Freshwater Scarcity:
The Current Situation in Southern Ontario

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ABSTRACT

Access to clean drinking water is essential for survival of humanity and the earth. With the global population approaching eight billion (Population Reference Bureau, 2018), protecting the availability of clean drinking water is becoming increasingly important to sustain the growing number of people on the planet. Unfortunately, many places in the world are experiencing drinking water shortages due to overconsumption and contamination of freshwater resources (Gleeson & Richter, 2017; Richey et al., 2015). Global changes in climate are also serving to reduce even further the availability of clean water and many parts of the globe are already struggling with freshwater supply (Weber et al., 2017; Veldkamp et al., 2016). While access to clean water remains a global concern, there are select places on the planet where there appears to be a sufficient supply. Southern Ontario is one such location where there appears to be an abundance of freshwater.

Streams, rivers, lakes, and groundwater serve as sources of drinking water, and are collectively referred to as “source water” (Emerson & Jesperson, 1998). Source water protection under the Ontario *Clean Water Act*, 2006 emerged after a fatal outbreak of Escherichia coli (E. coli) in 2000 into the drinking water system in Walkerton, Ontario. Following that incident, new provincial policies were implemented to protect raw drinking water at source (Ministry of the Environment and Climate Change, 2014).

Ontario is experiencing the same threats to its drinking water supplies as the rest of the world; that is, contamination and overconsumption (Bruce et al., 2017; Anderson et al., 2016), in addition to the effects of climate change (McDermid et al., 2015). Contamination originates largely from industrial activities, but also from wastewater treatment plants, which do not have the ability to treat contaminants such as micro-plastics that are present in consumable products (Pivokonsky et al., 2018; Baldwin et al., 2016). Bottled water companies are permitted to withdraw more water than can be replenished by natural processes, which can deplete water resources (Bruce et al., 2017; Griswold, 2017). Additionally, reductions in government funding to provincial environmental agencies, federal contaminated sites and rapid urban expansion in the Greater Toronto Area, contaminated soil dumping in the Oak Ridges Moraine, the Canadian

'myth of water abundance,' water contamination on First Nations reserves, and *Bill 108*, all represent a threat to the sustainability and management of freshwater resources in southern Ontario.

Despite the issues prevalent for freshwater resources in the world, the general consensus amongst Ontarians is that there is an abundance of clean drinking water in the province (Warren, 2016; Schindler, 2006). However, Ontarians do not understand that, without immediate changes to source water protection, southern Ontario may find itself in the same dire situation as the rest of the planet.

This paper will examine the current state of the world's freshwater resources to supply potable water, the status of southern Ontario's freshwater resources, and the actions and policy changes that are required to protect the availability of clean drinking water to support the needs of future generations of Ontarians.

FOREWORD

It is easy for many of us in countries that are blessed with lots of freshwater to take water for granted. This is particularly the case in southern Ontario, where we can turn on the tap and have immediate access to water. We assume that it will always be there because that has been the case for generations before us, and we have no information or awareness to suggest otherwise. Neither the government nor the media has raised any concerns about the future of southern Ontario's freshwater resources, and much of the population has likely forgotten that access to freshwater is essential for life. Ontarians are not being told the truth about the state of freshwater resources in the province, and the province appears not to be taking action to ensure a long-term sustainable supply.

Much of the rest of the world is already struggling with access to freshwater. In some of these areas, lakes and rivers are diverted and/or filled to make room for expanding cities. Groundwater levels are falling as industries and bottled water companies withdraw more water than can be replenished by nature, and what little freshwater remains is being contaminated by agriculture, industry and resource mismanagement. The people in these countries know first-hand what it is like not to have access to freshwater.

Global climate change is complicating the management of freshwater supplies because less is becoming available due to less rain (in some areas) and high rates of evapotranspiration (in others). Climate change is a significant problem for countries already experiencing scarcity of freshwater resources. Without freshwater, the ability to continue growing the population will be affected. For areas with a currently sufficient supply of freshwater, such as southern Ontario, the impacts of climate change may be perceived to be much less. However, that largely depends on how the freshwater resources are being managed. Given Ontario's lack of awareness and management of this important resource, climate change will likely play a much more significant role than it should.

