E. coli*) well owners are contacted as soon as possible by the public health officer within their region. The public health officer interviews the well owner to try and determine what led to the positive test result, the well owner is requested to conduct a retest, and advised on measures to prevent future contamination (see Figure 1.2).

Figure 1.2. Well test flow chart



At the very least, well owners are advised to conduct well testing for microbiological contaminants once per year and a chemical test every three to five years (AEP, 2015). However, these recommendations may vary depending on the depth of the well, time of year, weather, and hazards in an area with Health Canada and AHS recommending microbiological testing be conducted at least two to three times a year with chemical tests being recommended less frequently (AHS, 2018; Health Canada, 2018). While well testing is an important mitigation strategy in the diagnosis of potential contamination, water treatments can be used to improve water quality. A variety of drinking water treatments are available to well owners to improve their water quality (see Table 1.1) (CDC, 2015; Health Canada, 2018). Treatments may be specific to contaminants or may offer protection against a suite of potential contaminants present in well water. The choice of which water treatment to use is left to the well owner.

Table 1.1. List of recommended drinking water treatments available to well users endorsed by Health Canada

Drinking Water Treatments		
Treatment	**Used against**	**Improves**
Distillation	Microorganisms, heavy metals and nitrates, iron Used in combination with activated carbon filters	Organoleptic properties, Microbial content
Ultraviolet light	Microorganisms and parasites	Organoleptic properties, Microbial content
Chlorination	Microorganisms, parasites, iron, manganese, H_2S organic compounds	Organoleptic properties, Microbial content, Chemical content
Ozonation	Microorganisms and parasites	Organoleptic properties
Ceramic candle filtration	Microorganisms and parasites	Organoleptic properties, Microbial content
Active Carbon Filters	Organic compounds, pesticides	Organoleptic properties, Chemical content
Reverse Osmosis	Heavy metals, Nitrates, Sulphates, Calcium	Organoleptic properties, Chemical content
Water softener	Calcium	Organoleptic properties
Green sand filter	Iron, Manganese, H_2S	Organoleptic properties
Sediment filter	Sediment suspended in water e.g., clay	Organoleptic properties

Source: Health Canada 2018

1.1.2 *Understanding well water testing as a public health challenge*

Currently, Canada is fortunate and contains 20% of global freshwater resources (Environment Canada, 2018). While most of Canada's population residing in urban and peri-urban areas may have access to safe drinking water that may be monitored and treated by municipal water supply systems, nearly 11% of Canadians rely on private water supplies that are often unregulated, owner-monitored, and treated at the discretion of the owner.

Approximately 10% of Albertans are estimated to use well water for domestic purposes. However, only a small portion of water well owners report testing their water frequently (Summers, 2010). This is not a phenomenon unique to Albertan well owners and has been reported in other provinces and countries (Hynds *et al.*, 2013; Roche *et al.*, 2013; Flanagan *et al.*, 2015; Malecki *et al.*, 2017).

Recent surveys of water wells in Alberta have shown that between 1.5-17% of wells were contaminated with microbiological contaminants alone (Coleman *et al.*, 2013; Invik *et al.*, 2017). This did not include contamination from exceedances in physio-chemicals and neither did it include the prevalence of contamination among water well tests submitted to private labs. Furthermore, while the prevalence of water well contamination was low in these studies, this was potentially biased because of the voluntary nature of the well testing program and the contaminants that were assessed for (Invik *et al.*, 2017).

Four weaknesses arise from the voluntary nature of the well testing program in terms of an environmental public health surveillance program for detecting contamination. Firstly, it relies on the assumption that well owners understand water well contamination and all the factors and mechanisms that could result in contamination. While certain factors may increase the probability of water well contamination (e.g., flooding or severe precipitation, old, damaged or uncapped wells, proximity to potential contaminant sources, formation of biofilm in the well casing, and aquifer type) there is some uncertainty around water well contamination and it can often be very difficult to predict when a well will be contaminated, the source of contamination, and the mechanism that led to contamination. Therefore, as a prescriptive recommendation to help well owners detect water well contamination Health Canada recommends regular well water testing (AEP, 2015; Health Canada, 2018).

The second weakness of the voluntary well testing program is that it assumes well owners' value and prioritize testing while being motivated enough to go through the process of well water testing. While AHS may not charge for water testing services, have numerous health centres for water sample bottle pick up and drop off, and even offer delivery services to very remote communities, water well testing may not be a priority for the majority of well owners to go through the inconveniences of testing on an annual or biannual basis.

The third weakness of the water well testing program is that although water testing is often framed as a 'well stewardship' practice, conducting a water test is a diagnostic measure and is not sufficient on its own as a measure of decreasing exposure to contaminants which may involve treatment or other actions (Zheng & Flanagan, 2017). Therefore, while testing is important in diagnosing potential contamination problems with the well, well treatments, and/or well maintenance may be required to resolve a contamination issue.

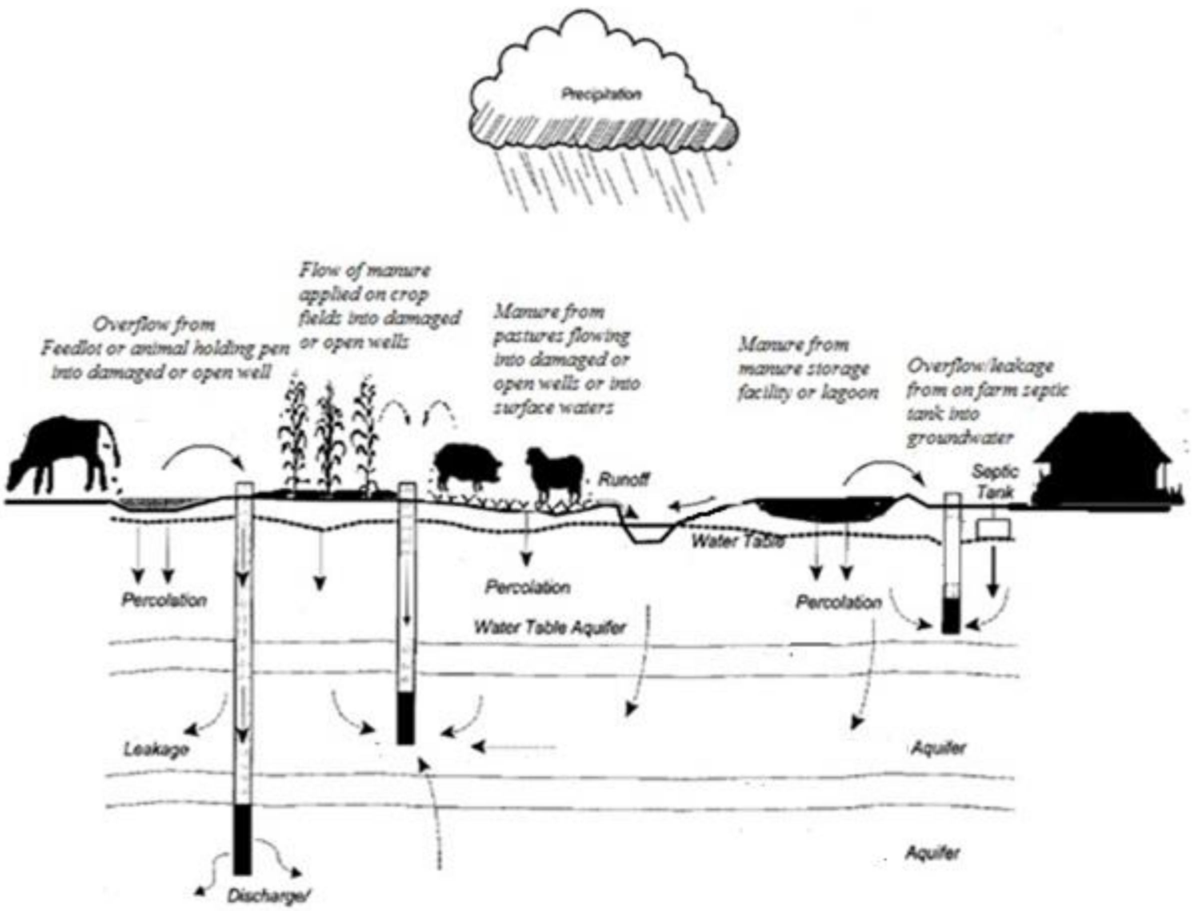
This brings us to the final weakness of the voluntary well testing program. It assumes the water well owner is willing and able to deal with the consequences of well contamination once detected through a water test. Well owners could be faced with a range of options once contamination is detected and confirmed from using a simple maintenance measure such as shock chlorination or purchasing treatments, to decommissioning the well, drilling a new well or seeking an alternative domestic water source if the well is identified as having a constant contamination issue. Hesitancy to test may arise if a well owner is unsure, they will be able to act on the knowledge that their well is contaminated. In the worst-case scenario, they may have to seek an alternative water source to have portable water on their property.

1.1.3 *Risks to water quality posed by livestock agriculture*

Agricultural activities impose a burden on both water quality and quantity (Pimentel *et al.,* 2004; Schwarzenbach *et al.,* 2010; Vörösmarty *et al.,* 2010). Specifically, concern has been raised over the potential impact of livestock farming on water quality. Alberta has the largest cattle industry in Canada with the current cattle population estimated to be over five million (Olson *et al.,* 2009; Bonti-Ankomah *et al.,* 2017). Although the number of animals has increased in the province, the number of livestock farms has decreased following trends in the country. Consequently, high densities of animals are reared in relatively fewer areas of land resulting in animal rearing activities such as concentrated feedlot operations (Beaulieu *et al.,* 2001; Burkholder *et al.,* 2007).

Waste products associated with livestock production are capable of contaminating both surface and groundwater. Manure released from livestock farms can be sources of several contaminants (Hooda *et al.,* 2000; Campagnolo *et al.,* 2002; Kolodziej *et al.,* 2004; Johnson *et al.,* 2006; Coleman *et al.,* 2013; Daley *et al.,* 2015; Allen *et al.,* 2017; Invik *et al.,* 2017; Invik *et al.,* 2019). Contaminants in manure may infiltrate surface or groundwater supplies through leakage in poorly built manure storage facilities, overflow during extreme precipitation events, and improper manure application practices to cropped lands (Burkholder *et al.,* 2007; Olson *et al.,* 2009). The risk of surface and groundwater contamination may be exacerbated by having high livestock densities within an area which can overwhelm the ability of the soil and substratum to absorb and attenuate contaminants (Campagnolo *et al.,* 2002; Coleman *et al.,* 2013). Although livestock are a significant source of manure, wildlife manure can also infiltrate surface and groundwater supplies (Hagedorn *et al.*, 1999). Furthermore, human faeces may also be a potential source of groundwater contamination within the farm (Figure 1.3.).

Figure 1.3. Possible routes of water well contamination from sources of faecal origin within a farm



Adapted from Ritter *et al.*, 2002

1.1.4 *Surveys of well water quality*

Previous surveys conducted on rural private water wells across the country reveal that between 2-40% of water wells fall short of safe drinking water standards with regards to either microbiological or chemical contaminants as stipulated by the Guidelines for Canadian Drinking Water Quality (GCDWQ) (Goss & Barry, 1995; Levallois *et al.*, 1998; Fitzgerald *et al.*, 2001;

Thompson, 2003; Invik *et al.*, 2017). In a well survey conducted in Alberta on over 800 farm wells, nearly 32% of wells exceeded the MAC for at least one contaminant with coliforms being found in nearly 7.6% of the wells (Fitzgerald *et al.*, 2001).

Recent findings from Alberta suggest that nearly 14.6 % of wells tested exceeded the MAC for total coliforms while nearly 1.5% exceeded the MAC for *E. coli* (Invik *et al.*, 2017). Coleman *et al.*, 2013 found that nearly 22% and 5% of water samples submitted for well testing were positive for total coliform and *E. coli* respectively. However, findings reported in the Coleman *et al.*, 2013., and Invik *et al.*, 2017 studies may not be representative of the prevalence of total coliform and *E. coli* contamination in private water wells as survey data were collected under a passive surveillance strategy (i.e., the voluntary water testing program). While some studies report associations between human *E. coli* infection within Southern Alberta (Waters *et al.*, 1994; Bifolchi *et al.*, 2014), direct causal relationships between infectious *E. coli*, prevalence in livestock, evidence of subsequent contamination of surface or groundwater, and subsequent infection in humans is contentious (Strauss *et al.*, 2001; Johnson *et al.*, 2003) but still possible as exemplified by the Walkerton tragedy (Hrudey *et al*., 2003).

Despite the reported levels of contaminants in private water well supplies and risks to groundwater posed by agricultural activities such as livestock farming, private well owners across the country rarely test their water quality (Corkal *et al.*, 2004; Jones *et al.*, 2005; Summers, 2010; Roche *et al.*, 2013). Only about 11% of private water well owners tested their water quality annually (Summers, 2010). The low proportion of well owners conducting water tests is concerning considering information gained from water well contamination surveys and the potential human health impacts posed by consuming contaminated water well (Corkal *et al.*, 2004; Schuster *et al.,* 2005; Jones *et al.,* 2006; Charrois, 2010). The need to exercise vigilance in testing and treatment of water well systems in Canada was brought to attention nearly 18 years ago with the Walkerton tragedy in which seven people died and hundreds more became ill after consuming *E. coli* contaminated water from a town well (Hrudey *et al.,* 2003).

1.1.5 *Perception of water quality in private water well systems*

The priority well owners give to water public health may be based on individual perceptions towards water. Perception is recognized as an important part of water quality judgements (de França Doria, 2010). Public perceptions of water quality are increasingly recognized in the development of water policy and management strategies as well as being an important part of garnering acceptance from the public towards water policy decisions (Jones *et al.,* 2007; de França Doria *et al.,* 2009; de França Doria, 2010). Although Canada sets out national guidelines for adequate drinking water standards in the GCDWQ there are differences in contaminants assessed and the standards of MAC of certain contaminants in different provinces (Jardine *et al.,* 1999; Turgeon *et al.,* 2004; Dunn *et al.,* 2014). While public health officials may use exceedances in the MAC to determine water well contamination status, there is no single definition of what constitutes "good" quality water as the construct of water quality may be subjective.

1.1.6 *Perceptions of water quality in association with livestock*

Perceptions of water quality may be altered by the presence of factors within the environment that are known or believed to be a hazard to water quality. The presence of livestock is one such factor. A survey conducted in Alberta revealed that only 0.7% of water well owners stated that livestock farming concerns were a motivation for conducting well water tests (Summers 2010).

Livestock farming concerns also ranked lower than other environmental factors likely to be associated with water contamination (e.g., oil/gas extraction activities and flooding/extreme precipitation events). Furthermore, only about 5.3% of participants noted proximity to livestock as a concern when choosing their well location (Summers, 2010). The apparent lack of concern among private water well owners in Alberta in considering livestock as a risk factor to water contamination is paradoxical given the densities of livestock in the province, the potential for livestock manure to contaminate water sources, and Canada's history with severe microbial water contamination events associated with drinking water contamination (e.g., Walkerton ON), (Hrudey *et al.*, 2003; Dupont *et al.*, 2010). However, determining the prevalence of waterborne illnesses can be problematic as many waterborne gastrointestinal illnesses may often be dismissed, misdiagnosed, and as such underreported (Hrudey & Hrudey, 2007; Jones *et al.*, 2007). Furthermore, water well contamination, factors associated with water well contamination, and the mechanisms that could lead to contamination may not be a priority issue or well understood by the public.

1.2 Study objectives and rationale for proposed study

Most water well owners do not test their well water as per recommended frequencies (Summers, 2010; Roche *et al.*, 2013; Flanagan *et al.*, 2015). Given the potential risks that livestock farming pose to water quality, the current density of livestock within Alberta, and the lack of stringent enforcement of water testing recommendations by well owners, this study seeks to investigate perceptions of well water quality among Alberta's rural well owners. Water public health and water testing may not be a priority issue because water well owners; may perceive the personal risks that could arise from water contamination as controllable, or are habituated to their water well sources; may be misinformed or lack information about well water quality and the potential hazards and mechanisms that could lead to well contamination; water well owners may be employing measures (e.g., water treatment devices, or using drinking water alternatives) that they believe could safeguard against illnesses that may arise from well contamination.

Therefore, this study aims to:

1. Describe the perceptions, knowledge, and beliefs rural Albertan residents have of well water quality and whether they associate livestock farming with water well contamination.
2. Identify key barriers faced by water well owners with respect to well water stewardship practices.
3. Identify factors that are associated with well water stewardship (i.e., testing and treatment).

1.2.1 *Research questions*

To address the study aims, I sought to answer the following research questions. 1. What are the sociodemographic characteristics among water well owners in rural Alberta? 2. What are the characteristics of wells and the patterns of water well use in rural Alberta? 3. What perceptions do water well owners have with regards to their drinking water quality and hazards they associate with water well contamination? 4. What factors (e.g., sociodemographic characteristics, perception of water quality, and previous knowledge or experience with water quality) are associated with well water stewardship practices (i.e., testing and treatment)? 5. What are the barriers to well water stewardship (i.e., testing and treatment) faced by rural well owners in Alberta?

1.2.2 *Conceptual background*

Based on evidence gathered from previous studies conducted on perceptions of drinking water quality in Canada, there appears to be a low priority towards water public health issues within the context of private water wells in many Canadian households, with the possible exceptions of some rural and Indigenous communities. This may be because perceptions towards well water and knowledge about the threats to well water quality may be lacking or misinformed. Furthermore, as a developed country with a relatively large portion of freshwater resources available, most Canadian residents are fortunate and do not experience most of the problems with water quality and scarcity experienced in low- and middle-income countries (Jones *et al.*, 2007). Access to advanced health care systems and water treatment technologies also means that waterborne illness may be controllable and may rarely result in adverse health impacts (Hrudey & Hrudey, 2007).

Therefore, drinking water contamination may not be a priority issue for most of Canada's residents serviced by private or municipal water systems. Access to drinking water alternatives also means that most Canadian households have a choice and can make decisions based on their preferences for different alternatives and the costs of choosing alternatives (e.g., bottled water compared to water well) (Jones *et al.,* 2007). Perceived safety of drinking water, inadequate knowledge of well stewardship, a lack of understanding of the factors and mechanisms that could lead to well contamination, and perceived control over ability to control water quality, may therefore act as factors that reduce the perceived need to conduct water testing.

1.2.3 *Theoretical approach*

Theoretical explanations on perceptions of water quality and our behaviour towards water contamination are often nested in health and environmental literature (Gardner, 1996). Health theories play a role in explaining both preventive health behaviours (PHB) and sick role behaviours (SRB) (Janz & Becker, 1984). Both water quality testing and water treatment behaviour can be contextualized as either a PHB or SRB as the assumption is testing and treatment measures are implemented to ameliorate detrimental impacts on human health. A preventive health behaviour is any activity undertaken by a person who believes they are healthy to prevent disease or for detecting disease at an asymptomatic stage. Sick role behaviours are activities undertaken by a person who feels ill in order to define their illness and seek a cure (Kasl & Cobb, 1966; Rosenstock, 1974; Straub & Leahy, 2014).

A dominant health theory is the Health Belief Model (HBM) (Rosenstock, 1974). The HBM assumes that decisions on the adoption of a health behaviour are based on six constructs that influence our perceptions of health risks (Straub, 2014). In this respect, the HBM could play an important role in understanding the adoption of health behaviours, such as water testing, to mitigate against well water contamination.

1.3 Mixed methods and the One Health approach

Understanding perceptions and the complex social, economic, and cultural factors that impact people's ability to act and adopt preventive health measures for human and animal health is an important underpinning of the One Health approach (Zinsstag *et al.,* 2015). Mixed methods research is useful for studying complex social issues such as perceptions, attitudes, beliefs, values, and motivations that underlie health behaviours within social, economic, organizational, and political contexts that cannot be easily captured by either quantitative or qualitative designs alone (Curry & Nunez-Smith, 2015). To comprehensively understand well owner perceptions of well water quality and delineate factors that influence their perceptions, I chose to use a mixed methods design guided by a One Health approach. Mixed method studies may use a pragmatic approach to research that draw both from a positivist orientation of quantitative methods and a social constructivist orientation of qualitative methods (Creswell, 2013; Curry & Nunez-Smith, 2015). The main principle underlying pragmatism as a worldview is that of tackling a research problem or situation with what works and using all available approaches to understand and solve the problem (Creswell, 2013; Curry & Nunez-Smith, 2015). Pragmatism is not strictly committed to one philosophy (e.g., positivist or constructivist) and can draw methods from quantitative and qualitative approaches. Researchers have freedom of choice to use methods that work best to the situation or circumstances in their approach to tackling a research problem. As there is no one philosophy that a pragmatist ascribes to, "truth" is not narrowly defined and "is what works at the time" (Creswell, 2013). Therefore, "truth" may be situational and vary among individuals or groups (Creswell, 2013; Curry & Nunez-Smith, 2015).

The formulation of perceptions is influenced by interactions between several complex factors (Beardslee & Wertheimer, 1958). Several factors have been identified in influencing perceptions of water quality (de França Doria, 2010; Thomas *et al.*, 2019). Given the complexity of factors that interact to formulate peoples' perceptions of water quality, a mixed methods research approach is suitable for studying perceptions of well water quality. Furthermore, recognizing that the construct of water quality may be subjective and therefore may differ among individuals or groups, gives more credence to the use of a mixed methods approach in understanding perceptions of well water quality in Alberta (Jardine *et al.*, 1999; Turgeon *et al.*, 2012).

My research is guided by a One Health approach. One Health is a transdisciplinary approach to health problems originating from the interactions of humans, animals, and their shared environments within our society (Zinsstag *et al.,* 2015; Hall & Cork Chapter 1 in Cork *et al.*, 2016). Water is one of the fundamental substances that sustains life. I chose to position my research using a One Health approach as multiple players are involved in achieving healthy and sustainable water resources in Alberta. By incorporating the perspectives of different stakeholders who are reliant on well water while engaging individuals or groups who have vested interest in the management of Alberta's water resources including water well owners, livestock farm operators, well stewardship groups, watershed management groups, and environmental public health officials involved in well water quality testing, I aimed to develop a holistic understanding of the issues and challenges faced by water well owners with respect to water quality and well stewardship in Alberta. In doing so, this research may be used to improve the current framework for water well management in Alberta while increasing the public acceptance of the framework to water well management. Outcomes of this study may make gains in our knowledge and have the potential to inform well water stewardship policy and practice while informing well stewardship initiatives such as the WWP and the no charge water testing program currently running in the province.

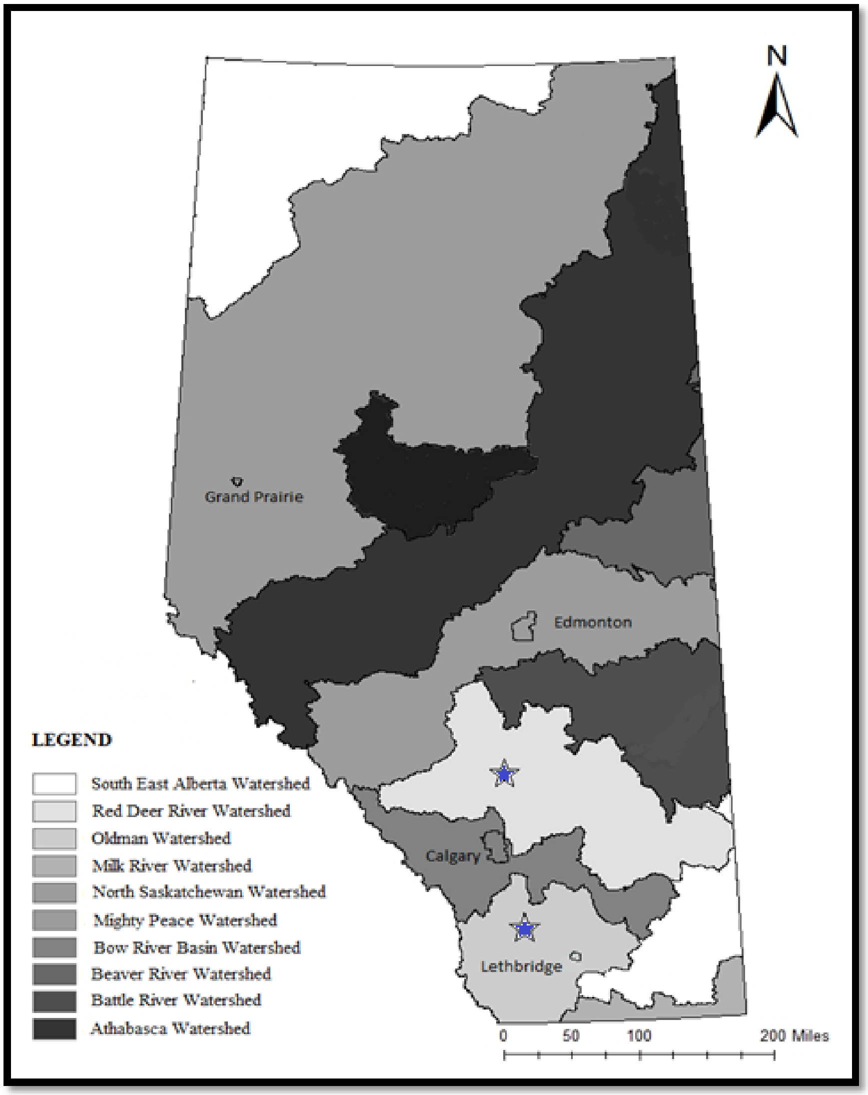
1.3.1 *Sampling*

This study focused on rural Albertan homesteads with private water well supplies. Specifically, homes that used well water for domestic purposes (i.e., drinking, cooking, and washing) were targeted in the sampling frame. A record of drilled wells in the Alberta Water Well Information Database (AWWID), retrieved from the Alberta Environment Groundwater Information System was used to select the sample. AWWID contains the drilling reports of over 500,000 wells in

Alberta drilled for both domestic and other uses. Because one of the aims of this study focused on whether perceptions of water quality were associated with livestock manure, only wells listed for domestic purposes and livestock watering were included in the sampling frame. Water wells listed in the AWWID as 'New Wells' under the 'Type of work' intended for 'Domestic', 'Domestic and Stock', 'Stock', 'Intensive livestock operation', and 'Industrial and stock' under the category 'Well use' within the AWWID database were selected. 1000 wells designated for 'domestic' use and 1000 wells designated for 'livestock' use were randomly selected for a total of 2000 wells from the AWWID database.

Participants mailing addresses were retrieved from the AWWID. Due to reliability issues with address information on the AWWID, for example, change of address and incomplete address information (Summers, personal communication, January 18 2016), participants were also recruited through targeted advertisements to the Watershed Planning and Advisory Council (WPAC's), water well stewardship groups (i.e., the WWP), readers of agricultural newspapers or newsletters in Alberta, and flyers in local rural grocery stores and community centres. Questionnaires, recruitment letters for participation in interview sessions and requests to conduct water quality tests were sent to participants selected in the final sample either by mail or email. Recruitment for a broader component of this study was done at a provincial scale. However, I mainly focused on participants within the Red Deer River Watershed and the Oldman River Watershed for my thesis.

Figure 1.4. Map of Alberta showing watersheds of interest for this study



Source: AESRD http://www.envinfo.gov.ab.ca/arcgis/rest/services/GDA/AlbertaWatersheds/MapServer

Studies on perceptions of water quality have mainly focused on eliciting responses from participants through cross-sectional studies (Imgrund *et al.*, 2011). This study used a cross-sectional design as interviews, questionnaires, and water quality report data were collected at one point in time. Cross sectional studies gather data on a sample at a specific time. The perceptions, knowledge, and experiences of water well owners in rural homesteads were explored through qualitative interviews using both inductive and deductive approaches to try and understand the factors that influence perceptions of well water quality within the rural Alberta context and explore factors that influenced well water testing behaviour as viewed through the theoretical lens of the HBM. Quantitative data were gathered through self-administered questionnaires sent to private water well owners in rural Albertan homes. Questionnaires have been used in previous studies to elicit perceptions individuals have of water quality (Summers, 2010; Roche *et al.*, 2013).

Finally, water quality reports were collected from testing conducted by well owners through the AHS and ProvLab on a subset of well owners to describe the prevalence of indicators of microbiological contamination. Specifically, total coliforms and *E. coli* were used as indicators of microbiological water quality contamination (Health Canada, 2017). Collecting data on the prevalence of total coliforms and *E. coli* served two functions:

1. To determine the prevalence of total coliforms and *E. coli* within our sample.
2. To have a positive behavioural outcome for well owners willing to participate in water testing as engaging water well owners in the process of water testing would benefit them.

1.3.2 *Qualitative component of the mixed methods study*

Qualitative research methods are useful in health research when exploring complex issues among groups or individuals. Unlike quantitative methods which may assume a positivist position, qualitative methods tend to focus more on exploring the subjective experiences among people (Creswell, 2013). Qualitative data were collected using interviews. Interview participants were selected by targeting private water well owners using their well water for domestic purposes. Thematic analysis is a widely used qualitative data analysis method (Green & Thorogood, 2014) and was the primary method used to analyse data generated from the interviews with well owners. Thematic analysis attempts to find meaning in data collected on participants' responses to questions and has been used to explore perceptions of water quality in previous studies (Jones *et al.*, 2005; Jones *et al.*, 2006). Further detail on analyses conducted for the qualitative portion of the study will be expounded on in chapters three and four.

1.3.3 *Quantitative component of the mixed methods study*

Questionnaires were used to collect quantitative data. The questionnaire collected socio-demographic information, well characteristics, well use information, perceived hazards to well contamination, perceptions of well water quality, barriers to well testing, barriers to well treatment, knowledge of well testing, and microbiological treatment recommendations. Descriptive statistics were generated for the dataset (e.g., means, medians, frequency counts). Multivariable analyses were then used to assess the relationship between independent and outcome variables. The quantitative technique selected for this study was a logistic regression which was used to investigate the association between independent variables (e.g., well characteristics and well use) and the dependent outcomes of well stewardship (i.e., testing and treatment). Further detail on analyses conducted for the quantitative portion of the study on will be expounded on in chapter five.

1.3.4 *Water quality testing and reporting*

Water quality reports were collected from a subset of participants. As domestic drinking water quality was the focus of this study, well owners were encouraged to take water samples from a tap they frequently used (e.g., the kitchen tap). Water quality testing services were provided for by AHS and the ProvLab. All participants receiving a questionnaire in the initial study mail out were requested to submit a well water quality sample to AHS for routine total coliform and *E.*

coli testing. The ProvLab conducted water testing on samples received from participants. Water testing involves checking for the presence or absence of enzyme substrate test for total coliform and *E. coli* (Colilert® IDEXX, Westbrook, ME, USA). A water sample is examined under light for a colour change from clear to yellow and visually compared to a comparator. The change in colour results from the breakdown of ortho-nitrophenyl-β-galactoside (ONPG) by β-galactosidase. This indicates the presence of total coliform within the water sample. If a colour change is observed, the sample is examined under ultraviolet light for fluorescence caused by breakdown of 4-methylumbelliferyl-beta-D-glucuronide by β-glucuronidase, indicating the presence of *E. coli* with as few as one colony forming unit per 100ml of water (IDEXX, 2016; Invik *et al.,* 2017). The MAC for total coliforms and *E. coli* used for drinking water is zero CFU/100ml of water (Health Canada, 2014). Water well owners were then sent a water quality report by the AHS which they were required to anonymize and submit (See Figure 1.5 and 1.6).

Figure 1.5. Summary of water testing procedure

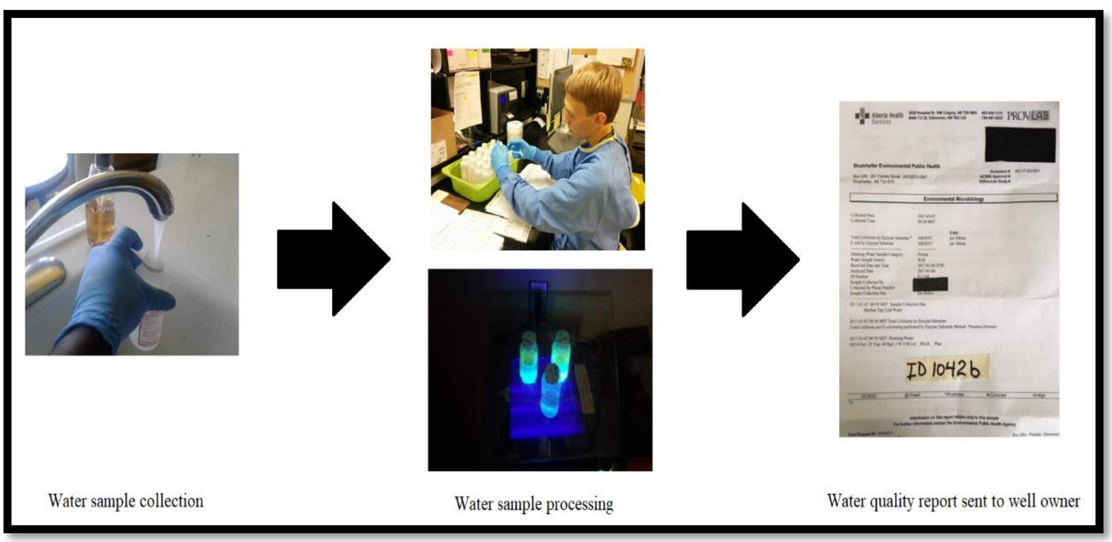
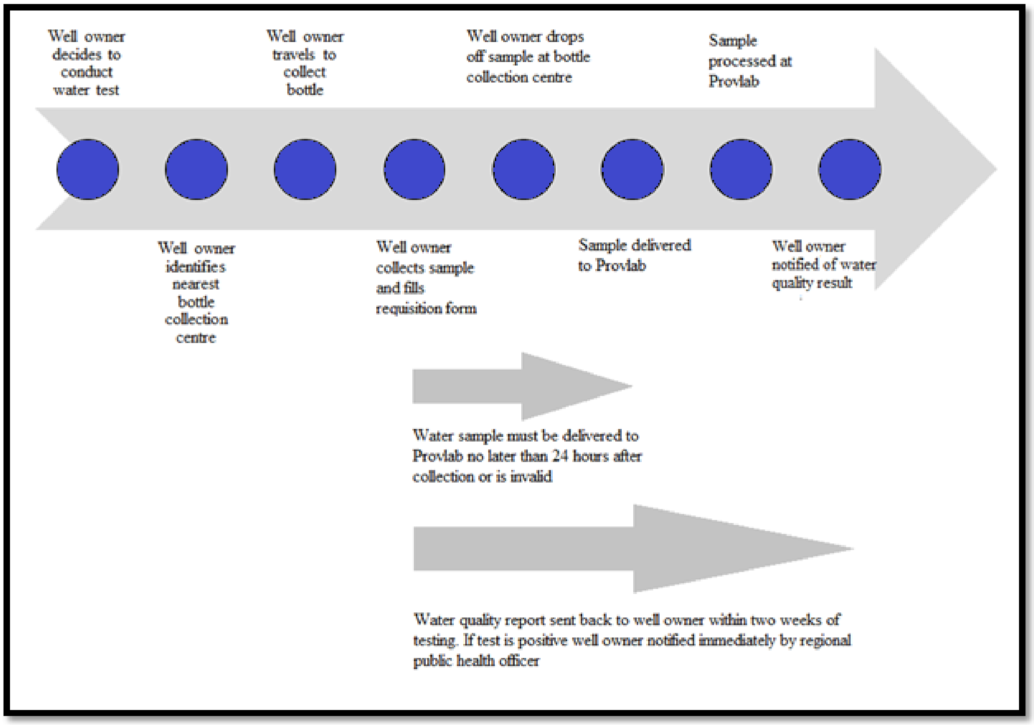


Photo credits: Abraham Munene and ProvLab

Figure 1.6. Simplified process of water quality testing from decision to test to water quality reporting



1.3.5 *Integration into a mixed methods study*

Using both qualitative and quantitative approaches enabled the understanding of factors influencing perceptions of well water quality within the rural Alberta context and well owners' decision-making process with regards to using well water stewardship practices. A convergent parallel design was used to combine the results of the qualitative and quantitative studies in the final chapter (Creswell, 2013). Data integration through merging was used in the final chapter to combine the findings from both the qualitative and quantitative components of this research. Merging is a data integration approach in which the qualitative and quantitative data are compared together looking for convergence and divergence among the qualitative and quantitative data (Curry & Nunez-Smith, 2015). Merging is also a preferred approach when the data collection steps assess similar domains being evaluated in participants (Curry & Nunez-

Smith, 2015). A staged narrative approach (i.e., a way to present mixed methods study findings) was used to present the findings of the mixed method study. Staged narrative approaches present findings in separate manuscripts or chapters (Curry & Nunez-Smith, 2015).

