SOURCE WATER PROTECTION IN PRIVATELY SERVICED RURAL AREAS

A Literature Review

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1. Introduction

Drinking water is the backbone of all communities, and is needed for human and environmental health, economic development, and overall community resilience (Hammond & Bradley, 2005; Wong & Brown, 2009). Drinking water contamination is a devastating and tragic event in any community. Yet, especially for rural areas, the management and protection of drinking water supplies can be very difficult due to human, technical, social, institutional and financial constraints (see Table 1) (Eledi, Minnes, & Vodden, 2017; Minnes, 2017). Source water protection is the protection of surface and groundwater sources that are used for drinking water (Patrick, Kreutzwiser, & de Loë, 2008). It can be an important first line of defense in ensuring drinking water safety (de Loë & Kreutzwiser, 2005). It has been found that in Canada, those served by private drinking water systems may be at greater risk of waterborne illness than those residents served by municipally operated (i.e. public) drinking water systems (Murphy, Thomas, Schmidt, & Medeiros, 2016). This is a significant amount of the Canadian population, as private water supplies serve an estimated 12% of the Canadian population, or approximately 4.1 million people (Murphy et al., 2016). The majority of private supplies are located in rural areas (Simpson, 2004). Private water systems, refer to those water systems not operated by a public entity (e.g., upper or lower tier municipality, local service board, etc.). Examples of these are household or communal wells or direct surface water connections (usually used for cottages) (O'Connor, 2002a). This literature review will outline source water protection tools for privately serviced areas (e.g., policies, regulations, programs, guidelines, etc.), as well as noted challenges, and opportunities associated with source water protection for these predominantly rural areas. This literature review has been graciously funded by the Rural Policy Learning Common's-Governance Network and is being conducted in conjunction with doctoral research being undertaken by the author. For the purposes of this literature review, the focus will be on source water protection for private residential household wells (i.e. non-municipal systems), in the context of Ontario, Canada. This literature review is rural policy focused, and therefore does not meaningfully address specifics on technical aspects of source water protection for these areas such as groundwater vulnerability mapping and other groundwater modelling techniques. Furthermore, this literature review solely concentrates on source water protection, however, it should be recognized that there are other important means of ensuring clean and safe drinking water for private drinking water systems, such as proper monitoring of water supplies and adequate filtration and treatment (Murphy et al., 2016; Simpson, 2004).

Table 1. Elements of Capacity for Source Water Protection (Ivey, de Loë, Kreutzwiser, & Ferreyra, 2006; Minnes, 2017; Noble & Basnet, 2015; Rawlyk & Patrick, 2013; Robins, 2008; Timmer, de Loë, & Kreutzwiser, 2007)

Element	Definitions
Institutional	The legislation, regulations, policies, protocols, governance arrangements, and delegation of responsibility to plan and enact source water protection.
Financial	The ability to acquire adequate funds to pay for source water protection efforts as well as for ongoing planning, governance, and management efforts.
Social	The social factors that influence source water protection governance and implementation. This includes social norms (e.g., values, attitudes, behaviours, sense of place, trust, reciprocity, commitment, and motivation)

	that impact public awareness, stakeholder involvement, community support, and public and private partnerships in source water protection efforts. This also incorporates structural networks, communications, and the relationships between different groups interests and actors.
Technical/human	The physical and operational ability of an organization to perform source water protection management and operations adequately. Also, having the human resources, with adequate knowledge, skills, and experience to properly create source water protection plans and implement needed measures.

2. What is Source Water Protection?

Source water refers to the raw surface and ground water supplies such as lakes, rivers, and aquifers, used to supply public and private drinking water systems. Source water supplies can be vulnerable to possible contamination by several point and nonpoint sources of pollution. These include specific point source threats such as spills and leaks of industrial chemicals, and more scattered non-point pollution sources such as nutrients, bacteria, oil, metals, chemicals, pesticides, and litter (Eledi et al., 2017). Source water protection refers to efforts taken to protect these surface and groundwater source water supplies. Outbreaks of waterborne disease in Canada have increased public awareness about the need to protect water quality and quantity, and the negative impact that water contamination can have on human health, the environment, and the economy (Canadian Council of Ministers of the Environment, 2004). For example, in 2000 a contaminated water supply in Walkerton, Ontario, resulted in seven deaths and thousands becoming seriously ill due to a water contamination in the public drinking water supply (Ferreyra, de Loe, & Kreutzwiser, 2008). The report following the Walkerton Inquiry conducted by Justice O'Connor, drew attention to the need for an integrated source water protection approach to managing potential impacts on drinking water sources (O'Connor, 2002b; Simpson, Duff, & Taylor, 2007). In addition, it has been found that the benefits of avoiding contamination at the source are far greater than the financial costs of implementing protective measures (Simpson & de Loë, 2014). The financial and social costs of not implementing source water protection measures (e.g., remediation efforts, death, loss of trust in government, etc.) can prove to be very high (Simpson & de Loë, 2014). For example, remediation efforts after a contamination can cost 30 to 40 times more than source water protection programs would have cost, with costs rising to as much as 700 times more costly in rural areas (Simpson & de Loë, 2014).

Source water protection ensures drinking water quality and quantity is not adversely impacted by land use activities, which vary depending on the local context of the watershed that contributes to the drinking water source (Ivey, de Loë, & Kreutzwiser, 2006; Simpson & de Loë, 2014). Examples of source water protection efforts include: mapping of aquifers or recharge areas; assessing potential contaminants; instituting regulations to restrict potential contaminants in sensitive areas; and public education and outreach programs (de Loë, Di Giantomasso, & Kreutzwiser, 2002). An important approach to the governance and management of drinking water that emerged out of the Walkerton Inquiry, following the Walkerton tragedy in Ontario, was the multi-barrier approach (Canadian Municipal Water Consortium, 2014; Ministry of the

Environment, 2004). The multi-barrier approach includes the following barriers in order to protect drinking water:

- "Water quality monitoring and management of water supplies from source to tap (e.g., source waters, drinking water treatment and water distribution systems);
- Legislative and policy frameworks;
- Public involvement and awareness;
- Guidelines, standards, and objectives; and
- Research and the development of science and technology solutions" (Canadian Council of Ministers of the Environment, 2004, p. 15)

Source water protection is an essential first barrier in the multi-barrier approach to drinking water protection (de Loë & Kreutzwiser, 2005). Moreover, source water protection has become an important policy development in Canada in order to prevent contamination of drinking water used for human consumption (Ferreyra et al., 2008; Ministry of the Environment, 2004; Rawlyk & Patrick, 2013). However, most source water protection policy, especially in Ontario, is focused on public drinking water systems (Minnes, 2017). The next section will exemplify the need for source water protection in privately serviced areas by summarizing potential groundwater contaminants and impacts on human health.