This Major Paper is a culmination of my Area of Concentration set out in my Plan of Study, which includes natural resource management, conservation biology and climate change. The intention behind these components and my learning objectives was to gain a thorough understanding of the theory and practice of environmental management as it relates to sustaining human and ecological systems. Although there are so many environmental challenges around the world worth exploring, I decided to focus my paper on clean drinking water because it is a resource that is essential to life, it is limited in nature, and its quality and availability are rapidly declining in many regions around the world. Specific to southern Ontario, my interest is rooted in how we take this resource for granted, how it is being contaminated, and how bottled water companies are permitted to take this resource at unsustainable rates; all with the approval of our provincial government. Specifics will be discussed within this paper.

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Much gratitude goes out to all those who participated in my research study. Your kind and insightful support has made valuable contributions to my research and expanded my knowledge beyond the context of this paper.

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“*Water is always on the move in the hydrologic cycle. It is the very foundation for all biological life on Earth, and the basic link between the biosphere and the anthroposphere*”

Malin Falkenmark & Johan Rockstrom, 2004, 3

1.0 INTRODUCTION

1.1 Context and Report Format

Access to clean drinking water is critical for mankind's survival and one of the basic human needs as outlined by psychologist, Abraham Maslow, in his famous 1943 paper, *A Theory of Human Motivation* (Webber, 2016). Today, issues of global freshwater scarcity are mounting with growing global populations, increasing agriculture, industrial and economic development, increased demand for natural resources, mismanagement of water resources (e.g., contamination and over-taking) and climate instability, which are all impacting our ability to manage freshwater resources globally.

The current literature confirms that managing freshwater is a major challenge and one of humanity's foremost priorities (Comte & Olden, 2017; Jakeman et al., 2016). Surface water resources are assumed to be more relevant to manage than groundwater, which is hidden beneath the ground. However, Jakeman et al. (2016) report that "groundwater represents over 90 percent of the readily available freshwater on Earth but remains a minor player in water resources management" (4). This suggests that many areas of the globe might be focusing on freshwater management in the wrong area.

Recent studies suggest that declining quality and quantity of surface and groundwater in the developed world cannot support the demands of agriculture, industry, urban growth, and ecosystem functions (Weber et al., 2017; Jakeman et al., 2016, 3). In some areas, the scarcity of clean water fails to meet even the most basic and essential needs of humanity (Weber et al., 2017; Postel, 2014). This is assumed to worsen with the demands of increasing populations.

In a time where multi-national companies own and control municipal water supplies (Bruce et al., 2017), where lakes, rivers and wetlands are disappearing (Verhoeven & Setter, 2009), where millions of people contract waterborne diseases every year (Postel, 2014), where contamination and over-taking of freshwater resources is diminishing the global water supply (Gleeson & Richter, 2017), and where access to clean freshwater is becoming less available every year (Veldkamp et al., 2016), the need to manage our water resources has never been more pressing.

Protecting water at its source is a logical first step in ensuring drinking water safety. The World Health Organization (WHO) has claimed that source water protection is “invariably the best method of ensuring safe drinking water and is to be preferred to treating a contaminated water supply to render it suitable for consumption” (WHO, 1993).

This paper defines source water protection, why it is important, and some possible considerations on how it can be improved and expanded in the Province of Ontario. Emphasis is placed on the reasons behind emerging global freshwater scarcity, and how southern Ontario, currently blessed with large quantities of freshwater, might experience the plight of the rest of the world unless action is taken.

This paper opens with the specific research objective and question and outlines the research design and methodology. Second is a technical overview on freshwater, which includes a definition, its characteristics (i.e., ecosystem services, surface and groundwater interactions), and its overall volume and accessibility. Third is a review of case studies that represent, by example, the global depletion of freshwater resources. The case of Walkerton, Ontario and its “next generation” influence on water resource management is also reviewed. Fourth, current legislation protecting source water in Ontario is reviewed, with context on whether there is sufficient protection of freshwater resources in the province. Fifth, this paper provides insight into how the current global freshwater shortage crisis can serve as a valuable case study for southern Ontario. Lastly, recommendations are offered to improve the management of source water protection in southern Ontario to ensure that future Ontarians have access to the same resource as generations before them.

1.2 Research Objective and Question

The overarching objective of this research is to identify gaps in the literature or in current practice regarding issues that may potentially impact the quality and availability of source waters (i.e., surface and groundwater) within southern Ontario, and to explore the contemporary challenges facing sustainable water use in the province.

Research Question

Is there appropriate protection and sustainable management of clean drinking water resources in southern Ontario, and what changes (if any) need to be made to address risks of impacts from contamination, over-use, and/or climate change?

