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Ontario's Small Non-Community Drinking Water Systems: How to Ensure Provision of Safe Drinking

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Abstract

Waterborne disease outbreaks associated with drinking water systems occur in Canada and elsewhere. Previous research has shown that the small non-community drinking water system (SDWS) users are at increased risk of becoming ill compared to the community drinking water system users. Although public awareness surrounding access to safe drinking water has been increased considerably since the Walkerton tragedy in 2000, the provision of safe drinking water in Ontario's SDWSs is relatively understudied. Furthermore, a key initiative to safeguard drinking water sources in Ontario, the planning for source water protection, does not include SDWSs.

Our research consists of three manuscripts addressing the following objectives: a) to examine contributing factors to adverse water quality incidents in SDWSs, b) to investigate risk awareness and perceptions of the SDWS owners in the provision of safe drinking water and protecting their water sources, c) to develop a sustainable operation model for Ontario's SDWSs.

We use a mixed methods approach by analyzing quantitative and qualitative data in different phases of the research. The study region, Wellington-Dufferin-Guelph, is situated in the heart of southern Ontario.

Our research investigates the relationship between operational characteristics of SDWSs and adverse water quality incidents and concludes that the presence of operator training, an upstream behavioural determinant, significantly reduces the incidence of adverse water quality incidents in SDWSs. The interviews with SDWS owners reveal the need for low-cost and easily accessible training opportunities, and financial support for some SDWS owners. Although the current literature on Ontario's SDWSs is limited, the review of the current water management strategies in Canada and across the world provides fruitful results to create of a unique model for Ontario's SDWSs using the Multiple-Barrier Approach framework. Our sustainable operation model consists of five main components: Commitment to providing safe drinking water; assessment of the system and source water; system operation and operator training; management of incidents and emergencies; and communication and raising awareness. Our model addresses the areas that need more attention for today, and in the future, such as protecting source water, financial stability, enhanced communication, and increased awareness.

Keywords

Small drinking water systems, water safety, source water, safe drinking water, Ontario's water systems, source protection, water system owners

Co-Authorship Statement

This thesis is comprised of a collection of three manuscripts, all of which have been or will be submitted to peer-reviewed journals for publication.

The currently published research manuscripts are as follows:

Chapter 2:

Sekercioglu, M.F., White, J., Shrubsole, D., & Baxter, J. (2018). Relationship between operational characteristics of small non-community drinking water systems and adverse water quality incidents in Southern Ontario, Canada. *Applied Ecology and Environmental Research*, 16(1), 777-789.

Chapter 3:

Sekercioglu, M.F., White, J., Shrubsole, D., & Baxter, J. (2018). Towards a Sustainable Small Non-Community Drinking Water System in Ontario: Owners' Risk Awareness and Perceptions to Water Safety. *Journal of Sustainable Development, 11(3), 71-84.*

All three manuscripts have been co-authored with my thesis supervisors. As the first author, I was primarily responsible for the data collection and analysis, with each chapter being co-written for publication.

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CHAPTER 1

INTRODUCTION AND REVIEW OF THE LITERATURE

Introduction

Providing safe drinking water to its citizens is one of the key characteristics of developed nations. Although waterborne disease outbreaks associated with drinking water systems do not frequently occur in Canada, when they do occur, the impact is significant. Previous research has shown that the small non-community drinking water system (SDWS) users are at increased risk of becoming ill compared to the community drinking water system users (Maier et al., 2014; Moffatt & Struck, 2011; Murphy et al., 2016a; Murphy et al., 2016b; Pons et al., 2014; Wedgworth et al., 2014).

Public awareness surrounding access to safe drinking water has increased considerably since the Walkerton tragedy[1], yet risk perception and awareness among Ontario's SDWS owners are understudied. Furthermore, a key initiative to safeguard drinking water sources in Ontario, the planning for source water protection, does not include SDWSs. The current regulatory framework for community drinking water system and SDWSs is fragmented with varying levels of stringency.

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[1] The Walkerton tragedy, an outbreak of gastroenteritis, caused seven deaths and affected over 2300 people as a result of contaminated water consumption from the community drinking water systems in the town of Walkerton, Ontario (Hrudey et al., 2003)

Even though, this research discusses several aspects of drinking water safety, the goal of this research is threefold: a) to examine contributing factors to adverse water quality incidents in SDWSs, b) to investigate risk awareness and perceptions of the SDWS owners in the provision of safe drinking water and protecting their water sources, c) to develop a sustainable operation model for Ontario's SDWSs.

The study region is Wellington-Dufferin-Guelph, situated in the heart of southern Ontario with 229 SDWSs (WDGPH, 2016). Public health services in the region is offered by Wellington-Dufferin-Guelph Public Health (Appendix A).

The thesis will be a manuscript based dissertation with three publishable articles.

Purpose and objectives of the thesis

The overall objective of this thesis is to examine the present and future challenges of Ontario's SDWSs in the provision of safe drinking water by assessing the effectiveness of the current policy and legal framework, and propose changes to this existing approach. We use mixed methods approach by analyzing quantitative and qualitative data in different phases of the research. Chapters two, three and four represent publishable articles. The chapter one, introduction and review of the literature, and chapter five, summary discussion and conclusions, provide a framework and integrate the work. Specifically, this dissertation goes through the following steps:

Chapter 1: Reviews the relevant literature

Chapter 2: Examines the operational characteristics of Ontario's SDWSs and their relationships with adverse water quality incidents. The assessment is developed using quantitative data collected from the regulatory agency.

Chapter 3: Describes and explains the risk awareness and perceptions of drinking water system owners. Examining their approaches and difficulties in providing safe drinking water to their clients and protecting their sources of water from contamination, this chapter reports the findings from our in-depth interviews.

Chapter 4: Develops a sustainable operation model for Ontario's SDWSs and provides recommendations to the regulatory agency, Ministry of Health and Long-Term Care, to improve the current SDWS policy and legal framework. In addition to literature and policy review, qualitative and quantitative data collected from the regulatory agency and in-depth interviews were used to develop the revised operation model.

Chapter 5: Summarizes the research findings and outlines the limitations of the work and discusses future research that stems from this work.

Declaration of the Researcher's Position

In the spirit of self-reflection, it is important to provide some relevant and important details about the researcher and his perspective, going into the field: The researcher has been working in public health for 14 years. During this time, the researcher worked in the Safe Water Program initially as a Public Health Inspector and later as a Program Manager. Since the Ministry of Health and Long-Term Care assumed the regulator role in 2008, his job assignments enabled the researcher to gain experience in the SDWS program. With his current role as the Environmental Health Manager at the Middlesex-

London Health Unit, the researcher oversees the SDWS program in the Middlesex-London region. The researcher selected the study region as Wellington-Dufferin-Guelph over Middlesex-London to eliminate conflict of interest and potential bias with individual water operators.

The researcher's professional role of being the manager of the SDWS program in Middlesex-London Health Unit may have brought potential subjectivity. It is important for qualitative researchers to understand their background which might affect several parts of the study. The researcher applied reflexivity throughout the study by documenting his assumptions at the beginning of the study, as summarized below, and by applying determined strategies to exclude them during the data collection period as well as data analysis and interpretation (Creswell & Miller, 2000).

The following is a direct quote from the researcher where his personal experience to the research question is applied: *"Based on my employment experience, there is a significant disconnect between public health professionals and the owners of SDWSs as the Small Drinking Water System Regulation does not require Public Health Inspectors to visit these systems with enough frequency to develop relationships. Assessments are completed either every two or four years based on their risk level. I also believed that for many owners, the safety of their drinking water source might not be the number one priority on their agenda as they have to address several other aspects of their business operations on a day-to-day basis.*

The overall research process, from data collection to analysis has been quite an eye-opener experience that has changed my initial perspectives. The owners of SDWSs were *very sensitive to ensuring the provision of safe drinking water but openly discussed their challenges to comply with the current regulatory framework. I have identified several areas for improvement and consider that there are sufficient resources and potential to enhance the SDWS program in the near future.”*

Review of the Literature

1.1 Drinking water safety

Water acts as a carrier for several disease-causing organisms and substances therefore, ensuring that water sources are safe by protecting them from pollutants is integral for the continued health of people (Coleman et al., 2013). Drinking water is considered safe when it does not contain disease causing organisms, unsafe concentrations of toxic chemicals or radioactive substances (MOE, 2006). According to the World Health Organization (2008), “safe drinking water does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages” (p. 1). Drinking Water Advisory, considerable evidence to water safety risk, has varying criteria in different parts of the world which poses a challenge to understand contributing factors and emerging challenges in the provision of safe drinking water globally (Murphy et al., 2016c). Waterborne diseases and illnesses are ongoing concerns around the world both in developed and developing countries. There are 1.1 billion people across the world with no access to safe drinking water which results in 1.7 million deaths per year with a majority of them being children in developing countries (Ashbolt, 2004; S. Hrudey & E. Hrudey, 2007).

In North America, there have been several waterborne disease outbreaks traced back to drinking water contamination in the last few decades. The presence of *Cryptosporidium* in municipal water supplies caused outbreaks in Cranbrook and Kelowna, British Colombia in 1996 with thousands of cases of gastrointestinal illness (CCME, 2004). In 1993, Milwaukee, Wisconsin experienced the largest known *Cryptosporidium* community drinking water outbreak which affected over 400,000 people and resulted in 58 deaths (DeSilva et al., 2016). In New Hampshire, the giardiasis outbreak in 2007 caused by contaminated community drinking water affected 31 people and is considered the recent history's largest waterborne outbreak in the region (Daly et al., 2010). In 2013, the *Cryptosporidium* outbreak from municipal water system in Baker City, Oregon affected 2780 people (DeSilva et al., 2016). Most recently, chemical and microbiological contamination of source water in the Flint, Michigan affected 99,000 people between April 2014 and October 2015 (Kennedy et al., 2016; State of Michigan, 2016).

Hrudey and Hrudey (2004) examined seventy drinking water related outbreaks in fourteen countries over a span of thirty years and concluded that a comprehensive approach where the water safety is ensured from source to tap is integral to prevent similar outbreaks in the future. Communication among the agencies involved in water management is also considered an important parameter to prevent the occurrence of waterborne outbreaks (Daly et al., 2010). In 2010, the occurrence of largest known *Cryptosporidium* outbreak in Europe, sickened 27,000 people in Ostersund, Sweden, pointed out the importance of interagency communication and application of the Multiple-Barrier Approach in drinking water systems (Widerström et al., 2014).

The Walkerton tragedy, an outbreak of gastroenteritis that caused seven deaths and affecting over 2300 people as a result of contaminated water consumption from a community drinking water system in the town of Walkerton in 2000 (Hrudey et al., 2003). The Walkerton tragedy has been a major turning point in revamping Canada's drinking water management. Less than a year after the Walkerton tragedy, North Battleford's *Cryptosporidium* outbreak affected close to 7,000 residents (Hrudey, 2011). Although no one was sick, the community water supply tests showed the presence of *Escherichia coli (E. coli)* bacteria in Ontario's Kashechewan First Nations community drinking water system in 2005, prompting a massive evacuation of the community and drew attention to their ongoing water crisis for several years (Hrudey, 2011).

The aforementioned waterborne disease outbreaks and estimation of 90,000 illnesses and 90 deaths related to contaminated drinking water in Canada every year (Government of Canada, 2017) demonstrate the necessity to ensure the provision of safe drinking water regardless of the system size and location. Pons et al. (2015) report that unsafe drinking water from SDWSs accounts for close to 50% of all waterborne disease outbreaks in the United States and Canada. The users of small drinking water systems and private household wells are at increased exposure to waterborne diseases (Bridge et al., 2010; Moffatt & Struck, 2011). According to Shrubsole et al. (2017), industrial discharges, inadequately treated sewage, and fertilizer runoff affect Canada's water quality. As such, water sources for Ontario's SDWSs, most often located in rural areas, are likely prone to contamination from these effects.

Waterborne diseases continue to occur in rural parts of Canada where most SDWSs are located (Maier et al., 2014; Murphy et al., 2016a). The Public Health Agency of Canada estimates over twenty million cases of *Acute Gastrointestinal Illness*[2] annually and there is evidence that small water systems may be at increased risk of acquiring *Acute Gastrointestinal Illness* (Murphy at al., 2016b). Pons et al. (2015) draw attention to the challenge to identify waterborne disease outbreaks in SDWSs, arguing that either small number of people or transient populations such as travelers, use these systems. Furthermore, many waterborne disease outbreaks in SDWSs cannot be documented as the national surveillance system in Canada is limited to enteric illnesses (Pons et al., 2015).

The effects of climate change and protecting groundwater sources from contamination have become emerging challenges. According to Schuster et al. (2005), water treatment failure and extreme weather events that affect water sources are the most common reasons of waterborne outbreaks in Canada between 1974 and 2001. A systematic review (Cann et al., 2013) examined eighty-seven waterborne outbreaks related to extreme weather events between 1910 and 2010, and concluded that the frequency of these outbreaks would increase with potential future effects of global climate change.

Drinking water systems play an integral role to protect public health by ensuring their users have access to safe drinking water. Justice O'Connor (2002a) in the Walkerton Inquiry Report identifies the goal of drinking water systems as "delivering water with a

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[2] "Acute gastrointestinal illness (AGI) is a global problem with mortality and morbidity affecting both developed and developing countries. It is caused by a variety of agents, and is frequently transmitted by food or water. Symptoms typically include diarrhea or vomiting, with additional secondary symptoms which frequently include fever, cramps, nausea and headache" (Thomas et al. 2008, p.8)

level of risk that is so negligible that a reasonable and informed person would feel safe drinking it" (p. 74). The water safety related incidents in Canada and elsewhere have not facilitated institution of a framework with a uniform approach to define and apply the same level of water quality standards across Canada. Although Health Canada (2012) establishes the water quality parameters at the federal level, provinces and territories may choose to create their own water quality standards. Ontario developed comprehensive regulatory documents, such as 'the Ontario Drinking Water Standards, Objectives, and Guidelines' where water system owners and operators are held legally liable. The Ministry of the Environment defines 'safe drinking water' as: "Water intended for human consumption shall not contain disease-causing organisms or unsafe concentrations of toxic chemicals or radioactive substances" (MOE, 2006, p.1). Under Ontario's current regulatory framework, the three main characteristics utilized to assess the safety of drinking water are microbiological, chemical and radiological, and aesthetic.

Microbiological characteristics of water such as the presence of bacteria, protozoa and viruses are important to monitor as they have been the most common cause of waterborne diseases (Pons, 2015). The guidelines that relate to these microorganisms are stringent because of their risk to cause adverse health effects. The consumption of contaminated water with human or animal feces is considered the greatest risk for getting ill from drinking water (Cabral, 2010).

*Chemical and radiological characteristic*s of water should be monitored closely as these substances may pose a health hazard at certain levels. They can either be present in water naturally or as a result of contamination. For example, a chemical, *Nitrate*, may be found in water sources which potentially causes serious health concerns (Government of Canada, 2008).

Aesthetic Characteristics represent the quality of water as it relates to the user acceptance such as colour, taste and odour. The Ministry of the Environment (2007) requires drinking water to be "aesthetically acceptable with taste, odour, turbidity and colour are parameters that, when controlled, result in water which is clear, colourless and without objectionable or unpleasant taste or odour" (p.1).

It is pertinent to note that the public tend to make decisions about the quality and safety of drinking water based on aesthetic qualities which can potentially be a misleading perception. One of the leading causes of the Walkerton tragedy was perceptions of water system operators and town residents regarding the chlorine smell in municipal water (O'Connor, 2002b). Risk perception of drinking water quality was mainly developed based on the water's aesthetic parameters for the Walkerton residents (Parr, 2005). In addition to technical training for the owners and operators of drinking water systems, there is a significant need to establish communication framework for educating the public regarding drinking water safety parameters.

1.2 Multiple-Barrier Approach

The Multiple-Barrier Approach is an integrative risk management framework to water safety. This research reviews the application of the Multiple-Barrier Approach principles in drinking water systems and proposes a sustainable operation model for SDWSs underpinned by these principles. The Multiple-Barrier Approach is a combination of procedures, processes, and tools to prevent or reduce the contamination of drinking water from source to the end user (CCME, 2004). It has two common forms of application:

- Comprehensive approach as described by the Canadian Council of Ministers of the Environment
- Integrated approach with risk assessment focus as introduced by the Walkerton Inquiry Report.

The Canadian Council of Ministers of the Environment's (CCME, 2004) document, "*From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water"* explains the application of the Multiple-Barrier Approach for all stakeholders in the water management sector in Canada. The Multiple-Barrier Approach is defined as "an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health" (CCME, 2004, p.15). The Figure 1.1 summarizes the comprehensive application of the Multiple-Barrier Approach where the water system is examined in three main sections:

- Protection of the water source
- Water treatment processes
- Distribution system

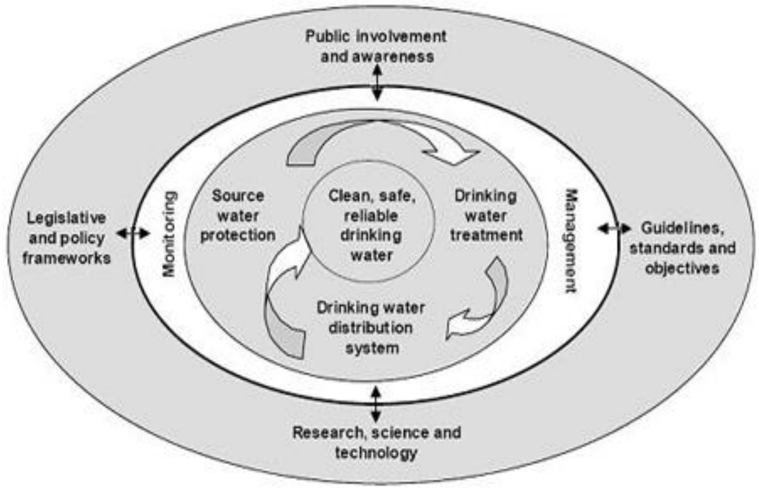

Figure 1.1: Components of the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach (CCME, 2004, p.16)

In addition, the Multiple-Barrier Approach uses tools and procedures to complement the management and monitoring of the water system, such as public involvement and awareness; legislative and policy frameworks; guidelines; standards and objectives; and research, science and technology (CCME, 2004).

The application of Multiple-Barrier Approach in a collaborative way requires a considerable preparation and commitment from all stakeholders in the provision of safe drinking water. Components of the model should work in harmony to complement each other. As the model demonstrates, water safety issues are often multi-dimensional and require interventions from different stakeholders. Research, science and technology along with public involvement form the foundation of the policy and legislative framework development process. The systems' water source, treatment and distribution processes are regulated with the overarching policies and legislative arrangements. The Multiple-Barrier Approach recognizes the system as a whole and establishes criteria to ensure sufficient protective mechanisms are in place. The Multiple-Barrier Approach does not only consider the present conditions of water operation but also recognizes the potential threats to the system in the future (Plummer et al., 2010); therefore, it can be effectively used by the regulators for developing policies and establishing standards (Dyck et al., 2015).

The second common form of application defined by the Walkerton Inquiry Report emphasizes the importance of establishing the Multiple-Barrier Approach with risk assessment focus and defines it as “putting in place a series of measures, each independently acting as a barrier to passing water-borne contaminants through the system to consumers, achieves a greater overall level of protection than does relying exclusively on a single barrier” (O’Connor, 2002b, p.5). The five barriers used in the Multiple-Barrier Approach are source protection, treatment, distribution system, monitoring program and response to adverse conditions (O’ Connor, 2002b). Table 1.1 summarizes risk management approaches and barriers for potential hazards in drinking water. Although each barrier offers a level of protection, there might still be failures. Hence, the barriers should be independent for better overall protection.

Table 1.1: An Example of the Multiple-Barrier Approach Hazard Barrier Typical Risk Management Approach (O'Connor, 2002b, p.74)

Hazards	***Barrier***	***Typical Risk Management Approach***
Pathogens, Chemical contaminants, Radionuclides	Source protection	Watershed protection plan, Upgraded sewage treatment, Choice of water source

Pathogens, Disinfection by-products, Chemical contaminants	Treatment	Water quality standards Chemically assisted filtration Disinfection
Infiltration, Pathogen regrowth	Distribution	Chlorine residual, System Pressure, Capital maintenance plan
Undetected system failures	Monitoring	Automatic monitors Alarms and shut-offs Logbooks, trend analyses
Failure to act promptly on system failure Failure to communicate promptly with health authorities and the public	Response	Emergency response plans, Boil water advisories (orders)

The application of Multiple-Barrier Approach minimizes the risk of receiving unsafe drinking water and has become the standard to drinking water safety in Canada (O'Connor, 2002b; Plummer et al., 2010). Whilst the term 'Multiple-Barrier Approach' is used commonly in Canadian water management literature, the concept has been recognized widely internationally. The World Health Organization's framework to ensure the provision of safe drinking water by utilizing 'water safety plans' stems from the Multiple-Barrier Approach principles (WHO, 2012). Similarly, Australia and New Zealand applied the Multiple-Barrier Approach principles when they established step-by-step process to identify and eliminate water safety hazards (NHMRC & NRMMC, 2011; MOH, 2017).