3. Potential Groundwater Contaminants and Impacts on Human Health

3.1. Potential Groundwater Contaminants

Though Canadians who rely on private drinking water wells for drinking water often rate their water quality high, numerous studies have found these water supplies are at risk of nitrate, bacterial and other contaminants (see Table 2) (Jones et al., 2006; Kreutzwiser, de Loë, & Imgrund, 2010). There are both quantity and quality threats to groundwater supplies that source private wells. Some of these threats are outlined in Table 2 below. These risks can be mitigated by proper source water protection efforts (Kreutzwiser et al., 2011)

Table 2 Potential Groundwater Contaminants, Their Properties, Potential Sources, and/or Pathways (Simpson, 2004, p. 1692)

Parameter	Properties	Potential sources/pathways
Nitrate	• Soluble in water • Tasteless • Colorless • Odorless	• Lawn fertilizers • Septic systems • Surface application of fertilizers, manure, and municipal biosolids • Plowdown legume crops
Pesticides	• May or may not dissolve in water • Tasteless, colorless, and odorless	• Application to fields • Leakage from bulk storage
Solvents	• Do not dissolve in water	• Leakage from farm vehicles, workshops, and bulk storage

	• May be tasteless, colorless, and odorless • Float or sink	• Discharge of hazardous household or farm wastes to septic systems • Some septic system cleaners
Fuels	• Do not dissolve in water • May be tasteless, colorless, and odorless • Float or sink	• Leakage from vehicles, workshops, and bulk storage • Accidental discharge to septic systems
Salt	• Soluble • Salty taste Colorless and odorless	• Surface application for winter de-icing and dust suppression • Naturally occurring

In addition to the above contaminants, climatic conditions can increase the vulnerability of groundwater supplies to contamination. For example, too little precipitation, can impact the quantity of water available. On the other hand, too much precipitation and subsequent flooding can submerge wellheads, allowing surface water to enter (Simpson, 2004)**.** Furthermore, some groundwater supplies are more vulnerable than others due to their geographical location. For example, some areas of Eastern Ontario that have fractured rock aquifers with low lying rock outcrops have been found to be vulnerable to groundwater contamination (Praamsma, 2016). In these geographies, due to thin amounts of rock or soil over the aquifers, and fractured rocks (allowing for pathways to groundwater supplies from the surface), these areas are highly vulnerable to contaminants. This can potentially cause contamination from the surface from human activity such as septic systems and agricultural practices (Praamsma, 2016; Wright & Novakowski, 2017). Simpson (2004) further explains ways pathogens can be introduced to private well water:

- "Fractures in rock, pores in coarse sediments, or macropores (e.g., wormholes) in sediments;
- Improperly constructed or decommissioned wells; and
- Improperly designed, maintained, or sited sewage disposal systems" (Simpson, 2004, p. 1683).

Some other notable threats to private drinking water systems include:

1. "Residential—septic systems and improperly stored or disposed of household hazardous materials and wastes.
2. Agricultural—inappropriate storage or application of nutrients, abattoir wastes.
3. Municipal—old and active landfill sites.
4. Industrial—spilled solvents or other harmful chemicals" (Simpson, 2004, p. 1684).

As mentioned above, unused or improperly decommissioned wells can offer a conduit for contaminants to groundwater supplies (Sustainable Water Well Initiative, 2006)**.** Generally, the risk of contamination of a drinking water well "decreases as the distance between the well and potential contamination sources increases" (Simpson, 2004, p. 1687). Keeping contaminants away from your well's source water supply is important (Rudolph, Barry, & Goss, 1998). Pathogens from septic systems were noted many times in the literature as a particular concern for rural areas, where sometimes numerous septic systems and private wells are located in close proximity (Central Lake Ontario Conservation Authority & Jagger Hims Limited, 2008; Wilcox, Gotkowitz, Bradbury, & Bahr, 2010). Other concerns from potential contaminants that can be located on or near rural residential or businesses properties include: the storage of fuel and other chemicals, winter road deicing, water softener use, fertilizers and pesticides, industrial/commercial chemicals and agricultural land uses (Central Lake Ontario Conservation Authority & Jagger Hims Limited, 2008; Simpson et al., 2007). Diffuse or non-point sources of contamination include: application of animal manure spreading, commercial fertilizers, and insecticides and herbicides to field crops (Rudolph et al., 1998). Point-sources of contamination at the farm scale include: septic fields, manure storage areas, and feedlots (Rudolph et al., 1998). All of the above potential contaminants to private wells pose significant human and environmental health risks. The next section will focus on the human health risks associated with the contamination of private residential drinking water wells.

3.2. Private Well Contamination and Human Health

There are many ways in which drinking water can impact human health. This is why the above explained multi-barrier approach to drinking water is needed (O'Connor, 2002b; Simpson et al., 2007). Examples of waterborne diseases and illnesses, and responsible pathogens, are outlined in Table 3 below.