1.4 Thesis aim and overview

The overall aim of this thesis was to investigate perceptions of well water quality in Alberta. Simply, my thesis sought to understand what well owners thought about their well water quality, the risks they perceived relating to well water contamination, and well stewardship practices currently used by rural Albertan well owners. These important questions have implications on informing well stewardship policy and programs currently running in Alberta. My thesis began with a systematic review of factors identified as influencing perceptions of well water quality in North America (i.e., Chapter two). Chapter three elaborated on factors influencing perceptions of well water quality in Alberta using an inductive qualitative approach. Chapter four evaluated how the HBM was used to understand well water testing behaviour. Chapter five detailed the factors associated with self-reported well stewardship (i.e., testing and treatment) in rural Alberta. Finally, chapter six summarized the mixed methods study findings and suggested recommendations for well stewardship policy and practice.

Chapter Two: Factors influencing perceptions of private water quality in North America: a systematic review

2.1 Abstract

An estimated four million people in Canada and 43 million people in the USA use private water supplies. Private water supplies may be vulnerable to waterborne disease outbreaks. Private water stewardship is often left to the owner. Perceptions of water quality become important in influencing the adoption of private water stewardship practices, therefore safeguarding public health.

We conducted a systematic literature review to understand factors that influenced perceptions of water quality among private water users. We searched six computer databases (Web of Science, Medline, Scopus, EBSCO, PubMed, and Agricola). The search was limited to primary peer reviewed publications and a technical report. We restricted the search to articles which published data on surveys of private water users within Canada and the USA. 204 full text were reviewed. 52 articles were included in the final review. Factors found to influence perceptions of water quality included organoleptic preferences, chemical and microbiological contaminants, perceived risks, water well infrastructure, past experience with water quality, external information, demographics, in addition to values, attitudes, and beliefs held by well owners.

As many jurisdictions in North America do not have mandatory private water testing or treatment regulations for households, delineating factors influencing perceptions is an important step in informing future research and guiding policy on the public health management of private water supplies.

2.2 Introduction

An estimated four million and 43 million people in Canada and the USA use private water supplies (Jones *et al.*, 2006; Flanagan *et al.*, 2015a). In the absence of municipal water distribution systems in rural populations, private water supplies are an alternative source of domestic water in developed countries. Private water supplies may be vulnerable to waterborne disease outbreaks (Said *et al.*, 2003; Schuster *et al.*, 2005; Charrois, 2010; DEFRA, 2014). Several chemical, and microbiological contaminants can contaminate private water supplies. Nutrients (e.g., nitrates), pathogens, pharmaceuticals, hormones, heavy metals, nanomaterials, and personal care products are some contaminants that have been identified in well water (Hooda *et al.*, 2000; Campagnolo *et al.*, 2002; Kolodziej *et al.*, 2004; Johnson *et al.*, 2006; Burkholder *et al.*, 2007; Coleman *et al.*, 2013). Well water contaminants are associated with illnesses including gastrointestinal illnesses, liver, and kidney problems, endocrine disruption, cancer, reproductive issues, and neurological disorders (Villanueva *et al.*, 2014).

Private water supplies in North America are often unregulated meaning that the management of private water supplies (e.g., water wells, cisterns, or boreholes) is the responsibility of the owner. As a guide to drinking water quality standards the GCDWQ sets out national drinking water guidelines in Canada. Similarly, the Safe Water Drinking Act is used to set out national and enforceable drinking water guidelines in the USA for private water sources that serve more than 25 people. Although both Canada and the USA have national guidelines for drinking water quality, individual provinces or states may have their own regulations on the construction of new wells and water testing with some jurisdictions requiring mandatory testing on wells upon the acquisition of new properties (Fox *et al.*, 2016). Unlike municipal water supplies which may be regularly monitored and treated, few enforceable regulations cater to testing and treatment of private water supplies serving private households in Canada and the USA (Jones *et al.*, 2005; Jones *et al.*, 2006; Flanagan *et al.*, 2015a; Fox *et al.*, 2016).

In the absence of regulations on the management of private water supplies, compliance to private water testing and treatment recommendations becomes essential in protecting the health of private water owners from illnesses that could be contracted from consuming contaminated water. Recent studies indicate that compliance towards private water testing and treatment recommendations in various jurisdictions is low (Flanagan *et al.*, 2015a; Flanagan *et al.*, 2015b). For example, Roche *et al.* (2013) found that nearly 80% of participants in their survey tested water quality at frequencies below the current provincial recommendations. Perceptions of water quality may influence the adoption and implementation of private water management practices (de França Doria, 2010). The choice of when to test water quality, what to tests to conduct, and what treatment devices to use on private water supplies are decisions that are based on both perception and knowledge of risks to private water contamination.

Perceptions have been broadly defined as a human being's primary cognitive contact with the environment or simply the way in which we understand the world around us using our senses (Deonna, 2006). However, this narrow definition, based on the sensory appraisal we make to understand our environment is myopic, and does not capture the complexity of factors involved in shaping perceptions (Beardslee and Wertheimer, 1958). Perception also has subjective components that are associated with learning and past experiences that are mediated by attention, memory, and the ability to retrieve information from memory (Hochberg, 1956).

Consequently, this raises the question; what factors are important in shaping the perceptions private water users have of their water quality? Little is known about the factors that influence perceptions of water quality among private water owners. A systematic review of studies on people reliant on private water systems, primarily water wells, for domestic use in both Canada and the USA to determine the factors that influence the perceptions of water quality within these two countries was conducted. Describing and understanding the factors that shape perceptions of water quality among private water users is an important step in developing well water management policies to increase compliance towards water testing and treatment in Canada and the USA. To guide the scope of our systematic review we wanted to answer the main question. What factors predominantly drive perceptions of private water quality in Canada and the USA?

2.3 Methods

2.3.1 *PICO framework*

A PICO framework (Schardt *et al.*, 2007) was used to help guide the questions of the review. As most studies included were observational, assessment for control groups was not feasible as there were no adequate comparisons for perceptions held by private water owners to a similar group.

Table 2.1. PICO framework

PICO	Characteristic assessed
Population of interest	Studies reporting on private water users within Canada and the USA*
Intervention	Factors influencing perception of water quality
Control	N/A
Outcome	Presence of water well treatment and water well testing

*some studies that reported on both private and municipal supplies were included in the review

2.3.2 *Search strategy*

Literature searches were made on both health and environmental databases. A search strategy was developed in consultation with a research librarian and the review team. Our review was informed by methods for conducting systematic reviews in agri-food research (Sargeant *et al.*, 2006). We searched 6 computer databases (Web of Science, Medline, Scopus, EBSCO, PubMed, and Agricola). The search was conducted between January and December 2017. The search was limited to primary peer reviewed publications and technical reports. The search excluded conference proceedings, review articles, and non-peer review articles. We restricted the search to papers published in English and to articles which published data on private water users within Canada and the USA. The search was restricted to publications within the last 31 years (01/01/1986-31/12/2017).

A combination of search phrases was used for each database but consisted of major search domains with associated synonyms required to capture relevant articles. Keywords searched were *private water, domestic water, household water, water well, drinking water, perceptions, knowledge, belief, attitude, information, awareness, testing, treatment, survey,* and *rural*. Reference lists for relevant primary articles and review articles were screened. Articles fitting the inclusion criteria were added to the final list. All study approaches were considered including quantitative, qualitative, and mixed methods. As the focus was on perceptions of water quality among private water users, studies that directly surveyed private water owners were included in the final literature search.

2.3.3 *Data extraction*

Each paper included in the final review was read independently by two authors and then assessed for relevancy in the review. The lead author (AM) extracted the following information: the main purpose of the study, the study population, study approach, methods of data collection, whether theoretical frameworks were used, notes on the context of use of the private water systems, whether a formal intervention was present, and results. The author also constructed a table identifying the study type, demographics, interventions being evaluated, and results relevant to the review study. The second author (DCH) independently verified data extraction and tabulation for the included articles. Each article included in the final list was independently rated by both authors for relevance to the review. Both authors met regularly over a period of four months to discuss the findings. In instances of disagreement, articles were reassessed independently, and consensus was reached following deliberation. A PRISMA flow diagram (see Figure 2.1) was used to narrow our selection of articles (Moher *et al.*, 2009). Articles were preliminarily screened by (1) reviewing the article titles generated by the keywords search, (2) reviewing article abstracts, (3) reviewing the full articles, and (4) sorting on relevance for the review.

2.3.4 *Quality of study and risk of bias*

As a measure of the quality of study, articles were evaluated by whether they were published in a peer reviewed journal (as the assumption is that articles published in reviewed journals have been adequately scrutinized by reviewers before publication) or were technical reports. Reviewers also ranked the quality of the study relative to the review's objectives on a scale. A risk of bias assessment from each study was conducted using the Strobe checklist assessment for risk of bias. Studies were ranked on a scale of one (high quality) to four (low quality) for their relevance to the review and based on the strobe checklist.

2.4 Results

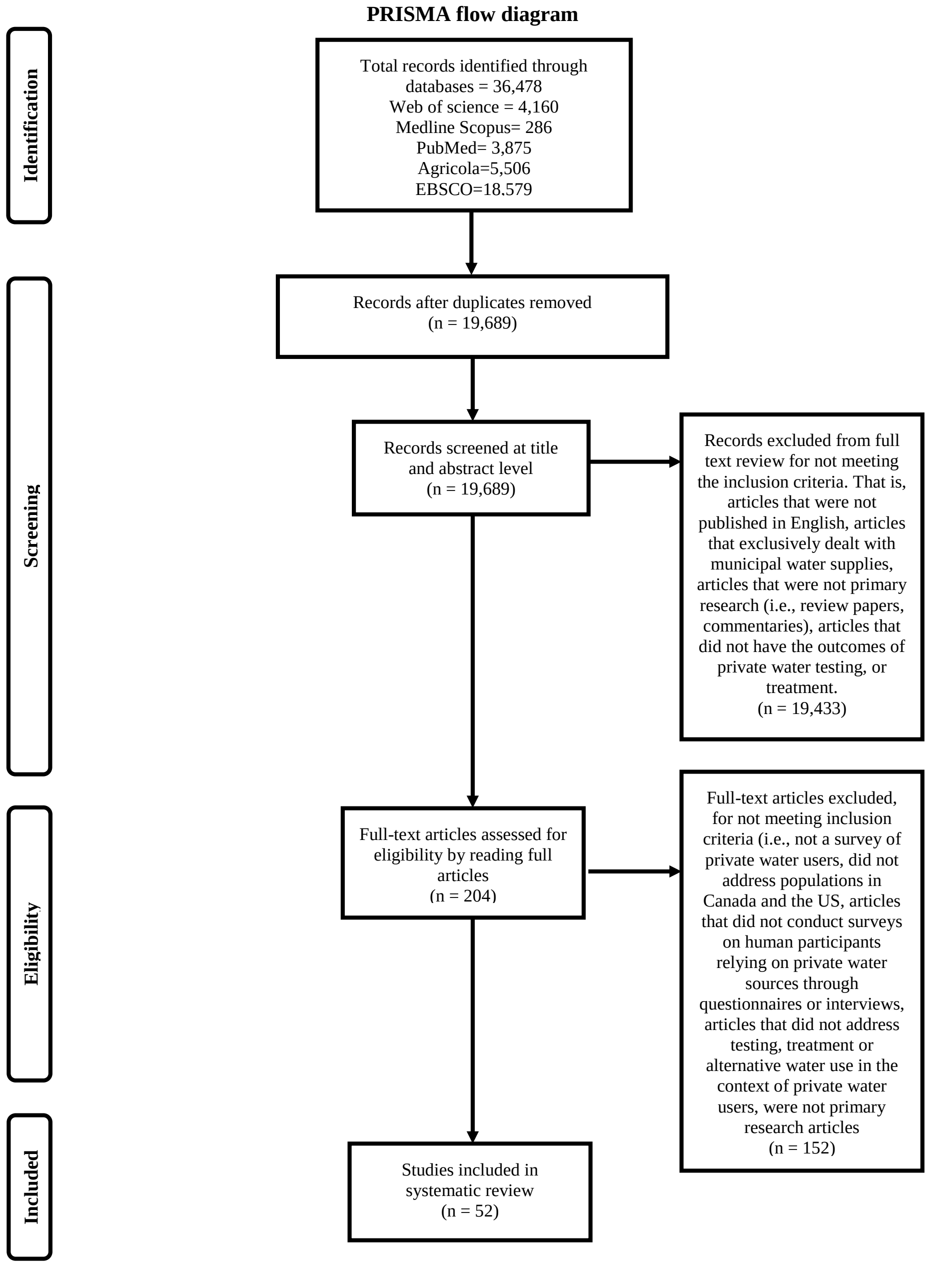
The database search included 36,478 articles using the keyword search. Web of Science (n = 4160), Medline OVID (n = 286), Scopus (n = 3,875), PubMed (n = 4,072), Agricola (n = 5,506), EBSCO (n = 18,579). Ultimately, 204 papers were examined intensively of these 152 articles were excluded for not meeting the inclusion criteria for this study. Fifty-two studies were included in the final review. Of the 52 studies identified 44 exclusively focused on surveys delivered to private water supply owners while ten studies surveyed both residents with private and municipal supplies. Most of the articles (n = 35) were from the USA while 17 articles reported on private water users in Canada. All studies were observational. Most of the studies used a cross sectional design (n = 49) with the rest reported on case control studies. Of the 52 studies included in the final review. Studies were also classified as quantitative (n = 48), mixed methods (n = 3) or qualitative (n = 3). Survey administration method varied. Questionnaire mail deliveries were used in 35 out of 52 studies and telephone surveys were used in 11 out of 52 studies. Other methods used to elicit participation included face to face interviews (3 out of 52) and focus groups (6 out of 52).

This systematic review included 52 journal articles with data collected on over 35,000 water well owners across Canada (n = 14,793) and the USA (n = 22,420). Perceptions of well water quality across Canada and the USA were found to be influenced by several factors. The main factors identified through this review were organoleptic properties of water, knowledge of chemical and microbiological contaminants, perceived risk, demographic factors, past experience with water quality, external information, values, attitudes, and beliefs about water, and water infrastructure (see table in Appendix B1.).

2.4.1 *Organoleptic properties of water*

Private water owners primarily relied on the sensory properties of drinking water sourced from their private water supply when it came to decisions regarding well management. Decisions on when to test water quality were often motivated by changes in either the taste, look or smell of the water (Flanagan et al., 2015b; Jones et al., 2006; Roche et al., 2013). Satisfaction with the organoleptic properties of water was not necessarily equated to concern over drinking water quality. For example, although most participants rated the organoleptic properties of their water from “good” to “very good” nearly 80% of surveyed participants indicated being concerned about water quality (Jones *et al.*, 2006).

Figure 2.1. PRISMA flow diagram for study selection



In contrast, organoleptic properties of drinking water were congruent with the perceptions of the safety of water for consumption. About 67% of participants who had issues with the organoleptic properties did not consider their water as safe to consume (Garcia *et al.*, 2016).

Sensory cues derived from the organoleptic properties of water were not only limited to water consumed but also to other water uses. For example, some well owners reported on the hardness of their water well as it tended to discolour their appliances or plumbing systems (Jones *et al.,* 2005). Due to psychological factors people expect sensorial information on the taste, odour, and colour of water to be congruent (de França Doria, 2010). However, what was not clear from the studies is what sense dominated when water well owners indicated a change in their water well quality. Evidence on how water well owners perceive the taste, smell, and odour of water sourced from their wells relative to alternative water sources such as bottled water or municipal tap water was also evaluated in some studies. Water well owners were unwilling to change to municipal water supplies due to their personal preference for the taste of their well water and fear of "chemicals" in city water (Murti *et al.*, 2016). Similarly, Jones *et al.,* 2005 found that water well owners preferred their well water over bottled water due to preferences in taste and skepticism to where the bottled water came from.

2.4.2 *Chemical and microbiological contaminants*

Due to the soluble properties of water, several chemical and microbiological substances can be found in private water sources. Some chemical and microbiological substances can pose a health risk to individuals consuming well water. Of the 52 articles included 13 out of 52 exclusively focused on assessing exposure to naturally occurring arsenic. Nitrate exposure was exclusively evaluated in five out of 52 articles. Radon exposure was exclusively evaluated in one out of 52 articles while two out of 52 articles evaluated the exposure of total coliform and *E. coli* in wells. Thirty-four articles were non-specific towards the chemical or microbiological contaminants (e.g., general bacterial and chemical contamination or a combination of microbiological and chemical contaminants). For studies exclusively focusing on exposure to one contaminant, some studies were clear about the thresholds for the MAC. The MAC is the specific level of a contaminant that is allowed in water for a specific purpose (e.g., human consumption). The contaminants assessed for and the MAC for specific contaminants may vary regionally (Dunn *et al.,* 2014). However, the MAC's of several contaminants in Canada and the USA are similar and reflect standards set out by the US Environmental Protection Agency. Studies examining naturally occurring arsenic as an exposure often quoted 10 µg/l as the MAC (Colt *et al.,* 2002; Shaw *et al.,* 2005; Flanagan *et al.,* 2015). For nitrate as an exposure, the MAC used was 10 mg/L in 6 studies (Poe *et al.,* 1998; Schwartz *et al.,* 1998; Lewandowski *et al.,* 2008). Lead exposure was assessed in one of the studies (Pieper *et al.,* 2015) with some studies quoting MAC's for each contaminant assessed (Postma *et al.,* 2011). However, in many of the studies that assessed exposure to contaminants or that were non-specific to a contaminant, MAC's were not used (Mechenich &Shaw, 1994; Strauss *et al.,* 2001; Schade *et al.,* 2015; Garcia *et al.,* 2016). Some studies also included a water testing component to evaluate the prevalence of contaminants of interest in their samples (see table in Appendix B2).

Knowledge of the level of contaminants within well water was an important factor when well owners had to decide on treatment systems to use in their wells. For example, half of participants indicated they would begin treating or finding other water sources before the concentration reached the MAC 10 mg/l of nitrates in their well water. Interestingly a similar proportion of participants indicated that they would wait until the concentration of nitrates in their water was >10mg/l or higher (Lewandowski *et al.,* 2008). However, the authors noted that stated intentions differed from the actual responses with only 21.9% opting to use a treatment system and about 25% opting to switch to bottled water and drilling a new well upon learning of exceedances. Flanagan *et al.,* (2016a) found that about 43% of water well owners installed water treatment with a further 30% seeking alternative water sources after being informed of exceedances in the MAC of arsenic in their well water. Therefore, even though some well owners knew their water wells exceeded the MAC for potential contaminants, their decision to adopt treatment or use alternative water sources may have been influenced by the perceived risk of the contaminant towards their health. These findings demonstrate the complexity in how the appraisal of the risks posed by contaminants may be highly subjective to individuals.

2.4.3 *Perceived risk*

Individuals responded to hazards they perceived within their environment. Risk perception is defined as the subjective judgement that an individual makes about the characteristics and severity of a risk (Slovic *et al.,* 1982). In order for an individual to make a decision on whether or not to use treatments or seek alternative drinking water sources they must first identify the hazard (e.g., nitrates), evaluate the risk of contamination based on potential risk factors in their environment and their exposure to those risks (e.g., test for contamination in an area with extensive manure or fertilizer spread and understand how likely they are to be exposed to nitrate contamination) and finally they must understand the consequences of the hazard and their ability to control those consequences (e.g., know about a health risk such as methemoglobinemia and make a judgement on the severity of the methemoglobinemia towards their own health). Given there are several contaminants that may be considered a hazard to well water the process of assessing the risk of general water well contamination without a specific preidentified hazard may be problematic for water well owners therefore making the decision of what treatments to use, whether to switch to an alternative or what and when to test for water quality more difficult (Jones *et al.,* 2006). Individuals were less likely to consume well water if they thought there were health risks associated with consuming water containing arsenic (Walker *et al.,* 2006). Similarly, water well owners were less likely to drink well water if they perceived a risk in drinking water regardless of aesthetic concerns (McLeod *et al.,* 2014). Perceived risk factors within the environment could also influence what people thought of their well water quality. Participants reported proximity to livestock, proximity to septic systems, proximity to oil and gas, proximity to mining areas, proximity to nuclear power plants, flooding, severe runoff events and drought as environmental risks that caused concern, and motivated well owners to test their water (Levallois *et al.,* 1998; Acharya *et al.,* 2008; Summers, 2010; Postma *et al.,* 2011; McSpirit and Reid, 2011; Merkel *et al.,* 2012; Murti *et al.,* 2016).

2.4.4 *Demographic factors*

Demographics can influence choices water well owners make of drinking water options. Factors such a participant's education, income, number of years within a residence, and place of residence have been noted as important factors that influenced perceptions of water quality and the willingness to use water treatment (Schwartz *et al.,* 1998; Shaw *et al.,* 2005; Chappells *et al.,* 2015; Garcia *et al.,* 2016). Low education and income were more likely to result in the lack of use of water well treatment devices (Schwartz *et al.,* 1998; Garcia *et al.,* 2016). Low education and income may also be socio-economic factors that predispose water well owners to certain risk factors. Garcia *et al.* (2016) noted that residents living in underprivileged communities within New Mexico had unreliable drinking water systems, poor sanitation, and a lack of access to water testing and treatment. Despite the risk of arsenic being randomly distributed within socioeconomic groups, individuals with lower income and lower education were less likely to adopt mitigation strategies such as well testing and treatment for their water wells (Flanagan *et al.,* 2016c). Furthermore, psychological factors influencing testing and treatment were more prevalent among those with higher incomes and education. Similarly, higher education and income were positively associated with the decision to test well water quality and use water treatment devices (Straub & Leahy, 2014; Lothrop *et al.*, 2015). Education and income were not always associated with positive outcomes on treatment and testing. No significant association was found between education and stewardship behaviours conducted by water well owners (Kreutzwiser *et al.*, 2011). Similarly, no significant association was found between education and income on water well treatment (Summers, 2010; Postma *et al.*, 2011). In contrast Shaw *et al.* (2005) found a negative association between income, education, and the decision to use water well treatment.

The number of years an individual had lived at a residence and the length of time they had used well water also seemed to be an important factor associated with water testing and treatment behaviour. This is because well owners may get habituated to their drinking water source. Shaw *et al.* (2005) found that the longer an individual had lived in the household the less likely they were to engage in water testing behaviour. Similarly, the longer an individual had lived within the household the less likely they were to conduct a water quality test within the last 5 years (Flanagan *et al.*, 2015a). However, some studies failed to find a significant association between the number of years lived within the home and well water stewardship practices (Lothrop *et al.*, 2015).

Age and gender have also been explored as demographic variables that can influence perceptions of private water quality. Evidence to show associations between age and gender on perceptions of well water quality have been sparse. Age and gender did not predict water testing behaviour among well owners (Straub and Leahy, 2014). With respect to gender, a significant association was found between women and the use of well water treatment systems. This is because the presence of children within a household may be identified as a reason for concern among parents and a reason for water well owners to choose alternative drinking water sources (Jones *et al.*, 2005; McSpirit and Reid, 2011; Merkel *et al.*, 2012; Feinman *et al.*, 2015).

2.4.5 *Past experience*

The role of past experience with water quality issues was important. Past negative experiences with well water quality were associated well water testing behaviour (Imgrund *et al.*, 2011). These experiences were either based on the individual well or within the well owners' community. Learning of water contamination among neighbours and experiencing unexplained gastrointestinal illness were noted as motivators for individuals to conduct water testing (Flanagan, *et al.*, 2015a). Despite past negative experiences being noted to influence perceptions of drinking water quality, determining the validity of reported past negative experiences may be subject to recall bias among surveyed participants. Furthermore, participants were not always able to attribute personal health problems, such as gastrointestinal illness, to drinking water from their wells. As gastrointestinal illnesses may be underreported and deemed controllable by participants it may be difficult to get an accurate representation of how past negative experiences with gastrointestinal illness influenced perceptions of well water quality (Jones *et al.*, 2007; Johnson, 2008; Feinman *et al.*, 2015). For water well contaminants which do not present direct clinical symptoms (e.g., pathogenic *E. coli*) and may have severe health consequences due to chronic exposure (e.g., arsenic) the role of past experience associated with negative health outcomes on perception of well water quality was difficult to determine. However, past negative experience with contamination indicated by water testing may have changed the perception of water well owners with regards to the safety of their drinking water (Lewandowski *et al.*, 2008). Previous positive experience with water quality testing may also have influenced the likelihood of well owners testing water quality in the future. For example, well owners reported being more confident in their water well supplies and therefore less likely to test their water quality if the result of the water quality test they had conducted in the past showed no evidence of contamination (Jones *et al.*, 2005). Recurrent problems with water quality as indicated by water quality tests may also lead individuals to worry more about their well water quality and therefore conduct frequent testing. For example, well owners who were identified as being high risk for arsenic contamination through water testing and who knew they were at a higher risk of arsenic contamination were more likely to conduct water testing than individuals who were identified as low risk for arsenic contamination (Schubert *et al.*, 1999). Similarly, well owners who had engaged in previous water testing and were aware of water quality issues were more likely to conduct routine testing (Renaud *et al.*, 2011).

2.4.6 *External information*

The impact of external information on changing perceptions towards well water quality to promote testing or treatment has been explored. External information sources were in the form of media campaigns, educational awareness programs or from prompts given by members of the community to encourage well water stewardship. The format of the information presented varied and included pamphlets and flyers distributed by private and public water public health agencies, news items, advertisements or advisories distributed through print media, social media, television or radio, information workshops, information solicited directly from water public health agencies (e.g., through phone calls), or information gathered from social informants (e.g., neighbours and friends) (Shaw *et al.*, 2005; Renaud *et al.*, 2011; McLeod *et al.*, 2014; Flanagan *et al.*, 2015b; Schade *et al.*, 2015; Ridpath *et al.*, 2016). Participants' responses to educational material was varied. Nearly 43% of participants installed water treatment systems in response to elevated arsenic levels while nearly 31% switched to alternative drinking water sources (Flanagan *et al.*, 2015b). Similarly, well owners were more likely to report higher arsenic testing rates in towns that had received educational intervention programs when compared to towns that did not receive programs (Flanagan *et al.*, 2016b). In response to media reports on the risk of cancer associated with arsenic exposure only 18% of participants used mitigation strategies that were useful against arsenic despite 66% having arsenic concentrations above the MAC (Shaw *et al.*, 2005; Walker *et al.*, 2006; Chappells *et al.*, 2015). Chappells *et al.* (2015) found that nearly 25% of participants reported making some change to their well water management practice in response to information received from either private testing laboratories or government departments. Well owners were more likely to engage in well testing programs after the dissemination of well management information through a well stewardship program (Imgrund *et al.*, 2011). Information on well water quality in the form of testing results was found to change participants perceptions of the safety of their drinking water (Poe *et al.*, 1998). Interestingly, not all information campaigns may increase well water stewardship. Nearly 28% of participants did not take any stewardship action despite being aware of elevated arsenic concentrations within their water (Flanagan *et al.*, 2015a). Exposure to media or other forms of external information may not be enough to change well water stewardship behaviour (Renaud *et al.*, 2011).

2.4.7 *Values, attitudes, and beliefs*

Values, attitudes, and belief towards health or the environment were found to influence people's willingness to adopt well stewardship practices. Well owners' decisions to conduct stewardship practices were more influenced by whether they were satisfied with their water quality and their knowledge and beliefs of water quality (Summers, 2010). Satisficing was identified as a phenomenon where well owners took on a simple belief about their well water and did not develop a strong enough knowledge base to accurately make judgements of their water quality.

Furthermore, most individuals in the survey believed that it was best not to do anything with their water well unless they had issues with it. Participants also held a wide variety of beliefs when it came to their water wells and these beliefs were not necessarily associated with negative health consequences. The role of imperfect and incomplete knowledge (e.g., wrong beliefs about aquifers and the origin of water in water wells) in the decisions of whether to adopt well stewardship practices was identified as a possible barrier (Summers, 2010).

2.4.8 *Water well infrastructure*

Available infrastructure, both physical and services available for well water quality maintenance, may influence stewardship practices. The availability of free well water testing services has often been used to encourage water quality testing among water well owners (Flanagan *et al.*, 2015a; Jones *et al.*, 2006; Kreutzwiser *et al.*, 2011; Roche *et al.*, 2013). Despite testing services being offered for free in several jurisdictions in Canada and the USA, compliance towards water testing recommendations was low (Roche *et al.*, 2013; Flanagan *et al.*, 2016b). Several barriers have been identified that inhibit water well owners from conducting regular testing (see Table 2.1). Individual well owners may face multiple barriers when deciding to go through with water testing (Summers, 2010; Kreutzwiser *et al.*, 2011). To increase compliance towards well water testing several studies have solicited participants suggestions on how to increase routine testing. Making pick up and drop off of water sampling kits more accessible, increasing reminders to participants to conduct water quality test, increasing educational awareness forums, providing incentives (or punishments), or making water well testing mandatory through legislation have all been stated as possible measures to increase compliance towards water testing. The availability of infrastructure for water well treatment may also influence habits towards water well protection. However, few studies have explored the reasons behind water well owner's choice of water well treatments.

Table 2.1. Barriers to water well testing and possible solutions provided

Barrier to water well testing	Recommendation to overcome barrier	Study
Inconvenience in dropping off and picking up water sampling bottles (time to get to water test locations and hours of operation for water testing centres)	Making bottle pick up and drop off more convenient for water testing or setting up services for delivering and picking up water sampling bottles	Jones *et al*., 2006, Roche *et al*., 2013, Summers 2010, Kreutzwiser *et al*., 2011, Imgrund *et al*., 2011, Flanagan *et al*., 2016b
No need to frequently conduct testing	Sending well testing reminders and making the issue of water well testing more salient to water well owners	Jones *et al*., 2006, Roche *et al*., 2013, Summers 2010, Kreutzwiser *et al*., 2011, Imgrund *et al*., 2011
Lack of information or misinformation on water testing	Provide educational/information awareness programs	Jones *et al*., 2006, Roche *et al*., 2013
Forgetfulness of procrastination	Sending reminders	Jones *et al*., 2006, Roche *et al*., 2013
No stated reason	Educational/ information awareness programs	Jones *et al*., 2006, Roche *et al*., 2013
Costs	Provide cost sharing or incentives	Jones *et al*., 2006, Roche *et al*., 2013, Summers 2010
No health problems attributed to water well testing or no problem perception	Provide educational/information awareness programs	Jones *et al*., 2006, Roche *et al*., 2013
Use of water treatment	Education/information awareness on what treatments to use	Jones *et al*., 2006, Roche *et al*., 2013
Interpretation of water quality result	Education/information awareness on what treatments to use	Summers 2010, Kreutzwiser *et al*., 2011

2.5 Discussion

This systematic review included 52 articles with data collected from private water owners in Canada and the USA. To the best of our knowledge only two previous literature reviews (de França Doria, 2010; Morris *et al.*, 2016) had attempted to provide a review of the factors influencing perceptions of water quality. The factors identified through this review were organoleptic properties of water, knowledge of chemical and microbiological contaminants, perceived risk, demographic factors, past experience with water quality, external information, values attitudes and beliefs about water and water infrastructure. The reliance on the organoleptic properties of water to make judgements on the safety of drinking by private water owners was profound and identified as a key factor in other reviews (de França Doria, 2010).

Water well management practices were discussed in the context of testing and/or treatments. Water well testing practices often tend to be the focus for researchers and intervention strategies (Jones *et al.,* 2006; Kreutzwiser *et al.,* 2011; Roche *et al.,* 2013; Flanagan, *et al.*, 2016a; Flanagan, *et al.,* 2016b). Widespread adoption of well testing and compliance towards recommendations set for testing tend to be problematic for water well owners to achieve. Interventions focusing on modifying well water testing behaviour based on incentives, legislation, education or community outreach activities have had moderate success on increasing compliance towards well testing (Kreutzwiser *et al.,* 2011; Flanagan *et al.*, 2015b; Flanagan *et al.,* 2016b).