The Multiple-Barrier Approach provides a multidisciplinary and collaborative approach that recognizes the system as a whole and establishes criteria to ensure sufficient protective mechanisms are in place to address complex issues encountered in water system operation. Drinking water sources vary from surface water to groundwater and require customized treatment processes to ensure the safety level is achieved before it reaches the users. The Multiple-Barrier Approach considers source water protection the first line of defense as keeping water sources clean reduces the health risks and reliance on treatment processes (Walters et al., 2012).

1.3 Source Water Protection

Source water protection is the most critical step of the Multiple-Barrier Approach as it addresses water quality through understanding the complex, multidimensional factors that affect water at the source. Justice O'Connor (2002b) points out that "…in a multiple-barrier system for providing safe drinking water, the selection and protection of reliable, high-quality drinking water sources is the first barrier" (p.89).

Establishing a source water protection strategy is an economic necessity as treating polluted water has been proven to be much more expensive than keeping water clean at the source (Patrick, 2008). Several case studies conclude that the cost of treating contaminated water is 30 to 40 times higher than protecting its source from contamination (Simpson & de Loë, 2014). Institutional arrangements for source water protection in Canada vary because there is no federal legislation, and provinces and territories use different strategies for ensuring water sources are protected. This research explores the possible consequences of the decision of not including Ontario's SDWSs in source water planning.

Source water protection became a priority for Ontario after the Walkerton tragedy. The Walkerton Inquiry Report made seventeen recommendations to establish the province's source water protection framework (O'Connor, 2002b). The provincial government acted on these recommendations by making laws which include the *Clean Water Act* and creating new institutions such as source water protection committees.

There is a common misconception about considering groundwater a safe source. Groundwater has several potential contamination sources which can be evaluated by an environmental assessment that includes but may not be limited to, type and location of the well, agricultural activities nearby, and surface runoff after a rain. Pons (2015) reports that groundwater is the primary source for 82% of SDWSs in Ontario. The result of not protecting our drinking water sources can be devastating as demonstrated by many waterborne disease outbreaks caused by unsafe drinking water in Canada and elsewhere.

International source water protection strategies: The World Health Organization (2012) promotes the use of a 'water safety plan', which has a specific section for source water management. The European Union developed a policy document, the Water Framework Directive (2000), which has been facilitating the creation of source water policies in the European Union member countries (Ivey et al. 2006).

The United States has been working to establish processes for source water protection for a few decades by maintaining two national programs: Source Water Protection and Wellhead Protection (OEPA, 2015). Although both programs have the same goal, their scopes and times of origin are different: The Wellhead Protection program was created in 1986 by the amendments to the *Safe Drinking Water Act* and focuses exclusively on groundwater systems with a particular focus on large community systems (OEPA, 2015). In 1996, the United States Congress recognized that the program was faltering due to lack of funding, therefore, initiated the creation of Source Water Protection program, which extends the protection net to all ground and surface water systems including non-community systems (OEPA, 2015). Today, in some states Wellhead Protection and Source Water Protection programs co-exist because of some legal and jurisdiction issues, although many states chose to amalgamate these programs (OEPA, 2015).

On the other hand, the Australian Drinking Water Guidelines focuses on ensuring the source water planning is in place for all drinking water systems (NHMRC, & NRMMC, 2011). New Zealand adapted the World Health Organization's approach and established a comprehensive source water protection planning for all water systems (MOH, 2017). Canada's source water protection strategy may be a viable model to other countries which have not taken proactive steps, as source water protection continues to receive considerable attention to ensure safe drinking water (Plummer at al., 2010).

Regulatory framework for Ontario's source water protection: The *Clean Water Act* was enacted in 2006 in response to the Walkerton Inquiry Report recommendations with the chronology of events presented in Table 1.2. The *Clean Water Act* mandated the creation of nineteen source water protection regions across the province (Appendix B) and a source protection committee in each region to prepare a 'source protection plan' (OAGO, 2014). The goal of the *Clean Water Act* is to ensure drinking water sources are protected adequately and communities use a science–based approach to protect their water supplies (MOE, 2008)

Table 1.2: Chronology of Key Events Leading to the Proclamation of the Clean Water Act (OAGO, 2014, p. 409)

May 2000: The drinking water system in the Bruce County town of Walkerton became contaminated with deadly bacteria.
June 2000: The Walkerton Commission of Inquiry was set up to examine the contamination of the water supply in Walkerton and to look into the future safety of the water supply in Ontario. Justice Dennis O'Connor was appointed Commissioner
January 2002: The Walkerton Commission released Part 1 of its report, which detailed the events in Walkerton and the failures that led to the contamination
May 2002: The Walkerton Commission released Part 2 of its report, in which it made many recommendations for improving the quality of water and public health in Ontario, including recommendations on source water protection.
June 2002: The Nutrient Management Act was proclaimed. This Act was not a direct response to the Walkerton tragedy
October 2006: The Clean Water Act was enacted in response to Justice O'Connor's recommendations on source water protection

Another legislative tool that plays a vital role in source water protection is the *Nutrient Management Act*. Despite the *Nutrient Management Act* was not an outcome of the Walkerton Inquiry Report recommendations; it complements Ontario's source water protection strategy (OAGO, 2014). The *Nutrient Management Act*'s goal is to manage nutrients such as fertilizers and manure in ways to ensure sustainable development is maintained without contaminating the environment and water sources (OAGO, 2014).

Most recently, the *Great Lakes Protection Act* was enacted in October 2015 to support the efforts in increasing the safety net for source water protection by addressing the potential adverse effects of climate change, reducing harmful algal blooms, protecting wetlands, and tackling other complex environmental issues in the Great Lakes basin (Government of Ontario, 2016). The *Great Lakes Protection Act* has been considered a significant milestone to protect and improve water quality in Great Lakes; however, the implementation outcomes are yet to be seen. The source protection plans for Ontario's 19 source protection regions and areas have been implemented since 2016.

Ontario's source protection regions and areas: The *Clean Water Act* establishes ten source protection regions, and nine stand-alone source protection areas, which form nineteen Source Protection Committees in the province as shown in Appendix B. Based on the Walkerton Inquiry Report recommendation, source protection areas have been created on watershed basis, as opposed to municipal boundaries (O'Connor, 2002b). The watershed boundaries are based on Conservation Authority boundaries that already exist under the *Conservation Authorities Act;* two new source protection areas, Northern Bruce Peninsula Source Protection Area and Severn Sound Source Protection Area, have been created as no conservation authority previously existed (Government of Ontario, 2015).

Source water protection for Ontario's small drinking water systems: The exclusion of SDWSs from source water protection plans placed the SDWSs owners and operators as well as the public who drink water from these systems at increased risk of waterborne diseases. The Office of the Auditor General of Ontario (2014) criticizes the lack of inclusiveness in source water planning within the context of private and abandoned water wells. Although SDWSs were not specifically mentioned in the Auditor General of Ontario's report, SDWSs mainly use water wells as their sources. After investigating the reasons for drinking water related outbreaks in Canada between 1974 and 2001, Schuster et al. (2005) conclude that the legal framework for water safety should include measures to protect the water source.

Pons (2015) reports that groundwater from wells is the primary source for 82% of SDWSs in Ontario. There is a common misconception about groundwater being a safer source of drinking water relative to surface water. Groundwater has several potential contamination sources such as agricultural activities nearby and surface runoff after a heavy rain. According to a recent study (Wallender et al., 2014), untreated groundwater continues to be a significant public health issue as it has been the cause of over 30% of waterborne outbreaks in the United States between 1971 and 2008. Kreutzwiser et al. (2010) examine the responsibilities of both governments and water well owners to ensure safe drinking water and conclude that water well owners should maintain the following practices to protect their water sources (p.7-8):

- Maintain septic systems;
- Limit fuel storage or maintenance of fuel storage devices;
- Limit use or proper disposal of hazardous household substances;
- Limit pesticide and fertilizer use and providing proper storage for chemicals;
- Store and use contaminants at a safe proximity from well;
- Maintain and trim shallow-rooted vegetation around the wellhead;
- Ensure drainage away from the wellhead;
- Maintain a 50-100 feet contaminant-free buffer zone around well.

In addition, several *Cryptosporidium* outbreaks from community drinking water systems (CCME, 2004; DeSilva et al., 2016; Hrudey, 2011; Widerström et al., 2014) demonstrate the importance of protecting surface water sources as well. Without a source water protection plan mandate, the responsibility for assessing the risk and taking action to prevent potential hazards to a SDWS water source rests with the system owner. There has been no previous research to investigate the level of awareness and perceived risk among the SDWS owners, and there is currently no system in place to communicate the importance of keeping SDWSs' water sources safe and secure from contamination. This research investigates the possible consequences of the decision of not including SDWSs in source water planning and develops a sustainable operation model for these systems by recognizing the importance of source water protection planning for SDWSs

1.4 Drinking Water Management

Drinking management strategies around the world have been shifting over the years from top-down and reactive practices to more collaborative and proactive approaches. The end point testing to ensure the water quality meets the standards has been replaced with comprehensive assessment of the system and identification of potential hazards at each stage of the process (Jetoo et al., 2015). The current challenge, specifically within the context of SDWSs, is recognizing the water safety risks and developing strategies to mitigate these risks. Risk management approaches vary significantly not only between countries but in the same country as well, such as in Sweden (Noren et al., 2016). Institutional arrangements for water management continues to be a challenge in many developed countries. As in the Iceland example, when the provision of safe water mandate is shared by four different governmental organizations, it is almost impossible to eliminate management gaps and inefficiencies and conflicts (Gunnarsdottir et al., 2015). In the United States, the water management is also a shared responsibility between federal and state and local governments (Dreelin et al., 2014). Wedgworth et al. (2014) note that although 80% percent of water systems in the United States are defined as small, not enough research is conducted regarding the water safety risks of these systems. Small drinking water systems in Finland face similar challenges with inconsistent risk management approach, inadequate source water protection strategy and limited financial resources (Pitkänen et al., 2011).

Similar to several other countries around the world, Canada's drinking water management is also decentralized and fragmented where different levels of governments take responsibilities (Bereskie et al., 2017; Hill et al., 2007). Canada is considered a freshwater-rich country in the world, yet, rapid population growth in some areas and climate change are among several reasons to ensure that managing and controlling drinking water resources should be done safely, effectively and efficiently. For example, the Federal Government provides guidance on drinking water quality parameters (Health Canada, 2017) but does not mandate the management of drinking water systems. Furthermore, the water quality standards developed by the Federal Government is not enforceable and, provinces and territories which regulate the public water systems have the option to adopt them or not (Bereskie et al., 2017).

The Walkerton tragedy and Justice O'Connor's report on this tragedy, the Walkerton Inquiry Report, facilitated the process for other provinces and territories to establish a new water governance framework with revised policy and regulations in water management (Patrick, 2009). Although Canada has come a long way with significant improvements in water management in the provision of safe drinking water, the multiple agency responsibilities in water management regulatory framework continue to cause discrepancies. One of the objectives of this dissertation is to assess the effectiveness of the current regulatory framework to provide safe drinking water in Ontario's SDWSs.

1.4.1 Drinking Water Management in Ontario

Ontario has a long history in water management and has taken a lead role to recognize the necessity of collaborative approaches to water management. The province's drinking water management has evolved over many years beginning with the first water system in 1837, a privately-owned piped system, using Lake Ontario's water with no treatment (OSWCA, 2001). The Ontario Water Resources Commission was created in 1956, first of its kind in the world, to address the need for collaborative approaches to water management (OSWCA, 2001). The Ontario Water Resources Commission's mandate was to oversee Ontario's water resources, including water treatment and supply in addition to finance and building water and sewage systems (OSWCA, 2001). In the early 1970s, the amalgamation of two organizations, Ontario Water Resources Commission with the Air and Waste Management and Pesticides Control Sections, resulted in the formation of the Ministry of the Environment (OSWCA, 2001).

The Ministry of the Environment was the only regulatory agency for the province's water systems until 2008 when the Ministry of Health and Long-Term Care took over the regulatory responsibility of SDWSs. Today, the Ministry of the Environment and Climate

Change[3] and the Ministry of Health and Long-term Care share the responsibility to oversee drinking water systems in the province. This research focuses on water systems under the responsibility of the Ministry of Health and Long-Term Care, SDWSs, mandated by the *Health Protection and Promotion Act.*

The Ministry of the Environment and Climate Change regulates community water systems where local municipalities are often designated as drinking water system owners with the mandate to supply safe drinking water to their residents. The three main legal documents mandate the quality of drinking water in Ontario's community water systems: *Safe Drinking Water Act, Ontario Regulation 169* (water quality standards), and *Ontario Regulation 170* (drinking water systems) (Drinking Water Ontario, 2015).

Approximately 20% of Ontario's population use non-community drinking water to access drinking water (Pons et al., 2014). The Ministry of Health and Long-term Care regulates SDWSs and offers guidance to private well owners (Pons et al., 2014). There is no universal definition of a SDWS due to extensive differences based on the assessment of systems' variables (NCCPH, 2015). This research focuses on small non-community drinking water systems that fit the definition of a SDWS under *Ontario Regulation 319*, (*Small Drinking Water Systems Regulation).*

SDWSs, located across the province, are defined as systems that make drinking water available to the public and are not connected to a community drinking water system (MOHLTC, 2015). There are five categories of SDWSs:

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[3] The government added "Climate Change" to the name of the Ministry of the Environment in June 2014.

> “1) Large municipal non-residential drinking water systems that serve such facilities as municipally owned airports and industrial parks, and large sports and recreation facilities. 2) Small municipal non-residential drinking water systems that serve such facilities as small community centres, libraries, and sports and recreation facilities. 3) Non-municipal seasonal residential drinking water systems that serve such facilities as private cottages on communal drinking water systems. 4) Large non-municipal non-residential drinking water systems that serve such facilities as large motels and resorts. 5) Small non-municipal non-residential drinking water systems that serve such facilities as motels, restaurants, gas stations, churches, and bed and breakfasts” (MOHLTC, 2015).

SDWSs are regulated by the Ministry of Health and Long-Term Care under *Ontario Regulation 319* and the owners of these systems are legally responsible for the safe operations of their systems by complying with the requirements set out by public health units based on a risk assessment at each system (MOHLTC, 2015).

Pons et al. (2014) point out that Ontario’s 9000 SDWSs, mostly located in rural and remote areas, are facing significant challenges to ensure the provision of safe drinking water. Although it is estimated that 20% of Ontario’s population use these systems (Pons et al., 2015), with the consideration of transient populations, the percentage of users is significantly higher than initially estimated, which iterates the importance of ensuring safe drinking water in these systems. Furthermore, susceptible and vulnerable population groups such as elderly and young children are among transient populations visiting SDWSs regularly. Ontario has undergone comprehensive planning to establish stringent criteria for source water protection but unfortunately decided to leave SDWSs out of this process.

Although there are internationally recognized common approaches for water management strategies, it is not feasible to apply ‘one-size-fits-all–approach’ to establish an efficient and effective water management model for Ontario’s SDWSs. Instead, well-designed research is needed to examine the current issues and future challenges of SDWSs before creating a sustainable operation model. This research aims at closing this notable gap in the literature by investigating the current challenges and providing recommendations to enhance the existing SDWS program.

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Chapter 2

Manuscript 1

Relationship Between Operational Characteristics of Small Non-Community Drinking Water Systems and Adverse Water Quality Incidents in Southern Ontario, Canada

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Abstract

Ensuring that water sources are safe by protecting them from disease causing organisms is integral for the continued health of people as drinking contaminated water leads to waterborne diseases which can be life-threatening. The purpose of this study is to examine small non-community drinking water systems' (SDWSs) operational characteristics and their relationships with adverse water quality incidents (AWQIs) which is defined as presence of total coliforms and/or *Escherichia coli.*

We explore the relationship between operational characteristics of SDWSs and the occurrence of adverse water quality outcomes using de-identified data provided by Wellington-Dufferin-Guelph Public Health, Ontario. We examine the associations between water system operational characteristics and the adverse water quality outcome using logistic regression models.

Our analyses indicate that operator training was associated with a lower risk for AWQI. None of the other predictors show statistically significant associations with AWQI: treatment method, water source, operating period, and sampling frequency.

Our research finds that the presence of operator training, an upstream behavioural determinant, is related to the incidence of AWQIs in SDWSs in Ontario, Canada. The high percentage of SDWSs with no treatment and lack of testing for chemicals are potential areas of concern for ensuring the provision of safe drinking water from these systems.

Keywords:

Waterborne diseases, small drinking water systems, safety, total coliforms, *Escherichia coli*, operator training

Introduction

Behavioral influences on multi-user, non-household, public water systems have been understudied in the developed world. The drinking water system, which includes water source, treatment, distribution, and discharge requires the use of technology and well-trained people to operate it. Several disease-causing organisms and substances are transmitted by water. Ensuring that water sources are of good quality and water treatment is done effectively are fundamental to protect the public's health (Coleman et al., 2013). In simple terms, drinking water is considered safe when it does not contain pathogens or unsafe concentrations of toxic chemicals or radioactive substances (MOE, 2006). Although approximately 15% of Canadians use Small Non-Community Drinking Water Systems (SDWSs), more than 50% of the waterborne outbreaks in Canada are associated with these systems (Pons et al., 2015). This study aims to examine the SDWS operational characteristics and their relationships with Adverse Water Quality Incidents (AWQIs).

There are several environmental determinants of water source contamination. Water quality degrades during extreme weather events such as drought and heavy rainfall, which consequently increases of the risk for adverse health outcomes in affected communities (Delpla et al., 2009). According to O'Dwyer et al. (2014), aquifer type and rainfall amount impact the vulnerability of groundwater sources. Collins et al. (2005) and Park et al. (2014) also identify a correlation between the increased rainfall amount and the presence of *Escherichia coli (*Migula, *1895)* in water sources (surface and/or groundwater). Another significant cause of groundwater contamination with total coliform and *E. coli* is industrial activities such as mining operations (Armah, 2014), livestock and other non-point sources. Total coliform bacteria include several soil bacteria and are not likely to cause illness, but their presence indicates that the water system may be prone to contamination; whilst E. coli is commonly found in the intestines of mammals, including humans (Armah, 2014). The genera that belongs to coliforms include several organisms including Citrobacter, Enterobacter, Klebsiella (Harwood et al., 1999).

Rizak et al. (2003) note that water source contamination should be addressed using a holistic approach. In addition to environmental effects, social and behavioral characteristics play significant roles in water contamination that cause waterborne human disease outbreaks (Heymann, 2005). Social and behavioral factors underpinned by complacency contributed to the Walkerton tragedy in Ontario, Canada in May 2000 when Escherichia coli O157:H7 entered the water system and led to the deaths of seven people and made over 2300 people ill (Huck et al., 2003). Hrudey and Hrudey (2007) analyzed the cause of 74 recent waterborne outbreaks across the world and identified the major contributing factors to these incidents as insufficient source water knowledge, lack of disinfection, and operational deficiencies, which suggests that adequate operator training could have potentially prevented these outbreaks. Ercumen et al. (2014) examine the correlation between water distribution systems and gastrointestinal illnesses and conclude that operational deficiencies result in significant increase of gastrointestinal illnesses among users. According to Craun et al. (2001) distribution system issues not addressed by the operators are the leading cause of waterborne outbreaks. In other words, ‘the environment’ or water source is not the major contributing factor, it is human and technological deficiencies. Pons et al. (2015) notes that etiology was not identified in more than half of the reported waterborne outbreaks in Canada and the United States between 1970 and 2014, however, *Giardia intestinalis* was the most commonly identified pathogen followed by Norovirus and *Campylobacter jejuni* respectively. Enhanced reporting and identification of waterborne outbreaks would contribute to the explanation of the region's general characteristics and initiate strategies to prevent future occurrences.

Climate change will impact the operations of SDWSs significantly with reduced water quality and availability (Grover, 2012). Frequent extreme weather events will result in increased number of waterborne outbreaks (Thomas et al., 2006; Cann et al., 2013). The operators and users of SDWSs will be unjustly affected as these systems have lower adaptive capacity and higher vulnerability than Community Drinking Water Systems (CDWSs) (Cann et al., 2013). Social dimensions of SDWS operation should be examined to address current and emerging issues for the provision of safe drinking water.

The operator training in SDWSs can be considered an upstream behavioural determinant (Gehlert et al., 2008; Williams et al., 2008) within the context of environmental and societal factors. Dreibelbis et al. (2013) argue that behaviour change underpins enhanced water safety practices at individual, community and structural levels.

Most of the research and regulatory attention has been placed on industrial and municipal water systems because of their size and potential health risks in the event of inadequate treatment. SDWSs are defined as systems that make drinking water available to the public but not connected to a CDWS (MOHLTC, 2015). SDWSs potentially fall through their regulatory cracks in Ontario and elsewhere as either they are not regulated or their regulatory requirements are considerably less stringent. Relative to urban water users, these factors could contribute to a greater potential risk faced by users of SDWSs. Furthermore, the number of people experiencing waterborne illnesses from SDWSs is predicted to be significantly higher than the documented cases since there is no national waterborne illness surveillance system (Schuster et al., 2005; Wilson et al., 2009). There is a substantial need to better understand the weaknesses and strengths. With many of them facing significant challenges for the provision of safe drinking water, it is estimated that 20% of Ontarians use over 9000 SDWSs across the province (Pons et al., 2014; Pons et al., 2015). If we consider transient populations such as travelers, the number of SDWSs users is considerably higher than the initial estimates.