1.3 Research Design and Methodology

Through various courses I have engaged with at the graduate level, I have been able to expand my understanding of the theoretical and contextual frameworks that have made this area of research relevant. My Plan of Study exemplifies the diversity of scholars I have studied, that have deepened my understanding of the role that economic, environmental, political and ecological factors play in resource management to preserve a future for generations to come. I critically engage with the concepts I have been exposed to through Natural Resource Management, Environmental Impact Assessment, Biological Conservation, Disasters: Concepts and Causes, Climate Change: Science and Policy, and Environmental Economics; courses that I took in the first two terms of the MES program. I also apply concepts and practices that I explored in my summer and fall term field experiences in the field of environmental assessment. Through these field experiences I was able to experience first-hand how impacted soil and groundwater affect the quality of freshwater supplies.

My studies have prepared me to consider the design of my research with a more ethical approach. In addition to human systems, I intend to consider ecological and generational factors to establish an approach of sustainable development. To achieve an in-depth understanding of specific issues or concerns that might exist around source water management in southern Ontario, I collect different forms of qualitative data. This includes semi-structured interviews via email or telephone (depending on the participant’s availability and preference), open-ended survey questions, case study research (analysis of past cases, understanding the data collection methods and inferring the data), a review of primary legal documents, a secondary literature review, a review of government documents, media reports, and an application of analytical methods.

Semi-structured interviews are described by Lioness (2008) as a qualitative data collection strategy wherein the researcher (myself) asks interviewees a series of fixed but open-ended questions (1). I created an open-ended survey for participants (see Appendices), which, according to Roberts et al. (2014) and their article, *Structural Topic Models for Open-Ended Survey Responses*, allows respondents the freedom to express their own views about a topic, which provides the researcher (myself) with exploratory data that may reveal unexpected issues, opportunities, or quotes (ibid).

Participants were interviewed via email and telephone, and the interviews ranged from approximately thirty minutes to one hour in length. This approach to my research required organizational staff, private organizations, government operatives, and myself, to work equitably together through the research process. Working 'equitably' also means sharing the research upon completion (Tuck, 2009). I have conducted interviews with organizational staff and project managers in government (i.e., Toronto and Region Conservation Authority and the Ontario Ministry of the Environment, Conservation and Parks), and interviews with members of a private environmental consultancy (i.e., a senior field technician and the President and Chief Executive Officer). The diversity of interviews in government and private institutions is pivotal in gaining an understanding on the current and emerging threats to southern Ontario's supply of freshwater. Participant selection was based on contacts that I made through my 2018 field experiences, through referrals, and through google searches of government agencies that are related to source water protection in southern Ontario.

Emails were sent out to various professionals in the field to ask if they would be willing to participate in the research. There are a few that did not respond to the interview request; namely, Ontario Nature (non-governmental organization), Ontario Watersheds (non-governmental organization), Environmental Defence (non-governmental organization), Nestlé Canada, and the Ministry of Natural Resources and Forestry.

The data from telephone interview sessions is stored as audio recordings, which is safely stored on a hard drive and on my personal computer. The data received through email responses is also saved and stored on my personal computer and external hard drive. No names are used throughout the duration of my research unless direct consent was provided.

2.0 TECHNICAL BACKGROUND

This section of the paper will review the critical points of current knowledge on freshwater and its relevance to human and ecosystem survival. The ultimate goal is to bring the reader up to date with the current literature relevant to the topic and to provide justification for further research in this area.

2.1 Freshwater as a Renewable and Non-Renewable Natural Resource

Natural resources have long been recognized for their essential role in ensuring human survival, and in supporting biological functions of the environment (Brown & Wolk, 2000, 3). Natural resources have been classified as renewable (e.g., solar energy, trees, soil nutrients and surface water) and non-renewable (e.g., fossil fuels, copper, gold, aluminum, and many other minerals and gems) (Wellmer & Sinding-Larsen, 2010; Farley, 2008). Freshwater demonstrates characteristics of both renewable and non-renewable resources. Freshwater is considered by the literature as a largely “renewable” resource (Addink & Addink, 2008). However, there are fixed stocks of water resources that are being withdrawn at rates that exceed natural rates of renewal. Most of these resources are groundwater aquifers; resources that are non-renewable and are often referred to as “fossil” aquifers because of their slow rates of recharge (Gleick & Palaniappan, 2010). The focus of this paper is on freshwater as a renewable resource; but groundwater, on a human timescale, is effectively non-renewable and can therefore be considered exhaustible.