Table 3 Examples of Water-Borne Pathogens and Associated Diseases or Illnesses (Simpson, 2004, p. 1691)

Pathogen	Disease/illness
Bacteria • Campylobacter jejuni • Escherichia coli (E. coli) • Salmonella • Shigella	• Campylobacter enteritis • Gastroenteritis • Salmonellosis • Shigellosis
Protozoans • Giardia lamblia • Cryptosporidium parvum • Entamoeba histolytica	• Giardiasis • Cryptosporidiosis • Amebiasis
Viruses • Hepatitis A • Norwalk • Rotavirus	• Hepatitis • Gastroenteritis • Rotaviral enteritis

Those relying on private drinking water systems in Canada are certainly not immune to waterborne diseases and illnesses. In Canada, Murphy et al, (2016) found:

"Waterborne illness related to the consumption of contaminated or inadequately treated water is a global public health concern. Although the magnitude of drinking water-related illnesses in developed countries is lower than that observed in developing regions of the world, drinking water is still responsible for a proportion of all cases of acute gastrointestinal illness (AGI) in Canada. The estimated burden of endemic AGI in Canada is 20.5 million cases annually – this estimate accounts for under-reporting and under-diagnosis. About 4 million of these cases are domestically acquired and foodborne, yet the proportion of waterborne cases is unknown. There is evidence that individuals served by private systems and small community systems may be more at risk of waterborne illness than those served by municipal drinking water systems in Canada" (Murphy et al., 2016, p. 1355).

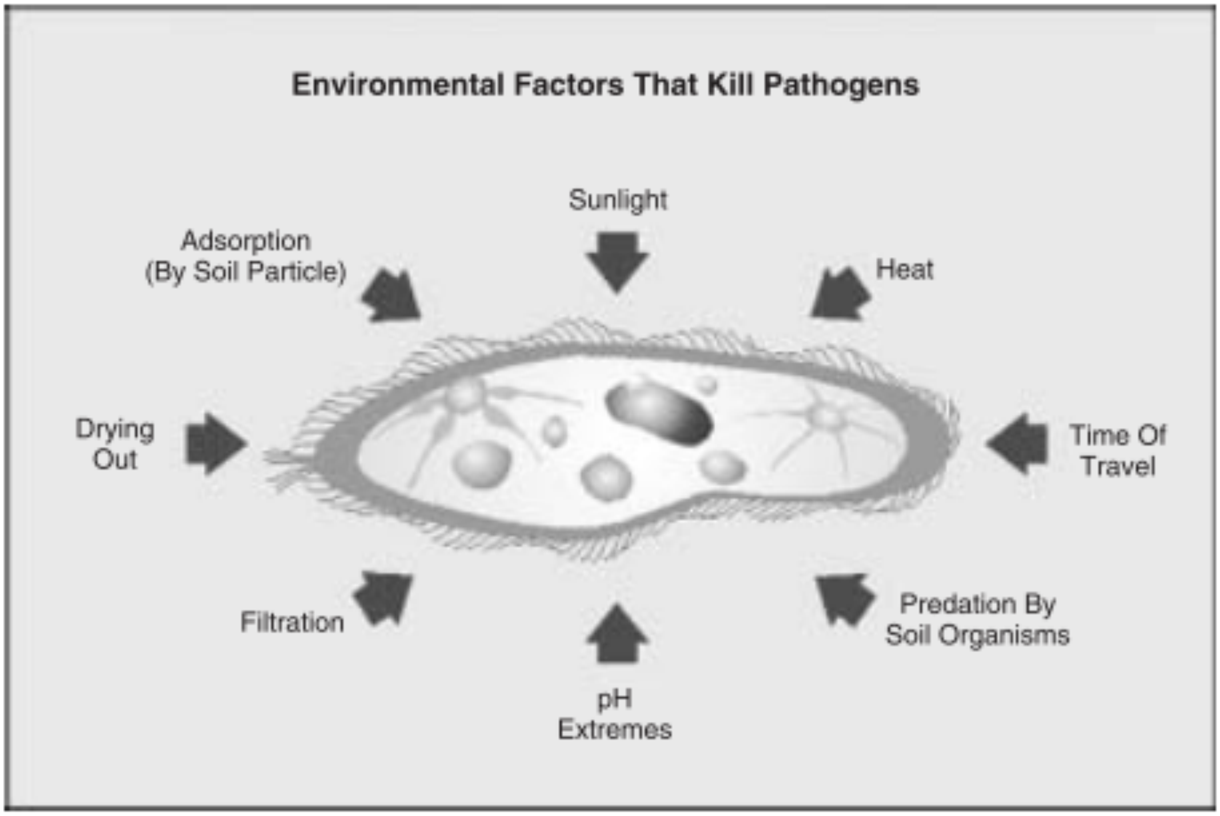
Source water protection provides a cost effective first step in order to protect drinking water sources (Eledi et al., 2017; Patrick, 2011; Simms, Lightman, & de Loë, 2010). Source water protection helps to prevent contaminants from entering a water source, however, these efforts require proper regulatory reforms and technical knowledge to support these actions (O'Connor, 2002b; Simpson et al., 2007). The next section will outline examples of technical and planning approaches for source water protection in privately serviced rural areas.

4. Technical and Planning Approaches for Source Water Protection in Privately Serviced Rural Areas

The literature related to source water protection tools to mitigate the contamination of private drinking water wells, include a wide array of natural processes, regulatory controls, and technical approaches, which all require a great deal of education and outreach for those charged to implement these tools (e.g., private well owners, government staff, elected officials, etc.) (Hynds, Misstear, & Gill, 2013; Kreutzwiser et al., 2011; Sarkar, Krishnapillai, & Valcour, 2012; Simpson, 2004; Simpson & de Loë, 2014). Firstly, Simpson (2004) explains there are environmental factors that kill pathogens, including the important role soils play in cleansing the infiltrating water (see Figure 1). Soil processes for filtering water infiltrating groundwater supplies include:

- Adsorption—bonding onto soil particles.
- Desiccation—drying out in the unsaturated zone.
- Filtration—by soil particles.
- Predation by soil microorganisms (Simpson, 2004, p. 1683).

Figure 1: Environmental Factors That Kill Pathogens (Simpson, 2004, p. 1684)



Technical and planning tools can be used to preserve and aid the natural environmental processes that protect private well supplies, as well as ensure sustainability of water supplies into the future. This section will summarize five ways to do this outlined in the literature: proper construction, maintenance, and decommissioning of wells; septic inspection programs; watershed planning; private well head protection plans; and voluntary, educational, and outreach programs. The listed five tools for source water protection in privately serviced areas are in no way an exhaustive list.