Pons et al. (2015) review of the waterborne disease outbreaks in SDWSs in the United States and Canada between 1970 and 2014, concludes that untreated and inadequately treated water systems have been the leading cause. Less is known about the predictors of inadequate treatment. Our study looks at a wider set of factors, so-called upstream behavioral determinants, that may be related to AWQIs. We seek to fill a knowledge gap concerning the relationship of SDWS operational characteristics and the provision of safe drinking water. The purpose of this study is to examine the SDWS operational characteristics and their relationships with AWQIs.

AWQIs are documented when a water sample test result does not meet the regulatory standards indicated for that test, or the water system may not be able to supply safe drinking water (MOHLTC, 2009). Although the Ministry of Health and Long-Term Care (MOHLTC) identifies 11 conditions for an AWQI, the detection of total coliforms and/or *E. coli* constitutes the significant majority of these incidents (MOHLTC, 2009). Locas et al. (2008) examine the groundwater quality in three Canadian provinces and conclude that sampling for total coliforms and *E. coli* is the best approach to assessing the bacteriological quality of drinking water. In Ontario, the detection of total coliforms or *E. coli* at any level in water sample constitutes an AWQI.

SDWSs are mandated by MOHLTC to meet similar water safety standards with larger municipal CDWSs. The regulatory oversight of SDWSs was transferred from the Ministry of the Environment (MOE) to local health units under MOHLTC in 2008. The Health Protection and Promotion Act (HPPA) regulates SDWSs, while the Safe Drinking Water Act provides legal oversight for CDWSs.

Five categories of SDWSs are: (1) Large municipal non-residential drinking water systems such as recreational facilities, (2) Small municipal non-residential drinking water systems, community centres and libraries, (3) Non-municipal seasonal residential drinking water systems such as privately owned cottages on communal system, (4) Large non-municipal non-residential drinking water systems such as motels, and (5) Small non-municipal non-residential drinking water systems such as restaurants and churches (MOHLTC, 2015). *Ontario Regulation 319* (Small Drinking Water Systems) established under the HPPA regulates SDWSs making the owners of these systems legally responsible for complying with the requirements (MOHLTC, 2015).

There are 36 health units in Ontario, and 29 of these health units are located in Southern Ontario. The study region is the health unit of Wellington-Dufferin-Guelph Public Health (WDGPH) which includes Wellington and Dufferin counties and the City of Guelph. This region, centrally located in Southern Ontario with 229 SDWSs (WDGPH, 2016).

We examine the operational characteristics of the 229 systems in this region with respect to experiencing AWQIs defined as an above guideline, positive test for total coliform and/or *E. coli.* The incidence of waterborne illness within the WDGPH has not been studied.

The objective of our study is to explore the relationship between characteristics of the water systems and the presence of the adverse outcome with total coliforms and/or E. coli between the years 2010 and 2015. We hypothesized that the presence or absence of AWQI can be predicted by whether the SDWS operator had received formal operator training or not after adjusting for water source (groundwater, surface water or other), treatment method (UV, chlorination, combination of the two, or none), operating period (seasonal, year round) and sampling frequency.

Methods

2.1 Data

The data for this study are a mix of outcome variables (presence of AWQIs with total coliforms and/or *E. coli* between 2010 and 2015), behavioral (operator training) and non-behavioral predictors (the location of the water system, water source, treatment method of the water system, operating period and sampling frequency) with 229 data points. As a result, the de-identified data employed in this study included information on characteristics of the water systems and operations as well as the presence of AWQIs with total coliforms and/or *E. coli.* Public Health Inspectors from Wellington-Dufferin-Guelph Public Health (WDGPH) collected these data between January 2010 and December 2015. The information includes the name, location and contact information of the water system, any positive total coliforms and/or *E. coli* water test results (AWQIs) between 2010 and 2015; water source (groundwater or surface water); treatment method (Ultraviolet [UV], Chlorinator, UV and Chlorinator, or no treatment); operation period (seasonal or year round operation); operator training as present or absent (whether the SDWS operator had received formal operator training or not); and sampling frequency per calendar year (number of samples in a calendar year) from 229 SDWSs in the region. Figure 2.1 depicts the AWQIs on the dot distribution map in Wellington-Dufferin-Guelph region.

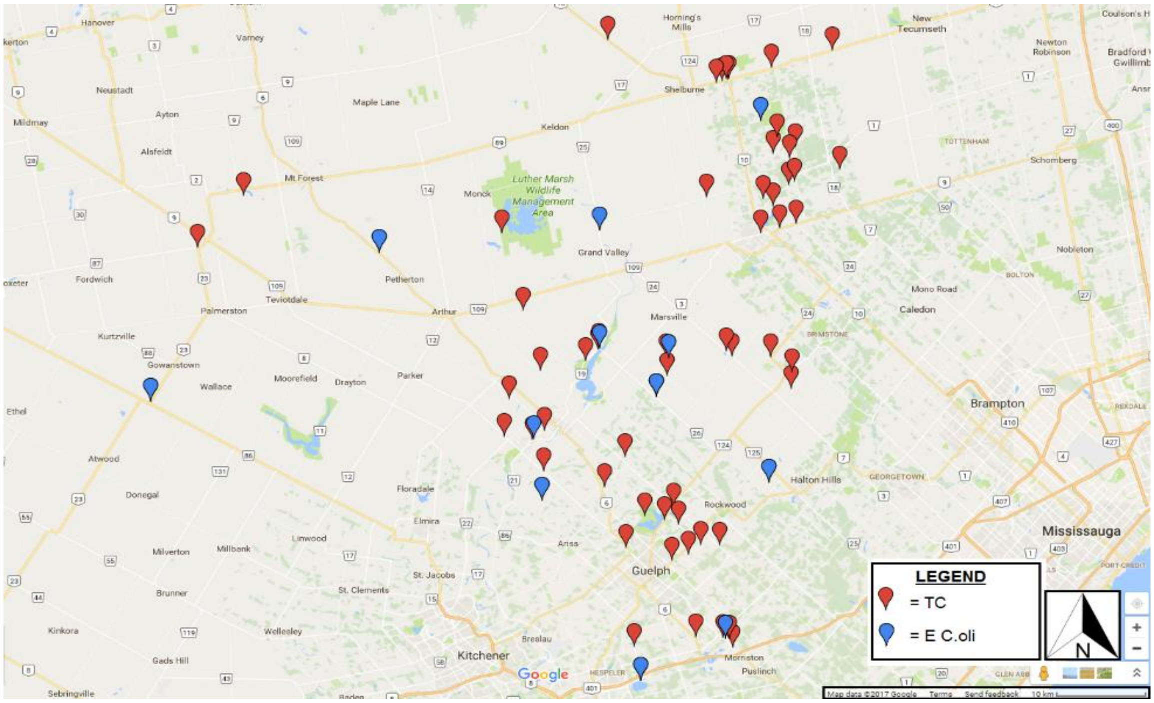

Figure 2.1 Map of Adverse Water Quality Incidents (AWQIs) in Wellington-Dufferin-Guelph Region

2.2 Analysis Plan

The overall analysis strategy compares those with and without AWQIs. We planned to detect important patterns in all individual variables as well as the relationship between predictors and AWQI in both bivariate and more rigorous regression analyses. We start with descriptive statistics and provide a mean and standard deviation for our only discrete numerical variable (count data) which was sampling frequency. Frequencies and percentages are provided for categorical variables: water source (groundwater or surface water, or other), treatment method (UV, chlorination, UV and chlorination, or none), operator training (present or absent) and operating period (seasonal or year around).

Two-sample t tests are used to compare mean differences between the groups (in those with and without an adverse water quality incident outcome) for sampling frequency with a student t-test. The Pearson chi-square test is employed to compare the distribution of categorical variables (water treatment, operating period, and operator training) in those with and without an AWQI. If the Pearson chi-square test assumption is violated (at least 80% of the expected counts are equal or greater than 5), we employ the Fisher's exact test as a substitute for the Pearson chi-square test when the expected counts are less.

We test pair-wise correlations between predictor variables using the Pearson correlation coefficient (r). We plan to remove the variable with lesser importance if *r* was greater than 0.80 for 2 predictors. The linear regression model is used to generate collinearity statistics. Tolerance and variance inflation factor (VIF) are used to test the assumption. Values less than 10 for VIF, and more than 0.1 for tolerance are considered violations. All the values are below the limits for *r* and VIF.

We also examine the associations between our outcome variable (AWQI) and all of the predictors (water source, treatment method, operating period, operator training and sampling frequency) using the logistic regression models in our inferential statistical analysis. We dichotomize the outcome into positive and negative adverse event which was defined by the MOHLTC (2009) guideline. Our logistic regression models explore the relationship between characteristics of the water systems (i.e. operator training, operating period, treatment, water source and sampling frequency) and the presence of the adverse outcome with total coliforms and/or *E. coli* in the past six years. The hypothesis of "the presence or absence of AWQI can be predicted by whether the SDWS operator had received formal operator training or not after adjusting for water source (groundwater, surface water or other), treatment method (UV, chlorination, combination of the two, or none), operating period (seasonal, year round) and sampling frequency" was tested in the study sample. We report odds ratios with 95% confidence intervals (CI).

Two-sided tests are employed with a significance level of 0.05 in our final model. All data analyses were performed using Stata (StataCorp. 2013). We also visually examine the map to verify the existence of clustering in data points.

2.3 Results

This study includes 229 SDWSs from WDGPH. Two of the systems are eliminated from the data due to missing data (the sampling frequency was missing) and 18 SDWSs are posted[4]. As a result, we include a total of 209 water systems in our final analysis. The WDGPH data show that only two systems tested for chemical parameters.

Overall, a total of 165 water systems (79%) do not have operator training whereas 44 (21%) had operator training. Table 2.1 shows the characteristics of water systems divided by the presence of AWQIs. The group with AWQIs has lower frequency of operator training as compared to the group without an AWQI (P=0.02, Table 2.1). We also examine the associations between operating period and AWQIs using the Pearson Chi-square test. The frequency is not significantly different between the groups (P: 0.71). Likewise, the associations between presence of treatment, water source and sampling

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[4] When a Small Drinking Water System is posted, the system owner is required to post signage regarding the public's access/consumption of water and the system is considered exempt from the operational requirements such as sampling, treatment and operator training (MOHLTC, 2015).

frequency with AWQIs are not statistically significant (P=0.47, P=0.32, P=0.48) (Table 2.1).

The distribution of water systems by treatment is depicted in Table 2.1. A total of 59 (27%) water systems do not use any treatment systems while 128 (61%) employed UV to treat water. Sampling frequency range from 0 to 26. The significant majority of the water systems (n=207, 99%) has groundwater source while only two water systems have surface water.

Table 2.1: Characteristics of Water Systems Divided by the Presence of Adverse Water Quality Incident

Variables	AWQI (n=68, 33%)	No AWQI (n=141, 67%)	P value
Sampling frequency; mean (SD)	4.32 (3.3)	3.97 (3.3)	0.48
Presence of treatment	51 (75%)	99 (70%)	0.47
Any treatment; n (No treatment; n (%)	17 (25%)	42 (30%)	
Treatment method	17 (25%)	42 (29%)	0.26
No treatment; n (%)	2 (2%)	10 (7%)	
Chlorinated; n (%)	47 (69%)	80 (56%)	
UV; n (%)	2 (2%)	9 (6%)	
UV and chlorinated; n (%)			
Operating period			0.71

Seasonal; n (%)	18	34	
Year around; n (%)	50	107	
Operator training			**0.02**
Positive; n (%)	8 (11%)	36 (25%)	
Negative; n (%)	60 (88%)	105 (74%)	
Water source			0.32
Groundwater; n (%)	68 (100%)	139 (98%)	
Surface water; n (%)	0 (0%)	2 (2%)	

Note: Significant values are in bold with significance level of 0.05; AWQI: Adverse Water Quality Incident; SD: standard deviation

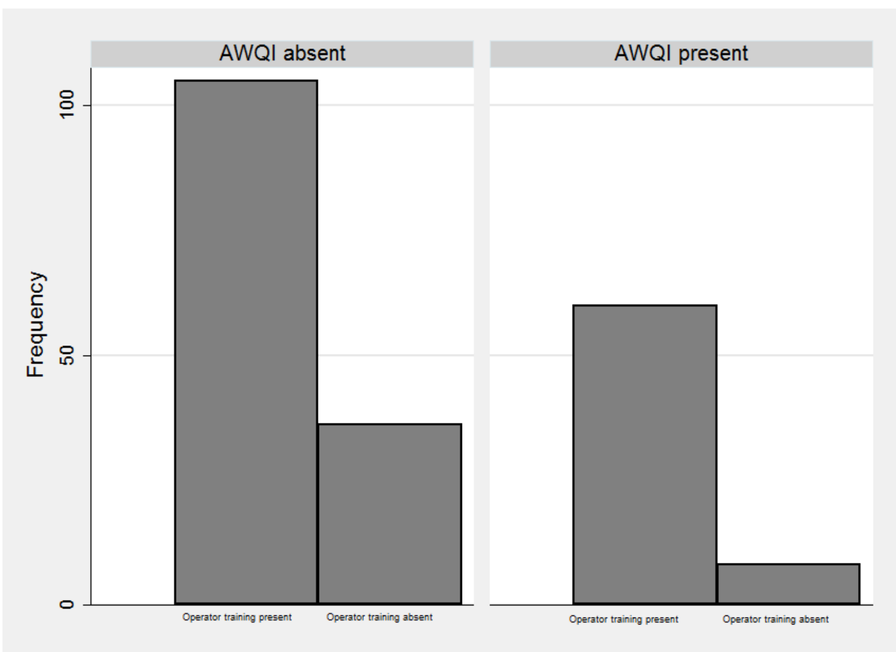

Figure 2.2: The Distribution of Water Systems by Operator Training and Adverse Water Quality Incident

To conclude, the results of the multivariate analyses indicate that operator training is associated with a lower risk for AWQI (OR= 0.38, 95% CI= 0.16 to 0.89, P= 0.02) (Table 2.2). The treatment method, operating period and sampling frequency do not indicate statistically significant results (Table 2.2).

Table 2.2: Summary of our Logistic Models for Adverse Water Quality Incidents

Variable	Effect estimate OR (95% CI); p
Seasonality	1.13 (0.58 to 2.19); 0.37
Sampling frequency	1.02 (0.94 to 1.11); 0.49
Treatment	1.27 (0.65 to 2.45); 0.72
Operator training	0.38 (0.16 to 0.89); 0.02
Treatment (3 categories)	1.12 (0.82 to 1.52); 0.73

CI: confidence interval; OR: odds ratio

2.4 Discussion

The findings support the idea that upstream behavioral determinants, specifically operator training, plays an integral role in the provision of safe drinking water in SDWSs. The summary of our findings are as follows: (1) the SDWSs with trained operators are significantly less likely to have an AWQI; (2) there is not a significant association between AWQIs and treatment method, operating period or sampling frequency; (3) the distribution of treatment methods is as follows: 61% of SDWSs used a UV treatment system (n=127); 28% of SDWSs do not use any treatment (n=59); 6% use chlorination (n=12); and 5% use a combination of chlorination and UV treatment system (n=11); (4) 1% of the SDWSs conduct chemical tests (n=2) while 99% of the SDWSs do not conduct chemical tests (n=207). The findings about the operator training suggest the presence of trained operators in SDWSs significantly associated with the possibility of experiencing AWQIs. Review of the causes of recent waterborne disease outbreaks shows that meeting the regulatory water quality parameters alone is not sufficient to safely operate a drinking water system (Rizak et al., 2013). It is also fundamental to note that the lack of a robust surveillance system results in underreporting of waterborne disease outbreaks in SDWSs (Schuster et al., 2005; Wilson et al., 2009) which consequently hinders the development of interventions to increase the safety net for these systems. Xie et al. (1999) argue that small water systems face challenges to meet the regulatory requirements and operator training is essential to increase these systems' capacity to meet the regulations. According to Murphy et al. (2015), both owners and operators should receive water system training so that they can have a better understanding of the challenges for the provision of safe drinking water. Upstream determinants are fundamental parts of the social environment where individual differences in expression of feelings, thoughts and activities are shaped (Gehlert et al., 2008). The focus on operator training can be a viable intervention to address upstream behavioral determinants. Preventing illnesses by establishing mechanisms to increase the percentage of operators properly trained in SDSWs, supports the efforts to reduce health disparities (Williams et al. 2008).

The Walkerton outbreak was a stark reminder the importance of operator training for the provision of safe drinking water. One of the major findings of the Walkerton tragedy was the complacency of the trained water system operators (Huck et al., 2003) where corrective action procedures were not diligently carried out prior to the outbreak. The operator training should be coupled with a better understanding of the consequences of not adequately responding to AWQIs. The Multiple-Barrier Approach (MBA) is an integrative risk management approach to water safety from source to tap. Baird et al. (2013) (as cited in Canadian Council of Ministers of the Environment, 2004, 16) explains the MBA as “an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health” (p.122). Water system operator training and establishing safety measures from source to tap are fundamental steps for the provision of safe drinking water.

Parr (2005) examined the societal effects and government approach to operator training just before the Walkerton outbreak and argues that the lack of consistency in training was a contributing factor to the outbreak. Training opportunities supported by the regulatory agencies assist SDWS owners and operators to enhance their capabilities for building and applying knowledge, which in return results in safer operations of these systems.

Over a quarter of the SDWSs in the Wellington-Dufferin-Guelph region operate with no treatment, yet a SDWS with no treatment system might be prone to contamination from external sources. Pons et al. (2015) reported that having no treatment system is one of the leading causes of outbreaks in SDWSs. Edwards et al. (2012) examined the safe operation characteristics of small commercial water systems in British Columbia, Canada, and concluded that the lack of a treatment system and water source vulnerability are among factors causing adverse conditions in SDWSs. Schuster et al. (2005) also identified treatment system failure along with inadequate operational practices as leading causes of waterborne outbreaks. The source water protection planning in Ontario does not include SDWSs therefore there is no enhanced safety net for these systems. Health risks of consuming water from an unprotected source are considerably higher compared to a protected water source (Davies, & Mazumder, 2003). The effects of climate change in the region, which include frequent extreme weather events, might put stress on the safety of the water sources. Thomas et al. (2006) and Cann et al. (2013) identify a correlation between increased amount of rainfall and waterborne disease outbreaks in Canada. SDWSs may not have sufficient resources and capacity to eliminate the adverse effects of extreme weather events which puts the safety of drinking water at risk. Dow et al. (2007) asked water system managers about the anticipated effects of climate change and identified water quality, financial impact and scarcity of supply as major concerns. Source water protection is an integral step to protect SDWSs from impacts of climate change. Furthermore, complimentary strategies for source water protection, such as shoreline stewardship and groundwater sales policies, may become increasingly important in ensuring the safety of SDWS and CDWS alike.

The findings concerning treatment method were expected given that all of the technologies used are well understood. UV was the most commonly used water treatment method among SDWSs. UV treatment has been available for over 30 years and has gained popularity in the past decade (Corfield, 2015). In addition to treating microbiological contaminants, UV systems are effective on chlorine resistant species such as Giardia parasite and are therefore considered a viable option to enhance water quality (Corfield, 2015). Although UV treatment does not affect water properties such as chemistry and taste, the regular maintenance of the system is fundamental to maintain a safe operation (McClean, 2008). The widespread use of UV treatment in SDWSs reminds how essential the training component is for the provision of safe drinking water.

The findings about a lack of chemical testing are concerning. Chemical testing is an integral step to investigate potential threats to the water source which can be naturally occurring or human-made. Our dataset showed that only 1% of the SDWSs had conducted chemical tests to understand the chemical composition of their water sources. Chemical contaminants in drinking water might cause several illnesses with serious and long-term health effects (Barrett, 2014). A study examining chemicals in water from 6013 private wells over a 12 month-period concluded that over 25% of the wells exceeded the acceptable levels of chemical contaminants (Harrison et al., 2000). Davies and Mazumder (2003) discussed the negative effects of agricultural, industrial and domestic use of chemicals on water sources and advocated for the reduction of their use and environmentally friendly disposal practices to reduce chemical contamination. Our study recommends greater emphasis on monitoring the chemical composition of the source water to confirm drinking water meets the regulatory limits.

There were several limitations of our study that shouldn't however undermine our findings about training. That said; this study involved secondary analysis of the existing dataset therefore the number of variables was limited by the existing database. A variable that would be useful to include in a model of AWQI was risk category. The definition of AWQI is narrow in that we defined as incidents with positive total coliforms and/or *E.*

coli test result as our dataset did not have consistent information for other conditions that may be classified as an AWQI. That said; the presence of total coliforms in water sources is considered as one of the best pathogen indicators (Locas et al., 2007).

Further research is needed to explore the determinants of adverse water quality events with total coliforms and/or *E. coli* as well as other AWQI events like treatment system failures, structural deficiencies, and exceeding chemical parameters. Examining other upstream behavioural determinants within the context of environmental and societal norms will provide a deeper understanding of the current challenges of SDWSs in the provision of safe drinking water. Exploration of the factors associated with the adverse events will require a prospective well-designed and well-conducted study with a larger dataset with a possibility of linking records from several databases to retrieve complete information about SDWSs.