Recent studies suggest that global freshwater resources are rapidly declining due to climate change and other human pressures on water resources (Comte & Olden, 2017; Jakeman et al., 2016; Veldkamp et al., 2016). It is important to consider that just because a particular water resource may be ‘renewable,’ this does not mean that it is ‘unlimited’. The sections below outline the physiological significance of freshwater systems.

2.2 Freshwater Requirements for Humans, Ecosystem Services and Sustainability

Human interactions with freshwater most often involve accessing fresh streams, rivers, marshes, lakes, and groundwater aquifers (Dodds, 2002). Humans and ecosystems depend on this water and require an abundance of freshwater to live. Accordingly, we rely heavily on this increasingly rare commodity.

Water is a remarkable substance with its inherent makeup of two hydrogen atoms bonded to a single oxygen atom; forming its chemical composition, H_2O. The reason scientists are looking for water on other planets is specifically rooted in its ability to sustain life. Water in its liquid form, however, is particularly valuable and it appears to be exclusive to Earth. This is because liquid water is scarce, and liquid water on a planet's surface is even scarcer because it only occurs in a narrow range of temperatures and pressure (Ball, 2007). Earth is one such planet that is fortunate to have liquid water on its surface; thus, creating life as we know it. Falkenmark & Rockstrom (2004) stress that "we should always be alert to the central role that water plays in the rich diversity of biological processes" (4).

Freshwater is defined by Petersen et al. (2019) as "water containing less than 500 ppm [parts per million] of dissolved salts" and constitutes only 2.5 percent of the total water on the earth; mostly stored in ice caps, in surface water, in soil and in groundwater reservoirs (1). Studies have quantified the water molecule as intrinsically significant to life on Earth, and its properties are considered "fixed" and "irreplaceable" in nature (Loucks & van Beek, 2017, 2; Brown & Wolk, 2000). Accordingly, if humans exhaust the resource by extracting more than can be replenished by nature, or by contamination and resource mismanagement, the consequences to all living organisms on Earth is likely to be significant.

For millennia, water resource systems have benefitted both people and their economies. Surface and groundwater are a source of water supply for municipal, industrial and agricultural consumers, and rivers provide hydroelectric power generation and inexpensive ways of shipping cargo (Weber et al., 2017; Swain, 2016). Humans rely heavily on freshwater for daily living and continued economic growth and prosperity, but it is also a source of water for wildlife and their habitats. Accounting for less than one percent of the world's water and approximately 0.8

percent of Earth's surface, this small fraction of global freshwater supports "100,000 species out of approximately 1.8 million (almost 6 percent of all described species)" (Dudgeon et al., 2005, 163). However, the International Union for Conservation of Nature (IUCN) and their *Red List of Threatened Species* (a globally recognized tool for assessing the risk of species extinction) found that of the freshwater species comprehensively assessed through the *Red List*, about "one-third are under immediate threat of extinction" (IUCN, 2017).

Freshwater ecosystems, the foundation for human sustenance, economic growth, freshwater biodiversity, and its associated ecosystem integrity, are increasingly threatened. It becomes ever more important to address the source of these threats to protect the well-being of humans and ecosystems for both present and future generations. Accordingly, many freshwater systems are threatened by water withdrawals and man-made reservoirs, over-exploitation, water pollution, habitat destruction/degradation, invasion by exotic species, and climate change (Veldkamp et al., 2016; Gosling & Arnell, 2013; Doll & Zhang, 2010). Such human pressures on water resources are growing in scale across the world, and it is imperative that we competently protect water at its source to preserve water resources for future use.

2.3 Ecosystem Services

Humans have managed their environments for millennia; altering landscapes in the pursuit of agriculture, civilization, and well-being. Human land use change has intensified over the past few centuries. Marked by the Industrial Revolution and the growth of the twentieth century, it quickly became clear that our growth pattern was desolating the environment at local, national, and global scales (McLamb, 2013; Farber et al., 2002). It also became clear that human-induced impacts on the environment are often "co-occurring and cumulative," and that anthropogenic activities pose serious risks to ecosystem services (Singh, 2016). As a result, trends have recently shifted towards protecting ecosystems and the services they provide on greater natural scales. This is particularly true at the watershed level.