Interventions based on getting water well owners to adopt well treatment are contingent on well owners understanding contaminants and the potential health risks they may pose. However due to the variety of possible contaminants found within water wells it may be very difficult to prescribe treatment devices, unless a contaminant is identified through testing, as one device may not be effective at removing all contaminants. The use of multiple water well treatment devices may offer more protection against several contaminants, however water testing will still need to be conducted to identify possible risks to a well. Therefore, educating private water users on options available for them with respect to water treatment may enable private water users make more informed decisions based on the identified risks to their private water sources. The need for more information on water treatment has been identified in previous surveys (Jones *et al.,* 2005; Roche *et al.,* 2013; Ridpath *et al.,* 2016).

2.5.1 *Gaps identified*

Despite the focus on well testing very few studies have tried to discriminate which health outcomes are perceived to be associated with drinking water contamination and more specifically toward individual contaminants (Levallois *et al.,* 1999). More studies are required to address this gap in knowledge between the perception of well water quality and the potential health consequences water well owners attribute to well contamination.

Maintenance of well water stewardship behaviour such as testing, post intervention, is also an issue that has yet to be adequately addressed. Despite the role research may play in active surveillance of water wells and motivating well owners to conduct water testing during the duration of the research program, there is very little evidence that behaviour such as water testing is continued after the research programs or other intervention programs end. Future research should investigate if well testing behaviour is maintained among well owners and this could be done by broadening the methods to include cohort studies and not only cross-sectional designs. Broadening active surveillance periods using research may also help in determining the period prevalence of well contamination over time and address reliability issues associated with surveys by following up on well owners' behaviour, in addition to determining the maintenance of water well stewardship practices.

Compliance towards water testing recommendations was still considered low in many jurisdictions. Changes in technology over the last 30 years and increased internet connectivity in Canada and the USA may provide water well owners with more access to information regarding their water wells, however a potential problem that arises is what information sources should well owners trust given that current policies in well stewardship are only recommendations. Studies need to be conducted on the quality of information provided by interventions such as educational programs or materials. Assessing the quality of information and how it is understood by water well owners may influence the adoption of well water stewardship behaviours and may be important in dealing with satisficing among well owners. Furthermore, more research needs to be conducted on sources of information private water owners have access to and the uptake of information based on its trustworthiness (Summers, 2010; Chappells *et al.,* 2015).

The adoption of qualitative and mixed method approaches to study perceptions of private water quality over the last decade and the shift away from quantitative studies has helped to develop a richer understanding of the issues faced by water well owners with respect to water quality. Qualitative and mixed methods research may be more beneficial in capturing the unique personal experiences and knowledge private water owners have of their water quality. Furthermore, incorporating the voice of private water owners in research is an important step in developing well management policy and practices and will directly tap into the needs of private water users. Despite having identified factors that influence well owner's perception of well water quality, it is important to note the paucity of research on how combinations of these factors influence well stewardship behaviour. There is little evidence to suggest that perceptions of well water quality and well stewardship practices (i.e., testing and treatment) are driven by a single factor and are more likely to be influenced by a combination of several factors. While research to date has done an adequate job of identifying factors that influence perceptions of water quality and furthermore predictors of well stewardship there is a knowledge gap in how these factors interact with each other to produce the desired outcome (e.g., water testing) in well owners. For example, although external information (e.g., educational forums) may help encourage well testing, if well owners conduct a test and have a negative test result due to the educational program, how does the past experience of having a negative well test result influence both their appraisal of susceptibility to water well contamination and their willingness to test their water in the future. More research is required on how factors that influence perceptions of water quality may act synergistically or antagonistically to influence well stewardship behaviour.

This review summarizes research that has been conducted on water well owners' perceptions of water quality over the last 30 years while identifying questions and areas that need further development in research. Policies and recommendations for well water testing, treatment and other management practices are highly contextual to the regions, however this study summarizes the most pertinent factors driving perceptions of private water quality based on research that has been conducted.

2.5.2 *Limitations*

Publication bias may have been present due to the selection of articles from peer reviewed journals. Furthermore, because we only selected articles published within the last 30 years there may have been a time lag bias with the selection of articles (Egger *et al.,* 2008). Despite the search for articles and selection of articles relevant for the review being restricted to the language spoken by the authors, no systematic bias has been found in reviews published in English (Morrison *et al.,* 2012).

2.6 Conclusion

Given that perceptions of water quality among private water users are influenced by several factors, researchers, educators and policy makers should appreciate the heterogeneity and interplay of these factors when planning private water management programs or developing policies. Education and communication strategies that focus more on individual well owners and their needs based on risks identified around their well need to be adopted as opposed to blanket policies or programs may be helpful. The use of surveys and qualitative research to identify the needs of individual well owners may help. This is especially pertinent because of the different interacting factors that may motivate private water users to comply with water testing recommendations.

Chapter Three: Perceptions of drinking water quality from private wells in Alberta: A qualitative study.

3.1 Abstract

Water wells are important in providing water for rural populations that are far removed from municipal water supplies. Over 400,000 rural Albertans use water wells for domestic purposes. The responsibility of water well management lies with well owners. Perceptions of well water quality become important in influencing the adoption of water well management practices such as testing, treatment, and well maintenance. This study sought to understand perceptions of well water quality among rural Albertans. Semi-structured interviews were conducted with well owners. A thematic analysis was used to analyze the data. Overall, water well owners were satisfied with the organoleptic properties of their well water. Activities perceived as a hazard to water well contamination were mainly agricultural or oil and gas related. Most water well owners reported using some form of mitigation strategy. Water well owners reported knowledge of well contamination events and the main illnesses associated with well water contamination were gastrointestinal illnesses. Perceptions of well water quality were influenced by several factors. Identification of these factors is useful to informing well stewardship policy and programs in the province.

3.2 Introduction

Groundwater wells are important in providing water for rural populations that may be far removed from the infrastructure of municipal water supplies. Unlike municipally supplied water, the responsibility of managing private water wells (i.e., testing, treating, and conducting well maintenance) is left to the well owner (Flanagan *et al.*, 2015; CDC, 2015; Health Canada, 2018a; AEP, 2018a).

Without the use of proper well management techniques, private water wells may be vulnerable to water contamination by either microbiological or physiochemical contaminants. More than 70% of 183 waterborne disease outbreaks were associated with groundwater supply systems (Reynolds *et al.*, 2008). Nearly 32% of water wells tested positive for at least one contaminant above their MAC (Fitzgerald *et al.*, 2001). Recent studies indicate that between 14-22% percent of water wells are contaminated with total coliforms and between 1.5-5% of wells are contaminated with *Escherichia. coli* at a given point in time (Coleman *et al.*, 2013; Invik *et al.*, 2017). *E. coli* and total coliforms are currently used as indicator species for microbiological water well contamination. Some private water wells are vulnerable to waterborne disease outbreaks (Corkal *et al.*, 2004; Schuster *et al.*, 2005).

Both anthropogenic and natural factors may lead to water well contamination. For example, agricultural, oil and gas extraction activities, sewage systems, landfills, and other anthropogenic activities can impact water quality and could result in groundwater contamination (Vörösmarty *et al.*, 2010; Pimentel *et al.*, 2004; Schwarzenbach *et al.*, 2010; Ritter *et al.*, 2002). Conditions such as extreme weather or climatic conditions (e.g., flooding) may increase the probability of exposure of wells to contaminants (Eccles *et al.*, 2013). Furthermore, naturally occurring substances in the soil and bedrock making up an aquifer can contaminate groundwater if they exceed the MAC safe for consumption (Lewis *et al.*, 1999; Ayotte *et al.*, 2003). Contamination could also occur if the well is not maintained properly through incrustation, biofouling, and corrosion within the well casing. Damaged wells may also increase the probability of exposure to contaminants (Buchanan *et al.*, 2013).

Perceptions of well water quality become an important part of influencing the adoption of private water management practices such as testing, treatment, and other mitigation strategies (de França

Doria, 2010). Drinking water quality standards provide limits on the MAC of contaminants acceptable in drinking water. However, the appraisal of water quality and what constitutes 'good' water quality may be a social construct influenced by more factors. Therefore, it is important to understand factors that shape perceptions of water quality to develop or inform policy and practice (Jones *et al.*, 2005; Jones *et al.*, 2006; Summers, 2010; Roche *et al.*, 2013). Little research has been done to understand the perception rural Albertans have of their well water quality. This is a critical gap for those planning educational and intervention strategies to cater to the needs of water well owners (Jones *et al.*, 2005). This study seeks to understand perceptions of well water quality in Alberta among rural residents and the factors that influence their perceptions by addressing this gap through interviews with well owners. Knowledge gained from this study will be useful in identifying factors influencing the perceptions of water well quality, identifying factors individuals associate with water well contamination, and informing policies on water well management in Alberta.

3.3 Methods

To understand perceptions of well water quality, well water owners were recruited and interviewed about their perceptions of well water. A thematic analysis on the interview transcripts was conducted. An inductive approach was used to interpret the data. Unlike quantitative research, qualitative research is not typically number driven as the focus of qualitative research is the experiences of the individuals or groups being interviewed and documenting them to provide a richer understanding of their perceptions about a topic under study (Sandelowski, 2001; Maxwell, 2010). Qualitative research has been used to study perceptions of well water quality in other parts of Canada (Jones *et al.*, 2005; Imgrund *et al.*,

2011) as well as issues pertaining to water governance and policy in Canada (Summers *et al*., 2003; Cervoni *et al.*, 2008; Orr *et al.*, 2016).

3.3.1 *Setting the context*

Over the last decade Alberta has experienced a growth in the livestock industry with livestock intensification practices being favored to maximize production. Currently, Alberta contains the largest beef cattle industry with an estimated cattle population of five million (Olson *et al*., 2009; Bonti-Ankomah *et al.*, 2017). Consequently, high densities of animals are reared in relatively fewer areas of land such as concentrated feedlot operations (Beaulieu *et al.*, 2001; Burkholder *et al.*, 2007; Bonti-Ankomah *et al.*, 2017). Livestock manure can be a non-point source for well water contamination and was historically an important factor in the Walkerton outbreak (Goss *et al.*, 1998; Ritter *et al.*, 2002). In addition to cattle production, Alberta is also the largest oil producing province in Canada accounting for over 75% of crude oil production (Natural Resources Canada 2018). Both livestock production and oil and gas could potentially lead to groundwater contamination. Exposure of a well to hazards may not always be controllable (e.g., living in a province or area with oil and gas extraction activities or living in an area where your aquifer does not produce adequate drinking water quality due to the natural composition of the aquifer). However, there are regulations on minimum distances water wells should be drilled from potential hazards (e.g., manure storage facilities, fuel tanks, sewage, and landfills) (Buchanan *et al.*, 2013).

3.3.2 *Theoretical approaches used to understand the construct of water quality*

There are two theoretical viewpoints taken to approach the construct of water quality. One was a positivist perspective where standards are set to define what is acceptable in terms of water quality, that is, having MAC for potential contaminants as we do in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2017). This is the approach public health officials may take when deciding whether to designate a well as having a contamination issue through looking for exceedances in contaminant levels. The other perspective would be to take on a constructivist approach where the perception of water quality is defined by its properties such as the organoleptic (i.e., sensory) properties, the factors believed to influence water quality, and the experiences and preferences of the well owner, which are more subjective. For example, preferences for the aesthetic objectives or organoleptic properties of water such as taste, colour, smell, or hardness of water may be subjective and based on what the well owner is used to and prefers (Jones *et al.*, 2005). On a day to day basis, the constructivist approach may play more of a role on judgements of drinking water safety and whether well owners choose to drink their well water. Relying on the organoleptic properties or past experiences to determine the 'safety' or how 'good' well water is for consumption may not be adequate as changes may occur to well water quality and it is sometimes difficult to detect and predict when and what causes changes to water quality. For example, well owners may not detect the presence of microbiological contamination in drinking water by simply relying on the organoleptic properties of their water. Well owners are therefore advised to conduct regular testing (AHS, 2018).

3.3.3 *Well use and participant recruitment*

Currently, the responsibility of managing water wells lies with well owners (AEP, 2018a; Health Canada, 2018a). Well owners were recruited through paper mail and emails sent to well owners identified on the Alberta Well Water Information Database (AWWID), watershed management groups, local media advertisements (e.g., newspapers), rural grocery stores, and community centres. A purposive sampling technique was used to recruit well owners. Purposive sampling is a technique often used in qualitative research to gain a detailed understanding of the experiences of individuals or groups. Furthermore, purposive sampling is useful in theory development. (Devers and Frankel, 2000; Barbour, 2001). Qualitative research is not reliant on probability sampling but is more concerned with reaching thematic saturation and focuses on collecting rich and detailed information on participants who will answer the study's questions (van Rijnsoever, 2017). Participants had to be a minimum of 18 years, used well water for domestic purposes (e.g., drinking, cooking, and washing), responded to questionnaires sent out, and submitted a coincident water sample for a microbiological water quality test. Participants were informed that the interview questions would cover broad themes related to well use, well water management practices, and well water contamination risk. Participants were informed that their perspective as well owners was a part of the research and would be important in guiding well management policy and practices in Alberta.

3.3.4 *Data collection*

Interview sessions were conducted in the summer (May-August) of 2017. A pre-test interview session with two of the authors (i.e., AM and JL) and a participant was conducted to trial the pre-planned questionnaire and probes (see interview guide in Appendix C2). Interview sessions lasted between 20 and 40 minutes. None of the participants had any prior relationship with the interviewer before being requested to participate in the questionnaires and interview sessions. Twenty in depth, semi-structured interviews either through phone or face to face at the participant's home were conducted. A trained facilitator moderated the interviews (i.e., AM). A pre-planned questioning route was developed to increase consistency among the interviews and to increase the detail of responses given by respondents (Jones *et al.*, 2005). Interviews were conducted until no new themes emerged from the interview sessions, that is, no new information was gained with additional interviews. (Small, 2009; Hennink *et al.*, 2017; Weller *et al.*, 2018). Interviews were audiotaped and transcribed verbatim. Notes were recorded on interview sessions with characteristics of the interviewees recorded.

3.3.5 *Thematic analysis*

A thematic analysis was conducted. Thematic analysis seeks to interpret data from the 'bottom-up' allowing the researchers to generate a rich and detailed interpretation from participants accounts (Braun & Clarke, 2006; Braun & Clarke, 2013). Thematic analysis is a widely used technique to analyze qualitative data (Braun & Clarke, 2013). The six-stage process of conducting thematic analysis recommended by Clarke and Braun (2013) was followed, this included:

Familiarization. The first author (AM) transcribed data, read and re-read through each of the transcripts several times. AM and JL reviewed the transcripts over a 5-month period. This rudimentary analysis involved taking notes of discussion points that arose from the data corpus.

Coding the data. After familiarization with the data, further discussion on the data led to the generation of succinct descriptive labels of the data corpus that summarized the content of the data corpus. Line by line coding of transcripts was undertaken. Interviews were separately read and coded by two of the authors. Generation of the codebook was done using qualitative data analysis software (NVivo, 2018). The codebook was reviewed by the study team.

Searching for themes. Different codes generated from the coding phase were clustered together to generate themes. Major thematic categories were developed inductively though the questioning route with minor sub-themes developed iteratively through discussion with two of the authors.

Reviewing of themes. Through iterative discussion AM and JL reviewed the themes generated and checked that the coded data fit into the data corpus.

Defining and naming themes. The themes were further defined into an analytical report that captured our interpretation of the data corpus.

Production of the report. The final analytical report generated, that is this article, was reviewed by the study team and captured our interpretation of the data corpus.

Rigor was maintained throughout the analysis. Rigor refers to the credibility, transferability, dependability, and the trustworthiness of the research (Lincoln & Guba, 1985; Morse, 2015). To increase the credibility of our research, the research team had extensive iterative discussions throughout the interviews and analysis. Peer-reviewing/debriefing during the data analysis process; refinement of the codebook throughout the analysis; and iterative discussions on the interpretations of the data. To increase the transferability, the codebook used was reviewed by the study team, the transcripts were coded by more than one member, and agreement regarding coding was established through regular meetings.

3.4 Results

Twenty well owners (M = 13) participated in the interviews. Mean (s.d.) age of participants was 55 years (10.17). All participants were rural residents with water wells and either lived on rural acreages and farms. Fourteen participants indicated having livestock on their property. Fifteen participants indicated having some form of water treatment. Microbiological contamination was assessed in each of the 20 wells. Three out of 20 wells were positive for total coliform with only one well testing positive for both total coliforms and *E. coli* (see table in Appendix B3)

3.4.1 *Organoleptic properties and satisfaction with water quality*

Organoleptic properties of water such as the taste, smell, odour, and hardness of water are often the only cues used to judge water quality. Well owners reported being satisfied with the quality of their well water. Participants stated it was either as good or better than other sources of drinking water such as municipal water and bottled water. An issue raised with half the well water owners was that their water was hard. Some participants also expressed that they would sometimes experience a 'rotten egg' smell or 'Sulphur' smell from their well water. Despite concerns raised by participants over the smell or hardness of their water, some participants stated that they 'preferred' hard water. This may have been because they had gotten accustomed to their well water and had developed a preference for their water, or it may have been due to a misconception of the properties of hard water.

3.4.2 *Perceived hazards to well water contamination*

Activities described by participants that could potentially be hazards to well water contamination were also explored. Both well owners who reported having livestock and those who did not, perceived livestock waste as a hazard to well water contamination (see table in Appendix B3). Well owners acknowledged that differences in farm management practices (e.g., differences in livestock farm types, generational differences, and enforcement of on-farm stewardship practices) could also play a role in their risk perception. Oil and gas activities were also noted by well owners as a potential source of contamination. Despite the oil and gas industry being stated as a potential hazard to well water quality, some well owners expressed some confidence that the industry was taking measures to protect aquifers and wells from contamination. Other participants expressed some uncertainty about the nature of alleged livestock or oil and gas operations in contaminating well water or how cases were handled. The proximity and intensity of the activities within their area played an important role in determining the perception of risk towards their wells. Other hazards to contamination mentioned included crop and fertilizer spraying, sewage, forestry practices, heavy rainfall, vermin accessing wells, old or abandon wells, and the density of wells drilled within an area.

3.4.3 *Mitigation strategies to protect against contamination*

Participants were asked about what mitigation strategies with respect to well water treatments, well maintenance, and on farm/acreage strategies they used and how likely these mitigation strategies were to protect against well water contamination or improve water quality. The most commonly used treatment among well owners was water softeners related to the hardness of the water. Participants reported use of other treatments or a combination of water treatments and well maintenance to improve their water quality (see table in Appendix B3). Water treatments are varied depending on what the water quality objective is and what contaminant is being targeted, but their main purpose is to improve water quality and reduce contamination.

Well owners felt that the management practices they had put in place on their acreages and farms and the treatments they were using were enough to protect their well water quality, leading to increased satisfaction with their drinking water quality. Broader farm management strategies included exclusion of livestock, through fencing, from wellheads, riparian areas, dugouts and other surface water, as well as adherence to manure storage and application guidelines.

3.4.4 *Knowledge about water contamination events in Alberta and Canada*

Participants were asked if they were familiar with any well water contamination events in Alberta or Canada to try and understand if their awareness of contamination influenced their use of mitigation strategies. Respondents were able to recall well water contamination events in the province and within Canada, however there was a range of responses and some participants could not recall hearing about well water contamination events. A frequently recalled incident was the Walkerton incident.

3.4.5 *Appraisal of disease outcomes related to well water contamination*

Participants were asked to describe diseases they thought were caused by well water contamination. They mentioned *E. coli* and gastrointestinal illness as the major diseases. Participants were asked whether they associate well water contamination with both heart disease and cancer. Well owners were skeptical about well water contamination resulting in heart disease. However, some participants, thought that cancer could be associated with well water contamination especially if water was contaminated from chemicals. In addition to these illnesses some participants were aware of other health complications associated with well water contamination, including issues with high blood pressure, methemoglobinemia, and tooth discolouration. However, no participants stated they had experienced gastrointestinal problems because of consuming contaminated well water, even though they attributed gastrointestinal illness to well water contamination. See table in Appendix B4 for Themes, sub-themes and quotes.

3.4.6 *Formulation of perception of well water quality*

The integration of the themes was used to generate a conceptual framework of factors interpreted as playing a role in influencing perceptions of well water quality from the interviews with participants. There were specific factors that seemed to be prominent in formulating the perception of well water quality for well owners at the individual and household level. These were the organoleptic properties, the mitigation or treatments well owners used, their past experiences with water quality, the location and characteristics of the well and knowledge of their well water quality. Other factors included the hazards they perceived within their environment, external information they received, their beliefs, values and attitudes of water quality, health and the environment. These may have acted at the broader community or societal level (see figure in Appendix A1).

3.5 Discussion

This study sought to understand perceptions of well water quality among rural well owners residing on acreages and farms in Alberta and the factors that were pertinent in the formulation of perceptions of well water quality. Overall, participants were satisfied with the quality of their well water with few participants stating problems. Oil and gas activities as well as livestock farming were the main factors perceived as hazards to well water contamination. Mitigation strategies to protect against well water contamination were not only thought of in terms of treatments or maintenance of the well, but also activities in and around acreages or farms that would minimize the risk of well and aquifer contamination. Well owners recalled knowledge of well water contamination events in Alberta and Canada with some participants expressing they had no knowledge of any contamination events. Gastrointestinal illness was the main disease associated with well water contamination among participants, and few participants endorsed heart disease as a possible consequence of well water contamination but did think cancers could arise from chemical contamination of well water.

Organoleptic satisfaction and confidence in drinking water safety was high among respondents. This is corroborated by evidence from a previous study conducted in Alberta where over 80% of well water owners did not worry about the safety of their well water (Summers, 2010). Previous studies conducted in Canada have shown that well water owners are usually satisfied with their water quality (Jones *et al.*, 2005; Jones *et al.*, 2006; Roche *et al.*, 2013). Sensory properties of water have been found to play a major role in determining the consumption of well water (Jardine *et al.*, 1999; de França Doria, 2010; McLeod *et al.*, 2014). Hardness of water was the major issue cited by most well water owners. Water hardness is not directly related to well water contamination, is less of a health concern, and more linked to the aesthetic objectives of water and maintenance of appliances used in the home (Health Canada, 2018b).

Participants reported several potential hazards to well water quality. However, the most commonly cited activities were agricultural and oil/gas activities. This is consistent with findings from a previous survey where oil and gas development were found to be an activity that prompted well owners to conduct well water testing (Summers, 2010). Most of the participants in our interviews did have some livestock on their property and most well owners irrespective of livestock ownership status, stated livestock manure as a hazard as shown in the table in Appendix B3. Biases in risk perceptions may exist among those who did not have livestock as they may have had negative views about livestock as a hazard to contamination compared to livestock owners. These biases were also evident from reviewing accounts of livestock owners who managed different species (e.g., pigs vs beef cattle) where one livestock production system may have been skeptical or unsure of another's practices.

Although oil and gas extraction were noted as a major activity likely to impact well water quality, dissonance was expressed by some participants when they phrased oil and gas activities as sources of potential well or aquifer contamination. This hesitancy of participants to criticize oil and gas activities for contamination may be explained by the attitude or value some Albertans may place in oil as a resource relative to water. Ontological insecurity may have been a phenomenon that was present in some well owners when framing the risk that oil and gas activities may pose to well water contamination (Davidson, 2018). Alberta is the only province in Canada that perceives oil as a more important resource than fresh water supplies (Royal Bank of Canada, 2017). The Alberta government recognized the potential of oil and gas activities to impact groundwater, therefore well water quality, and implemented the Coalbed Methane Baseline well water testing program in the mid-2000's. The program was initiated to test baseline well water quality data before drilling energy wells for Coalbed Methane (AER 2014). Furthermore, there is a Well Water Restoration and Replacement program for wells that have been found to be negatively impacted by energy activities (AEP 2018b). Despite this, the proximity and intensity of these hazards within the well owners' area seemed to play an important role in determining the risk perception of well contamination in their wells. Jones *et al.*, (2005) reports similar findings where well owners reported agricultural practices and developments within their area were perceived as potential factors that could result in well or aquifer contamination. Well owners demonstrated some knowledge of other hazards that were associated with well water contamination such as abandon or old pit wells, vermin getting into the well head, sewage, some of which had been reported in previous literature (Summers, 2010; Buchanan *et al.*, 2013). It is important for well owners to be cognizant of these hazards and inspect the well, and the area around the well to identify potential hazards.

Many well owners had some form of treatment on their wells as shown in Appendix B3. Summers (2010) noted that water softeners were the most widely used treatment among well owners and this was similar to what was observed in this study. Water softeners are not considered effective against microbiological and chemical contaminants (Health Canada, 2018b).

Well owners reported having point of entry well water treatment devices such as water softeners, sand filters and point of use treatment devices such as reverse osmosis and ultra-violet devices (see table in Appendix B3). In addition to treatment devices well owners discussed maintenance measures such as shock chlorination and management strategies to mitigate against well contamination, especially if they felt their well had increased potential for contamination.

Knowledge or awareness of water contamination events within Alberta or Canada were explored. Participants provided accounts of contamination they had heard of either from neighbours in their community or through media. When speaking with respect to contamination attributed to oil and gas companies, some participants cited concerns that resolving contamination issues that were linked to companies was often a complicated issue as some felt it was either hard to trust the company in proving the contamination was a direct result of their activities or the motive of the victims claiming contamination. The most widely noted well contamination incident was the well-publicized Walkerton incident in Ontario. Knowledge or awareness of well water contamination has previously been noted as a factor influencing well owner’s perception of well water quality and testing behaviour (Flanagan *et al.*, 2015).

Disease outcomes related to well water contamination was discussed. Well water contamination was associated mostly with gastrointestinal illnesses. When asked about the possible association of well water contamination resulting in heart disease or cancer, respondents were particularly skeptical about contamination causing heart disease and were more likely to link cancer to chemical contamination of well water. Chronic exposure to contaminants such as arsenic in well water have been associated with a number of health issues including cancer and cardiac disease (Wu *et al.*, 1989; Lewis *et al.*, 1999). This may demonstrate some lack of understanding of the consequences of specific well water contaminants and their impact on health. Despite this there were participants who were able to talk about other health complications they believed or knew to be a consequence of consuming contaminated well water. For example, methemoglobinemia, a condition that can be caused by drinking water with high nitrates, and tooth discolouration, which can result from high fluoride exposure in consumed well water especially in children. This may have indicated that some participants had an awareness of the potential of well water contaminants on health.

3.5.1 *Implications*

Understanding well owner's perceptions of their water quality is important in the development of educational and awareness programs that encourage well water stewardship (Jones *et al.*, 2005). The findings of this study highlight the important factors formulating well owner's perceptions of well water quality. Recognizing the factors that formulate perceptions of water quality is useful in developing communication strategies for educational and awareness programs. Developing interactive educational messages that take less of 'one shoe size fits all' approach and take into account the individual needs, experiences, and context of the well owner may be beneficial as an education strategy. A current program in which this could be implemented is the Working Well Program, a well owner education program organized by various agencies of the government of Alberta. Online resources such as the Domestic Well Water Quality in Alberta online information tool hosted by the Alberta Environmental Public Health Information Network (AEPHIN) and the Water Wells that Last Generations may be a helpful resource for well owners (AEPHIN, 2018; Buchanan *et al.*, 2013). Future research could potentially address investigating the most effective outreach strategies to target well owners and educate them on stewardship practices. It is important to recognize that there are several stakeholders who utilize aquifers, some of who may be perceived as polluters and others as the victims. Despite the shared utility of aquifers, the responsibility of well water stewardship (i.e., testing, treatment, and maintenance) lies with the well owner. It is important to recognize that ontological insecurity may be a phenomenon present in some well owners who own livestock as well as how people think about the hazards posed by the oil and gas industry as these are activities that may be tied to their livelihood or sense of being. Some well owners may overestimate the impact of their actions or trust their own management actions to avoid that dissonance or internal conflict that may arise when reality may be inconsistent with their beliefs. A positive aspect about this study was that some livestock owners interviewed were transparent and willing to admit that livestock manure does pose a threat to well contamination and stated actions they were taking to protect their water sources. Creating a forum in which different stakeholders (e.g., livestock owners, acreage owners, researchers, and policy makers) could help in fostering a transparent environment where stakeholders can learn from each other's experiences, concerns, limitations, and learn to be critical of their own stewardship practices in order to improve on well stewardship behaviour. This may prevent scapegoating or scaremongering among different stakeholders. Indeed, 'understanding the audience' or understanding the diversity of characteristics of well owners has been identified as important in developing communication strategies in well owner stewardship programs (Morris *et al.*, 2016). Furthermore, it is important for educators and policy makers to recognize that there are several factors that may act at different levels (e.g., individual, household, community or societal level) when well owners are formulating their perceptions of well water quality (Thomas *et al.*, 2019) and therefore develop messages and tools that may help in the adoption of stewardship practices.

Increasing awareness of hazards that could increase a well's exposure to contaminants and increasing well owner education on the mechanisms of contamination, and types of contaminants found in well water is important. Furthermore, it may be important to educate well owners on some of the consequences or health problems associated with drinking contaminated well water. Future research could address this by specifically investigating well owner knowledge of well water contaminants and mechanisms behind contamination. Furthermore, increasing awareness of well stewardship practices such as testing, educating well owners on well water treatment and maintenance options as well as other on property mitigation strategies, may be essential to safeguarding Alberta's domestic well water supplies.

3.5.2 *Limitations*

The study has some limitations. The findings are situated within a select group of well owners in rural Alberta with a specific set of potential hazards for well water contamination found in Alberta at a specific time. Qualitative research does not aim to achieve statistical generalizability but focuses on recognizing and documenting the diversity of perceptions within a population (Barbour, 2001; Malterud, 2001; Green and Thorogood, 2014). I interviewed rural acreage and farm owners with varied socioeconomic profiles, provided a description of the context of the sample, the data that were collected, the level of the theory generated, as well as described how the literature relates to our emerging theory. Therefore, some of the findings may be transferable to rural well owners residing on acreages and farms in Alberta. However, future studies may be needed to identify additional potential challenges faced by well owners living in impoverished conditions when conducting well water stewardship (e.g., ability to participate in well stewardship initiatives and access to well water treatments). Although interviews are a pragmatic way of collecting data on a phenomenon, dialogue during interviews is only limited to the perspective of the interviewee as there is no feedback or modification of thought as would occur with techniques such as focus group discussions. Interviews were a preferred method due to problems with the logistics of getting rural well owners together for group meetings. I was also limited in conducting microbiological tests on wells at a point in time and did not conduct chemical testing therefore did not have a history of contamination for each well.

3.6 Conclusions

An in-depth qualitative study to explore and understand rural well water owner's perception of their well water quality was conducted. Participants were satisfied with the organoleptic properties and safety of their well water. Many well owners did not have any microbiological contamination as only three wells tested positive for indicator species at the time of the study. Several hazards to well water contamination were mentioned. The two major activities that were perceived as a hazard were livestock farming and oil and gas activities. Participants expressed some knowledge about well water contamination that had occurred, although there were still participants who were not aware of well water contamination in Alberta or Canada. Finally, gastrointestinal illnesses were the major diseases associated with well water contamination. However, no participants reported having suffered from gastrointestinal illness they attributed to their well but did indicate other health problems that they believed were related to their well water quality. Mitigation strategies discussed were not only limited to well water treatment devices and well maintenance but also included on farm or on acreage strategies that participants believed contributed to the protection of the aquifer and their well. It is important to educate well owners on the importance of conducting frequent testing, the treatment options available, and well maintenance strategies to protect their wells against contamination.

Chapter Four: Exploring Well Water Testing Behaviour through the Health Belief Model

4.1 Abstract

Health problems can arise from consuming contaminated well water. Well water testing can help prevent negative health outcomes associated with consuming contaminated well water. The aim of this study was to understand the factors influencing well owner decisions to conduct water testing through the theoretical lens of the Health Belief Model (HBM). I conducted semi-structured interviews with 20 well owners and used a framework analysis to analyze the data. The results demonstrated that well owners' perceived susceptibility to well water contamination was low, while the severity of contamination, benefits of testing, and self-efficacy towards testing were high. Cues to action to promote testing focused on increasing well owner education and awareness. Participants faced some barriers to water testing. The HBM can be used to understand well water testing behaviour and help inform and improve well stewardship programs.

4.2 Introduction

Health problems could arise from drinking contaminated well water. Well water contaminants are associated with several illnesses and disorders (Villanueva *et al.,* 2014). Private water wells are an important domestic water source serving over 10% of Canadians (Corkal *et al.*, 2004; Statistics Canada, 2019). Approximately 10% of Alberta's rural residents rely on private wells for household use (Summers, 2010). Private wells in Canada may be susceptible to waterborne disease outbreaks (Corkal *et al.,* 2004; Schuster *et al.*, 2005; Charrois, 2010). Microbiological pathogens may be contracted from consuming contaminated well water (Charrois, 2010; Centres for Disease Control and Prevention, 2019). Private wells may also be vulnerable to physiochemical contaminants such as arsenic (Yu *et al.*, 2014). A recent study in Alberta found the prevalence of *E. coli* and total coliforms in private wells to be 1.5% and 15%, respectively (Invik *et al.*, 2017). Well contamination can occur through several scenarios that either impact the aquifer or the well. Weather or climatic conditions (e.g., flooding), old, damaged or uncapped wells, proximity to potential contaminant sources such as manure, sewage, landfills, industrial activities, formation of biofilm in the well, and the natural geology of the aquifer are all factors that may be associated with well contamination (Lewis *et al.*, 1999; Ritter *et al.*, 2002; Eccles *et al.*, 2013; Buchanan *et al.*, 2013).

To protect well owners from the risks associated with consuming contaminated well water, the government of Canada recommends regular well water testing to assess for both microbiological and chemical contaminants. The responsibility of private well water testing is left to the well owner. Well owners decide which test to conduct (i.e., microbiological or chemical) and how often they should test (Health Canada, 2018). Predicting the sources and timing of well contamination can be difficult. Well water testing becomes crucial in detecting well contamination and potentially protecting well owners from diseases associated with consuming contaminated drinking water.