2.5 Conclusion

In Ontario, there are 36 health units with over 9000 SDWSs in their respective jurisdictions. Our analysis using the data from 229 SDWSs located in the Wellington-Dufferin-Guelph region provided critical insight for operation and safety of these systems.

Our research concluded that the presence of operator training, an upstream behavioural determinant, significantly reduces the incidence of AWQIs in SDWSs. The high percentage of SDWSs with no treatment, lack of interest in testing for chemical parameters, and source water protection are potential areas of concern to ensure the provision of safe drinking water from these systems. Future research should attempt to flesh out the risk awareness and perceptions of SDWS owners to understand the challenges and lessons learned to operate these systems.

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Chapter 3

Manuscript 2

Towards a Sustainable Small Non-Community Drinking Water System in Ontario: Owners' Risk Awareness and Perceptions to Water Safety

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Abstract

In Ontario, small non-community drinking water systems are defined as systems that make drinking water available to the public but are not connected to a community drinking water system. This study, using qualitative research approach, examines the awareness and perceptions of risk among small non-community drinking water system owners in providing safe drinking water to their clients and protecting their water source. Our study yields the need for developing a sustainable operation model for small non-community drinking water systems. The study results provide recommendations to the regulatory agency for effective and efficient administration of the program such as offering customized and affordable training opportunities and developing effective communication strategies for owners and operators.

Introduction

Waterborne disease outbreaks occur due to technical or operator failure at small, non-community drinking water systems throughout the developed world in places such as the Province of Ontario, Canada (Figure 3.1) (Pons et al., 2015). What makes water quality management of Ontario's small non-community drinking water systems, which include facilities such as community centres, golf courses, libraries, motels, restaurants, churches and gas stations, important and relevant is the significantly different regulatory regimes that govern municipal water supplies and small non-community drinking water systems. Small non-community drinking water systems have essentially been excluded from Ontario's relatively new source water protection framework. As a result of the current and emerging challenges including climate change, sustainable operation of SDWSs is crucial in ensuring the provision of safe drinking water. Sustainability of a water system depends on its operational capacity with adequate financial and technical support as well as social and environmental dimensions, and the regulatory regime (National Research Council, 1997).

Figure 3.1: Map of Canada with provinces (Natural Resources Canada, 2006)

Instead of public health units or Ministry of the Environment, which oversee Ontario's public water systems, the owners of small non-community drinking water systems facilities play fundamental roles in ensuring safe drinking water is provided from their treatment systems, and there has been a paucity of research concerning the efficacy of this approach. Our study aims to address this research need by describing and explaining the risk awareness and perceptions of drinking water system owners' in providing safe drinking water to their clients and protecting their sources of water from contamination.

As described in subsequent sections, a qualitative research approach is employed by conducting interviews with the SDWS owners. The regulatory agency for Ontario's SDWSs is the Ministry of Health and Long-Term Care. Public health units represent the

Ministry at the local level. The results of our study will provide insight for the regulatory agency for effective and efficient administration of the program. Furthermore, our study results will establish foundational principles to develop a sustainable operation model for SDWSs.

3.1 Small Non-Community Drinking Water Systems in Ontario

There is no universal definition of a small non-community drinking water system. Within the Canadian context, the definitions and regulatory frameworks vary significantly among its provinces and territories (Figure 3.1). In Ontario, small non-community drinking water systems are defined as systems that make drinking water available to the public and are not connected to a community drinking water system (MOHLTC, 2015). Since the Ministry of Health and Long-Term Care (MOHLTC) assumed the responsibility as the regulator in 2008, over 9000 public water systems across Ontario have been identified as small non-community drinking water systems, mostly located outside of the urban centres (Pons et al., 2014).

It is estimated that 20% of Ontario’s 13.92 million people (Ministry of Finance, 2017) use small non-community drinking water systems; however, this does not include transient users of these facilities, such as travelers. Therefore, the number of small non-community drinking water system users is likely considerably higher, which further emphasizes the importance of ensuring safe drinking water in these systems (Pons et al., 2015). Furthermore, susceptible and vulnerable population groups, such as the elderly and young children, who are relatively more susceptible to diseases transmitted via unsafe drinking water are using these systems regularly.

3.2 Some Recent Drinking Water Contamination Incidents

Recent drinking water tragedies in Canada and the United States have heightened awareness of human and other errors. Just over a decade ago, the Walkerton (Ontario) drinking water tragedy occurred involving a public drinking water system. An outbreak of gastroenteritis caused seven deaths and affected over 2300 people in this outbreak and was the result of consuming contaminated water from the community drinking water systems in the Town of Walkerton (Hrudey et al., 2003). Along with other reasons, human error and inadequate water testing procedures played an important role in the occurrence of Walkerton tragedy (O'Connor, 2002). Less than a year after the Walkerton tragedy, North Battleford's Cryptosporidium outbreak affected close to 7000 residents in the Province of Saskatchewan (Hrudey, 2011). Although no one was reported sick, the community water supply tested positive for *Escherichia coli* (*E. coli*) in Kashechewan First Nations, Ontario in 2005 which caused a massive evacuation of the community and drew attention to the community's ongoing water crisis for several years (Hrudey, 2011). Most recently, inadequately treated community drinking water in Flint, Michigan caused by chemical and microbiological contamination of the water affected 99,000 people between April 2014 and October 2015 (Kennedy et al., 2016; State of Michigan, 2016). The recent drinking water incidents figured heavily in how Canadians think about their water supplies.

Although not all of these incidents involved small non-community drinking water systems, the problems are actually magnified for them given that there is no mandatory management structure for small non-community drinking water systems. Pons et al.

(2015) reviewed the waterborne disease outbreaks in small non-community drinking water systems in the United States and Canada between 1970 and 2014, and reported that untreated and inadequately treated water systems had been the leading cause of these outbreaks.

The aforementioned major drinking water contamination incidents in Canada, namely, Walkerton, Kashechewan, and North Battleford resulted in a comprehensive revision of drinking water management in Ontario and other jurisdictions. One of the outcomes was to amend the regulatory framework for small non-community drinking water systems in Ontario.

3.3 Regulatory Framework for SDWSs in Ontario

Ontario's regulatory framework for drinking water is complex involving various stakeholders, which creates issues for the small non-community drinking water system owners to figure out how to manage their systems on their own. Since the Walkerton tragedy, the provision of safe drinking water has become a priority for Ontario's government agencies. The Walkerton Inquiry Report offered several recommendations to improve the drinking water management framework and served as a guide for all levels of government to demonstrate the best drinking water management practices (O'Connor, 2002). Yet, the challenge for SDWS owners to understand the legal responsibilities and demonstrate safe operational practices continues. Since the changes have been made based on the Walkerton Inquiry Report's recommendations, better coordination among government agencies has been established.

The administration of the small non-community drinking water system program is a unique example of this enhanced coordination among public institutions. To utilize and maximize this local capacity, the Ministry of the Environment transferred the oversight of small non-community drinking water systems to the Ministry of Health and Long-Term Care in 2008. Ontario’s 35 public health units have a wealth of experience in inspecting local establishments open to the public such as food premises and public swimming pools.

Ontario Regulation 319 (Small Drinking Water Systems), enacted in 2008 under the *Health Protection and Promotion Act*, requires the owners of small non-community drinking water systems to take responsibility for the provision of safe drinking water by complying with the conditions of ‘Directives’ issued by Public Health Inspectors (MOHLTC, 2015). Small non-community drinking water systems are located across the province and in many cases in remote areas, therefore site specific-risk assessments are required to adequately measure the risks in these systems. The Risk Categorization (RCat) Tool was developed by the Ministry of Health and Long-Term Care to have a consistent approach to the systems’ assessments and corresponding preparation of the Directives. During their assessments, Public Health Inspectors give consideration to the water source, treatment method and small non-community drinking water system owner’s knowledge and training (MOHLTC, 2015). The Laboratory Results Management Application assists PHIs in monitoring the water test results and ensuring that the small non-community drinking water system owners are sampling with frequency identified during the risk assessment.

3.4 Source Water Protection

Source water protection is a crucial step of the Multiple-Barrier Approach as it addresses water quality and quantity by recognizing complex, multidimensional effects at the source. According to Justice Dennis O'Connor (2002), protecting drinking water sources constitutes the first step to preventing contamination. Establishing a source water protection safety net is an economic necessity because treating polluted water has been proven to cost more than keeping water clean at the source (Patrick, 2008). Also, social and environmental factors play a significant role in ensuring water sources are protected from contamination. Small non-community drinking water systems have been left out of Ontario's source water protection framework which causes discrepancy among systems, namely small non-community drinking water systems and community drinking water systems, providing drinking water to the public. Including small non-community drinking water systems and recognizing the perceptions of the small non-community drinking water system owners is fundamental to ensure a better source water protection in Ontario. Thus, how owners manage their properties and interact with their neighbours and their properties can have a considerable impact on ensuring the safety of source water.

As noted above, contaminated water was one of the causes of the Walkerton tragedy, and protecting drinking water sources became a priority after this incident. Justice O'Connor (2002) made 17 recommendations in the Walkerton Inquiry Report to establish the province's Source Water Protection framework. The provincial government acted on Justice O'Connor's (2002) recommendations by enacting laws including *the Safe*

Drinking Water Act, 2002, Nutrient Management Act, 2002, and Clean Water Act, 2006; and creating new institutions such as Source Water Protection Committees. The Clean Water Act, 2006 establishes the legal framework for Ontario's SWP and stems from the application of the MBA principles (de Loë et al., 2016). This study will explore the possible consequences of the decision to exclude SDWSs from source water protection planning.

3.5 Risk Literature

The risk awareness and perceptions of the small non-community drinking water system owners of the provision of safe drinking water and protecting water sources have been understudied. Examining the small non-community drinking water system owners' perceived risks may be useful and beneficial for the provincial government in creating an efficient and effective model for the small non-community drinking water systems.

3.5.1 Definition of Risk

Risk is a subjective and multidimensional term with several definitions. Most of our day-to-day activities such as walking on the street, drinking a hot beverage involve some level of risk. Risk can simply be defined as the possibility of an adverse event and the magnitude of its consequence (Sjöberg et al., 2004). Eiser et al. (2012) define risk as a function of likelihood and value; whilst Slovic and Peters (2006) argues that risk is a natural reaction to danger. Given the fact that risk is a widely accepted norm, individuals often assess and perceive risk inaccurately (Jewel, 2009). There are often differences in definition of risk between experts and lay public (Slovic, 2000). For ease of discussion, this study categorizes the regulatory agency, the Ministry of Health and Long-Term Care and public health unit representatives as ‘experts’, and the SDWS owners as ‘lay public’.

In several instances such as the Walkerton tragedy, the water system operators’ risk perception was no different than the lay public’s perception of safe drinking water (Parr, 2004). Therefore, the risk was not assessed properly to respond with appropriate measures. Increasing risk awareness of the SDWS owners by offering training opportunities can potentially reduce the risk for the provision of unsafe drinking water.

Although earlier studies assessed risk within the context probability and magnitude parameters with an objective perspective; in recent decades the researchers widely accepted the subjectivity of risk (Slovic, 1997) and the need for multi-dimensional assessment by considering culture, location, and societal factors (Slovic, 2000). Spence and Walters (2012) note that the water safety related research and policy work mostly examines the “objective dimensions” while the “subjective dimensions” are often neglected. The ongoing challenges to access safe drinking water in Ontario’s First Nations is a fine example to define the need for multi-dimensional approach to defining risk and recognizing its subjectivity. There is a significant difference in perceptions of water between Aboriginal and non-Aboriginal community members as some Indigenous people view ‘water’ a living thing with spiritual connection (Lavalley, 2006). To better communicate the risk and adequately train water system owners, cultural and societal factors should be considered. Furthermore, the owners’ risk perceptions should be well understood. This study recognizes the subjective dimensions to examine risk awareness and perceptions of the SDWS owners.

3.5.2 Risk Perception

Since people often make decisions based on their risk perceptions, understanding how people interpret and respond to risks are as important as knowing possible outcomes (Brady, 2012). Elliott (2003) defines risk as a ‘judgement’ rather than a ‘physical form’ and argues that “perceptions of risk will depend heavily on assessments of the probability of an event and the severity of the impact, should the event occur” (p. 215). On the other hand, Brown (2014) notes the individual’s frame of reference for risk perception as lifetime experience in addition to other emotional stressors. An important consideration for the regulatory agency should be recognizing the subjectivity of risk perception and ensuring the training programs and procedures are developed with extensive consultation with the SDWS owners.

According to Sjöberg et al. (2004), the significant differences between the ways content experts and lay public perceive risk may create obstacles to rational decision making. Kraus et al. (1991) argue that experts should do a better job in explaining the risk to lay public and have consistent messaging. Considering the Town of Walkerton’s water system operators lay public, the content experts which can be considered the regulatory agency employees at the time, there was a significant discrepancy regarding the definition and the parameters of safe drinking water (Parr, 2004). Our study contributes to closing the gap between content experts, public health inspectors and the targeted audience, the SDWS owners.

In some cases, lay public might consider an event or a condition as ‘risky’ where experts in that area could see little to no risk; the opposite could also be true. Elliott (2003) agrees with Sjöberg et al. (2004) and summarizes key differences in risk frames used by professionals and the public in Table 3.1.

The recognition of considerable differences in defining, analyzing and accepting risk between environmental professionals and members of the public can be addressed by establishing effective and efficient risk communication strategies. When the regulatory agency communicates risks in the provision of safe drinking water to the SDWS owners, the aforementioned differences should be taken into consideration. Slovic (1987) defines the communication between lay public and experts as 'a two-way process' and notes the need for respect and recognition for efficient and effective risk management and communication.

Table 3.1: Differences between professional and lay public risk frames (Elliott, 2003, p.216)

	Environmental professionals risk frames	*Lay public risk frames*
Meaning of risk	Expected value of loss	Variability and potential for extreme outcomes
Method of inquiry	Analytic and conceptual	Experiential and reflective
Basis of trustworthy risk-management systems	Reliable physical systems	Good people and institutions

Acceptability of risk	Assessed relative to costs and other risks	Preference for absolute reductions, often to zero risk

Sjöberg et al. (2004) note "risk perception is the subjective assessment of the probability of a specified type of accident happening and how concerned we are with the consequences" (p.8) and they argue that social and cultural norms play an important role in defining it. Brady (2012) agrees with Sjöberg et al. (2004) and notes that when individuals have knowledge and control over the hazard or event they perceive it differently compared to incidents where individuals have little or no control. Valerie (2014) also supports Sjöberg et al. (2004) and emphasizes the unconscious emotional processes individuals experience during risk perception. Compared to other jurisdictions, Ontario has the highest population depending on groundwater sources, yet the risk of unsafe drinking water from groundwater sources is not well understood (Nowlan, 2007). Furthermore, the traditional approach to make drinking water laws with an economic development focus has not shifted to enable new laws where sustainability, social and cultural norms are considered in the process (Nowlan, 2007). Recognizing subjectivity and valuing social and cultural norms in understanding the SDWS operator perception of risk in the provision of safe drinking water constitutes a foundation to build a framework that will serve the needs of the system owners and enhance the drinking water safety net.

Flynn et al. (1994) examine the effects of gender and race on perceptions of environmental health risks and report that females and non-white males perceive risk significantly different from white males. Gender and race are closely related to other social dimensions such as income, education and control over health risks (Flynn et al., 1994), therefore accepting and framing risk differ between individuals and socio-groups. Overall, risk perception is a subjective and multi-dimensional concept and listening to the SDWS owners is the first step to create an efficient and effective communication strategies for the SDWS program. This study addresses a significant gap in the current drinking water related research where the perspectives of SDWS owners may enhance the efficiency and effectiveness of the current program delivery model.

3.5.3 Awareness and Risk Perception of Safe Drinking Water

Understanding how managers interpret and respond to risks is a key aspect of the changes in water management in Ontario and a consequence of downloading water protection (Brady, 2012). Considering the importance of judgment and individual frames of reference in the risk literature, risk perception is a subjective concept which varies from one person to the other. Castleden et al. (2015) examine the public health implications of drinking water-related behaviours and perceptions and conclude that an enhanced understanding of public perceptions related to drinking water safety results in developing effective communication strategies.

The recent Kashechewan and North Battleford drinking water contamination events in Canada, which were associated with community drinking water systems, resulted in a change in public behaviour towards tap water (Davids, 2006; Hrudey, 201; Walkerton Report, 2000). These two events resulted in increased numbers of people preferring not to consume tap water and exploring alternatives such as bottled water (Dupont et al., 2010). Per unit volume, the cost of bottled water is between 240 to 10,000 times higher than tap water (Jaffee, & Newman, 2013; Saylor et al., 2011). Although there is no study examining the overall financial burden to increased bottled water use since Walkerton tragedy, the increase in the bottled water use is well documented (Jones et al. 2006; Jones et al.; 2007). Doria (2010) argues that past experiences affect the users' perceptions of water quality in tap water. Other studies conclude that the major contributing factor for Canadians deciding not to drink tap water is their perceived potential health concerns (Dupont et al. 2010; Jones et al. 2006; Jones et al.,2007; McLeod et al., 2014).

Social determinants of health, such as the conditions in which people live and work contribute to the development of risk perception. To explore the social determinants of health for the provision of drinking water, it is fundamental to investigate downstream factors such as the attitudes and behaviours of water system owners and operators. These downstream behaviours are underpinned by upstream determinants such as social, economic and environmental factors (Bravemen et al., 2011). Also, recognizing the level of adaptive capacity, the ability to respond to change, provides a sound foundation to create sustainable water system operations. There is a gap in knowledge and literature which needs to be filled by conducting further investigation. This study aims at closing this gap by focusing on the attitudes and perceptions of the SDWS owners within the context of social determinants of health and examines the effect of social, economic and environmental factors on the provision of safe drinking water in SDWSs.

The Walkerton tragedy affected the public's perception of drinking water from community water systems (Turgeon et al., 2004). Parr (2004) examines Walkerton residents' perceptions towards safe drinking water before and after the tragedy and the effects of these perceptions, especially in the earlier stages of the tragedy. The Walkerton residents' perception of safe drinking water was based on parameters such as taste, and smell. Moreover, respondents perceived that the chlorine-added drinking water as low-quality tap water (Parr, 2004). Other studies also confirm the importance of aesthetic factors in the public's perception of safe drinking water (Doria et al., 2009; Doria, 2010; McLeod et al., 2014); yet the literature lacks information regarding the perceptions of water system owners.

There are other factors that affect perception. Drinking water safety, especially in smaller communities, requires collaboration among water management officials and residents as the operation of water systems results in significant expenses. According to Johnston (2008), the public considers chemicals with which they are familiar such as lead and arsenic riskier than those that are less familiar such as cadmium, perchlorate, even though they pose the same level of concern based on the regulatory limits.

Although several studies and reports (Davids, 2006; Doria, 2010; Dupont et al. 2010; Hrudey, 2011; McLeod et al., 2014; O'Connor, 2002) examined the drinking water users' risk awareness and perceptions regarding tap water in general populations, there is a clear gap in the research literature documenting the perspectives of the drinking water system owners who provide drinking water from their systems. The results of this study will enhance the ability to actively apply the current knowledge into new program where the SDWS owners' risk awareness and perceptions in the provision of safe drinking water are considered.

3.6 Methods

3.6.1 Research Area

The study was carried out in one health unit in Ontario, Canada and the strategy for selection being in a central location as well as having both rural and urban communities in its geography. Of the 36 health units in Ontario, the majority (29) are located in Southern Ontario. The study region is Wellington-Dufferin-Guelph Public Health's jurisdiction which includes Wellington and Dufferin Counties, and the City of Guelph. This region is centrally located in Southern Ontario with 229 SDWSs (WDGPH, 2016). Acknowledging its central location and the number of systems, this region provides a good representation for Southern Ontario.

3.6.2 Study Participants

16 SDWS owners in Wellington-Dufferin-Guelph region participated the interview. They came from all major types of businesses such as golf course, summer camp, restaurant, community centre, church, recreational facility, municipal building, and conservation area. All participants owned their systems for five or more years and seven of the owners lived on the property where the system was located. Fourteen of the participants were both owner and water system operator. Being both an owner and operator is a common practice in SDWSs as hiring a water system operator is often cost prohibitive.

The researcher scheduled in-person or telephone interviews with the SDWS owners, who participated in the study. For the interviews, the first preference was meeting face-to-face at a time and venue chosen by the study participant. When meeting in-person was not possible, a telephone interview was conducted at a mutually convenient time. All participants had the study clearly explained and informed consent was secured. There was no financial compensation for their participation in the study.

The interviews were face-to-face (n=10) and over the telephone (n=6), and took between 35 and 90 minutes. The interviews were audio recorded and later transcribed by the researcher. The analysis was managed using NVivo (Richards, 1999). The use of inductive grounded theory enabled an iterative and interactive approach to construct theory from data (Charmaz 2012; 2006). When the saturation point is reached, it means sufficient perceptions are collected and the new data would not change the newly generated approach (Tolhurst, 2012), In this study, the perceptions and concepts became evidently similar by the 12^{th} interview and the researcher continued the interviewing with a few more participants to ensure no new information and perspective were disclosed or discussed. As a result, the interviews were concluded when the saturation point was reached after 16 participants.