Advances in research have brought the significance of ecological preservation into economic terms to help better understand its value. For example, in 1997, Robert Costanza et al. evaluated the world's ecosystems in terms of the essential services they provide (such as clean air, water purification, flood control and carbon sequestration), and attached an economic value of $33 trillion (USD) per year (Costanza et al., 1997, 259). In 2014, Costanza et al. provided an updated estimate based on updated ecosystem service values and land use change estimates between 1997 and 2011. The study estimated that the global ecosystem services in 2011 was worth $125 trillion (USD) per year, with an estimated loss of ecosystem services in this time due to land use change and other human pressures to be upward of $20 trillion (USD) annually (Costanza et al., 2014).

Ecosystem services (see Figure 1) are the benefits that human society obtains from ecosystems. When grouped into four categories, ecosystem services include provisioning (products that are derived from ecosystems such as food, clean water, fuels, medicines, etc.), regulating (ecosystems contributing to the overall stability of natural systems such as climate, water purification, and carbon sequestration), cultural (intangible benefits such as spiritual development, aesthetic, reflective, etc.), and supporting (soil formation, habitat, biodiversity, nutrient cycling, etc.) (Adamowicz & Olewiler, 2016; Austen et al., 2015). It is commonly accepted among the literature that the amount and delivery of ecosystem services is largely based on the efficiency of ecosystem functions; that is, the physical and biological processes that contribute to an ecosystem maintaining itself (e.g., wildlife habitats and carbon cycling) (Austen et al., 2015; Schröter et al., 2014). It is also commonly accepted that freshwater vitally supports the efficiency and delivery of ecosystem services, in addition to preserving natural ecosystem integrity and long-term ecosystem sustainability of freshwater environments (Adamowicz & Olewiler, 2016; Austen et al., 2015; Schröter et al., 2014).

Figure 1: Ecosystem Services and their Human and Ecological Benefits (Source: The Nature Conservancy, 2019)

Assigning a monetary value to ecosystems remains highly controversial amongst researchers; however, the controversy itself is beyond the scope of this paper. For the purposes of this research, ecosystem valuation is viewed by many researchers as an economic tool that humans can use to better understand the inputs and outputs of water through the hydrologic cycle; which in turn can be beneficial by raising awareness and conveying the importance of ecosystems and biodiversity to policy makers (Austen et al., 2015; Groot et al., 2012). Since the publication of Costanza et al.'s initial global valuation of ecosystem services, similar methodologies have been applied by other scholars. For example, a 2012 study published in the *Journal of Marine and Freshwater Research* found that global wetland ecosystem services are worth the equivalent of over $47 trillion (USD) per year (Groot et al., 2012, 50). The study also concludes that biodiversity and its associated ecosystem services "can no longer be treated as inexhaustible and free goods" (Groot et al., 2012, 51).

Specific to southern Ontario, it is estimated that the Greenbelt (see Figure 2) provides $2.6 billion (CAD) per year in ecosystem services, with the value of watersheds alone at over $1 billion (CAD) annually, and an equivalent of $131 million (CAD) per year in natural water filtration services (Molnar et al., 2012, 5). The Greenbelt was created to permanently protect environmentally sensitive areas in southern Ontario, and encompasses the Oak Ridges Moraine, the Niagara Escarpment, and Rouge Park. The Greenbelt also intersects four major watersheds and protects the habitats within them, in addition to the streams and groundwater reserves (Molnar et al., 2012).

It is estimated that more than three-quarters of Ontario's watersheds have been lost to agriculture, urban development, and land clearance and filling; and significant declines in ecosystem services from the declining watersheds have already impacted the southwestern Ontario region (Westcott, 2018a; Postel & Thompson, 2005). Forest cover has also diminished in the province, and old growth forest accounts for "less than 0.1 percent" of the land in southern Ontario (Molnar et al., 2012, 14).

As urban, industrial, residential, and agricultural areas develop and expand, it has become increasingly important to protect ecosystems and their delivery of ecosystem services; however, paradoxically, they become more compromised as changes in land use disrupt and interfere with the functioning of ecosystems, subsequently affecting ecosystem integrity and the delivery of ecosystem services (see Section 5.3 for details).