4.2.1 *Microbiological well water testing in Alberta*

Well water testing services for microbiological contamination (i.e., assessment for presence of *E. coli* and total coliforms) as well as chemical testing for physiochemical contaminants is currently offered at no charge to well owners in Alberta through AHS. Well water sample submissions are facilitated through more than 100 health centres across the province where well owners can pick up and drop off water sampling bottles. Well owners take a water sample from their well water source through bottles provided by AHS and fill out a requisition form that contains the name, address, sample collection site, and location information of the person submitting the sample. After well water samples are dropped off at health centres, they are couriered to the ProvLab in either Calgary or Edmonton to undergo routine testing. Due to the nature of the testing kit used, samples for microbiological analysis must be received at the laboratory within 24 hours of collection for the water sample to be viable for testing (Invik *et al.*,2017; AHS 2018b).

Despite the importance of well water testing as a contamination detection measure, a low proportion of well owners comply with testing recommendations set within their jurisdictions (Summers, 2010; Roche *et al*., 2013; Flanagan *et al*., 2015). Summers (2010) found that only about 10.7% of well owners in Alberta tested their water on an annual basis. Canada-wide recommendations state that microbiological well water testing should be conducted at least two to three times a year (Health Canada, 2018) while provincial recommendations state that microbiological well water testing should be conducted at least twice a year (AHS 2018a).

4.2.2 *Theoretical model*

A dominant health theory used in explaining health behaviours, such as testing or screening for disease, and in the development of health promotion and intervention programs is the Health Belief Model (HBM) (Rosenstock, 1974; Janz & Becker, 1984). The HBM assumes that decisions to adopt a health behaviour are based on six constructs that influence perceptions of health risks (Straub, 2014). These constructs are perceived susceptibility, perceived severity, perceived barriers, perceived benefits, cues to action, and self-efficacy (Janz & Becker, 1984; Straub, 2014). The perception of how susceptible an individual is to a health threat will influence the adoption of health behaviours. The severity of the health threat as to whether it will cause death, disability, pain, or minor consequences on health may influence an individual's decision to adopt health behaviours. The perceived benefits an adopted health behaviour will have, and the barriers faced while engaging in the behaviour also factor into the individual's decision to adopt the health behaviour. Self-efficacy, the perception or belief that the individual can carry out the health behaviour, is also an important factor in the adoption of the behaviour. Cues to action are factors (e.g., media messages and social pressure) that may motivate a person to engage in a health behaviour (Rosenstock *et al.*, 1988; Carpenter, 2010). Perceived susceptibility and severity make up threat perception related to the risk of well water contamination, while perceived barriers and benefits, cues to action and self-efficacy relate to the adoption of testing as a mitigation strategy to the risk (Straub & Leahy, 2014). The HBM has been used to help explain health behaviour change in several settings including smoking, diagnostic exams, vaccine adoption, dieting, sexual risk-taking behaviour, and exercise (Mullen *et al.*, 1987; Downing-Matibag & Geisinger, 2009; Bean & Catania, 2013). To the best of my knowledge, only one study has assessed the suitability of the HBM in explaining the adoption of well testing as a health behavior to mitigate against the risks of well water contamination (Straub & Leahy, 2014).

To help understand well water testing behaviour in the rural Alberta context, I conducted a qualitative study. Our aim was to explore and understand factors influencing well owners' decisions to conduct microbiological water quality testing viewed through the theoretical lens of the HBM. Qualitative studies are an important way of informing water policy and well water education programs (Jones *et al.*, 2005; de Franca Doria, 2010; Imgrund *et al.*, 2011; Munene *et al.*, 2019). Considering the low compliance to well water testing recommendations by well owners in Alberta (Summers, 2010) and the inherent dangers of not testing, this study will be helpful in informing policy makers, regulators, educators, and environmental public health practitioners by helping them understand well owner perceptions about well water quality and the barriers that currently exist to well-water testing. This information will be helpful in improving well water stewardship programs and identifying ways to increase compliance to testing recommendations.

4.3 Methods

4.3.1 *Study Design*

This study is a secondary analysis of qualitative data originally collected on and inductive qualitative design to understand factors influencing perceptions of (Munene *et al.*, 2019). Secondary analysis allows qualitative researchers to change the goal and focus of the original study while using and expounding on the richness of the data that are collected in qualitative research (Hinds et al., 1997; Heaton, 2008). A limitation of secondary analysis of qualitative data is the usefulness of the data for reanalysis (Hinds *et al.*, 1997; Thome, 1998). In this paper I addressed the specific question of understanding water testing behaviour using a deductive approach informed by the HBM.

4.3.2 *Participant recruitment*

I primarily identified participants through the Alberta Well Water Information Database (AWWID) with requests to participate in the study sent through paper mail and email. Additional recruitment was done through online advertisements sent to watershed management groups, recruitment at well workshops, advertisements in rural newspapers, rural grocery stores, and community centres. I used a purposive sampling technique. Purposive sampling and involves selecting interviewees who are likely to generate useful and meaningful data to answer the research questions (Marshall, 1996; Green and Thorogood, 2014). Participants must have met the following criteria to be eligible for the interviews; participants had to be at least 18 years of age, must have had a water well which they used for domestic purposes (e.g., drinking, washing, and cooking in the household), must have responded to the questionnaires sent previously and must have voluntarily submitted a recent microbiological well water quality test as part of the study prior to being interviewed (Munene *et al.*, 2019).

4.3.3 *Data collection*

I developed an interview guide to understand what factors were pertinent in influencing perceptions of well water quality in Alberta and what factors could be used to understand well water testing behaviour using the HBM. The study team consisted of three professors and the doctoral student. Interview sessions were conducted between May and August 2017. Semi-structured interview sessions were conducted either by phone or face to face at the participants home. All interviews were conducted in English. A pre-planned questioning route was developed to increase consistency among the interviews and to increase the detail of responses given by respondents (Jones *et al.*, 2005). The interview was pre-tested with two members of the study team and a participant to trial the pre-planned questionnaire and probes. The duration of the interviews was between 20 and 40 minutes. Interviews were audiotaped and transcribed verbatim. Field notes were written during and after the interview sessions. All data were anonymized (Munene *et al.*, 2019). Saturation was determined when both code and meaning saturation were achieved, that is, no new themes arose from further interviews (Hennink et al., 2017).

4.3.4 *Data analysis*

I used a framework analysis to explore the subjective experiences of well water owners around the six constructs of the HBM (Gale *et al.*, 2013; Braun & Clarke, 2013). Framework analysis includes seven steps: transcription, familiarization with the interviews, coding, developing an analytical framework, applying the analytical framework, charting data into the framework matrix, and finally interpreting the data (Braun & Clarke, 2013; Gale *et al.*, 2013). Following transcription, line by line coding of transcripts was undertaken. Interview transcripts were separately read and coded by two of the authors. Two members of the study team independently reviewed the data and met frequently to discuss concepts generated from the data in the process of familiarization with the interviews.

I developed major coding categories based on the constructs of the HBM though the questioning route. Codes were developed and modified using a constant comparison technique with discussion between two of the authors (Watling & Lingard, 2012). A codebook was developed by two of the authors and was reviewed by the study team. The generation of a coding system is important while conducting semi-structured interviews as the codebook ensures that the concepts and ideas generated through the analysis are the same between coders enhancing the credibility of the findings (Morse, 2015). The codebook was created using qualitative data analysis software (NVivo 11 for Windows, QSR International, Melbourne. Australia). I selected the HBM as the analytical framework with the six constructs of the HBM being *a priori* themes. Sub themes were developed according to the codebook. Excerpts from the interviews were used to populate the thematic categories based on the six constructs of the HBM with direct quotations from participants through charting and indexing. To interpret the data corpus and evaluate how well participants perceptions were appraised with the constructs of the HBM, two members of the study team (i.e., AM and JL) independently ranked participants comments as either low, medium or high in relation to five constructs (i.e., susceptibility, severity, barriers, benefits, and self efficacy) based on the wording and phrases participants used when responding to questions based on the constructs of the HBM (e.g., if a participant stated “I do not think contamination is very likely” when asked about susceptibility of contamination of their wells, their statement was ranked as low). We could not rank cues to action as this construct is what participants proposed as approaches to increase compliance to well water testing.

The foundations of rigor in qualitative research are based on the credibility, transferability, dependability, and the trustworthiness of the completed research (Lincoln and Guba, 1985; Morse, 2015). To ensure the credibility of our research, the research team had extensive discussions throughout the interviews and analysis. To increase transferability and dependability, the codebook used was reviewed by the study team, the transcripts were coded by more than one member, and agreement regarding coding and statement ranking was established through regular meetings.

4.4 Results

4.4.1 *Participant characteristics*

I interviewed twenty well owners. Participants were predominantly white (n=20) and men (n=13) who resided on farms (n=14) and acreages in Alberta. The median age of participants was 58 years, range (35 to 74 years). All participants submitted a well water sample prior to being interviewed as part of this study. In addition to the sample submitted, well owners were asked about their well water testing habits, that is, whether they had previously tested, how often they tested their water, and the process of testing. Half of the well water owners interviewed stated they had conducted well water testing at the minimum recommended frequency of once per year or more. The prevalence of *E. coli* and total coliform contamination in our sample was 5% and 15% respectively as shown in the table in Appendix B3.

4.4.2 *Constructs of the HBM as they relate to well water testing*

Water testing as framed within the context of the six constructs of the HBM and the sub themes informing decision making are presented in the table in Appendix B5. Exemplary quotes are provided to reinforce the themes and sub themes.

4.4.2.1 Perceived Susceptibility

Many participants (n=14) stated that they did not feel they were susceptible to well water contamination or there was a low risk of contamination to their water wells. Participants commented that the mitigation strategies they used (e.g., testing, well treatments, and well maintenance and on property mitigation strategies) were enough to protect them against well water contamination. Participants also stated that characteristics of the water wells such as where it was located, the wells accessibility, and the depth of the well as reasons for their perceived lower susceptibility of contamination. For example, when asked about susceptibility to well water contamination one well owner said:

> I think it is very unlikely... The depth of the well I guess, you know no cattle, no manure, in or around that area and that nothing can get in through the cap. It was formerly a well pit and I think it was at great risk for contamination because it had flooded in 2013 and so I had to have it changed and have that whole well system removed… (the well water goes) through the filter because there is a little bit of light clay that comes through it. I just have it monitored with the bacterial test once a year and a chemical about every five years. I think it would be very difficult

> to do (contaminate) where it is located and where it is set up and managed now. …that really would almost be impossible for it to be contaminated.

Despite many participants expressing low perceived susceptibility towards well water contamination, a few participants (n=5) felt that their wells were at risk of contamination. Some participants were unsure about the source, mechanism and time at which well water contamination could occur; however, sentiments towards susceptibility to contamination were still low amongst these participants and they considered the risk of their well getting contaminated as minimal. For example, when asked about how likely it was for them to have a contaminated water well, one well owner mentioned “I think it’s something a person needs to be vigilant about. Things change, industries change. It doesn’t keep me awake at night. If that makes any sense.”.

4.4.2.2 Perceived Severity

Most participants (n = 16) felt that the consequences of well water contamination on their health, their family’s health, the community, or livestock could be very severe. Sentiments expressed included very adverse consequences of well water contamination such as death, serious illness, and being unable to use water on their property in the event of well water contamination. For example, one well owner stated the implications of well water contamination could be dire and mentioned the Walkerton incident which is one of the most well publicized well water contamination events in Canada. “… I guess if you look at Walkerton it can kill people.”. Nonetheless, some participants felt that well water contamination did not necessarily have to have severe consequences. For example, one well owner stated when referring to the level of microbiological contamination.

> … but ok let's say if your bacterial count must be zero? (for the maximum acceptable concentration of *E. coli* and total coliforms). We've had it tested and it was literally 1, and not *E. coli*… just the coliforms, and they (the public health officials) are like yeah, your well is contaminated.

4.4.2.3 Perceived Barriers

The inconvenience of dropping off a water sample coupled with limited hours of operation at drop off health units were a constraint to the well water sample submission process. Well owners expressed that it was difficult to submit a sample especially if the hours of operation for the health centre conflicted with their schedules. Furthermore a few participants expressed that they had to make special trips (i.e., plan trips outside their routine) to submit samples. This may have been a component of the inconvenience of doing a well water quality test.

Despite the constraints stated by participants with respect to the logistics of submitting a well water test most of the participants reported that the procedure was relatively "easy" (n=17). Furthermore, participants expressed satisfaction with the no charge well water testing program currently being offered by the AHS. Feedback times for result reporting to participants were noted as timely for bacterial testing. However, participants did note that there was a longer wait time for result reporting when chemical tests were run on their well water. Participants also expressed trust in the testing process and the health officials conducting the tests. The fact that well water testing is a no charge service offered by the AHS was also noted and appreciated by well owners. When asked about barriers participants one well owner said. "No (issues with testing). You just have to make a trip into town when they need it. I guess that's the only barrier." Another participant stated:

> …I think it (testing) is very well done. Probably the only inconvenience is having to wait till 9 o'clock to draw the water then to get it in. But I understand that minor inconvenience is due to the timing of when the test needs to be done.

Participants identified factors that they felt would help eliminate barriers and motivate well owners to conduct testing more frequently. Due to the inconvenience of picking up and dropping off water bottles at health service centres, having a delivery service for the water bottles, mailing the water bottles to the households, or having a home testing kit were raised as possible measures to reduce barriers to testing. One well owner suggested that having a "home testing kit" may help eliminate barriers to testing. Another participant mentioned having a mail out service for water bottles:

> …you know because that is limiting (hours of operation) that going to town between the hours of, I think ours are 9 am and 2 pm on a Tuesday or something. You know, if they offered a mail out service…

Although well water sample delivery services were discussed, some participants expressed that there were constraints of having such a service offered by the government. The additional costs of running such services and the possible reluctance of having public health officials going on private rural properties to collect water samples were raised as possible difficulties in implementing a water test delivery service. Some participants raised the issue of implementing mandatory well water testing regulations within the province. However, the logistics associated with the costs of enforcing such regulations was cited as a major barrier with enforcing the legislation. One well owner mentioned when discussing the costs of implementing a delivery service:

…I don't think the taxpayers should pay anymore money for the government to come and get my (water) sample. I think as an owner; I am choosing to live on this land. I am choosing to have to learn and deal with well systems. It's my responsibility to take care of myself, not the government.

When discussing the costs and logistics of a well water sample delivery service another well owner stated:

Like phone people, say you are from the government doing the testing for bacteria, take the sample. I think quite a few people would say, yeah that's a good thing. But I also think there are quite a few people who are really hesitant just to have somebody come and test. Are you going to put anything in my water? And all that kind of stuff. Well then you gotta say feel free to bring in the sample yourself. But if they'd really like to do it but they are wary of strangers at the door, then there is always the option. So maybe it's a mix of both, but I can see the huge costs behind this. So maybe it just starts with learning people, teaching people, about what it is because I don't think there is really knowledge for people that they have to do that.

An additional constraint mentioned by well owners was some difficulty in filling out the water testing requisition form. Two participants expressed that some of the information that is required to be filled on well water test requisition form may have been a bit difficult to obtain (i.e., the geolocation in latitude and longitude coordinates of where their well was located). One participant mentioned:

> If you know it (the testing service) is there, it is a great service (the free testing) and again it is easy, they provide nice bottles, the labelling identification is relatively easy…you have to work at the labels, have you seen the labels … and one thing they did ask for I think is the legal land description, uh it was a latitude and longitude. The GPS coordinate I can get easy, but the latitude and longitude. They wanted it in minutes and degrees.

4.4.2.4 Benefits to well water testing.

Most well owners felt that there were benefits to well water testing (n = 17). Participants described the value of protecting their own and their family's health. They noted that well water testing was a diagnostic measure that assured well owners that their well water was safe to use and that it gave them "peace of mind" over their home water source. Participants also stated that water testing to monitor for any potential problems with the well was a "good" thing to do. Health benefits were not only framed to human health but also to livestock using the same well water source. Ensuring that well water was safe to drink for livestock to maximize productivity was noted as important. For example, one well owner stated when discussing the health benefits to their livestock. "Well just to be sure there are no problems with anything, health wise you know…and you know because its for livestock as well, livestock health can be affected by bad well water too.".

Some participants also noted that having their water tested for contaminants could also help them maintain the water infrastructure (e.g., piping, toilets, and sinks) within their household. One participant mentioned when discussing benefits to water infrastructure within the home "…and even saving appliances with the hard water, if you can get that taken care of, your appliances will last longer, so better health and better lasting everything."

The benefits of testing were also viewed in the context of the community with some well owners noting that recognizing problems with their wells may signal wider contamination of the aquifer within their community and therefore testing was a way of keeping themselves and their community members safe. For example, when discussing the benefits of well water testing participant 10 stated "Well it's beneficial to the community because most of the people out here now have tested their water and they know that this region that we live in there is widespread nitrate contamination.”

4.4.2.5 Self-efficacy

Self-efficacy was determined by a well owner’s belief that they could conduct well water testing. Most well owners (n=20) expressed that conducting a well test was relatively easy, and all participants had been through the process of getting their microbiological well water tests done as part of the study and were therefore familiar with the process. Participants one and 15 stated:

> I think if you are offering a free test it’s just as simple as picking up the bottles and dropping them back off again. I do not know what more incentive there can be. The incentive has to come from the person too, you know. The test is free. Just get out and do it.

> No (no issues with doing the testing). I just get sample bottles from the health unit here and I take samples and I give it back to them and they send it to the laboratory and it gets tested and they come back with the results within a few days and that’s it, and I do that once a year.

The alignment of participants statements with the constructs of the HBM, sub themes discussed within the context of the constructs and the number of participants endorsing each rank is presented in the table in Appendix B6.

4.4.2.6 Cues to Action

Well owners recognized the need for creating more awareness of the well water testing program and recommendations in the province. Educational initiatives and advertisements through local media were proposed as ways of raising awareness towards well water testing. Participants four and 11 stated:

> I know a lot of people that number one: They do not know it is free, they do not know the facility exists, they do not know how to do it. So, some more advertising or I guess education from the agency to the public would certainly be helpful and I guess certainly some education to suggest that the need is important. Do not just do it because it is free, and it is there. Do it because you should do it.

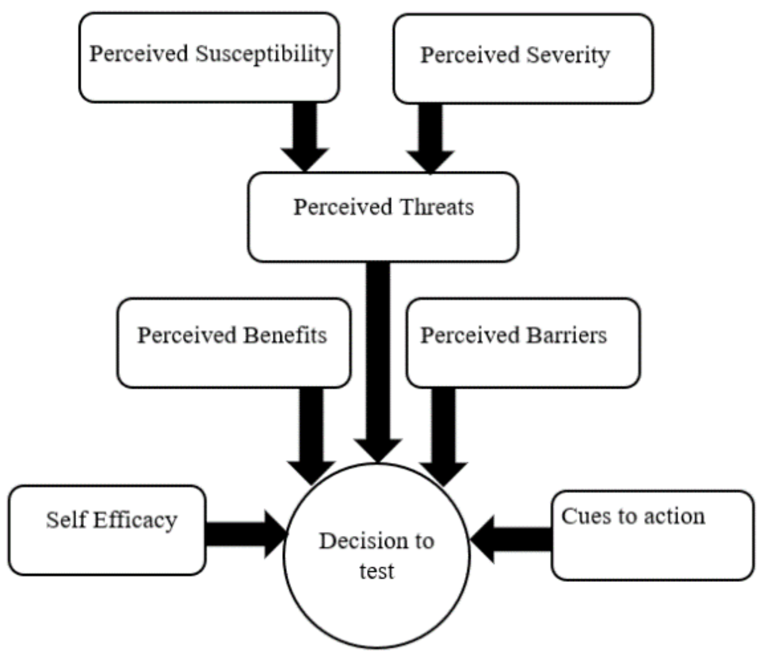
> …more public information, because you got all kinds of people moving out into rural areas and they haven't got a clue as to where their water comes from. They haven't got a clue that they need it to be tested and I only found out that I should be shocking my well every year, and I've been here for 8 years, you know, and so there you go. Proof is in the pudding that homeowners and landowners need to have their wells tested. It's one of those mundane things, like changing the batteries in your smoke detector. Oh, it's a great idea, but nobody ever does it, until somebody gets sick, you know.

4.4.3 *A synthesis of the HBM and water testing behaviour*

For the group interviewed, perceptions of susceptibility to water contamination were low. The severity of well water contamination was framed in terms of the consequences to human health (i.e., illness and mortality). Furthermore, consequences were also framed in terms of the problems of getting alternative water sources on the property in the event of contamination, maintaining appliances, and production loss because of well water contamination if well water was used for livestock. While all owners had tested their water as part of the study, a few barriers were noted in the submission process including the logistics of getting a sample in for water testing, the hours of operation of the sample drop off health facilities. Elimination of barriers faced by well water owners testing (i.e., logistical issues in submission of samples) were noted as some of the major ways to remove barriers towards well water testing in the province.

Benefits accrued from well water testing included safeguarding human, animal, and community health. Having knowledge of well water quality and "peace of mind" over the drinking water sources were also noted as important to well water owners. As all well water owners had tested their water for this study, many well water owners believed and found the process of well water testing as feasible. Cues to action were presented as ways that would motivate well water testing behaviour. Strategies suggested increasing well owner awareness, education, increasing the visibility of the free well water testing service, and reminding well owners to test. Engaging in the study was also a cue to action for well owners who chose to submit water samples. The HBM as applied to context of well water testing behaviour is presented in Figure 4.1.

Figure 4 1. Health Belief Model as applied to water testing behaviour in the context of well water owners interviewed.



4.5 Discussion

The aim of this study was to understand the factors influencing well water owners' decisions to conduct water quality testing as viewed through the theoretical lens of the HBM. The framework analysis using the HBM delineated individual level perceptions and constraints faced by well water owners in conducting testing. The decision to conduct well water testing was based on people's perceptions of the susceptibility of their wells to contamination, the severity of the consequences of contamination, the benefits of well water testing, and the barriers they faced to getting it done. The decision making was also influenced by the cues to action they received and their self-efficacy. They believed there were cues that might help people achieve higher rates of compliance.

Well owners were confident in the safety of the drinking water from their wells and felt that their wells were not susceptible to contamination. Similar findings have been reported among well owners in Canada (Jones *et al.*, 2005; Summers, 2010; Imgrund *et al.*, 2011). This is congruent with previous studies assessing the suitability of the HBM where susceptibility and severity were found to be weak predictors of the adoption of a health behaviour with susceptibility more likely to influence threat perception (Carpenter, 2010; Straub & Leahy, 2014).

In addition to severe negative health outcomes such as mortality and morbidity, the severity of well water contamination was also framed as severe because well owners would need to find and purchase alternative water sources. Worrying about the potentially negative health impacts of well water contamination has been found to be an important factor in decisions to conduct well stewardship practices such as testing, treatment, or in the choice to have alternative drinking water sources (Jones *et al.*, 2005; Thomas *et al.*, 2019). Well water contamination can have a range of health consequences depending on what contaminants individuals are exposed to, the level contaminants individuals are exposed to, the duration of exposure, and the hosts immune system. For example, while microbiological well contamination by *E. coli* may lead to gastrointestinal illness in healthy adults, it may have more severe consequences in very young children, the elderly, and immunocompromised individuals (CDC, 2019).

Participants identified logistical constraints in submitting water samples (i.e., problems with the hours of operation of well water drop off facilities, inconveniences in the time and distance travelled to water bottle drop off centres) were cited as the major barriers. Others have found the inconvenience of submitting well water samples for testing as a barrier to water testing (Jones *et al.*, 2005; Roche *et al.*, 2013). However, as well water owners had conducted water testing as part of our study some of the perceived barriers towards well water testing may have been ranked lower. Hexemer *et al.*, (2008) reports similar findings where some of the perceived inconveniences of water testing were removed from their study (i.e., getting well owners to go through the process of testing and delivering testing kits).

The benefits of well water testing were discussed. Well water testing mainly served to bring peace of mind to participants and provide confidence in the safety of their drinking water. Providing peace of mind to well owners about the safety of their well water quality has been identified as an important benefit of well water testing (Jones *et al.*, 2005; Summers; 2010). These benefits were not only discussed from the perspective of human health but in some cases, were also discussed in the context of livestock health, and benefits to detecting aquifer problems in their community. Identifying that some well owners may perceive additional benefits beyond their own personal or family health may be an important communication message to encourage testing as it recognizes and understands the diverse experiences and perspectives among well owners (Morris *et al.*, 2016).

Self efficacy was evaluated by well owner's perception or belief in their ability to conduct testing. A strength of this study was that it was possible to validate participants stated preference by having well owners go through the testing process. All well owners were able to conduct the test and most of the well owners in this study acknowledged that conducting a well water test was feasible. The high self efficacy shown by the participants in conducting well water tests was a positive indicator that with the current AHS program conducting well water testing was feasible.

Cues to action were factors that would motivate well water testing behaviour. Factors that motivate well water testing are useful as they could be targeted by health officials to increase compliance towards testing (Jones *et al.*, 2005; Straub & Leahy, 2014). Most recommendations stated by well water owners to increase compliance towards testing had to do with educating well owners about the importance of well water testing and stewardship, raising awareness of water testing services, and reminding well owners to conduct testing. Factors such as reminding well owners to conduct testing and providing minor incentive for well owners to conduct testing were cited as possible cues to action in reminding well water owners to conduct well water testing in the future (Straub & Leahy, 2014). Increasing well owner education about well water stewardship practices and the importance of well water testing is currently facilitated by the Working Well Program (WWP) in the province. Increasing the visibility of this program and providing more access to well water stewardship information through media may help increase compliance towards testing.

Our findings have important implications for the delivery of well water services. Most well owners perceived their well water as safe. Educational messaging could focus on improving environmental public health literacy enabling well owners understand potential hazards, sources of contamination, mechanisms that could lead to well contamination. As well owners identified logistical problems in getting their water tested, these concerns may be mitigated by finding ways to make the submission of samples easier to increase compliance (Morris *et al.*, 2016). Increasing the visibility of the no charge well water testing service and well owner education programs such as the WWP may be an important step in raising awareness about the services currently offered. Having community driven initiatives based on public health engagement with watershed management and local community groups may be an important strategy in increasing well owner education and compliance towards well stewardship practices (Paul *et al.*, 2015; Thomas *et al.*, 2019).

4.5.1 *Limitations*

There are limitations to the study. The findings are situated within a narrow profile of well owners in Alberta with a specific set of potential risk factors to well water contamination found in Alberta at a specific time, and therefore may not be generalizable in other settings. A deductive approach was used based on the HBM to understand well water testing behaviour which may have biased other potential explanations for the behaviour. As participants in our study had conducted a well water test as part of the study prior to being interviewed, this could have potentially influenced their perceived susceptibility to well water contamination (Rosenstock, 1974; Carpenter, 2010).

4.6 Conclusions

I carried out a study to explore and understand factors influencing well water owner's decisions to conduct water quality testing as viewed through the theoretical lens of the HBM. To the best of our knowledge this is the first qualitative paper to examine how the HBM can be used to understand well water testing behaviour. The HBM was suitable in understanding individual behavioural factors that influenced well water testing. I determined susceptibility to well water contamination to be low among our participants while most participants appraised the severity of well water contamination as high. Although most well owners acknowledge testing was easy to conduct, believed they could conduct testing and recognized the benefits of well water testing, there were logistical barriers in the submission of water quality tests and most of the cues to action had to with increasing awareness and visibility of the well testing program.

Chapter Five: Factors associated with self reported water well stewardship behaviour in Alberta

5.1 Introduction

Adequate access to safe drinking water is crucial to protecting and maintaining public health. In many parts of Canada, drinking water safety is not often thought of as a risk to public health. With advances in monitoring, treatment, healthcare technology, and with most of the population relying on municipal water supplies, few people may think about the quality and safety of the drinking water coming from their taps. Despite the increasing access to municipally supplied water, there is still a portion of the population that relies on private water supplies (e.g., water wells, boreholes, and cisterns).

Over four million people in Canada rely on private water supplies for household use, with many rural households relying on water wells (Corkal *et al.*, 2004; Statistics Canada, 2011). In Alberta, over 400,000 people are estimated to rely on private water wells for domestic use (Summers, 2010). Water wells may be vulnerable to contamination from several sources (Charrois, 2010). Surveys conducted on rural private water well supplies across the country have found the prevalence of well contamination by both microbiological and chemical contaminants to be between 1.5-40% (Goss *et al.*, 1998; Levallois *et al.*, 1998; Fitzgerald *et al.*, 2001; Coleman *et al.*, 2013; Invik *et al.*, 2017). In a well survey conducted in Alberta on over 800 farm wells, nearly 32% of wells exceeded the maximum acceptable concentration (MAC) for at least one contaminant (Fitzgerald *et al.*, 2001). Two recent surveys found that more than 17% and 1.4% of water wells exceeded the MAC for total coliform and *Escherichia coli* respectively (Coleman *et al.*, 2013; Invik *et al.*, 2017; Invik et al., 2019). However, data from the Invik study were adjusted for clustering by the location of wells. Both acute and chronic exposure to water well contaminants can result in negative health outcomes. Water contaminants are associated with several illnesses and disorders (Villanueva *et al.*, 2014). In Canada's history major contamination events (e.g., the Walkerton incident) brought prominence for the need to protect public drinking water supplies (Hrudey *et al.*, 2003; Hrudey & Hrudey, 2007).

In Alberta, the testing, treatment, and maintenance of well water is left to the well owner (AEP, 2015; AHS, 2018; Health Canada, 2018). With the exception of legal requirements for water well testing upon the acquisition of a new property and water testing when a new well is drilled, it is the sole responsibility of the well owner to determine when to test the well, what to test for (i.e., conduct a microbiological and/or chemical test), what treatments to use to improve water quality and when to carry out regular well maintenance (e.g., shock chlorination). However, exceptions exist to semi- public use wells (e.g., campsite wells and gas station wells) which undergo regular testing and inspection by the AHS. Water well testing is an important well stewardship practice to detect water quality changes. Current well testing recommendations for microbiological contamination state that well testing should be conducted at least once per year and testing for chemical contamination be conducted at least once every three to five years (AEP, 2015). However more frequent testing may be recommended (AHS, 2018; Health Canada, 2018). To encourage testing, well water testing services for microbiological and chemical contaminants are currently provided at no financial cost (or a minimal fee) to the well owners (AHS, 2018). A low proportion of water well owners adhere to the minimum water well testing recommendations (Jones *et al.*, 2006; Summers, 2010; Roche *et al.*, 2013; Flanagan *et al.*, 2015). Summers (2010) reported that less than 11% of water well owners in Alberta tested their water annually. The low proportion of water well test submissions presents a challenge for environmental public health because it limits the ability to detect contamination and mitigate against potential waterborne disease outbreaks either in individual wells or within an aquifer.

Additionally, water well treatment and maintenance are important in well water stewardship. A variety of well water treatments are available to well users to improve water quality and remove microbiological and physiochemical contaminants. Ultraviolet filters, reverse osmosis filters, distillers, constant chlorination devices, water softeners, ceramic candle filters, and jug filters can all be used to improve water quality (Jones *et al.*, 2006; CDC, 2015; Health Canada, 2018). Furthermore, well maintenance measures such as shock chlorination can help remove bacteria from the well and increase the longevity of the well. Summers. (2010) found that up to 60% of well owners reported using some form of treatment on their water wells. Furthermore, only 30 % reported shock chlorinating their wells on a regular basis. To help well owners choose water treatment devices Health Canada offers a list of water treatment devices that can be used to remove both microbiological and chemical contaminants (see Table 1.1).

Few studies have evaluated factors likely associated with water well testing and treatment behaviour among well owners in Alberta (Summers, 2010). To address this gap, I sought to understand well stewardship practices in Alberta. The objectives of this chapter were to:

1. Describe well use, well characteristics, and well stewardship (i.e., testing and treatment) among water well owners.

2. Identify factors that were likely to be associated with self reported well stewardship practices (i.e., testing and treatment) among well owners.

Understanding factors associated with well testing and treatment behaviour among well owners is important in informing and improving well testing and stewardship programs.

5.2 Methods

5.2.1 *Conceptual and theoretical models*

The conceptual background underlying this chapter is that there may be a low priority towards water public health issues within the context of private water wells in many Albertan households reliant on private wells. This may be because perceptions of water quality and knowledge about the threats to water well quality are lacking or misinformed. Well owners largely rely on the organoleptic properties of water to determine its safety for consumption (Jones *et al.*, 2006; de Franca Doria, 2010; Roche *et al.*, 2013). In many cases microbiological or chemical contamination may not be detectable by relying on the organoleptic properties of water, therefore, there is a lack of information or misinformation on what the actual status of their well water quality is based on recommendations within the CGDWQ, unless the well owner has conducted testing. Advanced health care systems and advanced water treatment technologies may also mean that exposure to waterborne illness may be manageable and rarely result in adverse health impacts (Hrudey & Hrudey, 2007). Access to drinking water alternatives also means that Canadian households have a choice and can make decisions based on their preferences for different alternatives and the costs of choosing alternatives (e.g., bottled water compared to water well) (Jones *et al.*, 2007). Perceived safety of drinking water, lack of information, inadequate knowledge of well stewardship practices, inadequate knowledge of the factors, and mechanisms that could lead to contamination, and perceived control over the ability to control the quality of well water consumed, may therefore act to impede water testing behaviour. Therefore, well stewardship practices such as well water testing may not be a priority for well owners in Alberta.