The interview questions were created based on the current literature including the results of the recent study where the relationship between SDWS operational characteristics and adverse water quality events were examined (Sekercioglu et al., 2017). The Information Letter (Appendix C), Consent Form (Appendix D), and Interview Guide (Appendix E) were submitted to Western University's Research Ethics Board (REB) and received the approval (REB108320) in September, 2016.

3.6.3 Data Collection

The research data included interview transcripts. Interviews were recorded with an audio recorder with participant consent. To increase rigour, the member checking process was used (Baxter, & Eyles, 1997). The results, discussion and conclusion sections, a total of 14 pages were shared with each study participant to provide them an opportunity for review and further input. The participants were also provided with the transcript of the interview. Nine out of sixteen participant reviewed their transcript and were satisfied with the results and interpretations.

The audio-recorded interviews were transcribed, verbatim, by the researcher. The interview data were analyzed by using NVivo9™, a qualitative data management software program. To gain insight and knowledge from the data and identify common themes, Thematic Analysis was employed. Vaismoradi et al. (2013) define Thematic Analysis as an "independent and a reliable qualitative approach to analysis" (p.400). According to Clarke and Braun (2017), Thematic Analysis brings flexibility and accessibility which results in generating useful results from the data collected. Although Thematic Analysis initially explains the importance of themes for the research purpose, the identified themes exist independently when the analysis is completed (Ho et al., 2017). Counting will be used through the results section to provide context for recognition of patterns (Sandelowski, 2001).

3.7 Results

The interview guide topics included operational practices, water safety, training, communication. The analysis of the interview data from the 16 SDWS owners yielded five main themes and addressed the purpose of the study. The key themes that emerged from the interviews are summarized at Table 3.2.

Table 3.2: Key themes from the interviews

I also drink the water
Revenue and business reputation loss
Financial constraints
Value of Training

Disconnected

Theme 1: I also drink the water

The majority of participants reported that their families also used the water supplied by SDWSs, which brought the conversations to a personal level and constituted a higher level of risk awareness.

> Jane, owner of a golf course stated: *'...Because I live here water is safe for my family not just for my customers. I think it has a bigger role that water is safe as I am drinking it too. It sounds selfish but it is real.'*

> Lisa who owns of a health and fitness club revealed: *'There is no hiding anything, all of our employees, all of our family, club members take water from the same system.'*

When participants were asked to describe their water systems and discuss their operational challenges, all of the respondents appeared to have a sense of ownership and responsibility. Five of the respondents experienced a challenge to describe and discuss their systems' operational challenges because of competing priorities in their day-to-day business tasks. James described the reliance on the regulatory agency and lack of knowledge regarding operational processes: *'Probably little lack of knowledge with respect to what we are doing, as everything is requested by the current Ministry of Health.'* Four participants discussed the occasional mechanical and treatment system malfunctions and noted the importance of acting promptly when those issues arose.

In response to the question “Please explain the importance of regularly testing your SDWS”, all the participants indicated that testing was an important step in the provision of safe drinking water and commented on the procedural and legal liability. Lisa stated: *‘We have the responsibility by law to test it regularly. As soon as we learned about the risks and all that, we quickly hired an outsourced company…’* Out of 16 participants, two of them delegated the full responsibility to an outsourced company to operate their SDWSs.

> Michelle, *a golf course owner, also commented on the importance of regularly testing: ‘...Should anything ever happen, accidents happen, we have a good record of showing due diligence…’*

> Nicole who owns a trailer park discussed the benefits of testing: *‘You have that peace of mind that you do not need worry about anything…I am also drinking the water myself here directly.’*

The participants were also asked what they knew about their source water. Respondents were able to demonstrate the knowledge about the location of their wells but the majority of the participants raised concerns regarding lack of control over surrounding areas as it may affect the safety of their water source. The conversations mainly focused on the agricultural or commercial activities of their neighbours, and the potential effects of those activities on groundwater quality where they had no control. Another golf course owner, Jane, illustrated the external factors that may affect the water quality:

> *“There is large 200 acres’ potato farm across from us who sprays and we keep the dog inside the house, close our windows, two or three times a*

> *year they rotate their crops corn to potatoes to nothing so that would be a possible source of contamination.'*

Chemical contamination risk was not considered an issue for 12 of the owners. The participants associated the risk of chemicals in drinking water with possibility of chemical spill. Nicole revealed: *'We don't have any dangerous industry people using chemical that can get into the water system, and there is nothing in our proximity.'*

Escherichia coli was considered the most serious contamination risk. Nine respondents made reference to the Walkerton tragedy when answering the questions related to water safety. Lori summarized health effects of unsafe drinking water in one short sentence: '*Illness or death, Walkerton always comes to mind*.' Lisa stated: '*Ever since Walkerton everybody takes drinking water a lot more serious. Everybody used to think all the water in Canada was safe.'* Nicole also commented on the same issue: *'I guess Walkerton was the fine example of that, people neglected the system and it did happen.'*

The participants were asked to react to the following statement: "*When people get sick, drinking water can be the source of illness*". While 12 respondents acknowledged the potential link between people getting sick and unsafe drinking water, three participants talked about the possibility of contamination from sources other than water such as food. Participants showed confidence in the safety aspect of drinking water from public water systems. The interview discussions revealed high levels of knowledge and awareness of the SDWS owners regarding the possibility of unsafe drinking water causing illness.

Theme 2: Revenue and Business Reputation Loss

The participants strongly associated unsafe drinking water with reputation and revenue loss and demonstrated unwavering vigilance for adverse water quality incidents. Jessica owns a recreational camp with thousands of visitors from Canada and across the world every year. Her reaction to an adverse water quality incident at her facility was:

> *'If there is something wrong with our water, we shut down. There is no question. There are health implications, legal implications, water is everything. If you do not have good water, you do not function.'*
>
> *Jessica continued: 'I like to protect people who come here. I am more worried about that than getting a fine because I did not do something.'*

Thus safe drinking water is linked to business reputation. The respondents commented on the detrimental effect of unsafe drinking water on their business. Bob, the owner of a tourist attraction that provides drinking water to hundreds of visitors every year stated:

> *'...you kind of take it for granted until you do not have it at your disposal, and you realize how absolutely important water and good quality water is to the operations.'*

Joe's input on the business reputation as a result of unsafe drinking water was similar to the other participants: *'We can lose customers, would not have anyone coming here, lots of complaints from people, increased fear from some people to come here.'* Lisa echoed several other participants' perspective: *'...if we do not test it and we get into some trouble, that would cost us our business.'*

The respondents showed empathy towards other well owners in their local community. James drew attention to potential impact on the community during an unsafe drinking water occurrence: '*It would have huge effects on the community. Everybody here is on well system. If groundwater is affected, it would affect all the rural houses.'*

Theme 3: Financial Constraints

There were several comments regarding the financial constraints being a potential barrier. Jeremy highlighted the importance of testing with a reservation on the cost: *'Regular testing is important as long as it does not cost a lot and can be managed by local resources.'* The participants expressed concerns about the lack of knowledge in best operational practices and sampling techniques where adverse water quality incidents occur if the proper steps are not followed.

Lori, the owner of a rural restaurant gave an example when proper sampling steps were not followed and retesting was required with an added cost: *'…But even taking a water sample improperly could cause an adverse effect on your water sample. Because the one that came wrong was taken by my husband who did not know what he was doing, not to blame him but I took small drinking water course once and I do believe that there is a lot to learn.*

Adam, the owner of a summer camp experienced financial constraints: *'I cannot afford to go to training but I have it from my previous experience.'* Another participant, Philip who owns a recreational camp had a similar perspective with Adam: *'You can train people with so many little things, so we are not like a big company that has training budget for everything they do but it is important a number of people know how the system works.'*

Theme 4: Value of Training

The respondents revealed the importance of training for the provision of safe drinking water in SDWSs. Barret illustrated the necessity for increased training: *'The requirements of the health unit are very simple but training should happen to be aware of the sampling procedures and what to do in case of an adverse result.'*

As the systems are different from each other, Barrett noted: '*Training is important and it is also important that the training be appropriate to the level of complexity of the system.'* Seven out of 16 respondents discussed the importance of sampling procedures and revealed that not following the recommended sampling procedures previously resulted in an adverse water quality incident in their system. Although the chemical contamination possibility was discussed in several interviews, the owners were not provided with adequate knowledge and tools to assess potential chemical contamination threats to their water supplies.

Participants also discussed the need for better communication of the training opportunities. Jane commented on the ambiguity in the types of training courses and provided example: *'Source water protection knowledge, I would say it is very important but I don't feel that I had a good training in that.'*

Theme 5: Disconnected

The participants were asked if drinking water safety came up in conversations with other SDWS owners. The responses clearly demonstrated the fact that the owners do not have a network to discuss these issues. The sense of community seemed to be lacking as participants mainly felt isolated. Lori, the owner of a rural restaurant commented on communication: *'I do not think I have heard anyone discussing this issue…not a lot of communication happening.'* Lisa revealed: *'I have not heard of any other SDWSs in this area.'*

Another question inquired about the best way to communicate with the SDWS owners. The responses did not yield one preferred method of communication as the respondents had different preferences on the most effective communication method and receiving updates from the regulator.

Barret commented: '*I would like hard copy mails. I like paper…I have a binder with a tab on water system, everything from the health unit.'* Lisa shared Barret's perspective:

> *'I do not think email will do it; there are just too many emails from different sources. If I get a hard copy mail from public health versus email, it is harder to miss. E-mails go rounds sometimes, it can go spam filter and you can miss it and you do not realize you missed it.'*

On the other hand, some respondents preferred email communication over the hard copy mail. According to Adam: *'Two ways of communication would be more efficient, email is one of them and meetings are very important…'* Dave who owns a recreational facility commented:

> *'I think emails would be the best, having kind of an email protocol, of there is anything in the area or there are updates we would automatically*

get emails…meeting in person would be excellent, once a year or twice a year.'

Lori also supported the email communication: *'My preference would most likely be an email. Because if I have an email, I can read it, and save it and throw it in a file to reference back to it.'*

Twelve out of 16 participants were dissatisfied with the communication they received from the government and considered the communication as the biggest gap. All of the participants agreed that there was a need for organizing regular local meetings with government representatives. These meetings would not only provide updates but would also enhance communication among the SDWS owners

3.8 Discussion

Qualitative methods employed in this study provided insight into SDWS owners' awareness and perceptions about the provision of safe drinking water and source water protection. Our results indicated key parameters to establish a sustainable operation for SDWS and also led to a series of recommendations we make in this article to revamp the communication strategy for the SDWS owners.

The SDWS owners were aware of the health risks of unsafe drinking water and demonstrated sense of ownership and responsibility to provide safe drinking water to their users. In many cases, their family members have been using the same water as they were either living on site or visiting their businesses. This was important as Madrigal and

Alpízar (2011) argues that lack of ownership and motivation results in poor operational performance in drinking water systems.

Losing revenue and business reputation was among the major driving forces to ensure the water system is operated in compliance with regulations. Some owners contracted out the regular maintenance services to ensure the operational and regulatory requirements are fully met. The SDWS owners' responses about their awareness and perceptions were significantly influenced by the Walkerton tragedy. Their motivation stemmed from awareness of the health consequences of drinking unsafe water, business reputation, revenue loss and participants and their families drinking the same water. Our study results support the previous findings (Dupont et al., 2010; McLeod et al., 2014) regarding perceived potential health concerns to drink tap water. This perceived risk has a positive effect on the provision of safe drinking water in SDWSs. In addition, family members drinking the water from SDWS also elevates the perceived risk (Janmaimool, & Watanabe, 2014). It is important to note that owners of SDWSs did not share the change in public behaviour towards tap water as Dupont et al. (2010) argued. Instead, participants of the study praised the safety of water from public drinking water systems. The study results support the findings of Brady (2012) and Sjöberg et al. (2004) regarding risk perceptions towards the events people have control over, as such SDWS owners showed confidence in water from SDWSs.

Although water system failures similar to the ones associated with water-related disease outbreaks do occur in SDWSs, the owners are strongly motivated to rectify the issues in a timely manner. In addition to adequate operational practices, raising awareness for source water protection among the SDWS owners would play an instrumental role in the provision of safe drinking water in SDWSs. Establishing systems to monitor water quality and assess the risks from source to tap will confine the effects of adverse water incidents (Patz et al., 2008). Currently, there is no system in place to monitor, assess, and when necessary, remediate any kind of contamination in source water.

The study results revealed the need for increased attention to protecting drinking water sources. Although source water protection is a fundamental step of the Multi-Barrier Approach to ensure safe drinking water, SDWSs have not been included in Ontario's Source Protection Plans[5]. The owners of the systems face significant challenges to protect their water sources and need a structured approach. A wellhead protection model similar to the one proposed by Frind et al. (2006) where contaminant types and aquifer structure is considered may be a viable option to support SDWS owners in protecting their water sources.

Hrudey (2011) argues that although the main focus for drinking water safety discussions has been the microbiological parameters, there is a growing concern regarding the chemical parameters and their potential long-term effects to cause illnesses such as cancer. This supports the study findings as participants did not seem to be concerned about chemical contamination of their water. As Justice O'Connor (2002) noted, the drinking water safety risk should be measured by considering all relevant parameters and appropriate preventive measures should be taken to address concerns regarding those

[5] "The Source Protection Plan is a locally-developed, science-based Plan that meets the requirements of the Clean Water Act, 2006 by protecting sources of municipal drinking water from contamination" Drinking Water Source Protection/Conservation Sudbury, 2017)

parameters. The study participants focused exclusively on industrial contamination possibility during the discussions about chemical parameters of their drinking water and did not mention about naturally occurring chemicals or farming activities nearby as potential issues. The lack of awareness may be due to the fact that the regulatory agency does not require routine testing for chemicals.

Financial constraints have been one of the main themes during the interviews. Participants shared their financial constraints as they had been trying to meet the regulatory requirements. Two activities they felt financial challenges were:

- Testing their water for microbiological and chemical parameters
- Accessing to training opportunities

The regulatory agency should develop strategies to raise awareness for chemical contaminants in drinking water and furthermore, reduce barriers to offer low-cost training and subsidized water testing opportunities.

Climate change will increase the frequency of extreme weather events such as floods and droughts and consequently cause the elevated risk of waterborne disease outbreaks (Patz et al., 2008). SDWSs may not have sufficient resources and capacity to eliminate the adverse effects of extreme weather events which puts the safety of drinking water at risk. Dow et al. (2007) investigate the perceptions of water system managers about climate change effects and identify water quality, financial impact and scarcity of supply as major concerns. The study participants indicated financial concerns and limited water quality intervention potential which makes SDWSs prone to climate change impacts. The SDWS owners should be made aware of potential risks that can compromise the provision of safe drinking water. The regulatory agency should consider strategies to support the owners of these systems to be prepared for the potential effects of climate change.

The perception of drinking water safety based on social, economic and environmental factors may potentially conflict with regulatory requirements. Until the Walkerton tragedy, the town residents and water system operators had a strong belief regarding the safety of groundwater from a well without treatment and considered the treatment process such addition of chlorine causing impurity in their water (Parr, 2004). The information provided by Public Health Inspectors was highly valued by the study participants therefore maintaining this relationship and enhancing it by developing new communication strategies

The respondents highly valued the information and guidance provided to them by public health units and therefore there was continued interest in learning more from the regulatory agency and complying with the regulatory requirements. Cox (2015) suggests focusing on participants' life experiences as well as social interactions, beliefs in training program design. The training programs for the SDWS owners should recognize different perspectives and integrate social determinants of health in addition to regulatory mandates. It is also important to note that programs or interventions that are designed to influence behaviour change are more successful when they target specific behaviours with an understanding of factors influencing that behaviour (Abraham, & Michie, 2008). The SDWS owners seemed very keen on accessing training and networking opportunities initiated by government agencies with the expectation that these opportunities would not be cost prohibitive.

The study results yielded the lack of sense of community among SDWS owners. Feeling of isolation was a common response by the participants. There is a significant need to establish and foster relationships so that the SDWS owners can regularly interact with each other. Creating a sense of community among local SDWS owners is a step in the right direction for the regulatory agency. All of the study participants were favourable to the idea of semi-annual meetings to receive updates and interact with other SDWS owners.

The SDWS owners raised concerns regarding the level of communication they had been receiving from the regulatory agency. This study generated some interesting results regarding the communication preferences of the SDWS owners. Based on the interview results, sharing the regular updates with the owners of SDWS owners by using both regular mails and electronic mails will ensure the updates are received by the target audience.

Overall, the study results provide valuable information for all of the stakeholders in water management systems. Investigating the current challenges of the SDWSs owners was an integral step to bridge the gap between practice and theory and established a foundation to develop an efficient and effective SDWS management program.

3.9 Conclusion

This study examines the risk awareness and perceptions of SDWS owners in the provision of safe drinking water and protecting their water source, and provides recommendations to the regulatory agency for effective and efficient administration of the SDWS program.

The SDWS owners are aware of the financial and non-financial consequences of an adverse water quality event, but nevertheless, they have not been offered opportunities to receive adequate training on best operational practices and assessing potential threats to their water source. According the study results, training opportunities initiated by the regulatory agency with a reasonable cost have the potential to gauge a lot of interest. On the other hand, the SDWS owners face financial challenges to meet the operational requirements such as regular water testing and operator training. The regulatory agency should establish mechanisms to provide financial relief which could include providing subsidy on water testing and low-cost training opportunities.

One particularly interesting result of this study is that the SDWS owners feel isolated, mainly for the following two reasons: 1) There is a certain level of disconnect as they do not receive regular communication from the regulatory agency; 2) They lack of a sense of community among the SDWS owners in the same region. The study results reveal the method of communication preferences that assist the regulatory agency in establishing new mechanism to stay connected with the SDWS owners.

Although the study design had several strengths and the saturation point was reached, the number of participants was a limitation. The participation opportunity was given to all SDWS owners in the region and the ones who accepted the invitation after the researcher’s efforts to recruit for participation in the study were interviewed.

Notwithstanding the identified limitation, the study yielded fruitful results for enhancement of the SDWS program by the regulator. Emerging environmental concerns such as more frequent extreme weather events will put water sources at risk of contamination and subsequently, SDWSs might be prone to operational and water source challenges.

It would be timely for the regulatory agency to develop effective communication strategies to support the owners and operators. Lastly, customized and affordable training opportunities are also key for success in increasing the awareness and knowledge in the provision of safe drinking water.

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Chapter 4

Manuscript 3

The Development of a Sustainable Operation Model for Ontario's Small Non-Community Drinking Water Systems: How to Ensure Provision of Safe Drinking Water and Source Water Protection

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Abstract

The provision of safe drinking water in Ontario's small non-community drinking water systems (SDWSs) pose a challenge for many system owners. Our study aims at developing a sustainable operation model for SDWSs by recognizing the importance of source water protection. Although the current literature on Ontario's SDWSs is limited, the review of the current water management strategies in Canada and across the world provided fruitful results to create of a unique model for Ontario's SDWSs using the Multiple-Barrier Approach framework. Our sustainable operation model consists of five main components: 1. Commitment to providing safe drinking water, 2. Assessment of the system and source water, 3. System operation and operator training, 4. Management of incidents and emergencies, 5. Communication and raising awareness. Our model addresses the areas that need more attention for today, and in the future, such as protecting source water, financial stability, enhanced communication and increased awareness. A sustainable operation model for SDSWs based on the Multiple-Barrier Approach framework addresses the shortcomings of the current water management framework for SDWSs and offers a viable strategy to establish a sustainable operation model with an integrated approach.

Introduction

Public awareness surrounding access to safe drinking water has increased considerably since the Walkerton tragedy in 2000, yet strategies to establish a sustainable operation model for Ontario's small non-community drinking water systems (SDWSs) have not been fully developed. The provision of safe drinking water in SDWSs and the sustainability of these systems pose a challenge for many system owners. Furthermore, a key initiative to safeguard drinking water sources in Ontario, the planning for source water protection, does not include SDWSs.

There is no universal or Canada-wide definition of a SDWS due to extensive differences in the assessment of system parameters (NCCPH, 2015). For example, Health Canada (2013) defines small drinking water systems as systems that serve between 501 to 5000 people, whilst the United States Environmental Protection Agency considers a system serving 10,000 or fewer people to be a small drinking water system (EPA, 2017). In Ontario, SDWSs are defined as systems that make drinking water available to the public and are not connected to a community drinking water system (MOHLTC, 2015). In Ontario, there are over 9000 SDWSs providing drinking water to the public with no connection to a community drinking water system; most are located in rural areas (MOHLTC, 2015; Pons et al., 2014). Examples of SDWSs include municipally owned airports, industrial parks, recreational facilities, community centres, libraries, motels, resorts, restaurants, churches, gas stations, and private cottages on communal water systems (MOHLTC, 2015). As the significant portion of the users are transient populations, it is difficult to get accurate and precise estimates of the percentage of the public using SDWSs. Although community water systems and SDWSs face similar challenges to provide safe drinking water, SDWSs typically have fewer resources to overcome these challenges (Murphy et al. 2016b).