4.1. Proper Construction, Maintenance, and Decommissioning of Wells

How a well is constructed, maintained, and subsequently decommissioned at the end of its life, can impact the health of groundwater sources as well as the water derived from the well (Simpson, 2004). Unused or improperly abandoned wells are a significant potential source of contamination, and need to be plugged and sealed in order to ensure there is no direct entry to the aquifer of surface water and contaminants, or movement of water and potential contaminants between underground aquifers. (Simpson, 2004). In many provinces in Canada the construction and decommissioning of wells are regulated. For example, The *Ontario Water Resources Act, 1990* and its Wells Regulation 903, regulates the construction, use, abandonment, and licensing requirements for wells (Environmental Commissioner of Ontario, 2017). In British Columbia, Ground Water Protection Regulation establishes standards on how all water wells are to be constructed, maintained, and, decommissioned (British Columbia Ministry of Environment, 2005). Similarly, in the United States many state and local policies regulate well construction, location, including regulations on factors such as setback distances, minimum well-casing depths, and protective caps and a grout seal to prevent surface water runoff from entering the well (Wilcox et al., 2010). Having these activities regulated is an important step in ensuring at the very least wells are constructed properly and decommissioned properly at the end of the well's useable life (Simpson, 2004).

4.2. Septic Inspection Programs

An important aspect of protecting rural drinking water and rural environments is the proper maintenance and stewardship of on-site wastewater systems (i.e. septic systems). As noted above, septic systems can pose a significant risk of contaminating private well supplies (Goss & Richards, 2008; Paul, Rigrod, Wingate, & Borsuk, 2015; Praamsma, 2016; Rudolph et al., 1998). Septic systems should be pumped out and inspected every 3-5 years with year round dwelling owners, and 6-8 years for seasonal owners (Worron, 2016). Re-inspection programs for residential septic systems are imperative. Worron (2017) explains that a septic re-inspection program provides,

> "… quick and inexpensive alternatives to making sure these systems are providing their service while at the same time not harming their surroundings in any way. This will ensure that our protected drinking water zones, freshwater lakes, and other natural resources are kept pristine, while at the same time preventing any harmful events from occurring that may threaten public health" (Worron, 2017, p. 87).

Furthermore, a 2006 report entitled the *Sustainable Water Well Initiative* (Prepared for the Ontario Ministry of the Environment) found that to properly protect private wells that septic system pumping and inspection should be mandatory (Sustainable Water Well Initiative, 2006). In Ontario, a septic re-inspection program is required under Ontario Building Code, for septic systems that are deemed to be a threat to a public drinking water system defined under the *Clean Water Act*, 2006 (Government of Ontario, 2017).

4.3. Watershed Planning

Appropriate standards and guidelines are needed for rural areas to protect the groundwater sources that supply private wells. This includes planning regulations for land use on the entire watershed contributing to these sources. It has been found that, "…these standards and guidelines should be compatible with those for municipal groundwater protection" (Frind, Rudolph, & Molson, 2001, p. 19). Despite this statement being from a workshop in Waterloo, Ontario in 2001, there has not been a great deal of movement on the subject area. Many of the information available for source water protection for private wells, relates to maintenance and best practices at the individual land owner level (Caldwell & Landman, 2013; Kreutzwiser et al., 2010; Ontario Ministry of Health and Long-Term Care, 2015; Summers, 2010). In terms of tools for implementation, experts and the literature pointed to zoning and land acquisition as appropriate tools. For example, after the capture zone and vulnerable areas are determined for private wells or groupings of private wells, protection zones and policies (zoning, by-laws, etc.) could be created to limit risky land use activities in order to protect the groundwater supplies contributing to private wells (Jatel, Curran, Geller, Everdene, & Garcia, 2009). For example, in 2011, the Ontario Building Code was changed to require Mandatory Maintenance Inspections every 5 years in all areas where septic systems (governed by the *Building Code Act, 1992*), are identified as a significant drinking water threat in source protection plans. Onsite inspections are required to be conducted by the principal authority defined by the Build Code Act (municipality, board of health, conservation authority). However, the regulatory tools under Ontario's *Clean Water Act, 2006* only applies to the protection of public drinking water source water supplies (McClenaghan & Lindgren, 2017). The *Clean Water Act, 2006* does provide some protection and opportunities for clusters of private wells to be elevated into source protection plans (Ontario Ministry of Environment, 2006). Thus far, these provisions have not been successfully implemented (McClenaghan & Lindgren, 2017).

In Ontario, there is a suite of other regulatory controls that can be used for the protection of water supplies and water systems serving privately serviced areas. Many of the Ontario provincial legislation, such as the *Planning Act, Greenbelt Act*, and the *Oak Ridges Moraine Act*, require municipalities to establish planning controls and by-laws that will provide protection to privately serviced areas (Central Lake Ontario Conservation Authority & Jagger Hims Limited, 2008). Some examples of policies to protect privately serviced source water supplies include:

- “Policies providing land use restriction relating to identified vulnerable areas and natural heritage features;
- Policies requiring assessment and monitoring and the implementation of measures to minimize threats to other neighbouring land uses;
- Policies requiring assessment and monitoring associated with the development of new subdivisions serviced by private water supplies;
- Policies or agreements regarding a municipal responsibility agreement to take over operation of private water systems in the event that the owner/operator fails to maintain the service;
- Policies and By-laws that specify the requirements for licenses and inspections relating to buildings, sewage systems, and in some cases water supplies; and
- Policies and By-laws that regulate, control, or ban the use of pesticides” (Central Lake Ontario Conservation Authority & Jagger Hims Limited, 2008, p. 46).

British Columbia's *Groundwater By Laws Toolkit* outlines some promising examples that could be used by municipalities for private well groundwater protection. This includes the use of zoning bylaws and development permit areas (Jatel et al., 2009). In Halton, Ontario, an Aquifer Management Plan was instituted to protect aquifers used for diverse purposes in the region. The following areas were targeted in this plan: hydrogeologically sensitive areas; groundwater quantity management; drinking water quality protection; water conservation; well construction and abandonment; contaminated sites; planning for groundwater management; monitoring and performance measurements (Holysh, 1999).