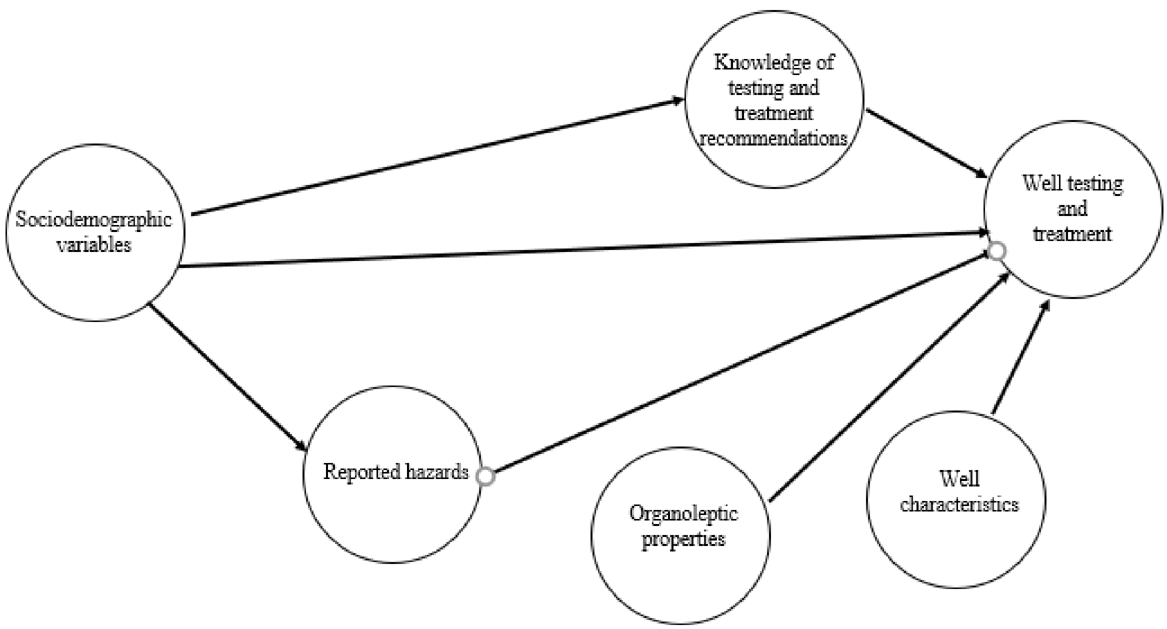
Building on the theoretical model used in Chapter four (i.e., the HBM) this chapter specifically assesses what barriers to well water testing and well water treatment are present, investigates whether sociodemographic factors, well characteristics, well use, reported hazards considered to lead to well contamination, and knowledge and beliefs about well water practices influence well water testing and treatment.

Well characteristics such as how the well was installed (i.e., drilled, bored, or dug) and the type of capping used to cover the well head, the age of the well and the depth of the well may influence perceptions of the risk of contamination and therefore ultimately influence whether or not well owners choose to engage in stewardship practices. Well use patterns or the presence of alternative drinking water sources may also factor into the decision as to whether well owners will choose to invest in testing or treatment as the assumption is that a well owner who chooses to use an alternative drinking water source other than their well may indicate they are not satisfied with some aspect of their well water quality. Additionally, well owners, overall satisfaction with their water quality may be associated with the use of water testing and treatments.

Sociodemographic variables such as age, gender, education, income, and location may also be associated with the adoption of well stewardship practices. Hazards perceived to lead to well water contamination within the well owners' location may also factor into decisions to adopt well stewardship practices.

When considering both well water testing behaviour and the use of well treatments, reported barriers to testing and treatment may influence well owners' ability to engage in frequent well water testing or adopt well treatments. Furthermore, the knowledge of testing and treatment recommendations may be associated with both well water testing behaviour and the use of treatments as the assumption is that well owners who know about testing and treatment recommendations may be more likely to engage in those stewardship practices than well owners without knowledge of the recommendations. A diagram illustrating the possible factors that may be associated with well water testing and the use of treatments is given in Figure 5.1

Figure 5.1 Factors that could influence the use water testing and treatment



5.2.2 *Sample Size*

The sample size was based on a sample size calculation and budgetary considerations. As water testing behaviour and treatment presence are important outcomes of interest within the questionnaire, the sample size calculation was based on the number of people required to detect a difference between the proportion of individuals who report regularly shock chlorinating their water well to an assumed reduction of coliform contamination within the well at an $\alpha = 0.05$ and power of 0.80. The study assumed that the proportion of wells with coliforms is about 22% as found by Bifolchi *et al.,* 2014. In this study it was assumed that shock chlorination leads to a

80% reduction in coliforms detected (i.e., assumed 20% of people will not shock chlorinate or do it improperly, variability with the well types, biofilm formation in wells, aquifers, and previous shock chlorination or other treatments regimes used. (Buchanan *et al.*, 2013; CDC. 2014). Shock chlorination was used because it is a measure that may protect against microbiological contamination of the well.

Using the formula:

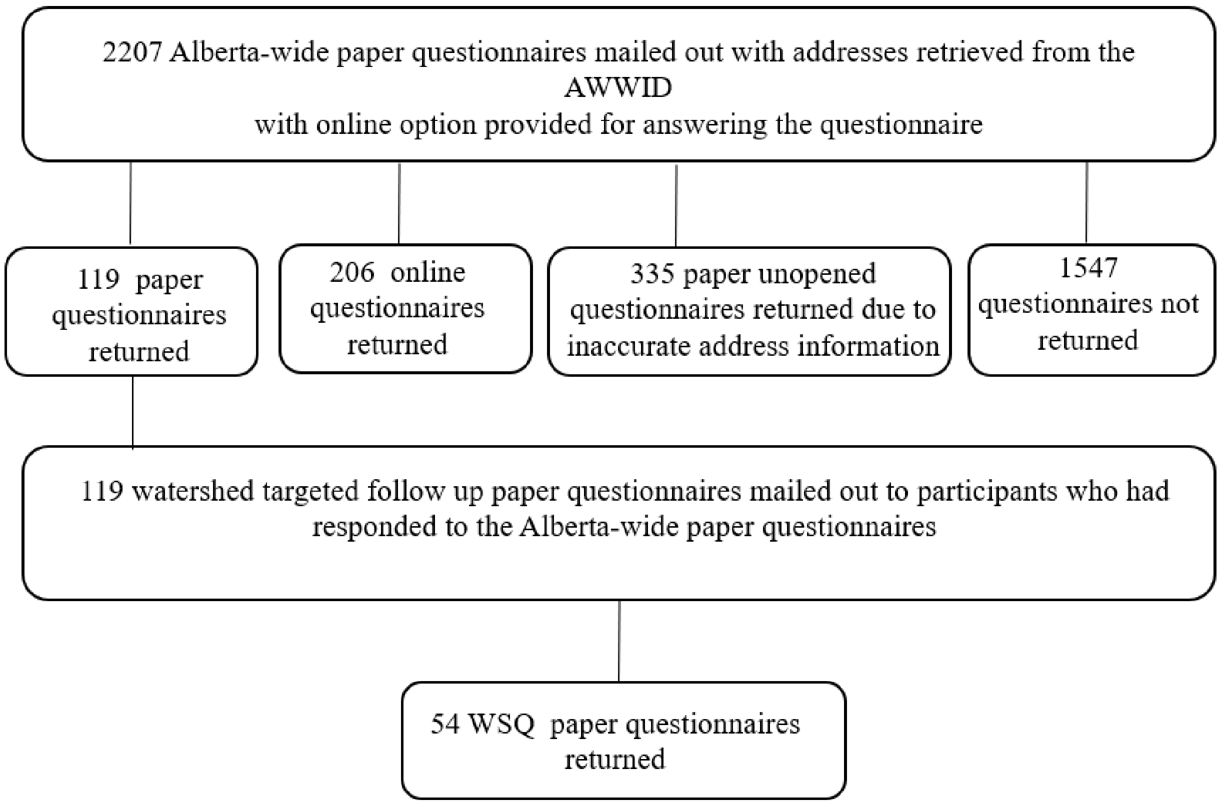
$$n = \frac{[Z_\alpha \sqrt{(2pq)} - Z_\beta \sqrt{p_1 q_1 + p_2 q_2}]^2}{(p_1 - p_2)^2}$$

where p1 = 0.22, p2 = 0.04, q1 = 0.78, q2 = 0.96, p = 0.13, and q = 0.96 (Dohoo *et al.*, 2014). I calculate n = 106. (Dohoo *et al.,* 2014). This sample size also enables me to design the study within the constraints of the budget and time.

5.2.3 *Sample selection*

Participants for the Watershed Questionnaire (WSQ) were selected from well owners who had participated in a previous Alberta-wide paper questionnaire on the study of water wells on properties in rural Alberta (i.e., the AWPQ) (Hall *et al.,* 2019) as shown in Figure 5.1. Participants had to be at least 18 years of age, must have had a water well which they used for domestic purposes (e.g., drinking, washing, and cooking in the household). Questionnaires were sent by mail and targeted participants from two selected watersheds (i.e., the Red Deer River Watershed and the Oldman River Watershed see Figure 1.4). The questionnaires were distributed and collected between June – October 2017. The WSQ questionnaire collected information on well characteristics, well use, barriers to testing and treatment, knowledge of well water management practices, and demographic information.

Figure 5.1. Questionnaire delivery schematic



5.2.4 *Data analyses*

Primary data analyses for this chapter focused on the follow up questionnaire (i.e., the WSQ). The data from the surveys were managed, screened, and prepared using MS Excel 2013. Statistical analyses of the data were conducted using STATA 14 (StataCorp, 2015). Likert type responses to questions assessing satisfaction with organoleptic properties of water, barriers towards well water testing, barriers to well treatment, and knowledge of testing and treatment were recoded to generate binary responses to questions (i.e., 0, 1) for the binary logistic regression.

Descriptive statistics and univariable analysis (i.e., frequency counts, measures of central tendency, and chi-square tests) were run to characterize the demographic profiles of water well owners, describe water well use, and well stewardship practices using STATA. A model building strategy outlined by Dohoo *et al.*, (2014) was used. The multivariable analysis selected for this study was a logistic regression. Logistic regression is described by the equation

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_n X_n$$

where p is the probability of the outcome variable of interest, X_1 to X_i are the independent variables and β_1 to β_n are the regression coefficients associated with each independent variable. The association between independent variables such as demographics (e.g., age, gender, years lived in current residence) barriers to testing, barriers to treatment, well characteristics, knowledge and beliefs about testing, and treatment were evaluated to the outcomes of:

1. Whether well owners had conducted microbiological water well testing.

2. The presence of well water treatments.

Logistic regression is used to calculate an odds ratio in the presence of more than one independent variable. An odds ratio is a measure of association that calculates the odds of disease in the exposed group divided by the odds of disease in the unexposed group (Patten, 2014; Dohoo *et al.*, 2014). An example of an odds ratio calculation used to asses one independent variable (i.e., knowledge of testing) to one dependent variable (i.e., presence or absence of testing) in this study is presented in table 5.1 below.

Table 5.1 Example of an odds ratio calculation

	Well owners who conducted test	Well owners who did not conduct a test
Well owners w knowledge of testing	a	b
Well owner w/o knowledge of testing	c	d

$$\text{Therefore, the Odds Ratio} = \frac{ad}{bc}$$

The advantage of using logistic regression is that it considers the impact of each independent variable on the odds ratio of the dependent variable of interest and avoids confounding by assessing the association of several independent variables together (Dohoo, 2014; Sperandei, 2014). Logistic regression has been used to investigate factors associated with well water stewardship behaviours and with perceptions of well water quality (McLeod *et al.*, 2014; McLeod *et al.*, 2015; Malecki *et al.*, 2017). Models were built using Stata 14 (StataCorp, 2015). To help explain the model building strategy a table containing clusters of independent variables hypothesized or assumed to be associated with testing or treatment was developed (see table in Appendix B7). To reduce the number of predictors, variables were screened for unconditional associations using Pearson Chi-squared tests at a liberal p value (i.e., 0.2) with independent variables with a p value <0.2 being included in the multivariable model building (Dohoo, 2014) (see table in Appendix B8).

Independent variables that were found to be associated with the outcomes (i.e., presence/absence of testing and treatment) below the cut off value of 0.2 were then input into the binary logistic regression. A manual model building, procedure informed by variables thought to influence well water testing and treatment behaviour was used to develop the models (Dohoo, 2014). The Wald test was used to assess if the significance of the independent variable coefficients were significantly different from zero and therefore the value of using those variables in the final model. (Dohoo, 2014). All variables dropped from the final model were assessed for confounding based on whether their inclusion back into the model led to a change greater than 20% in the regression coefficients for other risk factors (Dohoo, 2014; McLeod *et al.*, 2014). Multicollinearity was assessed using the variance inflation factor (VIF). Predictors with VIF values greater than 10 were removed from the final model (Dohoo, 2014). Two-way interactions between factors retained in the final model were assessed for the evaluation of modification (Dohoo, 2014). Comparisons between models were assessed using the Likelihood Ratio test to evaluate the significance of the final model and compare them to reduced models (see table in Appendix B9). The Hosmer-Lemeshow Goodness of Fit Test (Kreutzwiser *et al.,* 2011; Dohoo, 2014) was used to assess the Goodness of Fit for the final logistic regression model selected.

5.3 Results

5.3.1 *Participant and well characteristics*

Participants demographics were compared to the Alberta census data (see Table 5.2).

A total of 54 well owners (m= 31) participated in the follow up questionnaire (see Figure 5.2). Three follow up questionnaires came back incomplete with 51 questionnaires being used in the analysis.

Table 5.2. Comparison of demographic characteristics between participants and residents of Alberta Canada

Variable			Sample (%)	Census population	Chi-squared statistic	Degrees of Freedom
Gender		Male	79 (74)	2,169,133(51)		
	(p<0.0001)	Female	27(26)	2,117,001(49)	24.3	1
		Unreported	5	N/A		
Age		20-29	2 (2)	617,096 (19)		
	(p<0.0001)	30-39	6 (6)	712,068(22)		
		40-49	12 (12)	578,762(18)		5
		50-59	35 (35)	568,615(17)		
		60-69	35 (35)	427,598(13)		
		>70	11 (11)	347,491(11)	81.6	
		Unreported	10	N/A		
Education		< High school	6 (6)	540,660(17)		
	(p< 0.05)	High school	24 (22)	895,885(28)		
		Some college	46(43)	1,019,570(32)		4
		Complete 4y degree	21(20)	530,085(17)		
		Graduate school	10(9)	219,845(7)	15.0	
		Unreported	3	N/A		
Income		<10k	1(1)	157,280(6)		
	(p<0.0001)	10k-19k	4(4)	365,480(15)		
		20k-39k	13(15)	431,480*(18)		
		40k-59k	11(12)	515,660*(21)		
		60k-79k	11(12)	515,660*(21)		6
		80k-100k	10(11)	310,340*(13)		
		>100k	39(44)	443,340(18)	46.4	
		Unknown	22	N/A		

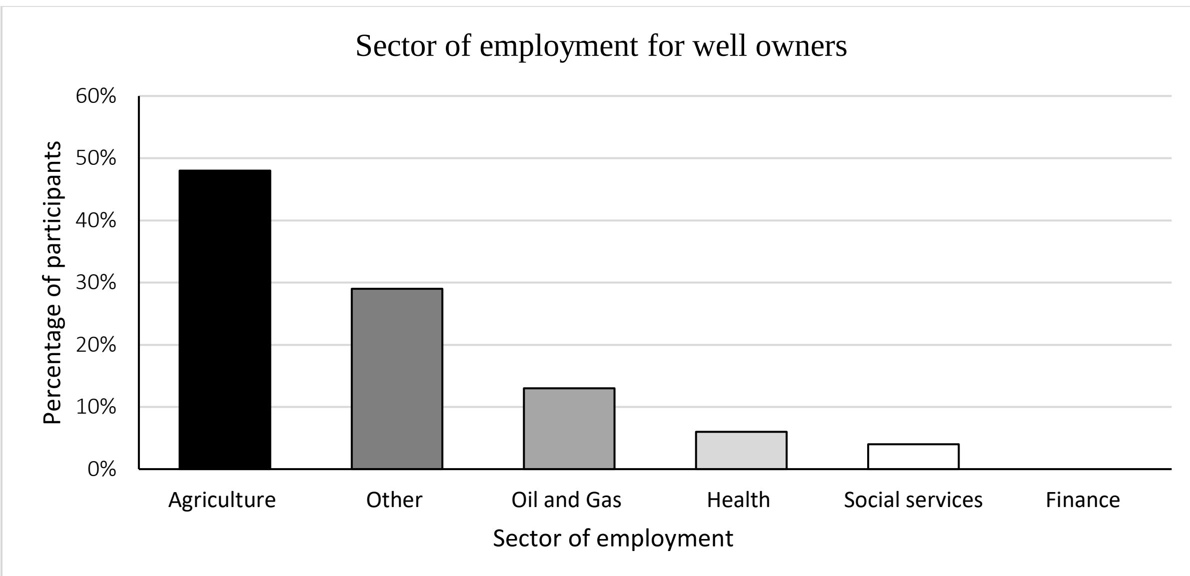
Assessed at $p < 0.05$
*income compared to the closest income category on census data as the census does not use the same categories
Data sources: Statistics Canada, CANSIM, table 111-0008. Statistics Canada CANSIM, table 051-0001. Statistics Canada CANSIM, Catalogue no. 98-400-X2016243

The median (IQR) age of participants in the WSQ was 59.5 years (50-63.5). The median (IQR) number of years well owners had resided at their current residence was 18 years (4.5-30). Most participants noted being employed in the agricultural sector (Figure 5.2)

Participants noted a median well depth of 45m (30-65). Most well owners 96% (49/51) reported having a drilled well. Almost all well owners reported having a well cap 98% (50/51) with nearly 61% (31/51) of well owners reporting having a well cap that needed to be removed by tools. Most well owners reported having a well without cracks on in the cap 98% (50/51) and many well owners 91% (46/51) reported having a well cap that fit tightly.

Nearly 40% (19/47) of participants who responded to the follow up WSQ reported drinking from a water source other than the well in the home.

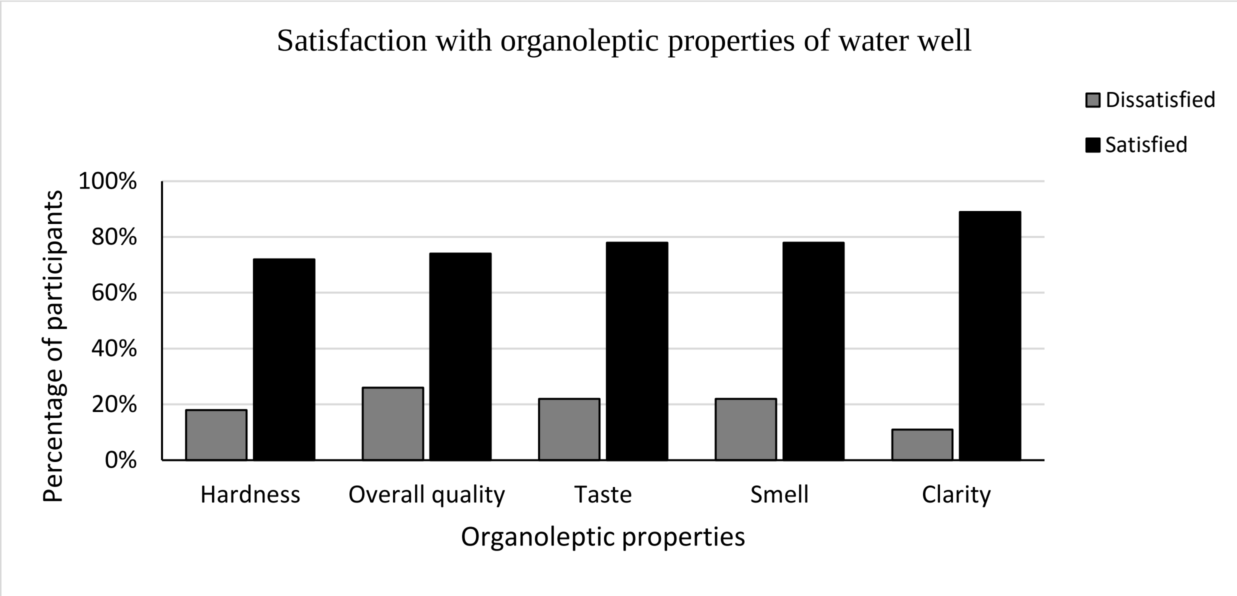
Figure 5.2. Sector of employment reported by well owners



5.3.2 *Perceptions of water well quality*

When asked about satisfaction with organoleptic properties, most participants were satisfied with the overall quality of their water 74% (34/46), taste 78% (36/46), smell 78% (36/46), clarity 89% (42/47) and hardness 72% (33/46) as shown in Figure 5.3.

Figure 5.3. **Satisfaction with well water quality**



5.3.3 *Well water testing behaviour*

Approximately 93% (42/45) of well owners reported having tested their wells for microbiological contamination in the follow up WSQ. However, only about 62% (26/42) of well owners reported conducting the test within the last year of the study as shown in Figure 5.4. Barriers to well water testing were explored. The main barrier to well water testing was procrastination by water well owners. Time taken to submit water well samples and the health centres being open at an inconvenient time were noted as the top three barriers. Most well owners reported knowing about the testing service, being able to find health care centres for testing, and did not find water tests costly as shown in Figure 5.5.

Figure 5.4. Microbiological testing frequency reported by well owners

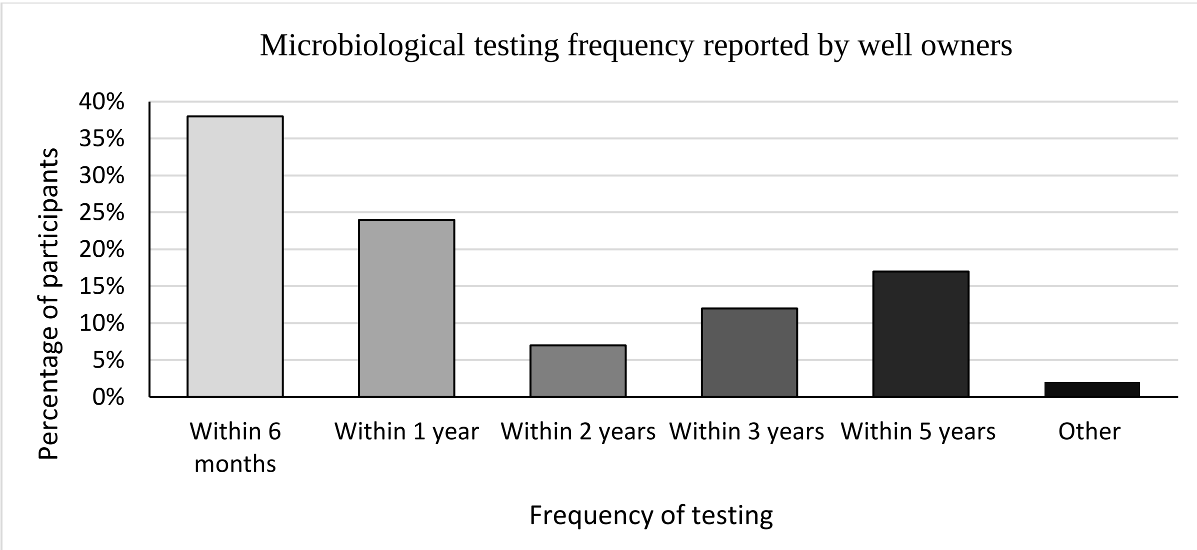
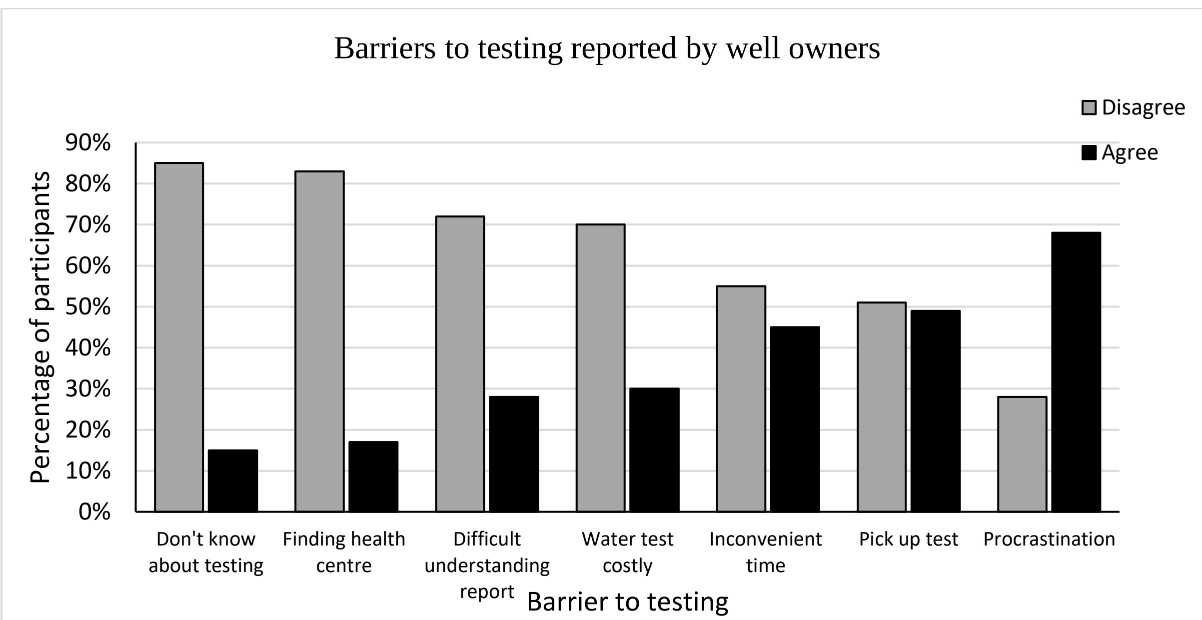
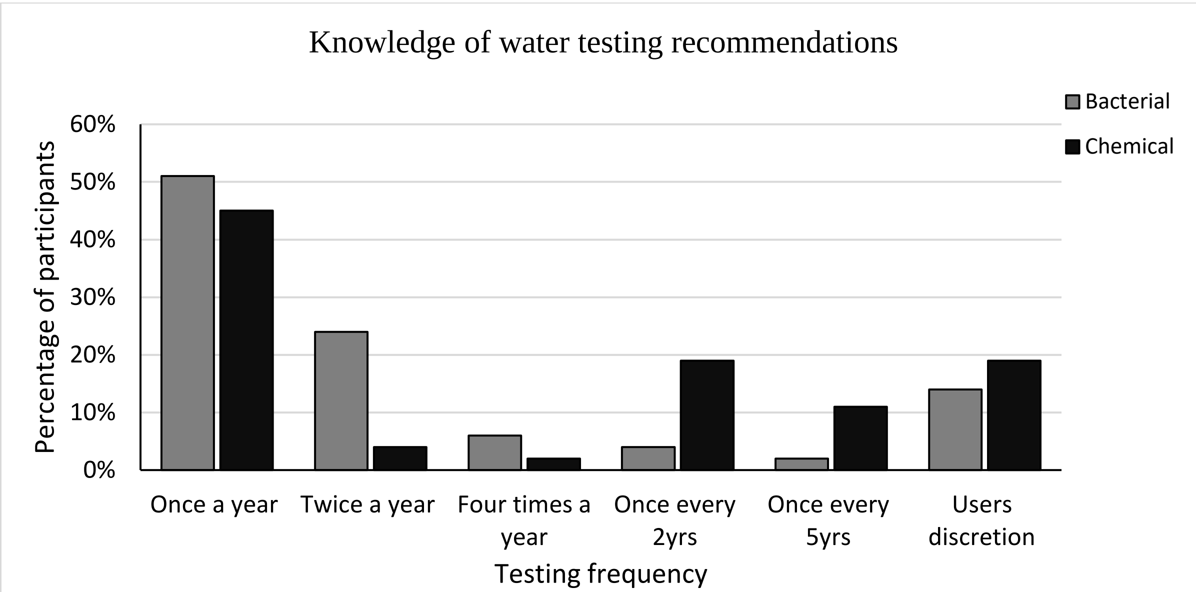


Figure 5.5. Barriers to testing reported by well owners



Approximately 51% (26/51) were aware of the minimum recommended testing frequency in Alberta for microbiological contamination with 80% (41/51) reporting testing at or above the minimum testing recommendations. Only 19% (9/47) of well owners were correctly aware of the minimum recommendations stated for conducting chemical tests on well water with approximately 70% (33/47) stating chemical tests should be conducted at or above the minimum current recommendations as shown in Figure 5.6.

Figure 5.6. Knowledge of well testing recommendations



5.3.4 *Well treatment and maintenance*

Approximately 62% (29/47) of participants reported having some form of treatment. The five most notable barriers to well water treatment reported by water well owners included expense of treatments, difficulty installing or using water well treatments, belief that soil and rocks over the aquifer protected against contamination, chlorination interfered with the smell and taste of water, uncertainty about which treatments to use, and treatment did not always result in perfectly safe drinking water as shown in Figure 5.7.

Knowledge of treatments considered effective against microbiological contamination was also evaluated. Most participants were able to correctly identify boiling and shock chlorination as effective measures against microbiological contaminants in drinking water as shown in Figure 5.8.

Figure 5.7. Barriers to water well treatment

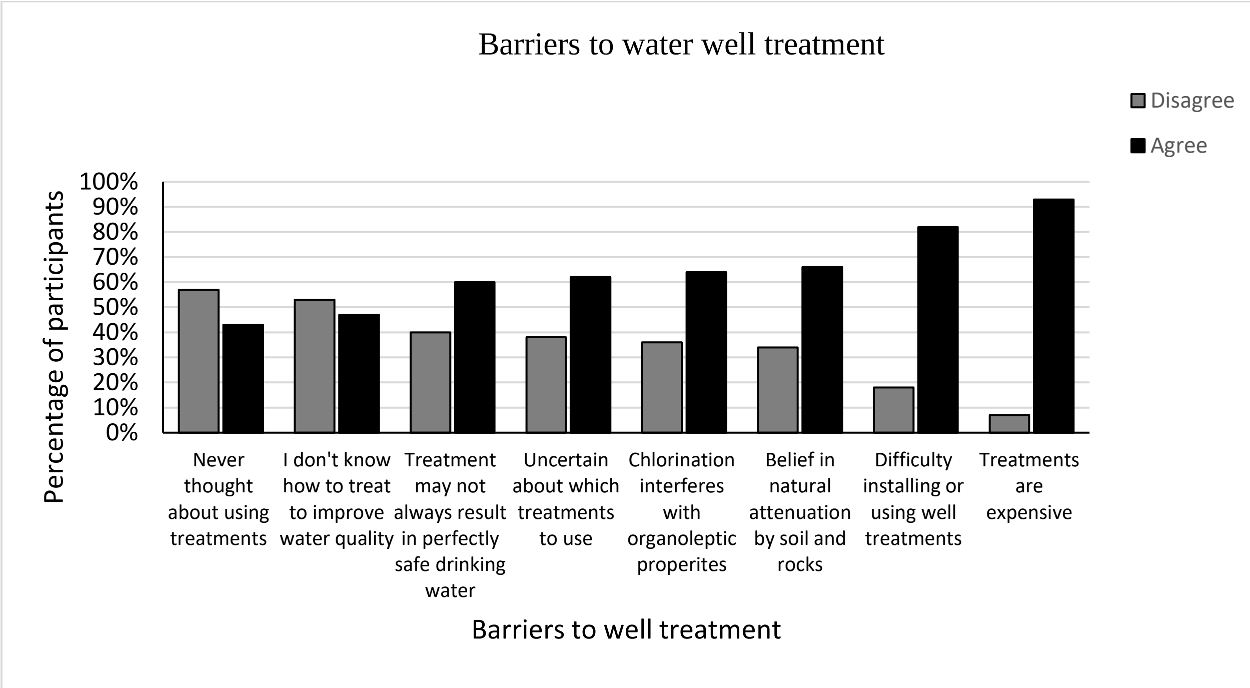
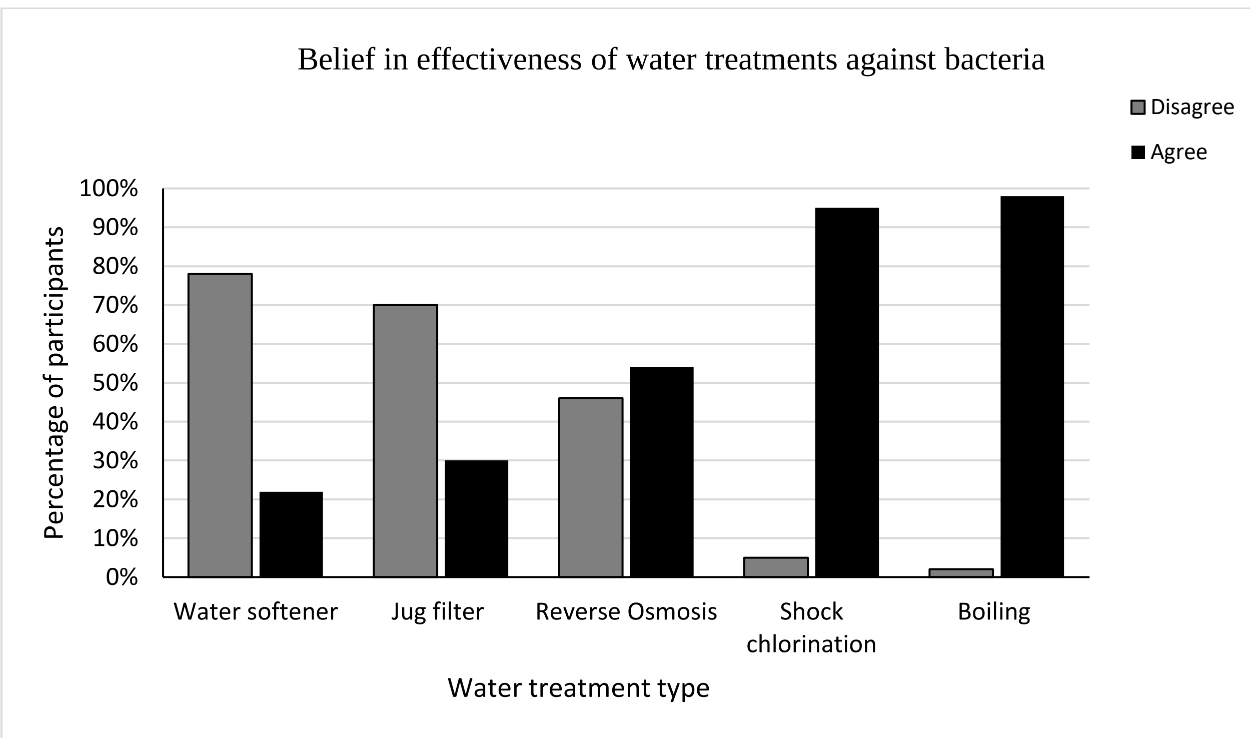


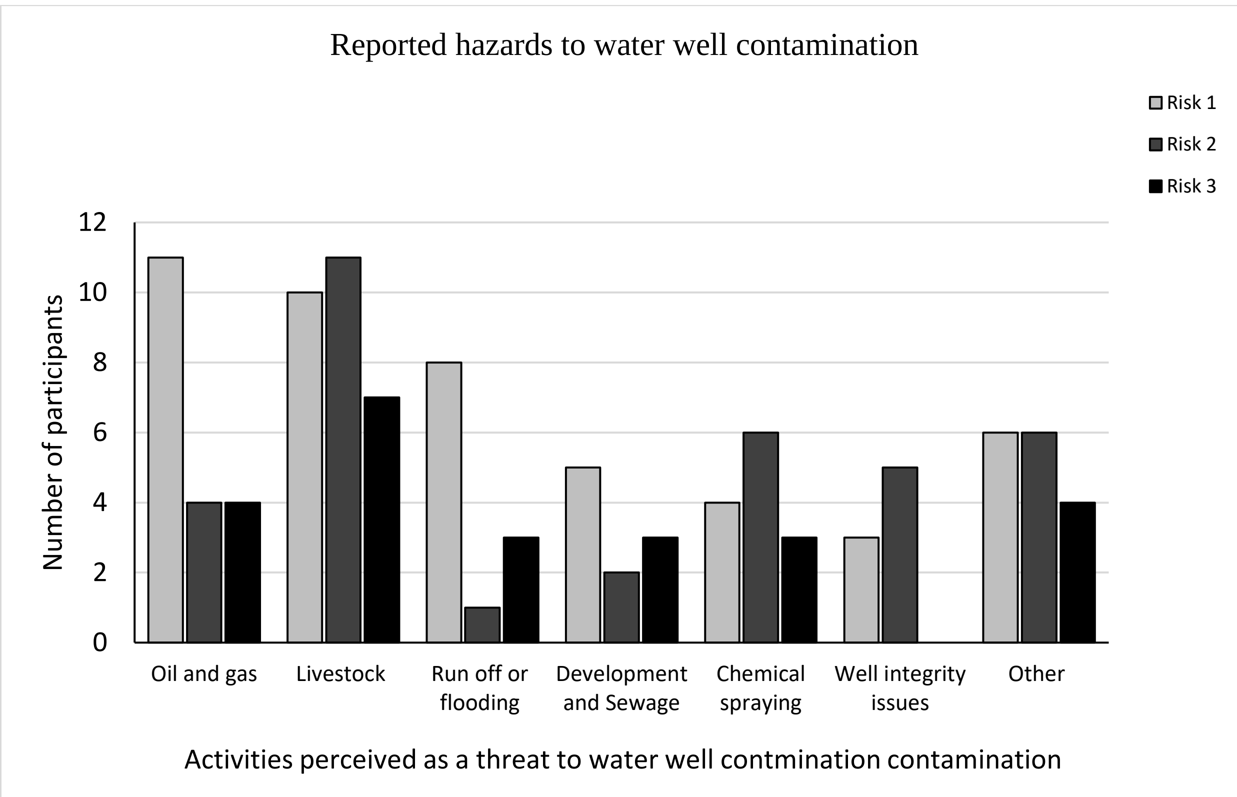
Figure 5.8. Treatments believed to be effective against microbiological contamination



5.3.5 *Risks to water well contamination*

Participants were asked to rank the top three threats likely to lead to water well contamination in their area. The most highly ranked threats to water well contamination were oil and gas activities, livestock farming activities, followed by surface run-off or flooding events, urban development, and sewage, chemical crop spraying, well integrity issues, and other more remote threats as shown in Figure 5.9.