Justice O'Connor (2002a) points out the difficulty of SDWS operation in the provision of safe drinking water as these systems have lower adaptive capacity, and limited financial and human resources as compared to community drinking water systems. Smit and Vandel (2006) define 'adaptive capacity' as the ability of a system to modify or tolerate its characteristics such as staffing and operational processes to cope better with existing or anticipated occurrences or hazards. Pike-MacDonald et al. (2007) and Walters et al. (2012) note the challenge for small water systems to meet the regulatory requirements in the provision of safe drinking water. Although Ontario made commitment to design the regulatory regime for drinking water systems based on the Walkerton Inquiry Report's Multiple-Barrier Approach principles, it is evident that SDWS policy and regulatory arrangements do not reflect this practice. The need for source water protection, the first principle of the Multiple-Barrier Approach, has not been considered for SDWSs.

The current regulatory regime for SDWSs was established only a decade ago when the Ministry of Health and Long-Term Care took over the regulatory role from the Ministry of the Environment and designated Ontario's 35 local public health units as SDWS program administrators. Since the local public health units assumed this responsibility, there has not been an evaluation of the SDWS program.

Sustainability of a water system largely depends on its operational capacity with adequate financial and technical support in addition to the social and environmental dimensions

(National Research Council, 1997). The current policy and regulatory arrangements for SDWSs leave room for improvement to better protect public health. Our study focuses on developing an effective and efficient approach to drinking water safety in SDWSs and argues that the development of a sustainable operation model requires inclusion of SDWS in source water planning.

4.1 Drinking Water Safety

Waterborne illnesses and diseases are ongoing concerns in many rural parts of Canada where most SDWSs are located (Maier et al., 2014; Moffatt & Struck, 2011; Murphy et al., 2016a; Murphy et al., 2016b). The Public Health Agency of Canada estimates 20.5 million cases of Acute Gastrointestinal Illness[6] annually in Canada; there are studies which conclude that small water systems may cause an increased risk of acquiring Acute Gastrointestinal Illness (Murphy, 2016a; Murphy et al., 2016b). According to Schuster et al. (2005), water treatment failure and extreme weather events that affect water sources were the most common reasons for waterborne outbreaks in Canada between 1974 and 2001. As a result of climate change effects and source water contamination, there may be an increased risk for waterborne disease outbreaks from drinking water systems today and in the future.

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[6] Acute gastrointestinal illness (AGI) is a global problem with mortality and morbidity affecting both developed and developing countries. It is caused by a variety of agents, and is frequently transmitted by food or water. Symptoms typically include diarrhea or vomiting, with additional secondary symptoms which frequently include fever, cramps, nausea and headache (Thomas et al., 2008, p.8)

Pons (2015) reports that groundwater is the primary source for 82% of SDWSs in Ontario. There is a common misconception about groundwater being a safe source. Groundwater has several potential contamination sources such as agricultural activities nearby and surface runoff after a heavy rain. According to a comprehensive study (Wallender et al., 2014), untreated groundwater continues to be a significant public health issue as it has been the cause of over 30% of waterborne outbreaks in the United States between 1971 and 2008. Protecting drinking water sources is the first step (Dore, 2015) and most reliable and effective way to ensure the safety of drinking water.

4.1.1 Source Water Protection

Source water protection is defined by the development and utilization of institutional arrangements, such as municipalities assessing drinking water safety risks and working with relevant stakeholders, to minimize or prevent potential pollutants from contaminating water sources that can be used for drinking purposes (Ivey et al., 2006). Protecting drinking water sources constitutes the most effective and efficient means to ensure water safety and requires integration of both water and land use management practices (O'Connor, 2002b; Simms at al., 2010). Several case studies conclude that the cost of treating contaminated water is 30 to 40 times higher than protecting its source from contamination (Simpson, & de Loë, 2014). In addition to being an integral step to protect public health, source water protection is a proactive approach to prevent contamination of source water which results in financial savings in water system operations (Minnes, 2017).

In recent decades, ensuring the safety of drinking water sources has been a widely accepted goal across the world and source water protection strategies are being considered a vital activity. In Canada, institutional arrangements for source water protection vary because there is no federal legislation, and the provincial and territorial governments determine source water protection strategies. Patrick et al. (2013) note that source water protection planning is required in only three provinces, namely, Ontario, Manitoba and Prince Edward Island where other provinces have either discretionary measures or no plans.

Ontario underwent a comprehensive revision of the drinking water management including the development of a source water protection framework after the Walkerton tragedy. The application of Walkerton Inquiry Report's 17 recommendations resulted in the introduction of new legislative documents, which include the *Sustainable Water and Sewage Systems Act*, the *Safe Drinking Water Act*, the *Nutrient Management Act*, and the *Clean Water Act*. The enactment of the *Clean Water Act* resulted in the establishment of source water planning process in the province. Nineteen source protection areas and regions (Appendix B) have been created with a mandate to develop and maintain source protection plans under the legislative oversight of the *Clean Water Act* (Minnes, 2017). SDWSs located across the province with no source water protection planning puts the public at risk of using unsafe drinking water.

The Auditor General of Ontario recently identified several shortcomings of the current source water protection framework, such as exclusion of private household wells actively in use and abandoned wells, potential threats to the Great Lakes, and lack of enforcement activities (OAGO, 2014). Although the Auditor General's report did not specifically mention the exclusion of SDWSs from source water planning as problematic, the comments about private household wells certainly imply the need to establish parameters to protect water wells that supply water to SDWSs. This should be considered a significant weakness of the current source water protection strategy. Ontario's source water protection framework has been successful in protecting water sources of rural municipal systems yet, it does not provide protection for non-municipal water systems such as private household wells and SDWSs (Minnes, 2017). The absence of source water protection puts SDWSs in a disadvantaged position compared to municipal water systems as SDWS owners may lack the capacity to prevent contamination to their water sources. This study discusses the possible consequences of the ongoing exclusion of SDWSs from source water protection planning and investigates the opportunities to develop a sustainable operation model, including source water protection strategies for SDWSs.

The result of inadequately protecting our drinking water sources can be devastating as demonstrated by several contaminated water incidents in Canada and elsewhere. The Walkerton tragedy, an outbreak of gastroenteritis, caused seven deaths and affected over 2300 people as a result of contaminated water consumption from a community drinking water system in the town of Walkerton in 2000 (O'Connor, 2002b). Though not specially linked to a SDWS, this tragedy has been a major turning point in revamping Canada's drinking water safety net whereby municipal water systems are generally considered safer than SDWSs. Most recently, chemical and microbiological contamination of source water in the Flint, Michigan affected 99,000 people between April 2014 and October 2015 (Kennedy et al., 2016; State of Michigan, 2016).

Subsequent to the Walkerton tragedy, the provincial government probed the reasons for such tragedy with a comprehensive investigation, and established a public inquiry led by

Justice Dennis O'Connor. The significance of the Walkerton Inquiry Report stems from the fact that Ontario’s water management has been reshaped based on its recommendations.

4.1.2 Walkerton Inquiry Report

Justice O’Connor released the Walkerton Inquiry Report in two parts in January and May 2002 respectively (O’Connor, 2002a; O’Connor, 2002b) both being relevant to the management of SDWSs including some specific recommendations about them. The first part of the Walkerton Inquiry Report focuses on the circumstances of the tragedy and examines the Ministry of the Environment’s processes for approvals and drinking water system inspections; public health unit accountability and staffing; communication among government agencies; and, water system operator training and certification (O’Connor, 2002b). The first part of the report also provides an overview of the water governance structure at the time with 28 recommendations for better institutional arrangements. Building on the recommendations from the first part of the Walkerton Inquiry Report and adding 93 more recommendations, the second part of the report offers a roadmap for the water governance structure in Ontario in several areas such as source protection, standards and technology, municipal water providers, provincial oversight, small water systems, and First Nations water systems (O’Connor, 2002a).

Justice O’Connor’s 121 recommendations in the Walkerton Inquiry Report established the foundation for Ontario’s new water management framework. The provincial government acted upon each recommendation, enacting many pieces of legislation including the *Safe Drinking Water Act,* the *Sustainable Water and Sewage Systems Act,* *and* the *Clean Water Act;* introducing stringent licencing and accreditation processes; and developing a source water protection framework (Plummer et al., 2010).

The Walkerton Inquiry Report's special section on small water systems recognizes the challenges of operating a SDWS and encourages revamping their water management structure (O'Connor, 2002a). To pursue the Walkerton Inquiry Report recommendations, the government enacted a specific regulation for SDWSs and transferred the responsibility from the Ministry of the Environment to the Ministry of Health and Long-Term Care.

The Walkerton Inquiry Report emphasizes the importance of establishing the Multiple-Barrier Approach to ensure drinking water safety. The Walkerton tragedy, as well as several other waterborne outbreaks, could have been prevented if the Multiple-Barrier Approach principles had been applied to water systems, regardless of whether they are municipal, SDWS or private household wells.

4.2 Multiple-Barrier Approach

The Multiple-Barrier Approach is a combination of procedures, processes, and tools to prevent or reduce the contamination of drinking water from source to the end user (CCME, 2004) and would add value to health risk reduction if applied to SDWS management. The Multiple-Barrier Approach is far more inclusive than older approaches focusing on treatment at source. The Multiple-Barrier Approach has two common forms of application:

- Comprehensive application as described by the Canadian Council of Ministers of the Environment
- Integrated application with a risk assessment focus as introduced by the Walkerton Inquiry Report.

The Canadian Council of Ministers of the Environment's (CCME, 2004) document, '*From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water'* explains the application of the Multiple-Barrier Approach for all stakeholders in the water management sector in Canada. Figure 4.1 shows a summary of the Multiple-Barrier Approach components where the water system is examined in three main sections: protection of the water source, water treatment processes, and the distribution system. In addition, the Multiple-Barrier Approach uses tools and procedures to complement the management and monitoring of the water system, such as public involvement and awareness; legislative and policy frameworks; guidelines; standards and objectives; and research, science and technology (CCME, 2004). The application of Multiple-Barrier Approach concept in a holistic way requires a considerable preparation and commitment from all stakeholders in the provision of safe drinking water. Components of the model should work in harmony to complement each other. As the model demonstrates, water safety issues are often multi-dimensional and require interventions from different stakeholders. Research, science and technology along with public involvement form the foundation of policy and legislative framework development process. The systems' water source, treatment and distribution processes are regulated with the overarching policies and legislative arrangements. The Multiple-Barrier Approach recognizes the system as a whole and establishes criteria to ensure sufficient protective mechanisms are in place.

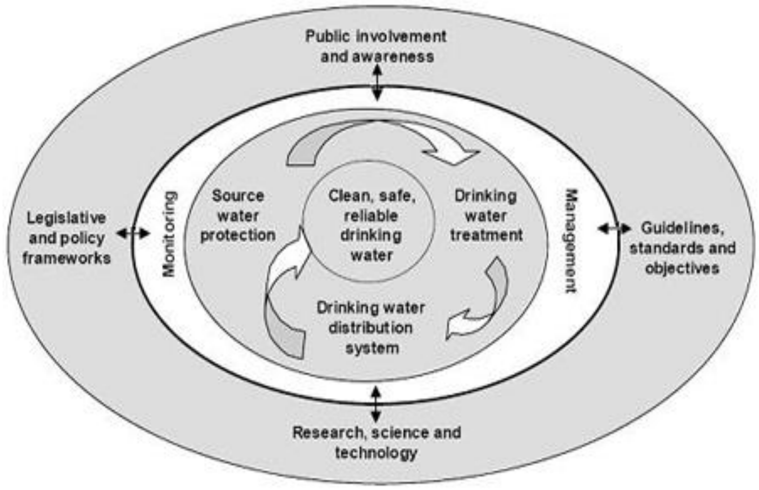

Figure 4.1:
Components of the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach (CCME, 20014, p.16)

The Canadian Council of Ministers of the Environment's definition of Multiple-Barrier Approach offers a viable solution to water systems in all sizes. It is an inclusive model that goes well beyond just engineering solutions to design, operate water systems, going further to combine with social aspects such as public involvement and awareness. The earlier approaches to ensuring water safety were focused on the treatment process; however, recent outbreaks in Canada and elsewhere have proven the necessity to consider several other factors in the provision of safe drinking water (Cool et al., 2010; Murphy et al., 2016b).

Even though the Multiple-Barrier Approach was a known concept among the subject experts, it received both national and international attention after it was addressed in the Walkerton Inquiry Report by Justice O'Connor: "Putting in place a series of measures, each independently acting as a barrier to passing water-borne contaminants through the system to consumers, achieves a greater overall level of protection than does relying exclusively on a single barrier" (O'Connor, 2002a, p.5).

The Walkerton Inquiry Report focuses on some aspects of the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach framework such as assessing the risks to water systems and establishing barriers for those risks. The recognition of risk and hazard identification for present and future operations is a key component of the Walkerton Inquiry Report's Multiple-Barrier Approach. The five barriers the Walkerton Inquiry Report identifies are source protection, treatment, distribution system, monitoring program, and response to adverse conditions (O' Connor, 2002b).

As summarized in Table 4.1, threats to drinking water safety should be identified first to tailor the barriers and later to develop strategies to eliminate or reduce those threats. For some hazards such as pathogens, more than one barrier needs to be established. Recognizing that source water may not be pathogen-free, then an appropriate treatment method should be chosen to eliminate pathogens in the water. Barriers act as critical control points of the overall operation with an end result of eliminating potential hazards using a risk management approach. For example, to eliminate the pathogen regrowth in some systems with distribution lines, maintaining a chlorine residual is a commonly used risk management approach (Silvestry-Rodriguez et al., 2008). Although the Walkerton Inquiry Report recognizes the importance of communication, training and raising awareness, it does not specify them in the Multiple-Barrier Approach context.

Table 4.1: An Example of Risk Assessment in the Walkerton Inquiry Report's Multiple-Barrier Approach (O'Connor, 2002a, p.74)

Hazards	***Barrier***	***Typical Risk Management Approach***

Pathogens, Chemical contaminants, Radionuclides	Source protection	Watershed protection plan, Upgraded sewage treatment, Choice of water source
Pathogens, Disinfection by-products, Chemical contaminants	Treatment	Water quality standards Chemically assisted filtration Disinfection
Infiltration, Pathogen regrowth	Distribution	Chlorine residual, System Pressure, Capital maintenance plan
Undetected system failures	Monitoring	Automatic monitors Alarms and shut-offs Logbooks, trend analyses
Failure to act promptly on system failure Failure to communicate promptly with health authorities and the public	Response	Emergency response plans, Boil water advisories (orders)

Similar to many other waterborne disease outbreaks, lack of training and communication were the leading causes of the Walkerton tragedy (O'Connor, 2002a). Casman et al. (2000) examine risk models for waterborne outbreaks and conclude that communication and training should be the basic parameters in drinking water safety within the frame of the Multiple-Barrier Approach. The Walkerton Inquiry Report demonstrates the integrated application of the Multiple Barrier Approach, yet, the Walkerton tragedy and several other waterborne outbreaks around the world have proven the necessity of a comprehensive approach to water management where different dimensions such as engineering and social aspects are recognized.

The Walkerton Inquiry Report's Multiple-Barrier Approach model describes principles for a day-to-day operation in the provision of safe drinking water but has shortcomings to build an integrated approach for a sustainable operation. Furthermore, a guide to the application of the Multiple-Barrier Approach in different types of water systems has not been developed in Ontario. The policy and regulatory arrangements for public water systems focus on technical guidance and lacks the holistic approach. This study focuses on the development of a sustainable operation model for SDWSs by recognizing the need to create a model underpinned by the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach. The next section examines water management strategies in Canada and elsewhere.

4.3 Drinking Water System Management Programs

Drinking water system management strategies vary significantly in Canada and internationally. Developing and maintaining a sustainable operation in water systems is a key consideration for the provision of safe drinking water for both today and in the future. A drinking water system management framework provides water systems with necessary resources to achieve and maintain compliance with regulatory requirements (EPA, 2003).

In addition, it is important to note the necessity of the social dimension in water management. As such, public awareness should be considered a fundamental piece of any water management strategy (Kot et al., 2015). In Canadian context, Driedger et al. (2014)

argues that the public's trust in public water systems has not been fully restored in Ontario since the Walkerton tragedy. According to Jones et al. (2007), the public's distrust in public water systems as well as consideration of aesthetic aspects of water causes the increased use of bottled water. Another Canadian study (McLeod et al., 2014) also confirmed the finding that people who believe the municipal water is not safe to drink, use bottled water as their drinking water source. The Canadian Council of Ministers of the Environment's guide brings a distinct and holistic approach to the application of Multiple-Barrier Approach and water system management with the recognition of social aspects such as public involvement and awareness. Although the Canadian Council of Ministers of the Environment offers a viable alternative to establishing a collaborative water management strategy based on the Multiple-Barrier Approach framework, Ontario has adopted the limited application of the Multiple-Barrier Approach with risk assessment focus as introduced in the Walkerton Inquiry Report.

Ontario's community drinking water systems are mandated to comply with the Drinking Water Quality Standard (MOECC, 2017). The owners of community drinking water systems report their systems' operational process, management and delegated responsibilities to the Ministry of the Environment and Climate Change for approval to start and maintain their operation. Ontario's Quality Management Standard ensures compliance in various aspects of the water system operation by focusing on the technical components and delegated responsibilities for regular operation (MOECC, 2015), yet it lacks social dimensions such as community capacity and safe drinking water awareness. Source water protection plans, complementing the water management framework of Ontario's community water systems, have been successfully implemented.

4.3.1 Management of Small Drinking Water Systems

In recent years, there has been increased attention to the management strategies for small drinking water systems across the world. The World Health Organization (2012) promotes a comprehensive guide for small drinking water supplies and encourages the application of water safety plans for the provision of safe drinking water. The use of water safety plans is considered a proactive approach to identifying and managing the potential risks and taking precautions as necessary (WHO, 2012). The World Health Organization defines the following six tasks to develop and maintain a water safety plan (WHO, 2012, p.9):

- Engage the community and assemble a team
- Describe the community water supply
- Identify and assess hazards, hazardous events, risks and existing control measures
- Develop and implement an incremental improvement plan
- Monitor control measures and verify the effectiveness of the water safety plan
- Document, review and improve all aspects of water safety plan implementation

Alberta is the only Canadian jurisdiction to follow the World Health Organization recommendations for developing water safety plans. Alberta's model mainly focuses on source water, treatment, storage and distribution aspects of the water supply system (Government of Alberta, 2015). By requiring the development of water safety plans, Alberta is ahead of most of other provinces with stricter criteria for water system operation. Alberta's model does not address the community engagement and awareness aspects of the water management as well as operator training component. Table 4.2 provides an overview of the different approaches around the world to manage small drinking water systems.

Table 4. 2: International Management Strategies for Small Drinking Water Systems

	New Zealand	European Union	The United States	Australia	World Health Organization
Source water	Detailed information on water sources and protection strategies	Limited guidance on source water protection	Focus on source water management strategies	Comprehensive assessment of the source water	Recognition of source water and potential contamination sources
Operational guidance	Guidance on treatment process and distribution system	Limited information on the treatment and distribution system	Offers operational guidance for the system owners and operators	Detailed operational guidance	Comprehensive guidance on operational processes
Training	No training requirement	No training requirement	No training requirement	Training requirement for the owner/ operator	Limited discussion regarding training needs
Risk assessment	Requirement for water safety plan with risk assessment				

	Comprehensive risk assessment	Risk assessment of the source water and system operation	Risk assessment using critical control points	Comprehensive risk assessment by ranking each potential hazard	
Financial planning	No discussion on financial aspects of the system operation	No discussion on financial aspects of the system operation	Consideration of financial planning	No discussion on financial aspects of the system operation	Recognition of financial security to operate safely

New Zealand has developed a model similar to the World Health Organization's approach to manage small drinking water systems. As such, water safety plans form the foundation of the water management framework where their approval is required to operate a water system (MOH, 2017). The major shortfall of New Zealand's framework is the exclusive focus on the technical and environmental parameters where community engagement processes, training opportunities and financial planning are not fully taken into consideration. The use of water safety plan has similar approach to the Walkerton Inquiry Report's Multiple-Barrier Approach framework where risk assessment is the main theme.

The European Union, with 65 million residents using small drinking water systems, also recognizes the World Health Organization's approach to the provision of safe drinking water in small drinking water systems, yet utilizes a different model called 'Framework for Action for the management of small drinking water supplies' (European Commission, 2014). The Framework is composed of four segments (European Commission, 2014):

- Duty to keep and maintain a register of water supplies
- Duty to record certain information in the register
- Duty to risk assess
- Reporting

The European Union acknowledges the challenges of small drinking water system operation and therefore establishes a system to ensure these systems are kept under the registry and public health officials are available for risk assessment when needed (European Commission, 2014). The European Union framework is quite similar to Ontario's current water management strategy for SDWSs. The European Union strategy lacks several critical components such as training requirements, source water protection, financial planning and community awareness. Since 2011, Iceland transitioned to a new national water management model with the use of water safety plans as introduced by the World Health Organization and accomplished a 14% reduction of diarrheal illnesses in regions where the water safety plans were in place (Gunnarsdottir,et al., 2015).