In general, for watershed based source water protection planning other information is needed to assess risks and plan adequate mitigation measures. Information needed for source water protection planning include a full data base of bacterial testing results and other baseline information on existing wells and the state of water quality and quantity at the watershed level (Krolik et al., 2013; Maier, Krolik, Randhawa, & Majury, 2014; Summers, 2010). To determine what regulatory tools would be appropriate for mitigating contamination to private well supplies, risk assessment should be performed for groundwater supplies. This would include the creation of vulnerability maps of groundwater that use a systems theory approach to consider the whole hydrological system that contributes to groundwater supplies (Balcoch, 2013; Gleeson, Novakowski, & Kyser, 2009). This may require an inventory of potential threats and employing groundwater modelling techniques such as establishing the possible pathways that contaminants could enter groundwater sources (Goss & Richards, 2008). For example, in previous research, flow systems have been simulated through three-dimensional mathematical modeling in order to identify the aquifer system sourcing a grouping of wells (Frind et al., 2001; Holysh & Gerber, 2014). Once the characteristics of the source aquifer is understood, then vulnerability of aquifer(s), sensitivity and risk can be analyzed. Goss and Richard (2008) explain in relation to assessing risk in an agricultural context:

> “To confirm that potential pathways are active requires some microbial source tracking. One possibility is to identify the molecular types of Escherichia coli present in each hazard on a farm. An essential part of any such index is the identification of mitigation strategies and practices that can reduce the magnitude of the hazard or block open pathways” (Goss & Richards, 2008, p. 623).

Context and local condition vary depending on the characteristics of the watershed contributing to a given aquifer. It was found in Southern Wisconsin, United States, that even though standard groundwater modeling methods and information about local hydrologic conditions can be used by planners to inform planning and regulatory decisions, proposed guidelines may vary depending on the context and differences in hydrological settings (Wilcox et al., 2010).

As identified previously, another prominent concern for the contamination of private wells is farming practices and the application of nutrients to land (Goss & Richards, 2008; Simpson, 2004). In Ontario, the *Nutrient Management Act, 2002* and O. Reg. 267, regulates the management of the land application and storage of particularly nutrients to farmland (e.g., manure, animal bedding, materials generated by non-agricultural operations such as sewage biosolids, pulp and paper biosolids and other by-products used in crop growth). O Reg. 267 regulates specific requirements for planning, storage requirements, and land application standards, such as maximum application of nutrients and setbacks from wells and surface or ground water (University of Guelph Ridgetown Campus, 2017). Creation of Environmental Farm Plans are a key tool in nutrient management, and watershed planning for groundwater protection. In Ontario, Environmental Farm Plans are created by farmers with assistance locally from the Ontario Soil and Crop Improvement Association, in partnership with the Ontario Ministry of Agriculture, Food and Rural Affairs and Agriculture and Agri-Food Canada. The workbook used to create Environment Farm Plans includes assistance directly related to source water protection for private wells including modules on septic systems re- inspection, wellhead protection, and water conservation (Simpson et al., 2007). Simpson (2004) explains, “the Ontario environmental farm plan is an example of a risk assessment approach that has been used successfully by farmers to evaluate environmental issues associated with their operations and to identify areas of environmental concern” (Simpson, 2004, p. 1701)**.** Evidently, the literature speaks to many land use planning and regulatory activities that can be employed to protect private wells source water supplies on a watershed level. The next sub section will speak to measures that can be employed at the wellhead level.

4.4. Private Well Head Protection Plans

In Canada, generally, private water wells are responsible for providing their own safe drinking water (opposed to a public operator for municipal systems) (Imgrund, Kreutzwiser, & De Loë, 2011). Protecting groundwater recharge to a private well, usually is done at a different scale and include different content from one done for a municipal well (Simpson & Myslik, 2005). Often in rural communities rural landowners do not have the same technical, financial or land use planning authority to implement source water protection for their private drinking water systems on a watershed level (Simpson et al., 2007). Simpson et al. (2007) explains that a, "private well owner has no authority to control activities on adjacent properties, the activities (e.g. threats) on their own land fall within their direct control" (Simpson et al., 2007, p. 156). In the absence or in addition to municipal controls on a watershed level for the protection of private well source water supplies, landowners can create private wellhead protection plans (PWPP). It is explained,

> "With a PWPP, the detailed definition of a private well capture zone may not be necessary in most cases because it may not extend beyond the boundaries of the property on which the well is sited. As a result the well owner can assume that their property encompasses their capture zone for the purposes of developing a PWPP. This is also a practical approach because it is difficult for a well owner to know with any accuracy where the capture zone lies beneath their property at any one time" (Simpson et al., 2007, p. 156).

There are many actions rural landowners can do on their own property to assess potential risks to their source water supplies (Furlanetto, 2017). There are resources available to assist rural landowner in creating their own private well head protection plans, to at least mitigate the contaminants they can control (Caldwell & Landman, 2013). For example, in 2017-2018 the Cataraqui Region Conservation Authority in Eastern Ontario, Canada will be running well and septic stewardship workshops for the public in collaboration with Ministry of Environment and Climate Change and Public Health Ontario. These workshops will help landowners assess risks to groundwater contamination on their property and to produce a Groundwater Protection Plan for their property (Furlanetto, 2017). Though this is not a regulatory approach, these types of educational and outreach programs are vital for the protection of source water supplies in privately serviced areas. The next section will speak to the literature on voluntary, educational and outreach programs.

4.5. Voluntary, Educational, and Outreach Programs

Stewardship of private wells, including source water protection activities, requires proper education and outreach to residents (Kreutzwiser et al., 2011). Educational programs increases and strengthens the level of awareness and commitment to source water protection (Simpson, 2004). Furthermore, a solely regulatory approach for source water protection for privately serviced areas does not allow the well owner to understand the purpose for source water protection efforts and does not facilitate implementation at the landowner level (Simpson et al., 2007). This is important, as in many rural areas, institutional capacity to enforce source water protection measures is lacking (Eledi et al., 2017). Fact sheets on the need for source water protection efforts for private wells, such as one created by Conservation Ontario, suggest best practices and advice on what kind of products to use in the vicinity of a well and the importance of keeping a 3 meter permanent grass buffer around your well (Conservation Ontario, 2007). In Ontario, there are also factsheets and private water system kits available to the public at no charge through local public health units and partner ministries such as the Ministry of Environment and Climate Change, Ministry of Agriculture, Food and Rural Affairs, and Ministry of Health and Long-Term Care offices (Simpson et al., 2007).