Figure 5.9. Reported hazards to water well contamination



5.3.6 *Factors associated with bacterial water well testing in multivariable analysis*

The final multivariable model included the following independent variables: knowledge of testing recommendations; difficulty in picking up and dropping off water sampling bottles; health centres being open at an inconvenient time; and procrastination. Knowledge of water testing recommendations was associated with the submission of a microbiological water quality test within the last year (OR 18.7, 95% CI 1.72- 203.23, p = 0.02). Disagreement with the statement the “water drop off health centres are open at an inconvenient time” was also associated with having submitted a water test within the last year (OR 0.07, 95% CI 0.01-0.58, p = 0.01), when adjusting for other variables in the model. No significant associations were found between agreement with the statements “picking and dropping bottles is time consuming”, and “procrastination” to having submitted a microbiological water quality test within the last year (Table 5.2) but were left in the final model because they improved the goodness of fit for the model and reduced the range of the confidence interval for significant predictors.

Table 5.2 Odds ratios for variables associated with bacterial water well testing used in multivariable analysis

Variable	Symbol	Number reporting	OR	95% CI	
				Lower limit	Upper limit
Knowledge of testing recommendation	Tstknow		18.72*	1.72	203.23
	Yes	20			
	No	25			
Picking and dropping bottles	Picksgrp2		2.19	0.30	15.87
	Yes	23			
	No	24			
Health centre hours are inconvenient	Inconvgrp2		0.07*	0.01	0.57
	Yes	25			
	No	20			
Procrastinate	Procrgrp2		0.52	0.05	3.59
	Yes	32			
	No	13			

n=51
$p<0.05$ = *
$p<0.1$ = **
OR = Odds ratio
CI = Confidence interval
Log likelihood = -18.07
LR chi2 = 17.69
Pseudo R2 = 0.33

5.3.7 *Factors associated with well treatment in multivariable analysis*

The final multivariable model included the following independent variables: overall satisfaction with water quality; belief in attenuation of contaminants by soil and rocks; uncertainty about which treatments to use; and years in residence. In the final multivariable model, when all other factors were adjusted for agreement with the statement “uncertainty in which well treatments to use” was marginally associated with the use of treatment (OR 0.16, 95% CI 0.04-0.98, p = 0.05). No significant associations were found between the participants overall satisfaction with water quality, agreement with the statement “belief in soil and rocks protecting from contamination”, and the number of years the participant had lived in their current residence as shown in Table 5.3 but were left in the final model because the goodness of fit for the model and reduced the range of the confidence interval for significant predictors.

Table 5.3. Odds ratios for variables associated with use of well treatment in multivariable analysis

Variable	Symbol	Number reporting	OR	95% CI	
				Lower limit	Upper limit
Satisfaction with water quality	OvSatgrp2		0.18	0.02	1.49
	Yes	34			
	No	10			
Belief soil and rocks attenuate contaminants	Aquifergrp		0.20	0.03	1.42
	Yes	28			
	No	17			
Uncertainty in treatments to use	Treatuncergrp		0.16*	0.04	0.98
	Yes	29			
	No	17			
Years in residence	Yrsresidence		1.01	0.95	1.07
	N/A	45			

n=51
p<0.05 = *
p<0.1 = **
OR = Odds ratio
CI = Confidence interval
Log likelihood = -19.47
LR chi2 = 9.95
Pseudo R2 = 0.20

5.4 Discussion

The purpose of this chapter was to describe well use, well characteristics, and well stewardship (i.e., testing and treatment) among water well owners as well as identifying factors that were associated with the self reported water testing and treatment. This information will be useful in guiding water well testing and stewardship programs as it provides an understanding of what profile of well owner is likely to test, treat, and could potentially inform programs by seeking ways to motivate well owners to engage in stewardship practices.

Approximately 40% of participants who responded to the WSQ reported having an alternative drinking water source in addition to their wells. Direct consumption of well water may increase the risk of contracting a waterborne illness should the water source be contaminated (Payment *et al.*, 1991). The median well depth was 45m. Shallow wells (i.e., less than 15m) may be at a higher risk of contamination and therefore testing may be recommended more frequently for shallow wells compared to deep wells (Buchanan *et al.*, 2013; AHS, 2017).

Overall 74% of participants to the WSQ reported being content with their overall water well quality. Similar findings were reported in a previous survey of water well owners in Alberta. Over 90% of well owners who drank their well water were certain about its safety (Summers, 2010). General satisfaction with well water quality in the province and other parts of Canada has been noted in previous studies (Jones *et al.*, 2006; Summers, 2010; Roche *et al.*, 2013; McLeod *et al.*, 2014).

Many well owners (93%) reported having tested their well water quality for microbiological contaminants, with 62% having reported doing so within the last year. Similarly, 81% of water well owners reported having tested their water well quality, however, only about 17.5% reported doing so at least once every two years (Summers, 2010). Low frequency of testing as per provincial recommendations has also been reported elsewhere in Canada and the USA (Roche *et al.*, 2013; Flanagan *et al.*, 2015). The higher proportion of water well owners reporting testing within the last year in this study may be because well owners had been requested to submit a water quality test as part of the study when mailing out the AWPQ and as 40% of participants to the WSQ had alternative water sources, some participants may have had some prior knowledge of the state of their well water quality and opted to have alternative water sources.

Barriers to well water testing were explored. The three most commonly mentioned barriers to well water testing stated by well owners were procrastination, time taken to pick up and submit water well samples as well as the water drop off facilities being open at an inconvenient time. Procrastination was noted as a major reason why well owners stated they failed to conduct stewardship practices (Summers, 2010). Furthermore, the inconvenience of submitting a water sample has been noted as one of the major constraints to water quality testing (Jones *et al.*, 2006; Roche *et al.*, 2013). Most well owners did not indicate finding health care centres for testing, lack of knowledge about the testing services, costs of testing, and difficulty in understanding the water quality report as barriers to testing.

When asked about the knowledge of well water testing recommendations slightly more than half of well owners were aware of the minimum testing recommendations with approximately 80% stating testing can be conducted at or above the recommended frequencies. This is consistent with current AEP and AHS water well testing policies. For example, AEP currently sets its minimum recommendation for microbiological water testing as once per year, whilst the AHS and GCDWQ recommendations recommend testing at least twice per year (AEP, 2015; AHS, 2018; Health Canada, 2018). However, testing may be recommended as many as four times a year depending on well depth and risks around the well (e.g., during flooding) (AHS 2017).

The three most notable barriers to well water treatment reported by water well owners included expense of treatments, difficulty installing or using well water treatments, belief that soil and rocks over aquifers protected against contamination. Considering the affordability of both POE and POU water treatments while factoring cost of installation and maintenance of the treatment devices is important in determining how many well owners would be willing and/or able to afford treatments (Janzen, 2017). Despite citing treatment expense as a barrier most well owners were able to correctly identify shock chlorination and boiling as effective water treatments against microbiological water contamination. Various water treatments are available depending on the contaminants well owners want to control, and their water quality objective based on both health guidelines and preference (CDC 2015; Health Canada 2018). While some treatment devices may be expensive it may be important to educate well owners on cheaper alternatives that may be used to reach water quality objectives. For example, simple measures such as boiling well water before use for human consumption are still considered effective at eliminating microbiological contaminants (CDC, 2015).

The three major activities perceived to pose a risk to water well contamination included oil and gas activities, livestock farming, and flooding events. Risks to water well contamination, specifically from livestock sources, were a concern for water well owners. Alberta currently has the largest beef cattle industry (Bonti-Ankomah *et al.*, 2017) and participants may be evaluating risks of water contamination from hazards they perceive in their environment. Cattle farming (i.e., both feedlot and dairy) had been identified as the two major livestock farm types rated as likely to pose a risk to water quality (Hall *et al.*, 2019). Similarly, in qualitative interviews conducted on well owners, livestock farming, and oil and gas activities were identified as two of the major perceived hazards to water well contamination (Munene *et al.*, 2019). In a previous survey conducted on water well owners both oil and gas and livestock were identified as activities that posed a hazard to water well contamination (Summers, 2010).

Water well testing within the last year was associated with knowledge of testing recommendations and disagreement that health centres for water well sample submissions were open at an inconvenient time, in the multivariable model. Knowledge of well water testing has been previously found to be associated with well testing (Kreutswizer *et al.*, 2011; Flanagan *et al.*, 2015). Well owners in this study who agreed that health centres were open at an inconvenient time were less likely to have submitted a water quality test in the last year. Well owners who had gone through the process of testing during the year may have been aware of the well testing program and procedure of testing and therefore would have been aware of the costs and inconveniences involved (e.g., time to pick and drop off samples) as well as the hours of operation of the local health units where they submitted their tests. Well owners who did not perceive testing as inconvenient were more likely to submit water well tests than individuals who found it inconvenient (Kreutswizer *et al.*, 2011, Flanagan *et al.*, 2015). No significant associations were found between, agreement with the statements "picking up and dropping off a water sampling bottle is time consuming" and participants agreeing their own "procrastination" was a barrier to well water testing conducted in the last year, despite participants mentioning these as barriers they faced to getting their well water quality tested. Time taken to submit water sampling bottles was found to influence well owner participation rates in well stewardship practices (Hexemer *et al.*, 2008). Similarly, agreement to the convenience of submitting a water test was found to be associated with testing (Kreutzwiser *et al.*, 2011). In contrast Flanagan *et al.*, (2015) found a negative association between participants who agreed finding health centres was easy and water testing.

The use of well water treatments was also evaluated in our study. Participants who agreed with the statement that they were “not sure about which treatments to use against contaminants” were less likely to report using treatments. This may indicate that knowledge of treatments against specific contaminants may be important in enabling well owners adopt well treatments. No significant associations were found between overall satisfaction with water quality. Organoleptic properties of water can influence the perception of the safety of drinking water quality (de Franca Doria, 2010; McLeod *et al.*, 2015). In previous studies participants who reported overall satisfaction with the organoleptic properties of their well water may not have felt the need to use water treatments. No significant association was found between well water treatment and participants who agreed with the statement “that soil and rocks over the aquifer protect the well from contamination”. Inaccurate beliefs about groundwater were reported to influence well stewardship behaviour (Summers, 2010), however, although over 50% of participants agreed that their may be some protection offered by the type of aquifer, participants may not have been likely to forgo treatment because of this belief. No association was found between the number of years lived at the current residence and the presence of well water treatment. Previous studies have shown that years lived in the current residence may be an important factor in explaining both treatment and well testing behaviour (Schwartz *et al.*, 1998; Shaw *et al.*, 2005; Chappells *et al.*, 2015). Albertans moving from cities with municipal water treatments to rural areas may not be aware of well water contaminants or may not have well water testing or treatment as a priority issue as both testing and treatment was being conducted by their local municipalities.

5.4.1 *Implications*

These findings have important implications on the communication of the risk of well water contamination and increasing education and awareness of well water stewardship practices in

Alberta. The majority of well water owners reported being satisfied with their water quality. Well testing was found to be associated with knowledge of testing recommendations and disagreement that testing was inconvenient demonstrates the importance of education. As knowledge of testing recommendations was found to be associated with well testing, educational messages should focus on influencing well owners' awareness of the current provincial water testing recommendations, the procedure involved in the submission of water tests, and the importance of conducting frequent testing. The importance of well water testing as a diagnostic measure to detect potential problems with well water quality cannot be overstated. The public health conundrum is without frequent testing by well owners it is difficult to assess the prevalence of well water contamination. Well testing therefore becomes an important diagnostic measure to track the quality of their drinking water. However as noted in previous studies, knowledge of stewardship practices alone may not be enough to motivate actions (Roche *et al.*, 2013).

Well owners who disagreed with the statement that testing was inconvenient were more likely to test. Given that well owners state facing some barriers to submitting water samples, finding ways to make the sample submission process easier and reminding well owners the importance of water well testing may help. Increasing the service hours for water sample drop off times at health centres may allow more well owners to conduct testing.

In addition to testing, our results indicate that there is a need to educate well owners about treatment options for water well contamination. As well owners may be uncertain about which treatments to use, educating well owners on well water contaminants and treatments to control contamination may be important. Furthermore, while some treatment options may be expensive having well owners recognize that simple treatments like boiling drinking water and shock chlorination can be effective at reducing the risk of microbiological well water contamination.

5.4.2 *Limitations*

The findings are situated within well owners in rural Alberta with a specific set of potential factors that were defined as predictors for well stewardship practices, at a specific time and, therefore may not be generalizable to all well owners in Canada. The small sample size of this study may have influenced the strength of association and the level of confidence in our estimates (Nemes *et al.,* 2009). Therefore, the magnitude of the odds ratios calculated in the final model may have been influenced by the limited sample size in our study. However, despite this limitation, this was the first study in Alberta to try and determine factors that predict well stewardship practices using multivariable statistics. Furthermore, many of the descriptive findings were similar to those of previous well surveys conducted in the province (Fitzgerald *et al.,* 2001; Summers, 2010). A low response rate may have also resulted in a selection bias. Participants were more likely to be older, more educated, and had higher incomes than the general Alberta population (see Hall *et al.,* 2019 and Table 5.2) and while recruitment effort employed different strategies (i.e., recruiting water well owners through several different means and sending several reminders), the choice to participate in the study was left to the well owners

5.5 Conclusions

This study was carried out to identify factors associated with the well stewardship practices of testing and treatment in addition to well use and perceptions of well water quality. Most participants were satisfied with the drinking water quality from their wells those who were concerned about contamination may have put measures in place to ensure drinking water safety (i.e., used treatment or had alternative water sources). Many well owners reported having conducted a water test within the last year and this may have been due to the request to test they had received in the AWPQ. Well water testing behaviour was associated with knowledge of water testing recommendations and disagreement that well water testing behaviour was inconvenient. Well water treatment behaviour was associated with certainty of which treatments to use. As such, there are a few recommendations that may increase compliance towards well stewardship practices; increased education of water well owners in rural communities with an emphasis on communicating the risks to water well contamination; harmonizing the message given to water well owners about recommended testing and treatment practices; increasing information sources for well owners to include more popular media (e.g., television, newspapers and radio) to increase the salience of well testing; and finally reducing barriers faced by well owners when submitting water samples by encouraging well owners to pick up bottles when they are in towns; increasing education of the sample submission procedure; increasing the visibility of the current no charge water well testing program; reminding water well owners to conduct frequent testing, and broadening mail out options for water testing kits and improving well owner knowledge of water well treatments.

Chapter Six: Conclusions and policy options for water well stewardship in Alberta

6.1 Recap of the thesis

This thesis presents the results of a study that a used mixed methods approach to investigate perceptions of well water quality in Alberta. The mixed methods approach gave depth to the study which may not have been possible using qualitative or quantitative methods alone. To the best of my knowledge, this is the first study in Alberta to investigate perceptions of well water quality using both qualitative and quantitative methods as guided by a One Health approach while considering the unique contextual factors that make well stewardship in Alberta a public health challenge. The first chapter of the mixed methods study set the context for the research and the methods used by introducing the public health challenge posed by well water stewardship, the risk livestock present to well water quality, the rationale for using a mixed methods design, the framework used to guide the research, and the research objectives. The second chapter was a systematic review of the factors influencing perceptions of private water quality in North America. This review was conducted to elucidate what was currently known about perceptions of private water quality, primarily well water, in North America, to identify gaps in literature, and to inform the questions asked in both the qualitative and quantitative portions of the thesis. To the best of my knowledge, this is the first systematic review investigating perceptions of well water quality and captures literature on the topic over the last 31 years. The third and fourth chapters were qualitative chapters based on 20 interviews with water well owners. Chapter three took a more inductive bottom-up approach (Sandelowski, 2001; Maxwell, 2010) to data interpretation where a thematic analysis was used to understand well owner perceptions of well water quality and to highlight the factors that influence perceptions of well water quality within the rural Alberta context. Chapter three identified both individual/ household factors as well as broader community and societal level factors that influenced individual well owner perceptions of well water quality. Chapter four took on a deductive top-down approach where the Health Belief Model (Rosenstock, 1974; Janz & Becker, 1984) was used to help explain water testing behaviour using a framework analysis. Low perceived susceptibility to water well contamination was a major factor within the HBM constraining water testing behaviour followed by barriers to testing. Chapter five investigated factors associated with the well stewardship practices of testing and treatment using data collected from the WSQ questionnaire, as well as describing the sociodemographic profiles of well owners and their well use habits. This final chapter reviews the advantages of using mixed methods to study well water public health issues, the major findings from the chapters, the policy options for well water stewardship in Alberta, the limitations of the study, and recommendations for future research.

A note on reflexivity. As the lead investigator and graduate trainee in this study enrolled in the Veterinary Medical Science program and an urban resident in Calgary, I was an 'outsider' looking into understanding perceptions of water well quality in rural Alberta. This provided its advantages as I was able to take participants' experiences and opinions about water well quality as 'expert', that is, each participant was an expert of their own well and their experiences. I was not an 'insider' and did not conduct this study with preconceptions or my own ideas about well owner's perceptions of water well quality and this reduced potential biases that would have arisen if my personal interests or situation conflicted with the subject of my research (Berger, 2013). The research team consisted of four additional researchers (i.e., Dr. David C. Hall, Dr. Jocelyn Lockyer, Dr. Sylvia Checkley, and Dr. Alessandro Massolo) with backgrounds in veterinary medicine, epidemiology, water public health, disease ecology, qualitative research methods.

There were clear advantages to conducting this study using a mixed methods approach. Firstly, for practical reasons related to questionnaire length and response rate. Long questionnaires tend to have lower response rates (Edwards *et al.*, 2002), thus limiting the number of questions asked on a single questionnaire while augmenting the data with interview data collected on a few participants allowed us to capture more data without necessarily having to burden our participants with longer questionnaires.

Secondly, from a theoretical perspective, water quality as a construct can be viewed either from a constructivist perspective (e.g., what constitutes as 'good' water quality may be subjective) or positivist (e.g., having a MAC for *E. coli* or total coliforms) the mixed methods approach was a suitable to answer questions that could neither be answered by qualitative or quantitative approaches alone (Creswell, 2013). Furthermore, as some of the main research objectives were aimed at finding solutions to deal with low compliance towards water testing among well owners the pragmatist worldview, a perspective that advocates for using whatever methods are necessary to understand and solve a problem, was practical (Creswell, 2013).

Thirdly, while quantitative analysis usually tends to take a top-down approach in terms of the research questions being asked, theories towards why certain phenomena may be occurring, and therefore the hypotheses tested and questions asked on a questionnaire, qualitative methods may take on an inductive approach where data generated from interviews is interpreted and used to formulate theories or explanations of why certain phenomena may be present (i.e., the bottom-up approach). For example, although our study was framed within the context of livestock farming as a risk factor to well water quality contamination, I was able to extract information related on the risks well owners perceived from oil and gas activities, other risks to well contamination, as well as potential biases that may have arisen in perceptions of livestock as a risk to well contamination that were present from livestock ownership status. An inductive approach was used to understand the factors involved in the formulation of perceptions of well water quality in Alberta (Chapter three). Using a deductive approach, the Health Belief Model was a psychological framework to understand well water testing behaviour (Chapter four) in which the low perceived susceptibility to contamination and barriers to testing were the main limitations faced by water well owners when submitting bacteriological tests.

Finally, mixed methods using surveys and qualitative methods have been advocated as a tool used for developing suggestions for water policy amendments and improvements (de França Doria, 2010). Understanding how people perceive and respond to risks is important in the development of effective health promotion programs (Zinsstag *et al.*, 2015). In the current policy, the responsibility of well water stewardship lies with the well owner. Therefore, hearing the voice of well owners and incorporating their experiences as well owners in this research was important as any practical issues they faced with well water stewardship (e.g., low perceived susceptibility and barriers to testing) may be used to inform future well stewardship policies and programs within the province.

Collectively, this mixed methods research adds to existing literature by comprehensively capturing literature on perceptions of private water quality in North America through a systematic review, identifying factors that constrain well testing behaviour as viewed through the lens of the HBM, identifying factors that influence perceptions of well water quality within the rural Albertan context, and finding factors associated with well water testing and treatment behaviour.

6.2 Revisiting aims of the study and major findings

The aims of this study were to:

1. Describe the perceptions, knowledge, and beliefs rural Albertan residents have of their well water quality, and whether they associate livestock farming with water well contamination.
2. Identify key barriers faced by water well owners with respect to water well management practices.
3. Identify factors associated with well water stewardship practices (i.e., testing and treatment).

To comprehensively understand well owner perceptions of well water quality and delineate factors that influence their perceptions a convergent parallel mixed methods design was used. (Creswell, 2013; Curry and Nunez-Smith, 2015; Henwood *et al.,* 2017) as presented in the figure in Appendix A2.

6.2.1 *Perceptions of well water quality.*

The perceptions of well water quality were mostly positive, that is, most water well owners were satisfied with their water quality (See Figure 5.3. Satisfaction with water well quality).

A general satisfaction with well water quality has been demonstrated in previous studies in the province and in other parts of Canada (Jones *et al.,* 2005; Summers, 2010; Roche *et al.,* 2013). The majority of well owners expressed having knowledge of well water testing recommendations (see Figure 5.6) and were able to correctly identify treatments that would protect them from microbiological contamination (see Figure 5.8). However, although knowledge of well stewardship practices was important it does not generally imply that knowledge alone motivates well owners to carry out well stewardship practices (Summers 2010). This is exemplified by the fact that only about 35% of well owners reported conducted testing within the last two years prior to initial contact (Hall *et al.,* 2019). Livestock farming, in addition to oil and gas activities, were identified as the major factors that were perceived as hazards that could lead to water well contamination. Similarly, Summers 2010 identified both livestock and oil and gas as activities that were perceived as hazards to increasing risk of water well contamination.

6.2.2 *Key barriers to testing identified*

Susceptibility towards well water contamination among well owners was low, that is, despite well owners stating hazards or activities in their area that could potentially lead to water well contamination most well owners did not feel that their own wells were susceptible to contamination (see Appendix B6 alignment of participants statements with the HBM). As a result, well water testing may not be a priority for most well owners. Furthermore, many well owners felt that the actions they had placed either on their properties (e.g., location of livestock or other potential sources of contamination, the location of their wells, or well treatments they were using would protect them from contamination). Major barriers to well water testing included procrastination, reporting it was time-consuming to pick-up and drop off water samples, and the health centres being open at an inconvenient time. Similarly, well owners expressed the inconvenience of submitting well water quality tests as a barrier during qualitative interviews (see Appendix B6 and Figure 5.5).

The major issues faced by water well owners when deciding whether to use treatments included treatment expense, the difficulty in installing and using water well treatments, belief in natural attenuation of contaminants by soil and rocks above aquifer, chlorination interfering with the organoleptic properties of their water well, agreement with the statement that treatments may not result in perfectly safe drinking water, and uncertainty about what treatments to use (see Figure 5.7)

6.2.3 *Factors associated with well water stewardship practices*

Knowledge of water well testing recommendations and disagreement with the statement that health centres for water well sample submission were open at an inconvenient time were associated with microbiological water test submissions (see Table 5.2). However, despite many well owners reporting knowledge of water well testing recommendations in the WSQ and reporting conducting water well testing, only about 35% of water well owners reported having conducted a water well quality test in the last two years at first contact with the AWPQ. Uncertainty about which well treatments to use was marginally associated with the presence of well treatments (see Table 5.3).

A convergent parallel design was used in which the qualitative and quantitative data were collected concurrently with each of the qualitative and quantitative databases analysed separately. The results of each database were then compared to assess for convergence or divergence in the final chapter (Creswell, 2013; Curry and Nunez-Smith, 2015). A summary of the results of the convergent parallel design combining both the results from the qualitative and quantitative parts of this study is presented in the Table 6.1.

Table 6.1. Summary of findings for convergent parallel design

Quantitative phase	Qualitative phase	Integration of findings
Most water well owners consumed their well water and were satisfied with their water quality.	Well owners reported satisfaction with their well water quality, and most did not think they were susceptible to water well contamination. Most well owners were not worried about water well contamination and well contamination data showed a low prevalence of contamination	Confirmatory: Convergence between quantitative and qualitative data
Oil and gas activities in addition to livestock were perceived as the major hazards that posed a threat to water well contamination.	Oil and gas activities in addition to livestock farming were identified as major activities that were perceived as a hazard to water well contamination.	Confirmatory: Convergence between quantitative and qualitative data.
Approximately 62% of water well owners reported testing in the WSQ with a similar percentage reporting treatment.	Only 50% of participants reported doing testing at or above the recommended frequency 75% of well owners had some form of treatment and all well owners	Confirmatory: Convergence between quantitative and qualitative data.

	conducted microbiological testing as part of the study.	
Barriers to testing and treatment were assessed. Major barriers to water well testing included procrastination, picking up the tests, health centres were open at an inconvenient time. Knowledge of testing recommendations and health care centres being open at an inconvenient time were associated with testing. Major barriers towards water well treatment included cost of treatment, difficulty in installing and using treatments, belief in natural attenuation of contaminants in the aquifer, chlorination interfering with organoleptic properties of water and belief that treatment does not result in perfectly safe drinking water. Uncertainty with which treatment to use was marginally associated with well treatment.	Testing behaviour explored through the lens of the Health Belief Model. Major constraints to well water testing behaviour included lack of susceptibility to water well contamination and barriers (i.e., inconvenience of submitting water well quality tests and hours of operation of health centres). Treatments as well as on farm mitigation strategies (e.g., keeping livestock away from the wellhead or locating well in an elevated area to protect from run off) to prevent water well contamination were discussed with most well owners believing what they were doing in terms of mitigation protected them from well contamination.	Confirmatory: Convergence and expansion.

6.3 Policy options for water well stewardship

The following policy options are presented to increase both the adoption and compliance to well water testing and treatment. The framework for these options is adapted from four approaches to encourage behaviour (Ophuls, 1977; Gardner, 1996).

Table 6.2. The four approaches to change behaviour

Approach	In context of water well stewardship
Mandatory water well testing	Set up laws, regulations and incentive programs to encourage water well stewardship
Increasing education and awareness	Provide information on well stewardship practices to change attitudes and stewardship behaviour
Increasing community engagement and partnerships	Motivating behaviour through local community outreach
Moral suasion	Use of moral arguments to encourage behaviour

6.3.1 *Mandatory water well testing*

Few well owners get their water well tested on a regular basis. Universal well water testing has been suggested as a way to increase compliance to testing (Zheng and Flanagan, 2017). Similarly, mandatory well water testing regulations (e.g., testing water well before the acquisition of new properties) have been shown to be successful in increasing well water testing behaviour (Flanagan *et al.*, 2016). Legislation may be a possibility. However, any new policy would have to consider when testing would be required, the frequency of testing, the penalties or incentives of such a policy (e.g., incentives for different livestock production systems to submit water samples) and concessions made to aid well owners with well treatment options (AEP, 2018a). Furthermore, enforcing such legislation and increasing infrastructure to support well water testing may be an additional cost to taxpayers. Also, by implementing such a policy the government may face liability issues in the event of water well contamination. For example, if a serious contamination event were to occur after a water well owner had diligently submitted their water quality tests, would the government be held liable for the contamination that occurred even though required testing was conducted? However, the advantage of such a regulatory approach to well water testing would be that it may streamline testing among all stakeholders utilizing water wells (i.e., of all socioeconomic, educational backgrounds, and risk profiles) and may guard against stakeholder groups shifting blame to other groups perceived as polluters.

6.3.2 *Need for increased education and awareness*

As reiterated by water well owners during our interviews, increasing the visibility of well stewardship programs in the province may help well owners get involved in recommended stewardship practices. Well owner educational programs and information sessions have been shown to have a positive impact on the adoption of well stewardship practices (Imgrund *et al.*, 2011; Chappells *et al.*, 2015; Flanagan *et al.*, 2016). Currently government led well stewardship programs comprise of the no charge well water testing program, the WWP, and the WWRRP. Advertisements to participate in the WWP are often placed on the internet, disseminated to local watershed management groups, and local communities to further increase participation. In its ten-year period the WWP has had nearly 7000 well owners attend their workshops (AEP, 2018b). Although this is a highly commendable effort by the government to increase well owner education there may be a lack of information on the treatment options available, the effectiveness of water well treatments and the cost of treatment could be an issue facing well owners. Furthermore, the effectiveness of the WWP as an educational and awareness program in sustaining well stewardship behaviour is still uncertain, that is, do well owners maintain frequent water well testing behaviour after attendance of WWP workshops). Increasing the visibility of the no charge testing services, the WWP, and the WWRRP through broader media advertisements and community engagement could help increase attendance of the workshops and compliance to testing. Establishing water well stewardship education programs for youth (e.g., through the 4H) program may also help in educating future generations on the importance of water well stewardship.

With respect to educating well owners about the risk of well water contamination, emphasis should be placed on communicating the uncertainty around predicting water well contamination, why it is important to conduct frequent testing to know what is going on with the well, and to have a recorded history of your water quality should any changes occur. Furthermore, although options for water treatment are available to well owners through Health Canada, it is important to increase awareness of these treatments and to help water well owners understand the importance of testing to select what treatments to prescribe. To increase the salience or importance of water testing among the public, establishing a water well awareness month or having biannual public health announcements reminding water well owners to submit water quality tests may help increase compliance towards water well testing. As there was an increase in the frequency of well owners who reported testing between the initial AWPQ and the WSQ, this may indicate some well owners may have been motivated to conduct testing by the fact that the study cued them to do so.

6.3.3 *Increasing community engagement and partnerships*

Because few well owners get their water well tested on a regular basis, unless they are reminded or motivated to do so, finding ways to motivate them to do so through community engagement may help. The framework for successful community engagement with respect to well water stewardship has already been laid out with the partnerships of the WWP and the WPAC's which have representatives from the AEP, the AHS, and AWWDA. However, these partnerships could be broadened. Understanding that water, or more specifically groundwater, is a shared resource is crucial to the stewardship of well water. Acknowledging that biases may exist as to groups that may be perceived as polluters when discussing well water is important. However, though some anthropogenic practices may increase the likelihood of water well contamination, it is important to recognize that those who are perceived as polluters should have interests in water and water well stewardship as their livelihoods depend on it. Listening to and understanding the experiences and perspectives of acreage well owners is just as important as listening to accounts of livestock owners or people working in oil and gas who reside in rural areas, share the land and utilize the water. Highlighting the well stewardship practices of industry players may be important in shifting these broad negative perceptions towards certain industries as polluters. As one livestock farmer put it when discussing water well stewardship and carrying out on farm activities to reduce the risk of contamination 'It's about management' and recognizing that those who are perceived as polluters may try to enforce well stewardship and broader water stewardship practices on their farms. However, it may also be important to identify managers who may not be as diligent in enforcing water well stewardship practices and educate them on the importance of conducting on farm activities and well stewardship activities that reduce the likelihood of contamination on their wells and for their neighbours.