In the United States, the Environmental Protection Agency promotes the utilization of 'Simple Tools for Effective Performance' mainly for small drinking water systems (EPA, 2003). The Simple Tools for Effective Performance framework highlights the importance of developing strategic plan for the water systems and consists of seven steps. The Simple Tools for Effective Performance framework uses the foundational pillars of the Multiple-Barrier Approach except the training requirement and community engagement. Although the Environmental Protection Agency's framework briefly discusses the source water protection concept, there is not enough emphasis on the importance of source protection plans and being proactive to protect the water source.

In addition to the Environmental Protection Agency's approach, each State has the option to develop its own water management program. For example, the State of Washington requires the development and utilization of Small Water System Management Programs by the owners of non-community public water systems (Washington State, 2017). The program is comprised of the following five sections: Information and records, water quality, system operations, financial planning, and next steps (Washington State, 2017). Under the water quality section, there is focus on developing a source water protection plan for the water system (Washington State, 2017).

Australia's strategy to managing small drinking water systems seems to be more participatory and holistic compared to other international strategies discussed earlier. The Australian Drinking Water Guidelines aims to provide a framework for drinking water systems considering scientific, economic, social and cultural aspects (NHMRC, & NRMMC, 2011). The Australian Drinking Water Guidelines, branded as 'the Framework', provides a structured and systematic approach from source to tap to ensure the provision of safe drinking water (NHMRC, & NRMMC, 2011). There are 12 elements that constitute the skeleton of the Framework (NHMRC, & NRMMC, 2011). The Framework concepts are similar to the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach principles by including societal factors such as community involvement and awareness.

According to Sinclair and Rizak (2004) “the Framework integrates quality and risk management principles, and provides a comprehensive, flexible, and proactive means of optimizing, drinking-water quality and protecting public health” (p. 1567). One shortcoming of the Framework is that there is no mention of the importance of adequate financial resources for system operation.

The recognition of the social components of water management, such as community engagement and user awareness, contributes to ensuring the provision of safe drinking water as documented in several cases, including the Walkerton tragedy. Although the World Health Organization proposes the use of water safety plans in water systems similar to Ontario’s SDWSs, the incremental improvement plan in the World Health Organization’s approach conflicts with the operation model for SDWSs. The Small *Drinking Water Systems Regulation* (Government of Ontario, 2013), mandating the SDWS operation, requires approval from the regulator that the system meets all of the legislative clauses before commencing the operation and at any given time when in operation (Government of Ontario, 2013), therefore incremental improvement plans might result in operation without full compliance with the regulations.

Drinking water management strategies across the world demonstrate different approaches to the provision of safe drinking water and prove that one-size-fits-all approach is not suitable for developing water management models.

Ontario has shown a considerable effort to modernize the water management practices since the Walkerton tragedy. Given the success to establish a regulatory framework for Ontario’s SDWSs over a decade ago, the current SDWS policy and legal framework needs revision with the light of successful water management strategies applied in other jurisdictions. The application of the Multiple-Barrier Approach as introduced by the Canadian Council of Ministers of the Environment offers a viable tool to examine the current gaps and make recommendation to enhance the SDWS program.

4.4 Drinking Water Management in Ontario

Canada’s water management is decentralized and fragmented where different levels of governments take responsibilities and create governance gaps (Bereskie et al., 2017), all of which come into focus in relation to small drinking water systems**.** The Federal Government provides guidance on drinking water quality parameters (Health Canada, 2017) but does not mandate the management of water systems. Furthermore, the water quality standards developed by the Federal Government is not enforceable where provinces and territories which regulate the public water systems have the option to adopt them or not (Bereskie et al., 2017).

The Ministry of the Environment was the only regulatory agency for Ontario’s water systems until 2008 when the Ministry of Health and Long-Term Care took over the regulatory role of SDWSs which has the following key implications: Better coordination of the program as the majority of SDWSs such as restaurants, golf courses and some churches have already been inspected by public health unit staff under the *Health Protection and Promotion Act* regulations; public health units have many more local offices across the province compared to Ministry of the Environment regional offices which eased access to these systems by public health units.

Today, the Ministry of the Environment and Climate Change[7] and the Ministry of Health and Long-Term Care are responsible for overseeing public drinking water systems in the province. Ontario's 35 public health units regulate SDWSs by representing the Ministry of Health and Long-Term Care on the local level. The Ministry of the Environment and Climate Change regulates community water systems where local municipalities are often designated as water system owners with legal responsibility to supply safe drinking water to their residents. The quality and safety of drinking water in Ontario's municipal water systems is overseen by the Ministry of the Environment and Climate Change through the *Safe Drinking Water Act*, *Ontario Regulation 169* (Water Quality Standards), and Ontario Regulation 170 (Drinking Water Systems) (DWO, 2015). *The Drinking Water Quality Standard* (Standard) is the operational guidance document for municipal water system owners created under the authority of the *Safe Drinking Water Act* (MOECC, 2017). The Standard requires each water system operator to develop a Quality Management System (MOECC, 2017). All of the policy and regulatory arrangements in Ontario's water management have been developed based on the Walkerton Inquiry Report's Multiple-Barrier Approach principles (MOECC, 2017).

As per the Walkerton Inquiry Report recommendations, the Ontario government revoked *Ontario Regulations 459 and 505* by replacing them with a more comprehensive legislative document, *Ontario Regulation 252* to regulate SWDSs (Region of Waterloo, 2008). With the regulatory agency change in 2008, SDWSs are currently mandated by

[7] The government added "Climate Change" to the name of the Ministry of the Environment in June 2014.

Ontario Regulation 319, *Small Drinking Water Systems Regulation*, under the *Health Protection and Promotion Act* (Government of Ontario, 2013).

Table 4.3 shows a comparison between municipal water systems and SDWSs. As summarized in the table, management approach to ensure the provision of safe drinking water for municipal water systems is considerably more stringent than the one for SDWSs. Municipal water systems benefit from source water protection which is considered the first and foremost important step of ensuring safe drinking water. On the other hand, SDWS water sources may be prone to any contamination source including agricultural or industrial activities in the neighbourhood. Operator training for municipal water systems is a structured model based on the system type where recertification is required based on the system classification. The regulation for the SDWSs offers neither a detailed description for the training nor recertification. Municipal water systems are being tested more frequently than SDWSs for bacteriological contaminants such as total coliforms and *Escherichia coli (E. coli)* (DWO, 2015; Government of Ontario, 2013). Furthermore, chemical testing requirements are not spelled out clearly in SDWSs. Lastly, municipal water systems report their adverse water quality incidents to two agencies to receive guidance, Ministry of the Environment and Climate Change and Ministry of Health and Long-Term Care, where SDWSs are only required to report to the Ministry of Health and Long-Term Care.

Table 4.3: Comparison between Municipal Water Systems and SDWSs

	Municipal Water Systems	SDWSs
Regulatory oversight	MOECC	MOHLTC

Legal framework	SDWA, Reg. 170	HPPA, Reg. 319
Source Protection	In effect	No protection
Operator training definition	Defined, structured based on the system size	No clear definition
Reporting AWQIs[8]	Central MOECC reporting line, public health	Public health
Source Protection	In effect	No protection
Operator training	Defined, structured based on the system size	No clear definition
Sampling	Regular bacteriological ad chemical testing	Regular chemical testing

MOECC: Ministry of the Environment and Climate Change; MOHLTC: Ministry of Health and Long-Term Care

Approximately 80% of Ontario's population uses community drinking water systems to access safe drinking water, whilst 20% rely on non-community drinking water systems (Bereksie et al., 2017; Pons et al., 2014). The Ministry of Health and Long-Term Care's local service delivery agencies, public health units, regulate SDWSs and also offer guidance for private household well owners (Pons et al., 2014). Our study focuses on small non-community drinking water systems that fit the definition of a SDWS under *Ontario Regulation 319*, also known as 'Small Drinking Water Systems'.

[8] Adverse Water Quality Incidents (AWQIs) are documented when a water sample test result does not meet the regulatory standards indicated for that test or the water system may not be able to supply safe drinking water (MOHLTC, 2009).

4.4.1 Overview of the Current Policy and Legal Framework for Ontario's Small Drinking Water Systems

The current SDWS policy and legal framework was established in 2008 and since then, Ontario's public health units have been working with SDWS owners and operators to ensure the provision of safe drinking water. The current policy and legal framework for SDWSs has many strengths. The *Ontario Regulation 319,* recognizes the necessity for a customized approach, which requires a site-specific risk assessment for each SDWS (Government of Ontario, 2013). The Regulation also provides detailed guidance on operational checks, sampling, and corrective action steps during adverse water quality incidents (Government of Ontario, 2013). As local public health units cover the entire province with many local offices, designating them as the regulator offers easy access to the regulatory agency for SDWS owners and operators. The Regulation clearly spells out the role and responsibilities of SDWS owners and operators for operations and treatment to corrective action steps (Government of Ontario, 2013).

On the other hand, the recent analysis of SDWS data obtained from Wellington-Dufferin-Guelph Public Health and interviews with SDWS owners in the Wellington-Dufferin-Guelph region raised several important issues in the current institutional arrangements that might put the provision of safe drinking water from SDWSs at risk, including lack of training opportunities for the owners and operators (Sekercioglu et al., 2018a; Sekercioglu et al., 2018b). According to a recent study (Pons, 2015), the percentage of Ontario's SDWSs using a treatment system and employing trained operators is significantly low. Furthermore, the treatment system in some SDWSs might not adequately eliminate pathogens such as *E. coli* (Pons, 2015) which might put the SDWS users at serious health risk. The current policy and legal measures do not provide solutions to the drawbacks of the current SDWS program.

The shortcomings of the current SDWS program policy and legal framework can be summarized in four main areas: Source water, operations, communication, adverse water quality incidents.

Source water: SDWSs do not benefit from Ontario's source water protection safety planning. When the province made significant improvements to source water protection pursuing the Walkerton Inquiry Report recommendations, SDWSs were not included in the planning of source protection areas. Furthermore, *Small Drinking Water Systems Regulation* does not have a section to provide direction on source water management.

Operations: Lack of training and funding opportunities create inconsistency and pose challenges for the operation of SDWSs. There is no official operator training offered by the regulatory agency and the training requirements are not specified in the Regulation (Government of Ontario, 2013). The Walkerton Clean Water Centre recently developed a course for SDWS operators (WCWC, 2018); however, accessibility and cost for this opportunity continue to be a challenge for system owners and operators (Sekercioglu et al., 2018b). The need for financial support to maintain the operation of some SDWSs such as the water testing costs, treatment equipment, and the hiring of trained operators has been a concern for several SDWS owners (Sekercioglu et al., 2018b). The current SDWS policy and legal framework does not provide any guidance to reduce or remove the financial barriers.

Communication: The dialogue between SDWS owners themselves as well as between the SDWS owners and the regulatory agency is neither consistent nor sufficient (Sekercioglu et al., 2018b). The current policy and legal framework lacks the social dimension of water management and does not facilitate networking between the owners and operators of SDWSs. Sections relevant to increased communication and creating a sense of community among SDWS owners and operators in respective public health unit jurisdictions should be included in the new model.

Adverse Water Quality Incidents: As defined by Justice O'Connor (2002a), response to adverse water quality incidents is an integral step of the Multiple-Barrier Approach, yet SDWSs are not required to have an Emergency Response Plan. Although there is a corrective action process in place for the SDWS owners and operators to follow during adverse conditions, it is often limited to seeking guidance from public health officials (Sekercioglu et al., 2018b). The Emergency Response Plan processes enable the identification of water system vulnerabilities and make enhancements to establish emergency procedures (INAC, 2014). The utilization of an Emergency Response Plan and the creation of networking opportunities where common challenges are discussed may result in improving relationships and support between water system owners (INAC, 2014).

With new and emerging threats to safe drinking water access, such as extreme weather events, effective and efficient interventions to enhance the current water management regime for SDWSs are required. There is an evident need to revamp the SDWS program with collaborative water management strategies.

4.5 Revised Model for Ontario's Small Drinking Water System Program

As discussed in the previous sections, there are considerably different strategies to managing water systems in Canada and across the world with need to establish a collaborative framework based on the Multiple-Barrier Approach principles. SDWSs are mostly located in rural areas with limited financial and operational capacity, and therefore, they require special consideration to ensure the provision of safe drinking water.

As the regulatory agency, the Ministry of the Environment and Climate Change until 2008, and later the Ministry of Health and Long-Term Care has not developed a drinking water system management framework for SDWSs. The current legislation, the *Small Drinking Water Systems Regulation*, mainly offers operational guidance with sections on treatment, operational checks and testing, and corrective actions (Government of Ontario, 2013). The policy documents provide guidance on risk assessment procedures and testing but are mostly limited to the interpretation of the Regulation (MOHLTC, 2015).

Our study utilizes the concepts presented in the Canadian Council of Ministers of the Environment's Guide and the Australian Drinking Water Guidelines and develops a water management model to improve the current policy and legal framework for SDWSs. Our model (Table 4.4) consists of five components with action items under each component and uses the Canadian Council of Ministers of the Environment's Multiple-Barrier Approach framework as the foundational standard.

Table 4.4: Sustainable SDWS Operation Model

Components	**Content**
Component A: Commitment to providing safe drinking water	• Enacting regulations and policies for sustainable SDWS operation • Securing adequate funds for operation • Developing Quality Improvement Plans
Component B: Assessment of the system and source water	• Conducting source water risk assessment • Assessing the water quality • Identifying potential hazards
Component C: System operation and operator training	• Ensuring the SDWS operation is compliant with the Regulation • Utilizing certified and suitable equipment with regular maintenance • Training SDWS owner/operator for best operational practices
Component D: Management of incidents and emergencies	• Establishing corrective action procedures • Preparing Emergency Response Plan
Component E: Communication and raising awareness	• Connecting with stakeholders • Networking with other SDWS owners & operators • Increasing community/user awareness

Component A: Commitment to providing safe drinking water

To create an efficient and effective model, water system owners and operators, regulators, and other stakeholders need to be committed to the provision of safe drinking water. Developing policies and legislative documents that meet the SDWS users' expectations and reflecting best practices in water management ensures the protection of public health (CCME, 2004). The most integral step to show commitment to providing safe drinking water is enacting regulations and policies to accomplish a sustainable operation based on the Multiple-Barrier Approach.

Several SDWSs have been achieving the highest possible levels of compliance, while keeping the costs and financial burden as low as possible. More affordable operator training opportunities and reduced water testing costs have the potential to increase compliance with the regulatory requirements (Sekercioglu et al., 2018b).

Quality Improvement Plans should be in place for the sustainability of the system and can include the following areas: Capital works, training, enhanced operational procedures, corrective action process, communication and reporting (NHMRC, & NRMMC, 2011). Developing Quality Improvement Plans for SDWSs will maintain the level of commitment to the overall goal, protecting public health.

Component B: Assessment of the system and source water

SDWS assessment is a fundamental step to developing effective strategies for prevention and control of potential hazards (NHMRC & NRMMC, 2011). Water quality may be affected in three areas: 1) the source water; 2) the water system where the treatment process takes place; and 3) the distribution system where the water goes through to the end user. Each critical control point that might affect drinking water safety should be marked on a flow diagram and assessed periodically (NHMRC & NRMMC, 2011). Ontario has a comprehensive source water protection planning process and SDWSs can benefit from this already existing structure. Identifying potential hazards and understanding the water quality under normal operation conditions complements the efforts to keep drinking water safe.

Component C: System operation and operator training

The effectiveness of barriers to prevent potential hazards depends on the success of day-to-day operations in a SDWS. The owners should have the legal liability to use of high quality water system equipment and ensure all adjustments and operational checks of the equipment are performed regularly by trained operators. Record keeping and documentation are the responsibility of the operator as well (NHMRC & NRMMC, 2011).

The SDWS owner and operator training is a key activity to accomplish the provision of safe drinking water. Only a trained owner and operator can ensure compliance with the regulatory requirements. Subsidies for operator training and water testing would help relieve some of that financial stress that most SDWS owners experience, especially the systems that are owned and operated by not-for-profit organizations

The utilization of Emergency Response Plans by trained owners and operators would support public health officials in addressing issues during adverse water quality incidents, since each SDWS has a unique setup and can continue to operate based on individual risk assessment to respond to possible adverse water quality incidents.

Component D: Management of incidents and emergencies

The Small Drinking Water Systems Regulation gives directions to address the management of incidents. Overall, the process to rectify adverse water quality incidents is well-defined with the exception of a source water contamination scenario (Government of Ontario, 2013). The gap in the current regulatory framework regarding the absence of Emergency Response Plans may increase the risk of unsafe drinking water for the SDWS users. There are several types of incidents such as power outage, source water contamination, mechanical failures, where Emergency Response Plans can be utilized in a timely manner (CCME, 2004). In addition, reaching out to the public and raising awareness on drinking water safety enables an effective advocacy for the current challenges in the provision of safe drinking water in SDWSs.

Component E: Communication and raising awareness

The communication among SDWS owners as well as between SDWS owners and the regulatory agency is neither consistent nor sufficient (Sekercioglu et al., 2018b). Our framework highlights the importance of enhancing dialogue between stakeholders by organizing regular meetings to share updates and introducing local SDWS owners and operators to each other. To increase user awareness, the SDWS owners may develop standardized procedures for the notification of adverse water quality incidents that are available for use when necessary (CCME, 2004).

4.6 Discussion and Conclusion

SDWSs are an integral part of public water systems annually impacting thousands of people, but at least two key challenges remain. Now that a decade has passed since the transfer of the SDWSs' regulator role from the Ministry of the Environment and Climate Change to the Ministry of Health and Long-Term Care, it is an opportune time to review the SDWS program and propose some changes to enhance the current policy and regulatory regime. Ontario's 35 public health units are reasonable choice to administer the SDWS program at the local level since they cover the entire province and each health unit is individually responsible for serving the population within its geographic border. Although the SDWS program had some successes, such as the completion of site assessments for over 9000 SDWSs in a considerably short period of time and strong local representation of the program by public health units; it has presented unique challenges related to water safety and communicating with owners and operators. The current policy and regulatory arrangements are not adequate to rectify these issues.

Access to safe drinking water is considered a human right (United Nations, 2010). From a global perspective, safe water needs to be pathogen free, aesthetically acceptable, physically accessible, and affordable (Scanlon et al., 2004). Different water management models in Canada and around the world aim at addressing not only today's issues but also the future emerging problems as well. Ontario's SDWSs experience unique challenges to ensure the provision of safe drinking water for their users. Without addressing the current policy and regulatory gaps, these systems might pose a considerable risk to public health.

The Multiple-Barrier Approach has different applications. In some cases, it is used to analyze the water system to establish barriers based on identified hazards, and in other applications, it acts as a facilitator to form of a holistic water management framework. Our study uses the latter application to create a model where technical, environmental, financial, human and social aspects are recognized in harmony. Our model was designed to be accessible by SDWS stakeholders such as operators, suppliers and regulators, and also be flexible enough to accommodate system specific characteristics. With the recognition of considerable differences among SDWSs, our adaptive model is built on five basic pillars to support both policy makers and SDWS owners.

Although the current SDWS program has strengths, namely, the requirement of a site-specific risk assessment and detailed operational guidance regarding sampling and corrective action processes, there are significant gaps that need to be addressed to run a more efficient and effective program. Our model addresses the areas that need more attention for today, and in the future, such as protecting source water, financial stability, enhanced communication and increased awareness. Future research could be done to investigate the potential to increase collaboration between the Ministry of the Environment and Climate Change and the Ministry of Health and Long-Term Care, as the two regulatory bodies responsible to ensure safe drinking water to Ontario residents.

A sustainable operation model for SDSWs based on the Multiple-Barrier Approach framework addresses the shortcomings of the current water management framework for SDWSs and offers a viable strategy to establish an operation with collaborative approach. After the Walkerton tragedy, Ontario has come a long way in improving the water regime. With emerging challenges including climate change effects, there is a significant need to revamp the SDWS program to maintain the commitment to provide safe drinking water.

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CHAPTER 5

Summary Discussion and Conclusions

Introduction

The two main objectives of this thesis were to examine the present and future challenges of Ontario's Small Non-Community Drinking Water Systems (SDWSs) in the provision of safe drinking water and to develop a sustainable operation model for them. The research utilized both qualitative and quantitative methods, and yielded fruitful results. Although there have been significant improvements regarding the water management in Ontario since the Walkerton tragedy in 2000, the administration of the SDWS program presents challenges in the provision of safe drinking water, specifically with the consideration of emerging issues such as climate change.

Key Findings

The research investigated the relationship between operational characteristics of SDWSs and adverse water quality incidents, and concluded that the presence of operator training, an upstream behavioural determinant, significantly reduced the incidence of adverse water quality incidents in SDWSs. The high percentage of SDWSs with no treatment, lack of interest in testing for chemical parameters, and sub-optimum source water protection awareness are potential areas for improvement to ensure the provision of safe drinking water from these systems.