As noted above, programs facilitated by regional actors such as Conservation Authorities can also be key in increasing educational efforts. However, in areas where none such actors exist, municipalities need assistance (Eledi et al., 2017). Murphy et al. (2016) urge that the stewardship of private wells should be a shared responsibility between private well owners and governments at all levels (Murphy et al., 2016).

In regard to increasing awareness and understanding of source water protection for private wells, Simpson (2004) outlines the following steps:

1. Help the community understand the need to protect groundwater resources.
2. Create an alert and informed community that may be helpful in promoting protection programs among neighbors.
3. Encourage the community to implement voluntary remedial measures, such as reducing the risk of land use practices (i.e., upgrade the construction of water supply wells). (Simpson, 2004, p. 1698)**.**

Ultimately, increasing the capacity of landowners and the general public on source water protection issues, both increases the attention and social support of land use controls. (Simpson, 2004)**.** However, it should be recognized there are some challenges in the implementation of source water protection programs in privately serviced areas. These challenges will be discussed in the following section.

5. Challenges for Source Water Protection in Privately Serviced Rural Areas

Management of water resources is commonly considered a “wicked problem”, as water management issues are, “often embedded in seemingly endless ecological, social and political interactions across temporal and spatial scales, are context-dependent, socially constructed and technically uncertain” (Ferreyra et al., 2008, pp. 304 – 305). These types of wide ranging challenges exist for the protection of source waters suppling private wells. In this section five prominent challenges outlined in the literature will be discussed: regulatory gaps; lack of water quality data and effective vulnerability mapping; costs to landowners; and effective public engagement.

5.1. Regulatory Gaps

Historically, a significant amount of drinking-water-associated waterborne illness outbreaks and contamination events have been attributed to unregulated water systems (such as private wells) (Balcoch, 2013). Regulations for private wells have been found to be weak or poorly enforced in Ontario (Kreutzwiser et al., 2011). As noted, the *Ontario Water Resources Act, 1990* and associated Wells Regulation 903 regulates the construction, use, abandonment, and licensing requirements for wells (Environmental Commissioner of Ontario, 2017). However, this regulation only covers enforceable regulations at point of installation, meaning after the well is installed there are no regulatory controls to ensure proper stewardship (McClenaghan &

Lindgren, 2017). Furthermore, the *Clean Water Act, 2006* (CWA) in Ontario has been criticized for providing little protection for private well supplies. McClenaghan and Lindgren (2017) explain:

> "…the numerous Ontarians who depend upon non-municipal systems for drinking water purposes generally lack the legal protection conferred under the CWA (although private well owners fortunate enough to be located within municipal Wellhead Protection Areas may derive some indirect protection under approved Source Protection Plans)"(McClenaghan & Lindgren, 2017, p. 6).

Source protection plans made under Ontario's *Clean Water Act, 2006* were further criticized by the Ontario Auditor General for not protecting the estimated 1.6 million Ontarians who derive their drinking water from private wells, and for not addressing risks posed by abandoned wells to groundwater sources (Ontario Auditor General, 2016). There are an estimated 730,000 abandoned wells in Ontario, and it is unknown how many of these have been decommissioned properly (Ontario Auditor General, 2016). Further legislation designed to protect groundwater supplies, such as the *Nutrient Management Act*, *2002*, was also criticized by the Ontario Auditor General in 2016 for weak enforcement (Ontario Auditor General, 2016). In regard to source water protection for private well supplies, the Ontario General recommended the following:

- "Considering the feasibility of requiring source water protection plans to address threats to sources of water that supply private wells;
- Phasing in remaining farms in Ontario that generate or apply nutrients so that they also must adhere to the requirements of the Nutrient Management Act; and
- Updating the Ministry's water-taking charges to improve cost recovery (Ontario Auditor General, 2016, p. 158).

In terms of an enforceable regulatory approach for ensuring the protection of source water supplies for private wells in Ontario, there is currently not the same mechanisms in place as for the protection of source water supplies for public drinking water systems (McClenaghan & Lindgren, 2017). This poses a potential vulnerbility to privately serviced areas. It was found in 2013 that,

> "over a third of the water samples from private wells tested positive for bacteria including E. coli. If private wells were held to the same safety standard used for public drinking water systems, water from these wells that tested positive for bacteria would be considered unsafe to drink" (Ontario Auditor General, 2014, p. 411).

Furthermore, private water supplies do not have the same amount of water quality data as municipal systems do. Water quality data is key in assessing risks and needed regulatory approaches to protect drinking water sources (Rudolph et al., 1998). The issue of lack of water quality data will be outlined in the next section.

5.2. Lack of Water Quality Data and Effective Vulnerability Mapping

Many of the previously outlined approaches for source water protection for privately serviced areas require assessment of risks to water supplies and delineation of capture zones to properly plan for said risks (Balcoch, 2013; Frind et al., 2001; Goss & Richards, 2008; McClenaghan &

Lindgren, 2017; Richards, Miller, & Green, 2013). In contrast to public drinking water systems in more urban areas,

> "the rural population depends almost entirely on groundwater, but rarely has access to historical water quality data. The individual users are generally responsible for their own quality monitoring. As a result, the condition of much of the rural groundwater resource is not well documented**.**" (Rudolph et al., 1998, p. 296)

Furthermore, in a report prepared for the Ontario Ministry of Environment and Climate Change on including other systems into the *Clean Water Act, 2006* (such as those in privately serviced areas), it was found,

> "In order to improve the ability of municipalities to use this system it will be important to improve access to the datasets necessary to conduct the analysis" (Central Lake Ontario Conservation Authority & Jagger Hims Limited, 2008, p. vi).