6.3.4 *Moral suasion*

Communicating well stewardship as something that should be done for the good of the communities as opposed to framing it as a 'recommendation' may help water well owners comply with well stewardship practices. Our interviews with well owners showed that many well owners recognized the importance of water testing not only to their health but also saw benefits to their animals and their rural communities. Therefore, framing water testing and well stewardship as a practice that is achievable, as a health behaviour (e.g., screening for breast cancer) but also as a pro-environmental behaviour (e.g., recycling) that will ultimately benefit them and their communities reliant on water wells may help increase compliance to well stewardship.

6.4 Limitations of this study

For the systematic review, publication bias and time lag bias may have been present due to the selection of articles from primarily from peer reviewed journals and over a specified time period. For the qualitative studies, because participants had conducted a well water test as part of the study prior to being interviewed, this could have potentially influenced their perceived susceptibility to well water contamination (Rosenstock, 1974; Carpenter, 2010). Furthermore, the study only collected microbiological test data on wells at a point in time and did not conduct chemical testing therefore did not have a history of contamination for each well. For the quantitative study, the findings are situated within well owners in rural Alberta and, therefore may not be generalizable to all well owners in Canada. The small sample size, in the quantitative portion of this study, may have influenced the strength of association and the level of confidence in our estimates (Nemes *et al.,* 2009). Low response rate in this study may have also resulted in a selection bias. Our participants were more likely to be older, more educated, and had higher incomes than the general Alberta population and may have been intrinsically more motivated to participate in this study.

6.5 Future directions

Having achieved the aims of this study some areas for potential future research have been identified.

1. The numbers of active water wells currently in use for domestic purposes is unknown in Alberta. A limitation of working with the AWWID in this study was that well report information submitted only contains the drill reports of the wells and what their intended use is. Once drilled it is difficult to identify the wells that are still active and if they are compliant with their original purpose. A census of wells may be required to know how many wells are still in use and what their purpose is. Furthermore, this may be useful in updating the AWWID with current well owner information as there are issues with the reliability of address and well use information provided on the AWWID.
2. Although the focus of our study was on the risk of livestock farming to water well contamination there are several factors, both natural, and anthropogenic, that could increase the risk of water well contamination. Oil and gas activities was one such activity that was perceived a hazard to water well contamination. However, it was unclear which contaminants well owners identified with oil and gas. During our interviews this was broadly stated as ‘chemicals’ and was not as specific as some of the gastrointestinal illnesses well owners identified associated with manure or sewage. An assessment of well

owner knowledge of well water contaminants in Alberta may be required to help answer this question.

3. Similarly, a more comprehensive assessment of the knowledge well owners have about well treatments that are effective against contaminants needs to be conducted. This study specifically focused on microbiological contamination, however as indicated by the study there were still many well owners who perceived treatments as expensive, difficult to install and use, well owners believed that treatment was not necessarily perfect and were uncertain of which treatments to use. Understanding what well owners know about well water treatment, the costs of treatment systems currently being used, and the options available to them may help increase the use of treatment devices.
4. Although livestock farming was a perceived hazard to well water contamination and has been identified as a risk factor to microbiological contamination in Alberta (Invik *et al*., 2019), future research could potentially investigate source tracking of microbiological pathogens found in well water to manure sources as the mechanisms of transmission of pathogens in manure, surface water, or runoff to groundwater are not yet fully understood.
5. The study focused on the perceptions of water well owners and their experiences. While the WWP, the AHS, and the AEP were engaged at various stages throughout the project, this study did not incorporate their perspectives and experiences as it was not an objective of the study. However, this may be an important next step in the discussion on the best way to improve water well stewardship practices among well owners in Alberta (Kot *et al.,* 2011). For example, understanding the limitations public health officials or the WWP have and identifying similarities and differences in perspectives between how the AEP

and the AHS approaches water well stewardship could help build more cohesive and informed policies on water well management in Alberta.

6.6 Conclusion

This study sought to understand perceptions of well water quality in rural Alberta, to understand barriers faced by well owners towards well stewardship, and identify factors associated with well stewardship. I found most water well owners were satisfied with their water well quality however there were still issues with the adoption of well stewardship practices. The province provides several programs and resources to help well owners including no-cost water well testing provided for by the AHS, well owner education through the WWP and the WWLG handbook, and even concessions for wells suspected to be contaminated by energy practices through the WWRRP. Currently, the responsibility of well water management lies with well owners, but there are resources and programs available to help them make more informed decisions regarding well stewardship.

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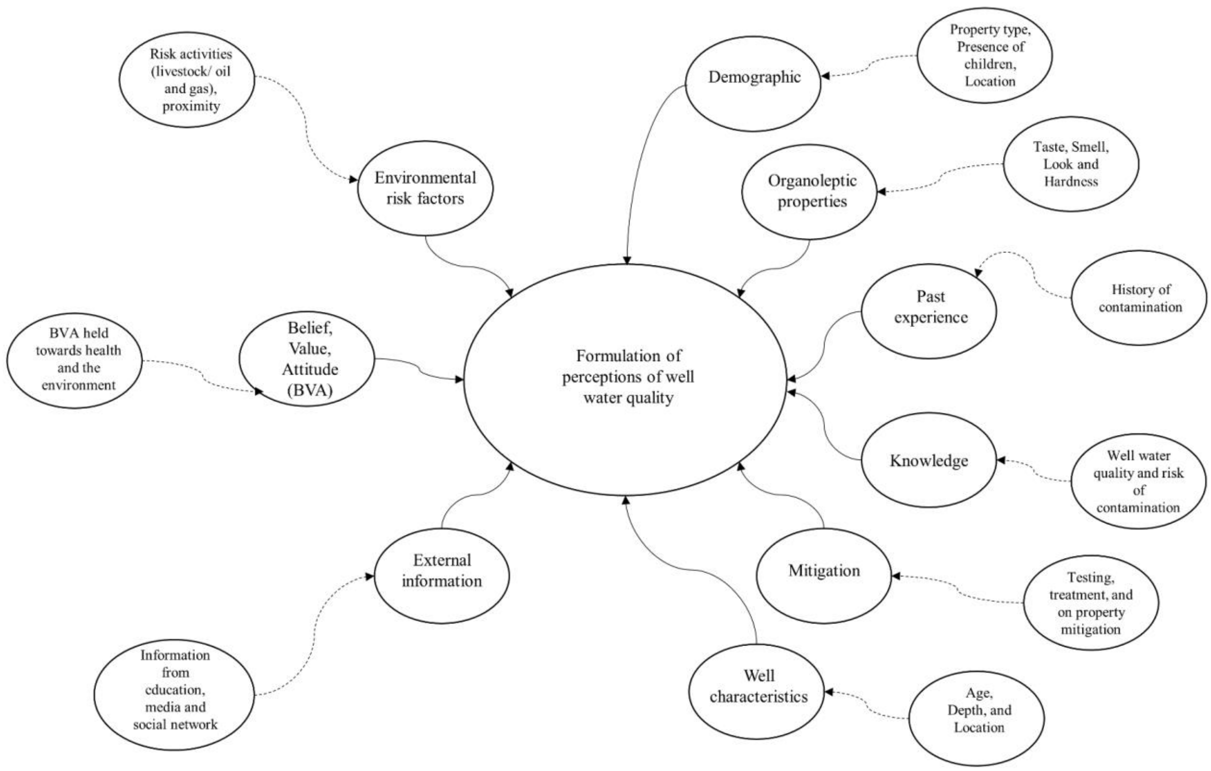
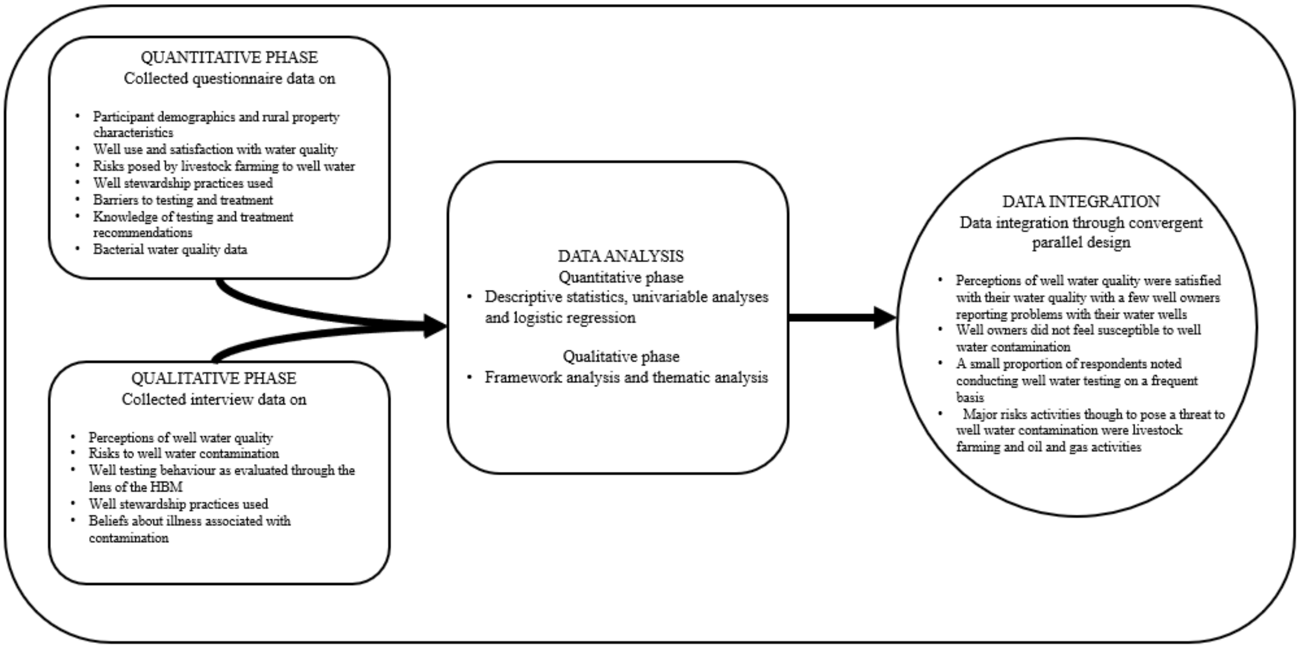
APPENDIX A: FIGURES

A.1. Formulation of perceptions of water well quality



A.2. Convergent parallel mixed methods design for studying water well stewardship practices in Alberta



Adapted from Creswell (2013)

APPENDIX B: TABLES

B.1. Factors identified to influence perceptions of private water quality

Article	Year published	Location	Sample size	Study approach	Factors discussed
Jones *et al.*	2006	Hamilton (CA)	246/550 residences response rate of 54.7%	Quantitative	Well infrastructure, Demographic factors, Organoleptic properties, Chemical and bacterial contaminants, External information
Flanagan *et al.*	2015	Maine (USA)	386	Quantitative	Demographic factors, Perceived risk, Chemical contaminants, Perceived risk, Organoleptic properties, Well infrastructure
Jones *et al.*	2005	Hamilton (CA)	16	Qualitative	Organoleptic properties, Perceived risk, External information
Flanagan *et al.*	2015	Maine (USA)	525/900	Quantitative	Chemical and Bacterial contaminants, Demographic factors, Values attitudes and beliefs, Well infrastructure.
Roche *et al.*	2013	Newfoundland and Labrador (CA)	618/ 3022	Quantitative	Demographic factors, Well infrastructure, Organoleptic properties, External information
Garcia *et al.*	2016	Texas, Arizona and New Mexico (USA)	47	Quantitative	Demographic factors, Organoleptic properties, Chemical and Biological contaminants, Past experience
Murti *et al.*	2016	Arkansas, Indiana and Oklahoma (USA)	41	Qualitative	Chemical and Biological contaminants, Organoleptic properties, External information,
Colt *et al.*	2002	New Hampshire (USA)	98	Quantitative	Chemical contaminants, water well infrastructure
Shaw *et al.*	2005	Churchill county, Nevada (USA)	351(convenience sample)	Quantitative	Chemical contaminants, Perceived risk, Demographic factors
Schwartz *et al.*	1998	New York (USA)	244	Quantitative	Demographic factors, Well infrastructure, Perceived risk and Chemical and bacterial contaminants, Organoleptic properties and Knowledge of contaminants
Poe *et al.*	1998	Wisconsin and New York (USA)	307	Quantitative	Chemical contaminants, Perceived risk
Lewandowski *et al.*	2008	Minnesota (USA)	483 surveys 377 testing kits	Quantitative	Well infrastructure, Chemical and Bacterial contamination, Organoleptic properties
Pieper *et al.*	2015	Virginia (USA)	2146	Quantitative	Chemical and bacterial contaminants, Organoleptic properties, Well infrastructure,
Postma *et al.*	2011	Gallatin County (USA)	188 households (320 children)	Quantitative	Demographic factors, Chemical and Bacterial contaminants,
Mechenich *et al.*	1994	Wisconsin (USA)	139	Quantitative	Chemical contaminants, Attitudes and perceived risk
Strauss *et al.*	2001	Ontario (CA)	647	Quantitative	Demographic factors, Biological contaminants,

Schade *et al.*	2015	West Virginia (USA)	498	Quantitative	External information, Chemical contaminants
Walker *et al.*	2006	Churchill county Nevada (USA)	351	Quantitative	Chemical contaminants, Perceived risk,
McLeod *et al.*	2014	Saskatchewan (CA)	1294	Quantitative	Demographic factors, External information, Values, Attitudes and Beliefs,
Acharya *et al*	2008	Alberta (CA)	33	Quantitative	Organoleptic properties, Perceived risk, Bacterial contaminants
McSpirit *et al.*	2011	West Virginia (US)	256	Quantitative	Demographic factors, Organoleptic properties, Perceived risk
Merkel *et al.*	2012	Pennsylvania (USA)	158	Mixed methods	Organoleptic characteristics, Demographic factors, Perceived risk, Values, Attitudes and Beliefs
Summers	2010	Alberta (CA)	1014	Quantitative	Demographic factors, Well infrastructure, Values attitudes and beliefs, Organoleptic properties, Chemical, External Information Perceived risk
Chappelles *et al.*	2015	Nova Scotia (CA)	420 (32 in depth interviews)	Mixed methods	Demographic factors, Perceived risk, Organoleptic properties, Chemical and Bacterial contaminants, Past experience,
Flanagan *et al.*	2016	Maine and New Jersey (USA)	344	Quantitative	Chemical contaminant, Values, attitudes and beliefs.
Straub and Leahy	2014	New England, Connecticut, Rhode Island, Maine, New Hampshire and Vermont (USA)	513/776 for children and 452/776 for parent	Quantitative	Demographic factors, Organoleptic properties, Perceived risk, External information
Lothorp *et al.*	2016	Arizona (USA)	31/34	Quantitative	Demographic factors, Chemical contaminants.
Kreutzwiser *et al.*	2011	Ontario (CA)	1567/4950	Quantitative	Well infrastructure, Bacterial contamination, Past experience, External information
McLeod *et al.*	2015	Saskatchewan (CA)	1294	Quantitative	Organoleptic properties, past experience
Schubert *et al.*	1999	Wisconsin (USA)	562	Quantitative	Demographic factors, Chemical contaminants, External information
Feinman *et al.*	2015	New Mexico (USA)	6606	Quantitative	Demographic factors
Imgrund *et al.*	2011	Ontario (CA)	22	Qualitative	Perceived risk, Well infrastructure, Values attitudes and Beliefs. Bacterial contamination
Jones *et al.*	2007	British Columbia (CA)	4612	Quantitative	Demographic factors, Perceived risk, Biological contaminants
Johnson	2008	New Jersey	266	Quantitative	Demographic factors, Values, attitudes and beliefs, Past Experience
Renaud *et al.*	2011	Quebec (CA)	542	Quantitative	Demographic factors, External information, Chemical contaminants
Ridpath *et al.*	2016	48 states within the USA	1100/1690 calls	Quantitative	Chemical and Biological contaminants, External information, Well infrastructure
Flanagan *et al.*	2016	New Jersey (USA)	711	Quantitative	Demographic factors, External information, Perceived risk, Chemical contaminants
Flanagan *et al.*	2016	New Jersey (USA)	670	Quantitative	Demographic factors, Values, attitudes and beliefs, Perceived risk, Chemical contaminant

Levallois *et al.*	1998	Quebec (CA)	222	Quantitative	Organoleptic properties, Chemical contaminants, Well infrastructure
Laflamme *et al.*	2004	Washington (USA)	6927	Quantitative	Perceived risk, Chemical contaminants,
Severtson *et al.*	2006	Wisconsin (USA)	545/649	Quantitative	Demographic factors, Perceived risk, Chemical contaminants, Past experience
Severtson *et al.*	2008	Wisconsin (USA)	897	Mixed methods	Chemical contaminants, Demographic factors, Perceived risk
Slotnick *et al.*	2006	Michigan (USA)	261 (221 with wells)	Quantitative	Chemical contaminants, Well Infrastructure
Kite-Powell *et al.*	2006	Oregon (USA)	102	Quantitative	Chemical contaminants
Tabbot	2006	New Jersey (USA)	50	Quantitative	Chemical and Bacterial contaminants, Organoleptic properties,
Hexemer *et al.*	2008	Ontario (CA)	248	Quantitative	Chemical and Bacterial contaminants, Demographic factors, External information
Swistock *et al.*	2012	Pennsylvania (USA)	701 well tests 450 survey responses	Quantitative	Chemical and Bacterial contaminants, Well infrastructure
Paul *et al.*	2015	Tuftboro (USA)	285	Quantitative	External information
Pintar *et al.*	2009	Ontario (CA)	2332	Quantitative	Demographic factors,
Yu *et al.*	2014	Nova Scotia (CA)	960	Quantitative	Demographic factors, Well infrastructure, Chemical contaminants
Malecki *et al.*	2017	Wisconsin (USA)	460	Quantitative	Organoleptic properties, Demographic factors, Chemical and Bacterial contaminants,

B.2. Prevalence of contaminants

Study	Contaminant	Proportion of participants exceeding MAC
Pieper *et al.* [33]	Arsenic	0.10%
	Cadmium	0.60%
	Chromium	0.00%
	Fluoride	0.40%
	Nitrate	1.30%
	Total Coliform	46%
	E. coli	10%
	Copper	12%
	Lead	19%
	Aluminium	3.80%
	Chloride	0.20%
	Copper	15%
	Iron	8.00%
	Manganese	10.00%
	pH	26%
	Silver	0.00%

	Sulphate	2.40%
	TDS	10%
	Zinc	3.10%
Walker *et al.* [39]	Arsenic	N/A (did not present proportion who actually exceeded MAC)
Poe *et al.* [31]	Nitrate	18%
Lothorp *et al.* [50]	Aluminium	31.30%
	Arsenic	37.50%
	Iron	6.25%
	Lead	6.25%
	Antimony	6.25%
	Water Hardness	N/A
Postma *et al.* [34]	Total Coliform	18%
	E. coli	<1%
	Nitrates	2%
	Lead	0%
	Copper	0%
	Arsenic	6%
	Fluoride	2%
	Synthetic Organic Chemicals	6%
Slotnick *et al.* [68]	Arsenic	25.30%
Hexemer *et al.* [71]	Bacteriological (*E. coli* and Total Coliforms)	15.40%
	Nitrates	25.30%
Tabbot *et al.* [70]	Total Coliform	14%
	Nitrates	58%
	Volatile organic compounds	26%
	Hardness	28%
Swistock *et al.* [72]	Total coliform	33%
	E. coli	14%
	pH	20%
	Lead	12%
	Nitrates	2%
	Arsenic	2%
	Triazane	<1%
Strauss *et al.* [36]	Total Coliform	17.10%
	E. coli	9.50%
Yu *et al.* [75]	Arsenic	4.5% of all water samples
Kite-Powell *et al.* [69]	Nitrates	55%* (7 and 48) during the two periods of data collection
Lewandowski *et al.* [32]	Nitrates	10%* (based on well type (drilled and Sandpoint)
Levallois *et al.* [42]	Nitrates	6% > than 10 mg N

B.3. Participant characteristics

I.D	Age	Gender	Education	Income	Livestock present	Stated livestock as a risk	Presence of treatment	Type of treatment	Total coliform status	E. coli status
1	58	M	4-year degree	Did not disclose	Yes	No	Yes	Water softener	Positive	Negative
2	36	F	4-year degree	160K+	Yes	No	No	None	Negative	Negative
3	61	M	Some college	40-60K	Yes	Yes	Yes	Reverse Osmosis and Water softener	Negative	Negative
4	63	M	4-year degree	20-40K	No	Neutral	Yes	Water softener and Filter	Negative	Negative
5	60	M	Did not disclose	40-60K	Yes	Yes	Yes	Water softener and Iron filter	Negative	Negative
6	67	M	Some college	20-40K	No	Yes	Yes	Ultraviolet, Reverse Osmosis and Water softener	Negative	Negative
7	52	F	Some college	20-40K	Yes	Yes	Yes	Iron filter	Negative	Negative
8	47	F	Some college	140-160K	Yes	Yes	Yes	Water softener and Reverse Osmosis device	Negative	Negative
9	57	F	High School	20-40K	No	Yes	No	None	Negative	Negative
10	35	M	High School	20-40K	Yes	No	Yes	Ultraviolet device, Filter, Water softener and chlorination	Positive	Negative
11	58	M	Some college	40-60K	Yes	No	Yes	Filter	Negative	Negative
12	43	M	High School	40-60K	Yes	Yes	Yes	Iron filter	Negative	Negative
13	58	M	Some college	Did not disclose	Yes	Yes	Yes	Reverse Osmosis device	Negative	Negative
14	59	M	High School	80-100K	No	No	No	None	Negative	Negative
15	74	M	4-year degree	40-60K	No	No	Yes	Filter	Negative	Negative
16	62	M	High school	40-60K	Yes	No	Yes	Chlorination	Negative	Negative
17	52	M	4-year degree	160K+	Yes	Yes	No	None	Negative	Negative
18	60	F	Some college	20-40K	Yes	Yes	Yes	Sand filter	Negative	Negative
19	47	F	4-year degree	Did not disclose	No	Yes	No	None	Positive	Positive
20	42	F	4-year degree	10-19K	Yes	Yes	Yes	Chlorination	Negative	Negative

B.4. Themes, sub-themes and quotes

Themes	Sub-themes	Quotes
Organoleptic properties and satisfaction with water quality	Satisfaction with water well quality and issues with smell, taste, look, and hardness of water	'…basically, just flavour difference. Bottled water is just flatter tasting, I guess. The water well does have a little more life to it.' (P.1) '…there's no odour. Um no taste. We do know that it is high in sodium, just from our test, but you do not taste a salty taste. It's very soft. Um so we do not have any residues, so like when you wash clothes or anything…I like it better than bottled water. I find bottled water tastes weird and so do my kids (laugh). My kids won't drink town

		water because they can taste the chlorine in the town water, and they refuse to drink the town water.' (P.2) 'I would never haul water in, my water is excellent, I test it all the time. Blaah (disgust) I wouldn't drink bottled water it's city water. People are just hoaxed. Dasani is Calgary water. I grew up in Calgary. So, it's treated water, whatever, no my water is good, I should bottle it. (P.7) '…yeah, and it's a very soft water, so it's really nice to bath in and all that stuff and, it tastes…it tastes good. Sometimes it has a slight smell...It probably tastes about the same (as bottled water). But just probably being from the city I am a little paranoid because I always used to drink the tap water in Calgary…' (P.9) 'Um the water is quite hard, so we have a reverse osmosis unit for our drinking water and the water will develop the rotten egg smell, hydrogen sulfide smell, um. So, we do try and shock it on a yearly basis.' (P.13) 'I'm from southern Alberta I like hard water. I like hard water and up there the water they have on the well, everybody swears it's the best water. The water I grew up with on the farm, down south here, to be honest I don't think it was potable. It was vile water. But it was hard and that's what I grew up with, that's what I got used to... like I don't like that soft water, it takes forever to get that soap off it.' (P.17) 'The regular water is very soft it feels very soft. It almost feels like when you are washing yourself like you don't get clean. But I talked to a water guy about this earlier and he says if you have hard water it actually takes the fat off your skin, which is actually a good thing. So, a lot of the people who shower here have to get used to it because it takes forever to lather (they meant hard water). Which is good but its not a problem.' (P.20)
Activities that pose a risk to water well contamination	Proximity to risk	'Uh well I know… just from speaking to different people over the years. There are a lot of people who have had pretty serious contamination through oil field practices and um…I think that's a very, very real situation in many areas. So yeah those kinds of things would definitely increase the likelihood of contamination.' (P.1) 'Like any oil field operations. Like we are surrounded by oil wells, and that is a concern to me that every time they come to rework the well…Uh we have a lot of oil field and gas drilling in our area so yup I am very concerned.' (P.5) 'I think if you are sitting beside a gas plant, and it is spewing some sort of sulphur dioxin or whatever into the water. You know we actually have neighbours between us and YYY who just had their dairy farm bought out because their water got infected by YYY …a big plant that is sitting there. And their cows actually backed off drinking it (the water) and so yeah there was contamination there for sure. It affected their cows, they didn't like the taste, I do not know if it affected their health, it affected their taste and it backed them off. And that went to court and that got settled… Yeah so, the cows drink a lot they produce a lot of milk, when they back off on water their milk production is going to go down. The owner ended up getting a massive amount of money so I don't know how much of this was just a whole a game…They just lucked out and got themselves into a crazy (explicative) game, but there was all kinds of veterinarians involved and water testing for about two years, and they never had a sick animal from it…from sulphur dioxins, or whatever they said were coming out of that plant and into the water.' (P.7) 'I would think here its actually, probably higher (oil and gas as a risk to contamination), you know with oil and gas drilling and things like that its more of a catastrophic issue. Whereas sometimes it may affect the volume of water as well if there are some fissures or cracks or anything like that…we've been here over 20 years and I've never had anybody complain about livestock, the only time I've ever had anybody complain about any sort of water well contamination would be from oil well drilling operations, never anything from livestock.' (P.13) '…for oil and gas, there's a couple of pipelines that run across my property, and if they ever break, I am going to have a problem, they are natural gas liquids, but I don't have any other activity like that in my place.' (P.17) 'Probably ourselves (with respect to the major risk of contamination), that we didn't see a leak, or I don't know due to circumstances something happened. Because let's say we have a really early winter and we are not allowed to spread (manure) over snow and we have a really late fall so then it gives a long winter. Then at some point then

		you might have an overflow, or your pits are full so where do you go with your manure? You can ask permission to go over snow, if its really an emergency then they'll come and check and give you permission to go over snow, its not ideal but that's the only thing I can see happening. For our own water well, we are our own biggest risk for now.' (P.20)
	Density or intensity of perceived risk	'…some people that we know, they live north of YYY and they've been subject to some fracking and they've been fighting with the oil company for years and years trying to get them to confess to destroying their water, all because they had clean water, the fracking came in and there water was horrible…So I know personally people that have had fights with oil and gas companies over the damage they are doing by interrupting and damaging our water well, or ground water. As an Albertan I kind of feel like I'm being disloyal, but people lives are at stake.' (P.11) 'Well you know there has been a lot of discussion about that in our area because of the coalbed methane operations in our area, we haven't experienced that (contamination), but we have had a lot of coalbed methane drills within a mile of our property here and this goes back to 2005 when there was a lot of activity going on with shallow gas here. YYY was the main operator and they did test our well and they had to do that because Alberta Environment may have told them so.' (P.15) 'Um probably livestock, certainly in southern Alberta, it's the biggest problem. I think it's a huge concern because I have seen nearby feedlots when there's been heavy, heavy rains when literally, water was pouring out of the feedlots down onto the ditches and the roads and we are very near the Oldman river, and I think there's a serious issue with contamination if you get those heavy rains.' (P.18) 'Like we have intensive livestock (pig operation), the only thing, like we as a hobby, we have like 10 cows. And if I were to live besides a feedlot with a lot of cows. I would be concerned because its pure run off. Our 10 cows have run off but that is just a small amount and you see it. But if it would be a lot of cows, I could see it being a problem, because it just runs off, it goes into a slough or somewhere and somehow it can get in, it goes into the bottom and kind of disappears into the earth and it does get filtered and if there is a lot for 20 years. Like I can see that becoming a problem, …in my opinion beef cattle are less regulated. Although …I don't know.' (P.20)
	Management and type of operation	'You know I think honestly. I've been in other ranches and other situations where I see that man, there's a real problem there. I do believe the general awareness now is probably better now than it was say 50 years ago…because for one thing, 50 years ago our province recommended to people that they winter their cattle down on creeks and rivers …for the natural shelter of the trees but that created a bacteria load from the faeces' (P.3) '…Yeah manure run off going into little creeks and streams, we see it all the time, we walk through it, it's a very apparent, in our area, specifically too we have a water …a smell that occurs when manure is deposited... Some of the farmers actually look after manure very well, they do injection, a technique for that, but other guys do not do very much at all. It just runs wherever it goes…Yeah well two years ago I would have said livestock was the number one (risk) for sure, maybe 3 years ago I guess Abraham, but in the last few years fracking has come into our area and it is all over the place. But there's also the junk that fracking pumps down there and it's gotta end up in the aquifers…filtration, they claim actually happens before it gets back into the aquifer. You see cases all the time in the media of people's water well source, drinking water getting wrecked because of oil and gas in the area. Having said that, I do understand that the oil and gas industry is trying pretty darn hard, and it certainly is way better than it was 15, 20, 30 years ago…' (P.4) 'Yeah it does because when you phone the Alberta government to complain about them getting to close with their manure spreading…you get a recording and virtually no replies. Yeah, it's called YYY acres and they've complained about this ever since I have been out there 25 years. It's a constant complaint. They spread manure… dairy manure, they spread hog manure, liquid manure, you know they are supposed to cultivate it within 24 hours…No doesn't happen, complain, nothing happens. They'll spread it in the wintertime.' (P.5)

		'In our particular place we have two horses (horse keeper living next to a dairy farm) so that's really not an issue, but if there is any large hog farms… like we've got a dairy barn about a mile and a half away from us, but they have to follow very stringent guidelines from the province on how they contain their manure and how they dispose of it and that kind of stuff. So, I am very confident contamination is very low risk from farm operations.' (P.11) 'Where we live there's a lot of people who do things in an old school manner because their parents have done it that way and one of the things they often do is spread manure when there is a heavy snowfall warning or a heavy rainfall warning, so that all the manure, all the nutrients from the manure get nicely washed into the ground. Which may have been an old farmer practice but is contrary to what all the standards of the day are. But people continue to do it here.' (p.12) 'Owning this farm and having expanded, we know the regulations around it, and I am totally not worried about any livestock operation that is modern contaminating water well. I am worried about old farms, old wells, that are not properly abandoned and yeah, those junkyard farms. The farms where you see all the old cars and all that kind of stuff. Modern farming, I don't see that. I don't see issues because I know the regulations… The managed farms yes. You can have old farms that's been there for 100 years but its being managed properly. It's the management.' (P.20)
	Other risks to contamination discussed	'I live in area where there is a lot agricultural …like crop agriculture and with all the chemicals that are sprayed on there continuously, and you know by air and by ground. I just can't imagine that stuff isn't getting into our water well.' (P.1). 'I guess in proximity of where it sits. It's in a well protected area I guess …not from farming…our only contamination risk would be our own sewer.' (P.3) 'Uh yeah …yeah two miles north, there was an abandon well, yeah it wasn't sealed.' (when speaking about risks to contamination) (P.5). '…uh mice and gophers and things that get into the well head.' (P.10) '…I mean forest harvest and or drilling activities, oil and gas although the latter two would not be the main ones' (P.14) 'like I've seen a lot of wells that were, were basically pit wells, or the well was, or to get to the well head you actually had to go down a ladder into the pit, and its absolutely amazes me that those things still exist. My brother has one in his place and I think he's absolutely insane, I keep telling him to drill a new well and get away from that thing because it is so easy for it to become contaminated.' (P.17)
Mitigation strategies to protect against contamination	In home treatment devices	'Uh… the only thing we have in our house is a water softener.' (P.1) 'Since my wife had the reverse osmosis system in a few years ago, my entire life, I have never tasted water as good as what we have …I way'd rather drink our own water than I would bottled water.' (P.3) 'It's now being softened, if we didn't have it softened it would not be super palatable water, there is a fair amount of iron in it, high pH, alkalinity is high and so yeah it is, yeah it's got a colour to it, it stains...' (P.4). 'We are really satisfied, because we have a treatment system for our drinking water. Which was put in about a year ago, because we had high nitrate in the water. Our treated water is probably the same quality as any bottled water you can buy. And we do not really find an off taste or a smell at any time.' (P.6) 'A triple filter, a U.V. system and a water softener.' (P.10).
	On property mitigation strategies	'…It (contamination) is not a risk at our ranch. We are very careful about the location and how we deal with our well and protect the top from having surface water flow into our well. We are very careful about that. I would make certain that that manure never got close to …or that run off, never got close to our well. They (the cattle) are kept a long way away from the well in the winter, and the cattle that we have…we custom graze our cattle. And I've got the first groups here now and they do not come into the buildings very often. They have access occasionally to the water but again it's out of a drinking water system …so that again, they are not anywhere near the well. I am very proud of what I do…we have a total of 9 dug outs that are fenced …to keep the livestock out of them. So, I have created with fencing…Riparian areas that have multiple purposes. Number one, it keeps the animals from accessing the water directly…' (P.3)