The results of the in-depth interviews with the SDWS owners indicate that they are aware of the financial and non-financial consequences of an adverse water quality event, but nevertheless, they believe that they have not been offered opportunities to receive adequate training on best operational practices and assessing potential threats to their water source. On a positive note, training opportunities initiated by the regulatory agency with a reasonable cost have the potential to gauge a lot of interest. The results of the study demonstrate the financial challenges experienced by some of the SDWS owners trying to meet the operational requirements including but not restricted to regular water testing. The regulatory agency, Ministry of Health and Long-Term Care, should establish mechanisms to provide financial relief which may include providing subsidy on water testing and low-cost training opportunities. One particularly interesting result of this study is that the SDWS owners feel isolated, mainly for the following two reasons:

- There is a certain level of disconnect as they do not receive regular communication from the regulatory agency

- They lack of a sense of community among the SDWS owners in the same region. This community or networking could have multiple positive impacts including sharing knowledge and increasing social capital generally.

The study results reveal the method of communication preferences that may assist the regulatory agency in establishing new mechanism to stay connected with the SDWS owners. There are a considerable number of SDWS owners who prefer to receive traditional mails from the regulator as the main communication method while others consider electronic mails as preferred mode of communication.

One of the major gaps in the current SDWS program is the fact that SDWSs do not benefit from Ontario’s source water protection planning. When the province made significant improvements to protect water sources of community drinking water systems based on the Walkerton Inquiry Report recommendations, SDWSs were not included in the planning of source protection areas. Although all of the province’s 19 source protection plans have been approved by the Ministry of the Environment and Climate Change and implemented since 2016, there has been no advocacy to consider the inclusion of SDWSs to the province’s source water protection framework.

Our revised operation model for SDSWs is based on the Multiple-Barrier Approach framework and is composed of the following five pillars:

- Commitment to providing safe drinking water
- Assessment of the system and source water
- System operation and operator training

- Management of incidents and emergencies
- Communication and raising awareness.

With collaborative approach, our model addresses the shortcomings of the current water management framework for SDWSs and offers a viable strategy to establish a sustainable operation model for Ontario's SDWSs. With emerging challenges such as climate change effects, there is a significant need to establish a sustainable operation model for the SDWS program to maintain commitment for the provision of safe drinking water for Ontarians.

Our research provides unique insight into the SDWS owners' risk perceptions and current operational challenges. Several components of the proposed operation model may be applied without significant financial or logistical arrangements. Although our research focused on Southern Ontario's SDWSs, the findings are broadly applicable in other areas and jurisdictions, including First Nations communities.

5.1 Limitations of the Study

There were some limitations of the study that should not however undermine the findings. The study involved secondary analysis of the existing dataset therefore the number of variables was limited to the information collected for this database. A variable that would be useful to include was risk category. For example, a comparison between risk groups could provide insight about the relationship between the level of risk and experiencing adverse water quality incidents. The definition of adverse water quality incident is narrow in that we defined incidents as events with positive total coliforms and/or *Escherichia coli (E. coli)* test results as our dataset did not have consistent information for other conditions that may be classified as an adverse water quality incident. That said; presence of total coliforms in water sources is considered as one of the best pathogen indicators (Locas et al., 2007). In addition, the dataset did not provide information regarding the timing of the adverse water quality incidents and when the operator training was received.

The results of our study may not be applicable to all regions of Canada as well as northern parts of Ontario, but the research region, Wellington-Dufferin-Guelph is centrally located in southern Ontario with similar demographics and rural urban variations to other parts of southern Ontario.

5.2 Recommendations for Future research

Further research is needed to explore the determinants of adverse water quality events with total coliforms and/or *E. coli* as well as other adverse water quality incident events such as treatment system failures, structural deficiencies, source water contamination and exceeding chemical parameters. Examining other upstream behavioural determinants within the context of environmental and societal norms will provide a deeper understanding of the current challenges of SDWSs in the provision of safe drinking water.

Exploration of the factors associated with the adverse water quality events will require a prospective well-designed and well-conducted study with a larger dataset with a possibility of linking records from several databases to retrieve complete information about SDWSs. The Ministry of Health and Long-Term Care collects SDWS data from 36 public health units in the province. Another potential database with considerable information about the history and conditions of water source for the majority of SDWSs is ‘Well Records’ administered by the Ministry of the Environment and Climate Change (MOECC, 2018).

It would be timely for the regulatory agency to develop effective communication strategies to support the owners and operators. The feeling of isolation is one of the key findings of the study and the reasons and possible solutions should further be investigated. Surveying the SDWS owners to gain more insight about their communication preferences and other program needs would be timely. Lastly, investigations of how other jurisdictions deliver customized and affordable training opportunities, especially exploring the opportunities to deliver services in northern parts of the province, will be key for success in increasing the awareness and knowledge in the provision of safe drinking water.

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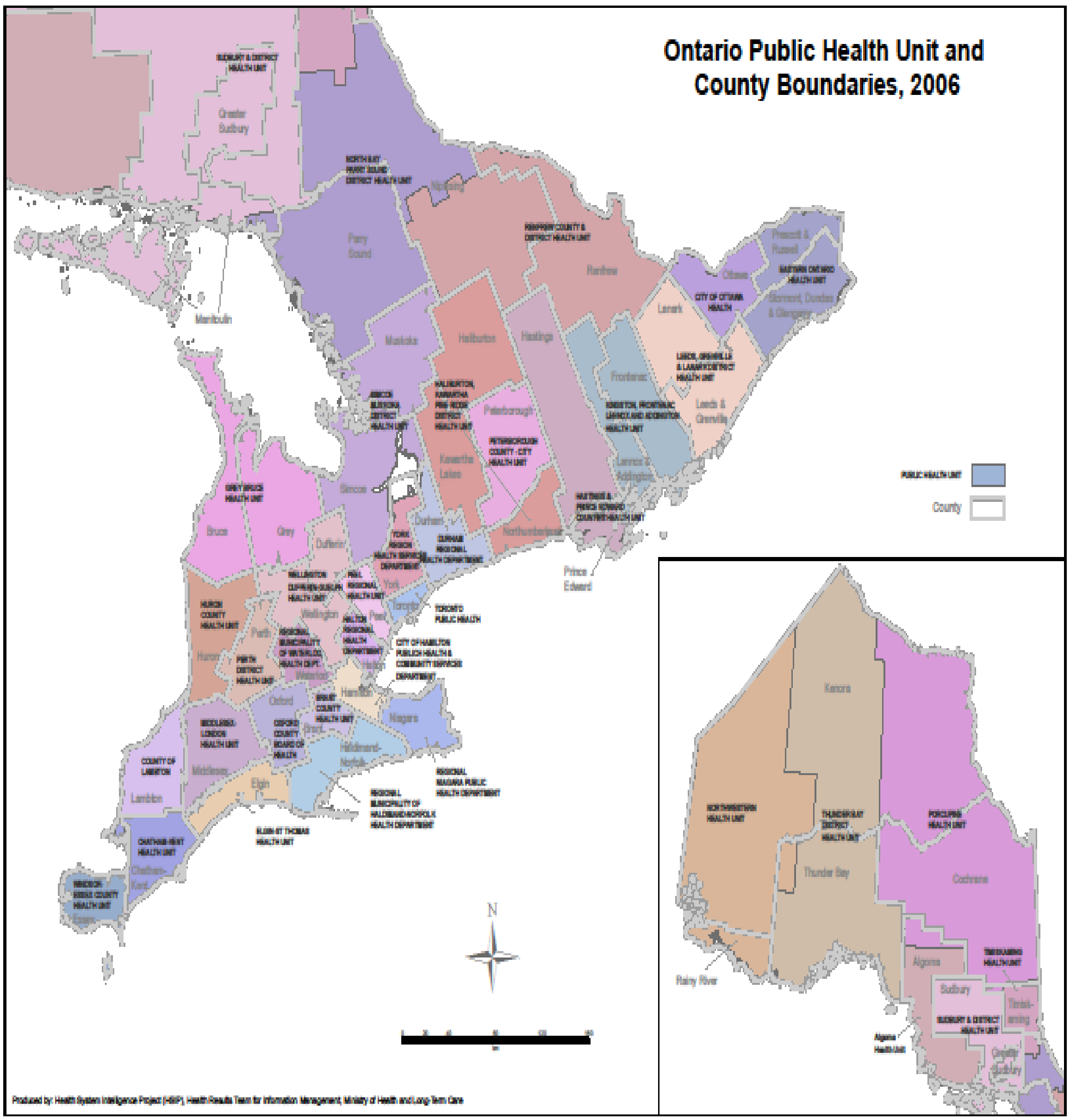
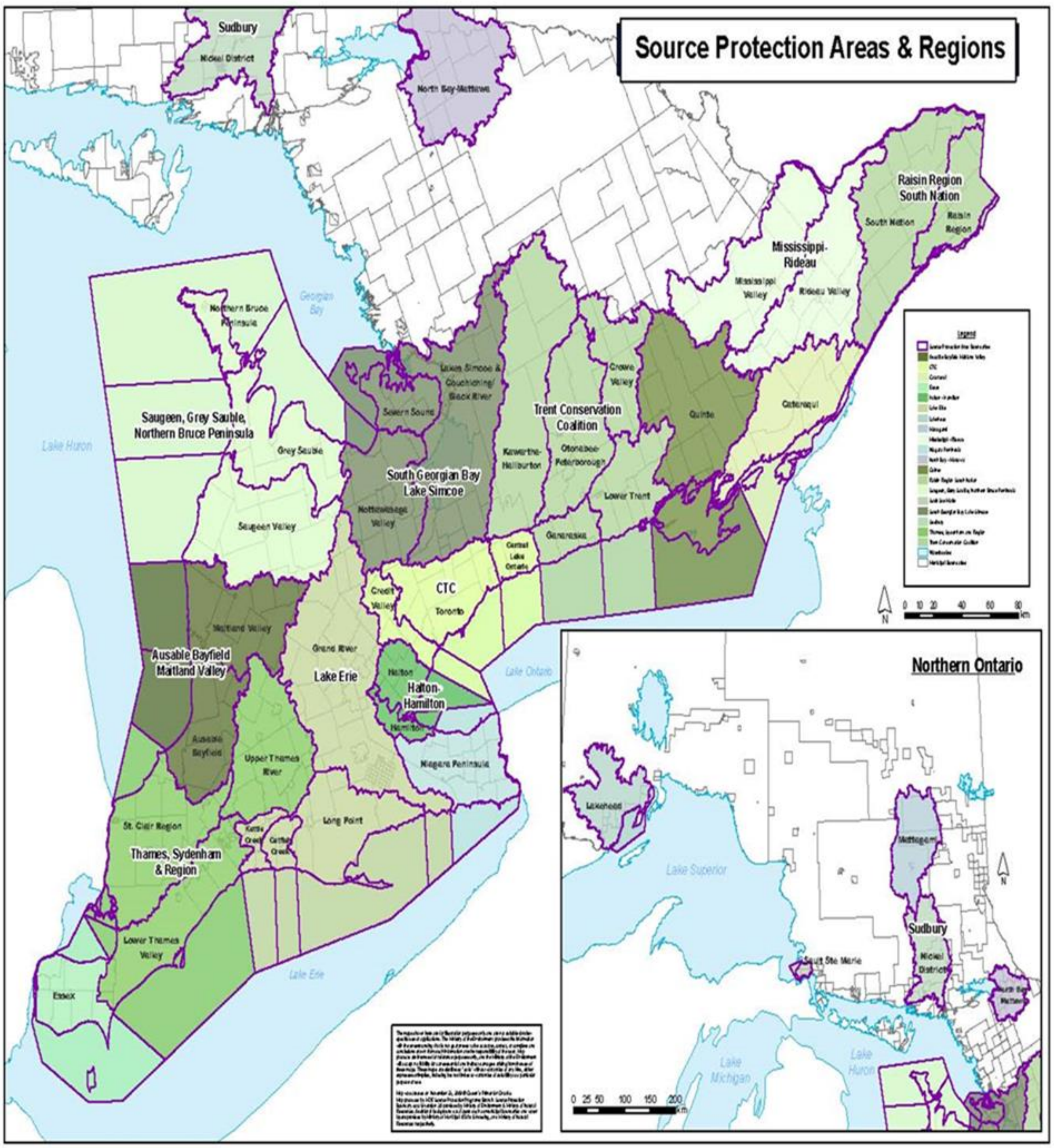
Appendix A

Ontario's Public Health Units (APHEO, 2018)



Appendix B

Ontario's Source Protection Areas and Regions (CTC Source Protection Region, 2018)



Appendix C

Information Letter

Information Letter

October 2016

Study Title: Ontario's Small Non-Community Drinking Water Systems: Risk Perception and Communication Relating to Drinking Water Safety

Principle Investigator: Dr. Jerry White, Department of Sociology,

Dear Sir/Madam:

I am Fatih Sekercioglu, a PhD candidate under the supervision of Dr. Dan Shrubsole in the Department of Geography and Dr. Jerry White in the Department of Sociology at Western University. We are conducting a study to examine awareness, perception and communication of drinking water safety risk in small non-community drinking water systems (SDWSs). I am writing to invite you to participate in this study.

If you agree, you will be asked to participate in a face-to-face or telephone interview with me at a time and place that is convenient for you. You will receive a telephone call from the primary researcher within the next 4 weeks to identify your interest in this study.

My questions will touch upon your experience as a SDWS owner as well as your risk awareness and perception regarding the operation of your SDWS.

Some example questions are as following:

- How would you characterize the water system you have responsibilities towards? Describe some of the challenges of managing your system
- Please explain the importance of regularly testing your SDWS?
- What do you think would be the best way to communicate with SDWS owners about how to manage their SDWS to minimize health risks?

The interview should take at most 1 hour to finish, depending on how much you like to talk about these issues. The interviews will be audio recorded. While there are no risks or harms, there are potential benefits the study results such as raising awareness of providing safe drinking water. If you would like to discuss this, or any other risks you perceive to be associated with your possible participation in this study, please do not hesitate to contact one of the research team members.

The results will be presented in aggregate form and no personal identification information will be used in any report or publications. The information collected (names, positions, aliases, interview transcripts) will be used for purposes of the study only. It will be of paramount importance to maintain your confidentiality, and to reduce the likelihood that you would be identifiable in the results of this research.

All personal information collected for the study will be kept confidential, encrypted if identifiable, and stored in password protected computer software programs or kept in a secured cabinet... All information will be destroyed no later than five years after completion of the study using data destruction tools. No other individual or agency will have access to this information except for me, Dr. Dan Shrubsole and Dr. Jerry White.

In order to ensure your ideas are interpreted correctly, the member checking process will be utilized where you will be given the opportunity to look at the preliminary interpretations and give me your comments. If you identify material from your transcript that you do not want to be included in the results you may ask for it to be withdrawn from my interpretation.

Your participation is completely voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time. You do not waive any legal rights by participating in this research. There is no penalty for withdrawing or skipping questions. You may keep a copy of this information sheet. Representatives of the University of Western Ontario Non-Medical Research Ethics Board may require access to study-related records to monitor the conduct of the research.

If you have any questions about the conduct of this study or your rights as a research participant you may contact the Office of Research Ethics, The University of Western Ontario at 519-661-3036 or ethics@uwo.ca or the principal investigator or primary researcher of the study (details below).

Sincerely,

Fatih Sekercioglu - Primary Researcher
Department of Geography
Western University

Dr. Jerry White-Principal Investigator
Department of Sociology
Western University

Appendix D

Consent Form

Project Title: Ontario's Small Non-Community Drinking Water Systems: Risk Perception and Communication Relating to Drinking Water Safety

Study Investigator's Name: Dr. Jerry White

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

□ YES □ NO

I agree to be audio / video-recorded in this research

□ YES □ NO

I consent to the use of unidentified quotes obtained during the study in the dissemination of this research

□ YES □ NO

Participant's Name (please print): ______________________________

Participant's Signature: ______________________________

Date: ______________________________

Person obtaining informed consent (Please print): ______________________________

Signature: ______________________________

Date: ____

Appendix E

Interview Guide

Questions

1) How long have you owned this SDWS?

1-a) During this time, have you had changes in your system's water quality? Smell? Taste?

Appearance? Texture?

1-b) Tell me about what you consider the most serious contamination risks in drinking water

1-c) What do you think are the potential health effects of these contaminants?

2) How would you characterize the water system you have responsibilities towards? Describe some of the challenges of managing your system.

3) How far away do you live from your SDWS? (Approximate distance in km's) How do you describe where you reside? A rural or urban area (the urban area: Population 1,000 or less)

4) What would be the impact of unsafe drinking water a) on your business b) on the community in the closest proximity?

5) How would you describe your experience in access to safe drinking water?

5-a) Do your experiences differ as a homeowner/renter, compared to your experiences in a professional role?

6) How do you describe environmental problems that can contaminate your SDWS source relative to other family or neighborhood problems?

7) Please give me your reaction to the following statement, “when people get sick, drinking water can be the source of illness”

8) Please explain the importance of regularly testing your SDWS?

9) Tell me about how you feel about the importance of a training to operate a SDWS

10) What activities do you participate in to reduce contamination, bacteria, or pollution in your system?

11) Tell me about how much “drinking water safety” comes up in conversations with other SDWS owners.

12) What do you know about your source water?

13) What do you think would be the best way to communicate with SDWS owners about how to manage their SDWS to minimize health risks?

Curriculum Vitae

Name:	Mehmet Fatih Sekercioglu
Post-secondary Education and Degrees:	*Istanbul Technical University* Istanbul, Turkey 1998, B.Sc.
	Ryerson University Toronto, Ontario, Canada 2004, B.A.Sc.
	University of Guelph Guelph, Ontario, Canada 2006, M.Sc.
	Wilfrid Laurier University Waterloo, Ontario, Canada 2011, M.B.A.
	The University of Western Ontario London, Ontario, Canada 2018, Ph.D.

Honours and Awards:	Environmental Health Foundation of Canada Continuing Education Award, 2013
Related Work Experience	Manager, Environmental Health Middlesex-London Health Unit 2012-Present
	Public Health Inspector/Acting Program Manager Wellington Dufferin-Guelph Public Health 2004-2012

Publications (Peer Reviewed):

Sekercioglu, N., Busse, J.W., **Sekercioglu, M.F.**, Agarwal, A., Shaikh, S., Lopez, L.C., Reem A. Mustafa, R.A., Guyatt, G.H., & Thabane, L. (2016). Cinacalcet versus standard treatment for chronic kidney disease: a systematic review and meta-analysis. Renal Failure, 38(6), 857-875. doi:10.3109/0886022X.2016.1172468

Sekercioglu, M.F., White, J., Shrubsole, D., & Baxter, J. (2018). Relationship between operational characteristics of small non-community drinking water systems and adverse water quality incidents in Southern Ontario, Canada. *Applied Ecology and Environmental Research*, 16(1):777-789.

Sekercioglu, M.F., White, J., Shrubsole, D., & Baxter, J. (2018). Towards a Sustainable Small Non-Community Drinking Water System in Ontario: Owners' Risk Awareness and Perceptions to Water Safety, *Journal of Sustainable Development, 11(3)* ***(In press)***

Published Case Study:

Pellecchia,A., **Sekercioglu, F.**, Terry, A. (2015). Knowledge Dissemination and Private Well Water Testing in Middlesex County, Ontario. in: Speechley, M., & Terry, A.L. [eds] Western Public Health Casebook 2015. London, ON: Public Health Casebook Publishing.

Conference Presentations:

2017 Sekercioglu, M.F. Kloepfer, J., Walker, R. *"Rural Engagement in Climate Change Adaptation: A Communication Strategy"* Canadian Institute of Public Health Inspectors Ontario Branch Annual Educational Conference, Brampton

2017 Sekercioglu, M.F., Quin, A.M. *"Geared towards Compliance: Evaluation of Public Pool and Spa Operator Training Program"* Canadian Institute of Public Health Inspectors Ontario Branch Annual Educational Conference, Brampton

2017 Sekercioglu, M.F., Quin, A.M. *"Geared towards Compliance: Evaluation of Public Pool and Spa Operator Training Program"* Pool and Spa Expo, Niagara Falls

2016 Sekercioglu, M.F., Quin, A.M. *"Enhanced private well water program in Middlesex County, Ontario, Canada"* National Environmental Health Association Educational Conference EHA Conference, Orlando

2014 Sekercioglu, M.F., Quin, A.M. *"A Qualitative Analysis of Private Well User Knowledge and Perceptions in Middlesex County"* Canadian Institute of Public Health Inspectors Ontario Branch Annual Educational Conference, Toronto

2014 **Sekercioglu, M.F.,** Richmond, C. "*Drinking Water Systems Review of Ontario's First Nations*" The Water Initiative for the Future: 2014 Graduate Conference, Kingston

2010 **Sekercioglu, M.F.,** "*Strategic Analysis of H1N1 Pandemic Influenza Vaccination Program in Wellington, Dufferin, Guelph Counties*" Canadian Institute of Public Health Inspectors Ontario Branch Annual Educational Conference, Guelph

Volunteer Service:

Canadian Institute of Public Health Inspectors Board of Certification Examiner, 2008-2017

Big Brothers and Big Sister of London, 2014-present

Heart and Stroke Foundation of London, 2015-present

WIL Employment, Immploy Mentorship Program, 2016-present

Canadian Institute of Public Health Inspectors Board of Certification, Ontario Representative, 2018-present