However, it was also found that the current tools and modelling techniques available for analyzing privately serviced systems, are still an art being developed (Richards et al., 2013). For example, depending on the different geography of some groundwater areas, some tools may be less effective. It was found in Eastern Ontario, "tools available for groundwater vulnerability mapping are not effective in fractured rock terrains with low lying rock outcrops" (Praamsma, 2016, p. 131). However, there have been pilot studies in 'near' Northern Ontario, where groundwater source protection methodologies were applied to clusters of wells in privately serviced hamlet communities serviced by clusters of individual wells. Hydrogeological mapping was done for five communities in order to delineate wellhead protection zones. Information used included water well records, geological mapping, groundwater contouring methods, and time of travel assessments. This pilot study resulted in further information about source areas, that could be used in community planning for these towns (Richards et al., 2013). Lessons learned from this study include:

- The decision to use the hamlet boundary, and not individual well clusters, as the basis for the present analysis was made in order to give the hamlets a document that would offer the greatest flexibility for future planning purposes;
- Although the application of the Technical Rules to the well cluster settings require only the definition of WHPA-A and WHPA-B zones around the clustered well communities, the extension of the methodology used in this study to include the 25 year WHPA-D zone was considered to be a valuable enhancement to the overall study program. It is recommended that the WHPA-D zone be included in any future well cluster assessments;
- Future studies following this methodology would benefit from detailed door to door survey information of actual groundwater usage within the hamlet communities. This would greatly assist in defining the WHPA-A zones for the final mapping, and is an exercise that would be ongoing as the community develops and expands. The delineation of the WHPA-A zones does not require any supplemental groundwater contouring software, and could be performed by the hamlet community planners (with the WHPA-B and WHPA-D being retained as currently delineated, and not changing over time);

- The present study would have benefited from a formal definition of what a well cluster comprises and, to-date, the legislation and guidelines are silent on this matter. A definition based on a density of wells in a given area would appear to offer the best potential to narrow the WHPA footprints on the ground (when compared to the methodology presented in this paper). However, the approach which was taken in the present pilot study was conservative and offered the hamlet communities a workable solution to defining well head protection areas." (Richards et al., 2013, pp. 7–8).

There is evidence that assessing risk on an aquifer level effectively in privately serviced areas is still a work in progress. Nevertheless, collecting as much information as possible on the characteristics of the source water supplies for privately serviced areas has been found to be beneficial for source protection planning for these areas. However, when vulnerabilities or risks are assessed, this usually requires costs to landowners to undertake best management practices (Simpson et al., 2007). In the next section, the issue of costs to landowners for source water protection efforts in privately serviced areas, is discussed.

5.3. Costs to Landowners

Costs associated with source water protection efforts to landowners can potentially be a barrier for the implementation of best practices (Simpson et al., 2007). Simpson et al. (2007) outline that rural water quality programs are beneficial when the recommended best management practices (BMPs),

> "…can achieve water quality goals without resulting in a net cost to the land owner. This is particularly relevant with water well maintenance and decommissioning where the recommended BMPs may provide little or no obvious financial benefit" (Simpson et al., 2007, p. 159).

For example, the Grand River Conservation Authority's Rural Water Quality Program provides cost-share grants and incentives to farmers to help them implement activities that will improve rural water quality in the region (Simpson & de Loë, 2014). It was found in the first 15 years of operation, the Grand River Conservation Authority's Rural Water Quality Program, "provided grants of approximately $7 million, and landowners have contributed more than $14 million, to implement more than 2190 projects" (Simpson & de Loë, 2014, p. 232). Similarly, there are further incentives in Ontario for farmers through The Canada-Ontario Farm Stewardship Program. This program is a voluntary cost-share program to help farmers adopt best management practices identified in their Environmental Farm Plans. Cost-share for specific categories include a 30-50 per cent ratio (Simpson et al., 2007).

As previously mentioned above, septic systems can pose a threat to private wells. Inspection of septic systems costs a landowners approximately $250, and pump outs of septic systems can be up to $600 depending on the state of the system and the leaching bed (Worron, 2016). Whether it is a mandatory municipal or a voluntary inspection and pump out program, this can be a significant cost to the landowner. Not to mention, if problems are found and systems need to be replaced. In Ontario there are some funds available for these efforts, though many depend on being located in certain designated areas (e.g., areas of concern under the *Clean Water Act, 2006*) (Worron, 2016).

Given the potential costs to landowners for source water protection measures in privately serviced areas, there has to be a significant buy in from landowners. It is important to have source water protection programs that provide private landowners both funding to implement best management practices, as well as the educational support that allows them to understand the importance of adopting these practices (Simpson et al., 2007). The next section outlines challenges associated with a lack of awareness of the need for source water protection, as well as methods for alleviating these challenges.

5.4. Effective Public Engagement

Given the above noted legislative gaps for private well protection, actions taken by the landowner are very important (Kreutzwiser et al., 2011). However, as described above, there are costs to landowners when implementing source protection efforts for private wells (Simpson et al., 2007). If the resident does not know why it is important to make these investments into source water protection, it is unlikely these actions will be taken, especially when most actions are voluntarily their responsibility and not regulated (Kreutzwiser et al., 2011).

Studies have shown that engaging private well owners to conduct stewardship requires more than mass-media campaigns (Renaud, Gagnon, Michaud, & Boivin, 2011). These efforts need to be,

> "combined with more personalized interventions that take behavioral determinants and local actor involvement into account, the campaigns might potentially provoke behavioral changes for which control depends on the individual. This study also demonstrates that individual health decisions need to be supported by enabling and reinforcing factors to help well owners to take action for their own health" (Renaud et al., 2011, p. 474).

There is a need to link source water protection efforts to human health, as safe and clean water, is vital to human health (Murphy et al., 2016). Further to this, the risk contamination of private wells is not always well understood. It was found,

> "The magnitude and sources of waterborne (enteric) illness in Canada are not well-defined. Enteric illness is largely under-reported, and existing national and provincial surveillance systems for enteric illness do not distinguish between infections caused by food, animal contact, person-to-person, environmental, or drinking water transmission…In a review of Canadian waterborne outbreaks between 1974 and 2001, two-thirds of the outbreaks occurred at either private or semi-private systems" (Murphy et al., 2016, p. 1356).