		'So, our well itself is up high, and it's got lots of good gravel around it, and there is nothing around it, nothing drives around it, there's a nice building right beside it, and there is no runoff into it. So, it is at the highest spot.' (P.7) '...and, so our cattle and like the corrals and where a lot of the, um the cattle live is actually quite a ways, 200 metres from where the well is, so I do not feel directly, like its going to do it really bad, but I could see where it (contamination) could come from.' (P.8) 'Like we have intensive livestock, the lagoon, you know the NRCB (Natural Resources Conservation Board) did inspections walked around it and made sure it looks clean and you keep it up and all those kinds of stuff... I know us for intensive livestock I know we always have to submit a sample and if you don't you get an email, oh where are your samples. So, I think we are doing a good job.' (P.20).
Knowledge about water contamination events	Knowledge of contamination events in Alberta and Canada	'I'm so glad you asked this question. Uh …I'm on our municipal district council… We are currently dealing with a hamlet by the name of YYY…it's one of our hamlets It has approximately 62 people in it, at the present time. We are…we in conjunction with the provincial government and the federal government are going to spend multiple millions of dollars putting in a water system there and a sewer waste water system …for the residence of YYY, because of the way the land is, the way the wells are, the way the sewers are … Right now, we are very, very … close to a potential health risk because of wastewater sewers, and wells and the contamination…' (P.3) 'Well yeah, on the other side of the lake, our lake we've had people that have had…or they claim they've had their well water messed up by fracking again. I mean that's hear say we have no evidence of that. We also, we used to live in the YYY area again, below YYY, there is a little community called YYY, which is just outside of YYY, and the whole area of YYY had water wells. They were not allowed to take water from the ground anymore, so yeah…' (P.4) 'Um…no nothing specifically comes to mind.' (P.12) 'You know I've heard rumours; I haven't heard any substantiated um, reports or events you know through Alberta with uh with fracking but not particularly manure so.' (P.14) 'I just think of the Walkerton thing and cattle contaminating the wells there and people dying from that.' (P.18)
Disease outcomes associated with water well contamination	Gastrointestinal illness	'…in my personal opinion it's not gonna cause cancer, and its not gonna cause heart disease, what it is gonna, I feel…personally I feel, with water well contamination, the first thing would be I think *E. coli*.' my personal opinion…the first thing would be I think *E. coli* would be the first thing. I'm gonna say no (to well water causing cancer and heart disease) because you know maybe because there are certain cases in certain places, you know where they have had chemicals flow into drinking water, maybe cause cancer, but not in our place in particular…no.' (P.3) 'Oh well water, yeah I mean the only illnesses I think would be stomach related and uh and the digestive tract more than anything else.' (P.14) 'Just in general, things that would make you sick from drinking water that wasn't good or anything... The same as the beaver fever (Giardiasis) or something like that, along that line.' (P.16) 'I don't know about heart disease or cancer, but I know it can cause serious problems from *E. coli* bacteria and other things like that. Um I am not concerned about anything like that can give you heart disease or cancer, I don't know enough about it to be able to answer than question correctly. I'm more concerned about bacterial infection and bacterial contamination.' (P.17)
	Other illnesses	'Umm…and that was a concern because of the high iron levels in our water was causing me some health problems… I have returned back to drinking the well water because the iron problem has been resolved with my body, I guess.' (P.1) 'Like I'm thinking more on the biological and the minerals or…like the nitrates did cause us a health problem, which wasn't a gastric problem. We were tired all the time, for quite some time before we tested our water and we realized after we tested our water and researched that, that could be because of the high nitrate.' (P.6) 'Hmm well you know; I do not think it would cause heart disease. The bigger problem with heart disease is that we see a lot of wells with really high sodium levels and its nice soft water and everybody wants that nice soft water,…you know, unless they get it

		tested they do not realize it is high in sodium, so then you are affecting your blood pressure, so I suppose that might be a problem, I do not worry about that. Cancer you know cancer is iffy. Who knows what causes cancer …I think if you are sitting beside a gas plant, and it is spewing some sort of sulphur dioxin or whatever into the water?' (P.7) 'Um nitrogen can block some of the oxygen. So, it can slow down brain development and cause miscarriages.' (P.12) '… No, it's high in fluoride. It's got triple the amount of fluoride in there that you are supposed to have so we've got to take that into consideration for the kids as they are young... The fluoride I never knew until the dentist said like you have high fluoride you gotta be careful with your kids, it's not that super bad but they get spots on their teeth.' (P.20)

B.5. Summary of themes, sub-themes and quotes based on HBM

Constructs of HBM	Sub-themes	Quotes
Susceptibility	Proximity to threat (e.g., livestock and oil & gas	you know …I don't think there is a great risk of well contamination from the local activity…right at this point and time it is not a concern for me, due to our location and proximity of cattle grazing and the amount of land that is actually physically back there."
	Current well stewardship practices (i.e., treatment and testing)	"Its kind of like a 15% kind of thing. You know that it's there, you know it can happen, it's not my daily weekly, monthly worry but its always kind of like keep it clean, chlorinate, check your stuff so you know it."
	Current on farm/acreage practices	"Um I do not think it is very likely because of the volume of the water, now its possible but not entirely likely… I am not worried about it because of the system we have on our water and the precautions we have taken."
	Well infrastructure (i.e., location of well, depth of well)	"Uh …I would say by everything that we have done and the people before us by drilling the well where they did …I would say we have quite low risk of any well water contamination…I mean the well is in a location where I can look at it any time I want to make sure there is not a problem showing up …I would say quite low risk (of well water contamination) yeah."
Severity	Illnesses and mortality associated with well water contamination	"Well I think it can be pretty severe, mainly in terms of if there is a chemical contamination that could cause some health issues and bacteria could certainly cause some uh digestive kind of G.I. tract kind of stuff that could definitely make people very sick, and if they happened to be sick already you know, it could be dangerous ..."
	Problems associated with finding alternative water sources on property in the event of contamination	"Oh yeah it's a real concern… If it's a 1 to 6 scale, I would rate it to 6 as a concern. I look at the implications of what would happen if we did have a contaminated well, we'd have to move…or haul water in. When you see people hauling water in, what a disaster."
	Implication on livestock health	"We run livestock and some…certain levels of the different things that compose the water can affect the health of the livestock as well. So, we have to keep that in mind always to be able to manage our livestock."
Barriers	Delivery of well water samples to sample drop off locations	"No other than the fact that it is really inconvenient the times to test the well, if it would make it easier for people to just drop their samples …and I am not sure, you know the chemical analysis, whether it has to be within a time frame, but its really awkward to get that done…other than its very difficult because, if you are working you have to have the sample taken, two hours before you send it in, and in YYY I have to have it in by nine o clock."
	Hours of operation of sample drop off locations	"Oh, do you know why they do not do it…There is a time window, so you go and you have to pay first of all, which I do not care, but some people have to pay ten dollars to get the bottle, and in our small towns you can only get it from the hospital, and you can only get it on certain days, so it is very restrictive. So, like for us we have to go to the YYY You can go Monday, Tuesday, Wednesday…that's it. You have to be there between

		8.00 in the morning and 5 in the afternoon, and you have to pay 10 bucks a bottle, and then you have to fill that bottle and then within that 24 hours have it back into them, so if you do not live near town, it becomes almost like you can't do it. You have to take two days off, you've got to take one day to take the bottle, bring it home, fill it up, take the next day to run it in. And it's got to be Monday, Tuesday or Wednesday."
Benefits	Safeguard human and animal health	"I think having them tested is going to tell us what is going on, with our water and therefore should be able to help us catch anything that might be coming in. Um…I think safety, knowing what is in your water and having it tested often enough tells you, you know where you are at, where your water is at and where you need to do the maintenance properly."
	Give peace of mind over well water quality	"Uh…its just peace of mind I guess, to know what our well is like."
	Knowledge of the state of the aquifer well is tapping into	"I think it is everybody, because if one of us was to find something really crazy in our well water, we would all be thinking holy (explicative), where is that coming from… what if its in an aquifer in the area."
Self-Efficacy	Well water testing is a relatively easy task to conduct	"Easy enough…Yeah the results come back in a couple of weeks or three weeks and they are always precise and always good. Give me the information that I need."
Cues to action	Home delivery service for sampling	"Well I guess the only thing that would make it for me easier. Is if they could mail the samples or … have someone pick them up." "Once a year maybe even, like a mobile truck, or something that can have the right temperature, or however it is they need, like a mobile truck that says…ok I'm coming to this area at this time, you know, come and meet me or I can stop by or you know."
	Education and awareness initiatives	"I guess an awareness program, flyers in the mailbox, you know if you have well water be aware of the dangers and be aware. You know something to make people aware, not scare them, but just a flyer, information sheets, fact sheets about wells and in general just to create more awareness would be a good thing."
	Do it yourself home testing kits	"I think the best thing is if they could have an at home kit (laugh). People could do it if they could do it in their own houses, they'd do it. Lots. The government should come up with an at home kit."

B.6. Alignment of participants statements with the HBM

Rank	**Tenet of HBM**	**Sub-themes**	**Number**
Low	Susceptibility	Proximity to threat Current well stewardship practices (i.e., treatment and testing) Current on farm/acreage practices (e.g., fencing off well area, limiting land use around well head) Well infrastructure (i.e., location of well, depth of well)	14/20
Low-medium	Barriers	Delivery of well water samples to sample drop off locations Hours of operation of sample drop off locations Lack of awareness of no charge water testing services Reminders to conduct water testing on a more frequent basis	17/20

High	Severity	Illnesses and mortality associated with well water contamination Problems and expense associated with finding alternative water sources on property in the event of contamination Implications on livestock health	16/20
High	Benefits	Safeguard human and animal health Give peace of mind over well water quality Knowledge of the state of the aquifer well is tapping into	18/20
High	Self-efficacy	Well water testing is a relatively easy task to conduct All well owners tested their well water quality as part of the study Few barriers were mention in terms of the process of conducting a water test	20/20

B.7. Variables thought to influence testing and treatment

Independent variable	**Dependent variable**	**Rationale, hypothesis or assumption behind association.**
Know about test recommendations	Testing	Assumption is that if participants know about the well test recommendations they will engage in testing (Flanagan *et al.*, 2015)
Finding a health centre is difficult	Testing	Difficulty in finding health centres that accept water samples is a limitation and will influence well owners' ability to engage in well testing
Picking up and dropping samples is time consuming	Testing	The time taken to pick up and drop off water samples may be an inconvenience and therefore influence well owners' willingness to engage in well water testing (Jones *et al.*, 2005; Roche *et al.*, 2013)
Doing a water test is costly	Testing	The costs of conducting a well water test may limit the willingness of well owners to engage in testing
Health centre is open at an inconvenient time	Testing	Hours of operation of health centres where sampling bottles are picked up and dropped off from may influence the access ability to conduct well testing if they conflict with the well owners' schedule
Procrastination	Testing	Procrastination had previously been noted as a factor influencing the submissions of water quality tests (Jones *et al.*, 2005; Summers 2010)
I didn't know about testing services	Testing	Well owners not knowing about the no charge testing services may not engage in well water testing
Years lived in current residence	Testing	Years lived in the current residence has been previously associated with well water testing behaviour (Shaw *et al.*, 2005)
Satisfaction with taste	Testing	Assumption that if there is a change in the taste of the well water and well owners are not satisfied with the taste this may prompt testing.

Satisfaction with clarity	Testing	Assumption that if there is a change in the clarity of the well water and well owners are not satisfied with the clarity this may prompt testing.
Overall satisfaction	Testing	Assumption that if there is a change in the overall satisfaction with the organoleptic properties of the well water and well owners are not satisfied with either of the organoleptic properties of their water this may prompt testing
Satisfaction with water hardness	Testing	Assumption that if there is a change in the hardness of the well water and well owners are not satisfied with the hardness this may prompt testing.
Livestock present	Testing	The presence of livestock may be viewed as a hazard that prompts well owners to test (Summers 2010)
Participant gender	Testing	Gender may influence well water testing behaviour (Merkel *et al.*, 2012; Straub & Leahy, 2014
Participant age	Testing	The age of a well owner has been associated with the intent to test (Flanagan *et al.*, 2015)
Recently moved from a city to a rural area	Testing	New rural residents reliant on well water may not be aware of the recommendations for well testing.
Well age	Testing	Well age may influence well water testing behaviour (e.g., newly drilled wells may be tested to determine water quality)
Participant income	Testing	Income may influence well stewardship behaviour (Flanagan *et al.*, 2016; Garcia *et al.*, 2016)

Independent variable	**Dependent variable**	**Rationale, hypothesis or assumption behind association.**
Uncertain about which treatments to use	Treatment	Uncertainty around which treatments to use to improve well water quality may limit well owners' willingness to use treatments
Difficulty installing and using treatments	Treatment	Difficulty in installation or use and maintenance of treatments may be a factor that limits well owners' willingness to install treatments
Recently moved from a city to rural area	Treatment	Well owners who recently moved from a municipal area with a municipal water supply system may not be aware of the need for well treatment
Satisfaction with Overall quality of well water	Treatment	Assumption that if there is a change in the overall satisfaction with the organoleptic properties of the well water and well owners are not satisfied with either of the organoleptic properties of their water this may prompt the use of treatments
Treatments are expensive	Treatment	The expense of a water treatment system may be a limiting access of treatments
Satisfaction with taste	Treatment	Satisfaction with the taste of well water may prompt well owners to use treatments to improve water quality

Satisfaction with clarity	Treatment	Satisfaction with the clarity of well water may prompt well owners to use treatments to improve water quality
Belief in soil and rocks over aquifer protecting against contamination	Treatment	Belief that the aquifer confers enough protection from well water contamination may inhibit the willingness of well owners to adopt treatment

B.8. Univariate analysis for variables used in the logistic regression models

Variables included in well water testing model			
Predictor	**Symbol**	**Outcome**	**Univariate analysis**
Know about test recommendations	Tstknow	Tested in last year	0.007
Finding a health centre is difficult	Heacengrp2	Tested in last year	0.013
Picking up and dropping samples is time consuming	Picksgrp2	Tested in last year	0.041
Doing a water test is costly	Costsgrp2	Tested in last year	0.005
Health centre is open at an inconvenient time	Inconvgrp2	Tested in last year	0.003
Procrastination	Procrgrp2	Tested in last year	0.18
I didn't know about testing services	Idktstgrp2	Tested in last year	0.17
Years lived in current residence	Yrsresidence	Tested in last year	0.012
Satisfaction with taste	Tastegrp2	Tested in last year	0.27
Satisfaction with clarity	Claritygrp2	Tested in last year	0.24
Overall satisfaction	OvSatgrp2	Tested in last year	0.75
Satisfaction with water hardness	Hardgrp2	Tested in last year	0.81
Livestock present	Livpresent	Tested in last year	1.00
Participant gender	Gender 2	Tested in last year	0.49
Participant age	Age2	Tested in last year	0.72
Recently moved from a city to a rural area	Cityrura	Tested in last year	0.89
Well age	Wellage	Tested in last year	0.77
Participant income	Incomegrp	Tested in last year	0.42

Variables included in the well water treatment model			
Predictor	**Symbol**	**Outcome**	**Univariate analysis**
Uncertain about which treatments to use	Treatuncertgrp	Presence of treatment	0.19
Difficulty installing and using treatments	Difftreatment	Presence of treatment	0.18
Recently moved from a city to rural area	Cityrura	Presence of treatment	0.153
Satisfaction with Overall quality of well water	OvSatgrp2	Presence of treatment	0.19
Treatments are expensive	Expenivet	Presence of treatment	0.19
Satisfaction with taste	Tastegrp2	Presence of treatment	0.11
Satisfaction with clarity	Claritygrp2	Presence of treatment	0.16
Belief in soil and rocks over aquifer protecting against contaimation	Aquifergrp	Presence of treatment	0.05
Livestock present	Livpresent	Presence of treatment	0.22
Well depth	Weldepth	Presence of treatment	0.86
Participant income	Incomegrp	Presence of treatment	0.24
Partcipant gender	Gender2	Presence of treatment	0.78
Satisfaction with water hardness	Hardgrp2	Presence of treatment	0.56
Doesn't know how to treat to improve water quality	Idktreatment	Presence of treatment	0.25

Variables highlighted in bold were less than 0.2 using chi squared analyses and were included in the logistic regression model analyses

B.9. Model comparison for water testing and treatment behaviour

Model 1											
Test1year	Odds Ratio	Std Err.	z	P>|z|	95% C.I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF
Tstknow	27.39	40.36	2.25	0.03	1.53	491.74	-13.04	23.57	0.0027	0.47	0.17
Picksgrp2	3.93	5.21	1.03	0.3	0.29	52.83					
Inconvgrp2	0.08	0.1	-1.9	0.06	0.01	1.08					
Procrgrp2	0.43	0.58	-0.62	0.53	0.03	6.17					
Yrsresidence	0.98	0.04	-0.28	0.78	0.91	1.07					
Costsgrp2	0.27	0.36	-0.97	0.33	0.02	3.7					
Idktstgrp2	2.95	5.75	0.56	0.57	0.06	133.21					
Heacengrp2	0.19	0.33	-0.96	0.34	0.01	5.58					
cons	1.36	2.52	0.87	0.87	0.03	51.87					
Model 2											
Test1year	Odds Ratio	Std Err.	z	P>|z|	95% C.I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF
Tstknow	18.72	22.78	2.41	0.01	1.72	203.21	-18.07	17.69	0.001	0.32	0.12
Picksgrp2	2.18	2.21	0.77	0.43	0.30	15.87					
Inconvgrp2	0.07	0.08	-2.47	0.01	0	0.58					
Procrgrp2	0.82	0.86	-0.19	0.85	0.1	6.43					
cons	0.69	0.95	-0.26	0.79	0.05	10.40					
Model 3	Odds Ratio	Std Err.	z	P>|z|	95% C.I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF
Tstknow	27.75	35.15	2.62	0.009	2.31	332.41	-15.07	19.49	0.0001	0.39	0.58
Inconvgrp2	0.06	0.06	-2.49	0.013	0.01	0.55					
cons	0.79	0.75	-0.24	0.81	0.13	4.99					

Model 1	Odds Ratio	Std Err.	z	P>|z|	95% C. I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF
OvSatgrp2	0.02	0.04	-2.17	0.03	0	0.69	-14.77	16.52	0.02	0.35	0.04
Cityrura	0.16	0.28	-1.04	0.3	0	4.97					
Aquifer grp	0.26	0.3	-1.16	0.24	0.03	2.45					
Treatuncergrp	0.02	0.04	-2.19	0.03	0	0.67					
Nvtreatm	2.79	1.67	1.72	0.08	0.86	9.02					
Yrsresidence	0.99	0.03	-0.24	0.81	0.91	1.07					
Difftreatment	0.12	0.22	-1.16	0.24	0	4.18					
cons	747.22	2812.96	1.76	0.079	0.46	0.12					
Model 2	Odds Ratio	Std Err.	z	P>|z|	95% C. I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF

OvSatgrp2	0.19	0.20	-1.54	0.12	0.02	1.56	-19.45	10.00	0.07	0.20	0.28
Cityrura	1.31	1.61	0.22	0.83	0.11	14.69					
Aquifergrp	0.23	0.21	-1.58	0.11	0.03	1.41					
Treatuncergrp	0.18	0.17	-1.80	0.07	0.03	1.15					
Yrsresidence	1.02	0.03	0.57	0.57	0.95	1.08					
cons	25.38	40.34	2.03	0.04	1.12	572.23					

Model 3	Odds Ratio	Std Err.	z	P>|z|	95% C. I		LL	LR chi2	Prob> chi2	Pseudo R2	GOF
OvSatgrp2	0.18	0.19	-1.58	0.11	0.02	1.49	-19.47	9.95	0.04	0.20	0.33
Aquifergrp	0.23	0.21	-1.57	0.12	0.04	1.42					
Treatuncergrp	0.17	0.15	-1.97	0.04	0.03	0.96					
Yrsresidence	1.01	0.03	0.53	0.59	0.95	1.07					
cons	30.27	42.02	2.46	0.02	1.99	459.64					

APPENDIX C: INTERVIEW GUIDE AND QUESTIONNAIRE

C.1. Interview primer script

Hello “participants name**”**

How are you doing today? Thank you for taking your time to participate in this interview session. Before we begin the questions, there a few housekeeping rules that I would like to run by you to ensure that we go through this interview smoothly.

1. This phone interview is being recorded. Audio recordings from our discussion will be transcribed and analyzed using method called thematic analysis. Transcriptions will be anonymized, meaning that your identities will be kept hidden in any subsequent articles or reports generated from this study. Only the people in this room will know what you said. By agreeing to take part in this interview you are allowing us to use anonymized forms of the data generated from you. Do you agree to participate (receive verbal acknowledgement from participant)?

2. The interview questions will cover three main themes, your well use, well water management practices, risk of water well pollution. The reason we are having these in-depth interviews with you is so that we can get your opinions and experiences with well water. We want to hear your voice as well owners and incorporate your perspectives in the research as it will be important in guiding well management policy and practices in Alberta.

3. It is also important to remember that there are no right or wrong answers. Each person’s thoughts, experiences, and opinions are equally valid. So do not hesitate to express them. Although we are affiliated with an academic institution (the University of Calgary) this is not an exam, no one is marking or judging you, so feel free to say whatever comes to mind regarding a particular question. You also have the right to refuse to answer any question that you feel uncomfortable with.

4. There are 9 main questions we will cover today. The interview should last between 30-45 minutes. However, if you feel the need to add more time to the discussion question please feel free to do so. Your opinion is of valued.

I take this opportunity to remind you that if at any point during our discussion you feel uncomfortable with any question you can decline to answer it. You are here voluntarily, and we greatly appreciate your time and thoughts.

Now do you have any questions?

…If not let us begin.

C.2. Qualitative interview questions.

Question 1: Tell me about the sources of the drinking water in your home?

Probe: How often do you drink water from your in-house tap?

Probe: Tell me about your satisfaction with the look, taste, odour, feel of the water you primarily drink in your homes?

Probe: How would you compare the look, taste, odour with other sources of drinking water you may have experienced (e.g. bottled water)?

Question 2: What comes to your mind when you hear of water well pollution?

*Probe***:** Do you feel water well pollution is a risk in your area?

Probe: Do you think water well pollution is a priority issue with respect to health for example do you think of well water pollution like you would of heart disease or cancer?

Probe: What illnesses do you think can be caused by well water pollution?

Question 3: Tell me about the current water well management practices that you use to protect your water well from pollution.

Probe: Describe what led you to use these management practices (testing, treatment and other).

Probe: Tell me about your beliefs towards these management practices and whether you believe they protect you against illness.

Probe: Can you tell me how you test water in your home? How often are you able to test your water well in your home?

Question 4: I would like to talk a bit about livestock manure and how it might affect your well water. Do you have any thoughts about that?

Probe: Can you describe any experiences that you may have had or know about with respect to water contamination by livestock manure.

Probe: What livestock species are likely to cause pollution in your area?

Probe: Is there anything people can do to prevent water well pollution by livestock manure?

Probe: How feasible is it to prevent water well pollution by livestock manure in your opinion?

Probe: How would you rank livestock as a risk to water contamination relative to other potential sources of water well pollution in your area?

Question 5: How likely is your well to get polluted? Or Is your well likely to get polluted?

Probe: What scenarios do you think would increase the likelihood of your well being polluted?

Question 6: How dangerous (or severe) do you think well water pollution can be? Or How big of a problem do you think well water pollution is?

Probe: Do you know of any water well pollution events in Alberta (Canada)?

Probe: Might you be concerned about your family's health from water pollution by livestock?

Question 7: Can we talk about testing and treating your water and how you go about doing it

*Probe***:** Have there been any problems in getting your water tested? What were they?

Probe: Have there been any problems in getting your well water treated (and what were they)?

Probe: How might these problems be addressed (or what do you think are the possible solutions to these problems)?

Question 8: What would help you get your water tested on a regular basis?

Probe: Is there anything the well water testers or government can do to get you to test your well water?

Question 9: How might you and your family benefit from getting your water tested?

Probe: Might this benefit only your family or others? May you expand on this idea?

C.3. Watershed Questionnaire

Study of water wells on rural Albertan properties: Part 2

Dear rural resident of Alberta

My name is Abraham Munene. I am a PhD student in the Faculty of Veterinary Medicine at the University of Calgary, supervised by Dr. David Hall. We are conducting a study to investigate what rural residents of Alberta think about well water, the related risks of water contamination, and what influences their thoughts about those risks and prevention.

This is a follow up questionnaire to the questionnaire you received in the Fall of 2016 and is the final component of this study. This portion of the questionnaire will cover questions to do with your well characteristics, sensory properties of your well water and consumption habits, barriers faced to water testing and treatment, knowledge about water well management, and demographics. We are interested in the opinions of a range of rural residents of Alberta who ***use water wells*** including farming and non-farming rural residents, residents who own animals and those who do not, and Albertans who may live in a rural property year-round or only some of the time.

We will use both data from the first questionnaire, this questionnaire, water quality reports, and qualitative interviews for analysis in the mixed methods research. This study is funded by Alberta Innovates Energy and Environment Solutions. If you did not receive the first questionnaire and would be interested in answering it, please contact me. If you do not own a water well but know someone in your neighbourhood who does, please pass on this questionnaire to them.

Sincerely,

Abraham Munene, PhD student, University of Calgary
abraham.munene2@ucalgary.ca
(587) 433 0028

SECTION A: WELL CHARACTERISTICS AND RISK OF CONTAMINATION

Water well characteristics may determine the risk of contamination of your well. Here we will ask you about some of your wells' characteristics and the likely sources of contamination in your area.

1. What type of well do you have?

❑ Drilled ❑ Bored ❑ Other ______________

2. When was your well drilled? ______year ______month

3. My well is ___________metres deep.

4. Check the box that best describes the cap (lid) on your well.

❑	❑	❑	❑	❑
No well cap	A cap that can be removed without tools or a key	A cap that requires tools or a key	Other _____________	I do not know

5. Does your well cap fit tightly?

❑ Yes ❑ No

6. Does your well cap have a crack?

❑ Yes ❑ No

7. Write down the top three threats that you think are likely to cause water well contamination in your area

a.____

b.____

c.____

SECTION B: WATER QUALITY PERCEPTIONS AND WATER CONSUMPTION

For this question we would like to get your opinion on how satisfied you are with the taste, smell, look, hardness and overall quality of your water in addition to water consumption habits. Please indicate how satisfied you are with.

	Very dissatisfied	**Dissatisfied**	**Neutral**	**Satisfied**	**Very Satisfied**
The **Taste** of my well water	1	2	3	4	5
The **Smell** of my well water	1	2	3	4	5
The **Clarity** of my well water	1	2	3	4	5
Hardness of my well water	1	2	3	4	5
Overall drinking water quality from my well	1	2	3	4	5

1. Do you drink water from sources other than your well in your home?

   ❑ Yes ❑ No

2. Which drinking water source within your home do you consume most water from? (e.g. bottled water, trucked water)

   ____

3. Have you recently moved from a city (on municipal water) to a rural residence with a water well supply?

   ❑ Yes ❑ No

4. If yes how long ago did you move to the rural residence (please specify year).

   ____

SECTION C: BARRIERS TO WATER WELL TESTING

This group of questions asks about some of the barriers you may face in getting your water tested. Please rate how well you agree with the following statements.

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Finding a health centre to conduct a water well test is difficult	1	2	3	4	5
Picking up and dropping off water sampling bottles is time consuming	1	2	3	4	5
Doing a water test is costly	1	2	3	4	5
It is difficult to understand the water quality report	1	2	3	4	5
Health centre is open at an inconvenient time	1	2	3	4	5
I didn’t know there were services to conduct water testing	1	2	3	4	5
Procrastination	1	2	3	4	5

Other reasons that may be barriers to getting your water tested (please specify).

____

SECTION D: BARRIERS TO WATER WELL TREATMENT

We have listed some of the barriers water well owners may face when deciding to use water well treatment. Please rate how well you agree with each of these statements

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Not sure of which water treatments to use against contaminants	1	2	3	4	5
Shock chlorination interferes with the taste and smell of my water because of the chlorine	1	2	3	4	5
Water treatment devices (e.g. Chlorination, U.V. filters Distillation) are expensive	1	2	3	4	5
Difficulty installing or using water well treatment devices	1	2	3	4	5

Other (please specify) ____

We have listed reasons why people may not choose to treat their well water. Please rate how well you agree with each of these statements.

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
I believe the soil and rocks over my aquifer protect me from contaminants	1	2	3	4	5
Never thought about using treatments	1	2	3	4	5
I do not know how to treat to improve water quality	1	2	3	4	5
Treatment may not always result in perfectly safe drinking water	1	2	3	4	5

Other (please specify) ____

SECTION E: WATER WELL MANAGEMENT KNOWLEDGE

Knowledge of water well management practices could influence testing and treatment habits. Here we would like to understand what you know about recommended water well management practices.

1. What is the Government of Alberta's recommended frequency for conducting water tests for bacterial contaminants?

❑	❑	❑	❑	❑	❑
Once a year	Twice a year	Four times a year	Once every 2 years	Once in 5 years	At my discretion

2. What is the Government of Alberta's recommended frequency for conducting water tests for chemical contaminants?

❑	❑	❑	❑	❑	❑
Once a year	Twice a year	Four times a year	Once every 2 years	Once in 5 years	At my discretion

3. Which of the following water treatments would effectively protect you from bacterial contamination?

	Strongly disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Reverse Osmosis filter	1	2	3	4	5
Boiling	1	2	3	4	5
Water Softener	1	2	3	4	5
Shock Chlorination	1	2	3	4	5
Jug Filter e.g., Brita filter	1	2	3	4	5

Other treatments that would make your drinking water safer from bacterial contamination.

____

4. Have you attended a well water workshop or information session in the last year (e.g., the Working Well Program)?

❑ Yes ❑ No

5. How did you hear about this study?

❑	❑	❑	❑	❑
Received a questionnaire in the mail	Online county advertisement	Watershed group	Working well workshop	Other ___________

6. Have you completed a well water test for bacterial contamination?

❑ Yes ❑ No

7. If *yes* when did you complete the test.

❑ Within the last 6 months ❑ Within the last year ❑ Within the last 2 years ❑ Within the last 3 years ❑ Within the last 5 years ❑ Other ______________

SECTION F: DEMOGRAPHIC INFORMATION

1. What is your gender?

❑ Male ❑ Female

2. What is your age? __________years.

3. How many years have you lived at your current residence ________years ________months?
4. Please put a check on the industry that best describes your occupation.

❑ Agriculture ❑ Health ❑ Finance ❑ Oil and Gas ❑ Environmental Services ❑ Social services

Other____

APPENDIX D: ETHICS STATEMENT

Conjoint Faculties Research Ethics Board
Research Services Office
3rd Floor MacKimmie Tower (MT 300)
2500 University Drive, NW
Calgary AB T2N 1N4
Telephone: (403) 220-4283
cfreb@ucalgary.ca

CERTIFICATION OF INSTITUTIONAL ETHICS REVIEW

This is to certify that the Conjoint Faculties Research Ethics Board (CFREB) at the University of Calgary has reviewed and approved the requested modification to the below research. The CFREB is constituted and operates in accordance with the current version of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (TCPS).

Ethics ID:	REB13-0473_MOD3
Principal Investigator:	David Hall
Co-Investigator(s):	Sylvia Checkley
Student Co-Investigator(s):	There are no items to display
Study Title:	Perceptions of water quality among rural Albertans and association with livestock.
Sponsor (if applicable):	Alberta Innovates - Energy and Environment Solutions

Effective: 10/31/2016 **Expires:** 10/31/2017

It is permissible for you to continue the above-named research with the modifications described below, which are based on the information provided in your modification summary request.
- include use of a secondary dataset from Alberta Health Services (AHS) that indicates geographic locations of wells (but not any other identifiable information) and whether or not owners of those locations submitted a water sample for testing to AHS in the past 5 years.

Restrictions:

This Certification is subject to the following conditions:

1. Approval is granted only for the research and purposes described in the application.
2. Any modification to the approved research must be submitted to the CFREB for approval.
3. An annual application for renewal of ethics certification must be submitted and approved by the above expiry date.
4. A closure request must be sent to the CFREB when the research is complete or terminated.

Approved By: **Date:**

John H. Ellard, PhD, Chair ,CFREB March 6, 2017

Note: This correspondence includes an electronic signature (validation and approval via an online system).

APPENDIX E: COPYRIGHT PERMISSION

E.1. Permission correspondence from BMC Systematic Reviews

Hello Paul,

I wanted to ask if I could use of the article **Factors influencing perceptions of private water quality in North America: a systematic review** in my dissertation and that will be added to the institutional repository at the University of Calgary and the Library and Archives Canada.
University of Calgary Theses Repository – The Vault http://theses.ucalgary.ca/ Library and Archives Canada http://collectionscanada.gc.ca/obj/s4/f2/frm-nl59-2-e.pdf
The citation for the article is Munene, A., & Hall, D. C. (2019). Factors influencing perceptions of private water quality in North America: a systematic review. *Systematic Reviews*, *8*(1), 111.
DOI: https://doi.org/10.1186/s13643-019-1013-9
Please let me know if this is ok or who handles these requests.

Have a good week.

Sincerely,

Dear Dr. Munene,

Thank you for writing to us. It is ok to use the article in your dissertation and add it to the repository.

Kind regards,

Puja Dayal
Project Coordinator Open Access, Production

BMC
Van Godewijckstraat 30
3311 GX Dordrecht, The Netherlands
E: puja,dayal@springernature.com
www.biomedcentral.com

E.2. Permission correspondence from Canadian Water Resources Journal

Hello Anjana,

I wanted to ask if I could use of the article **Perceptions of drinking water quality from private wells in Alberta: A qualitative study** in my dissertation and that will be added to the institutional repository at the University of Calgary and the Library and Archives Canada.
University of Calgary Theses Repository – The Vault http://theses.ucalgary.ca/ Library and Archives Canada http://collectionscanada.gc.ca/obj/s4/f2/frm-nl59-2-e.pdf
The citation for the article is *Abraham Munene, Jocelyn Lockyer, Sylvia Checkley & David C. Hall (2019) Perceptions of drinking water quality from private wells in Alberta: A qualitative study, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, DOI:* 10.1080/07011784.2019.1601599
Please let me know if this is ok or who handles these requests.

Have a good weekend.

Sincerely,

Abraham

From: TCWR-production@journals.tandf.co.uk <TCWR-production@journals.tandf.co.uk>
Sent: May 10, 2019 11:45 PM
To: Abraham Munene
Subject: Re: Request to use article for dissertation #TrackingId:3699075

Dear Abraham,
Sure. Please use it.

Regards,
Anjana Bhargavan (Ms.)
Canadian Water Resources Journal / Revue Canadienne Des Ress