It has also been found that the effective engagement of home-owners in private well stewardship in Newfoundland, Ontario and across Canada is negatively impacted by complacency, inconvenience, cost, privacy concerns, and ignorance (Kreutzwiser et al., 2011; Murphy et al., 2016). Furthermore, some transient rural populations such as second home owners from urban areas, may not be aware that their tap water is derived from a private well supply (Simpson et al., 2007). It is imperative that private well owners are educated on the specifics of their particular well and surrounding area, in order to properly evaluate source water threats, and properly enact source water protection efforts (Simpson, 2004).

Simpson & de Loë (2014) reinforce the need to involve landowners and the general public in all source water protection planning, and that source water protection educational and outreach programs can be a way to share risk perceptions and engage citizens (Simpson & de Loë, 2014, p. 229). It was found to encourage stewardship of private wells, "local initiatives, better educational materials, and enforcement through real estate laws are all required" (Kreutzwiser et al., 2011, p. 1104). Effective public engagement of domestic well owners is of the utmost importance (Summers, 2010; Sustainable Water Well Initiative, 2006). It is essential to get communities involved in managing activities on their land and to understand factors influencing private well stewardship behaviours (Kreutzwiser, de Loë, & Imgrund, 2010). For example, surveys can be used to gauge current stewardship practices and the current levels of knowledge of residents. Then educational and outreach events can be tailored specifically to knowledge gaps in the area of concern (Imgrund et al., 2011). In addition, before consultation and educational sessions begin, there should be procedures in place to address inevitable concerns and potential conflicts with the subject matter (Kreutzwiser & Loë, 2002).

As mentioned above, there is the need for further data on water supplies sourcing privately serviced areas (Richards et al., 2013). To properly engage the public, better data sets on both environmental health and human health consequences of potential vulnerabilities to these private well supplies, is needed (Murphy et al., 2016). However, there is a need to provide the technical capacity for residents to understand the implications of the data. In previous studies done on privately serviced areas source supplies, potential threats and vulnerabilities were found in a case study area in Eastern Ontario (Kozuskanich, Novakowski, Anderson, Crowe, & Balakrishnan, 2014). This study highlights the challenge of conducting technical groundwater research in social and political contexts. The study ignited panic amongst the case study community's residents as well as confusion on the state of their source water supplies (Schliesmann, 2014; Township of Rideau Lakes, 2014).

Other key findings from a survey distributed to residents in Alberta regarding well stewardship, found that there is still room for improvement in the Canadian context in this area:

1. "Survey respondents demonstrated a low level of participation in well maintenance and stewardship practices…
2. Most respondents demonstrated a low level of knowledge with regards to the source of their well water and the functioning of their well…
3. Most survey respondents have a false sense of security regarding the risks posed by their well and unjustified confidence in their knowledge of their water supplies…
4. Awareness of well stewardship practices was not sufficient to motivate many survey respondents…
5. Health and aesthetic concerns and a desire to follow good practice were key motivators for engaging in water well stewardship practices…
6. Financial costs are not a significant barrier in undertaking well stewardship practices…
7. Many respondents indicated the need for more information on how to undertake proper well stewardship practices…
8. Respondents indicated that they would likely seek information from a number of sources if they had questions about their water well" (Summers, 2010, pp. iv–v).

Increasing financial capacity in rural communities is not always an option, also as found by Summer (2010), financial costs are not always even a significant barrier in undertaking stewardship practices. Creating effective and implementable policies that meet the needs and goals of all stakeholders, including the general public, and that can be created in a cost efficient manner, has been a problem for planners and activists in watershed planning (Webler & Tuler, 2001). Engaging the public in watershed planning, governance, and management has been proven to get local level actors better involved in the management of their water, thus increasing the technical capacity and number of people (i.e. human capacity) involved in watershed management efforts (de Loë & Kreutzwiser, 2005; Robins, 2007). Furthermore, others have found that engaging the public in water management is an essential part of both governing and managing water systems (Conrad & Daoust, 2008; Hamstead, Baldwin, & Keefe, 2008; Hardy & Koontz, 2008; Özerol & Newig, 2008; Rouillard, Benson, & Gain, 2014; Sharpe & Conrad, 2006). It is clear that education and outreach are essential activities, whether water supplies are being protected on the watershed, aquifer, or wellhead level (Kreutzwiser et al., 2011; Simpson, 2004; H C Simpson et al., 2007).

6. Conclusion

According to Statistics Canada one-third of rural and small town residents rely on private wells for their drinking water (Hardie & Alasia, 2009). This is not an insignificant part of the Canadian population, with approximately 4.1 million residents (12% of the total Canadian population) relying on private supplies, most of which are in rural areas (Pogoda, Felleiter, & Majury, 2017). Similarly, in Ontario private wells serve a mainly rural population and approximately 1.6 million Ontario residents (Ontario Auditor General, 2016; Simpson, 2004). It is clear that reducing the risk of waterborne illness from private well supplies requires proactive source water protection (Simpson et al., 2007). This literature review has highlighted ways in which source water protection for privately serviced areas can be conducted, as well as the challenges to implementing source water protection in these areas. Though well owners bear most of the responsibility for protecting these privately serviced areas (Imgrund et al., 2011), the Walkerton Inquiry does call for the Province of Ontario to play a role in providing these private well owners with the technical expertise to provide safe drinking water (O'Connor, 2002b). This is incredibly important, as private well system owners typically have fewer resources, experience and technical knowledge in order to implement a multi-barrier approach in delivering safe drinking water (Murphy et al., 2016). Serious consideration of who could and should be involved in raising technical capacity of private well owners should be undertaken (Ontario Auditor General, 2016). Murphy et al. (2016) state, "engaging private well owners in the stewardship of their wells is an on-going responsibility shared by private well owners and governments at all levels" (Murphy et al., 2016, p. 1367). Evidently, we all have a role in providing clean and safe drinking water for all drinking water supplies, private or public, for current and future generations (O'Connor, 2002b).

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