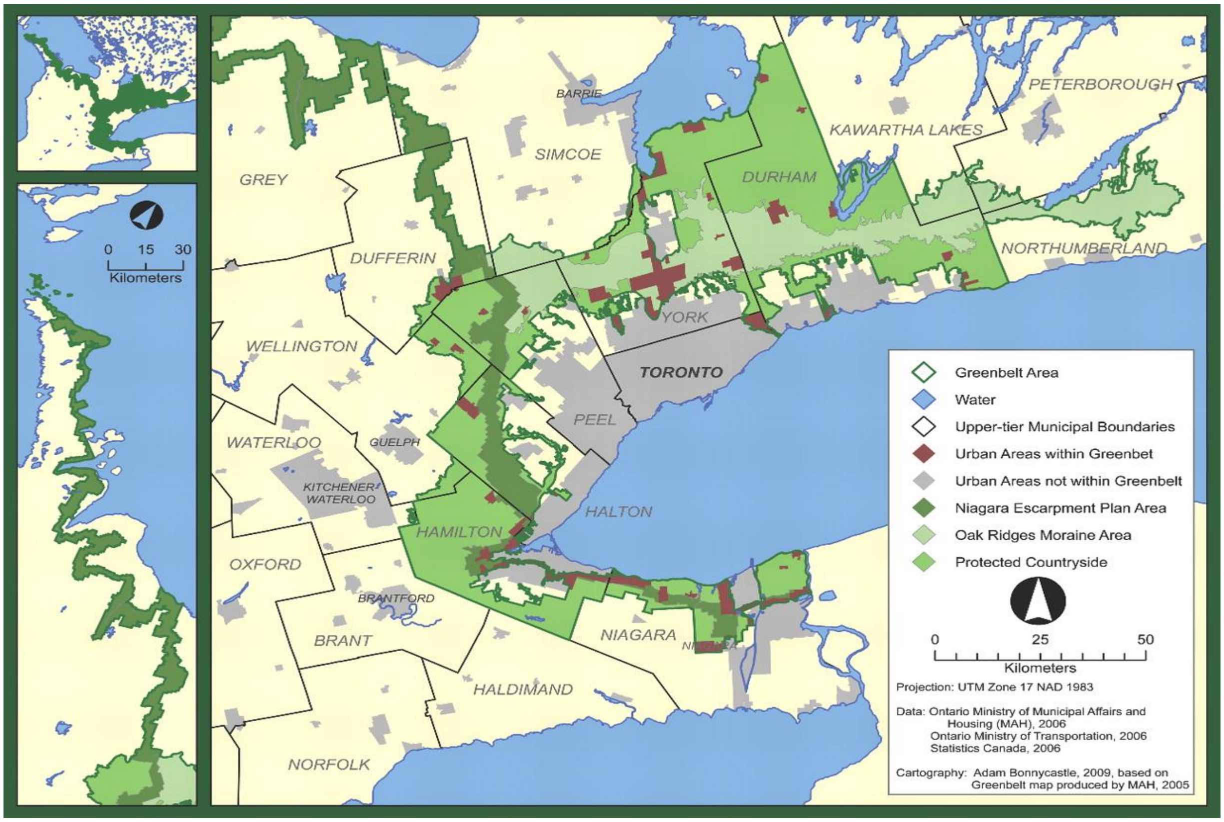

Figure 2: Ontario's Greenbelt (in green) and built-up areas (in grey) (Source: Ontario Ministry of Municipal Affairs and Housing (MAH), 2006)

2.4 Watershed Contributions to Source Waters

Surface water, groundwater, humans, and ecosystems are all interconnected in ways that require an "integrated approach" to sustainable use and management of freshwater resources (Fienen & Arshad, 2016). This is particularly true at the watershed level. In comparison with the enormous marine waters (such as oceans), freshwater occurs as small and very small inland waters. These inland sources of freshwater are particularly reliant on natural stocks of precipitation. For example, when precipitation falls on the ground (as rain or snow), it can soak into underground aquifers or run-off into surface waters (Findlay, 2004). Watersheds (defined by Schwoerbel (2016) as "a land area that channels rainfall and snowmelt to creeks, rivers, lakes and wetlands") are the most striking collections of freshwater, in addition to underground water in the fissures in rocks and in sediments (Schwoerbel, 2016, 1).

As an area of land that serves to drain precipitation, watersheds connect and encompass groundwater, surface water, land, and freshwater ecosystems, and they provide a wide variety of valuable ecosystem services; including the supply and purification of freshwater (Postel & Thompson, 2005). Watersheds range in size from small ponds to large areas of land that can extend municipal, provincial or national borders; and thus, watersheds are interconnected and are affected by adjoining ecosystems and human activities outside of their boundaries (Molnar et al., 2012). Watersheds are an important support system for plants and animals, and they provide drinking water for people and wildlife. Accordingly, protection of freshwater in our watersheds (and sub-watersheds) is essential to maintaining the health and well-being of all living organisms.

2.5 Interactions of Surface and Ground Waters

Streams, rivers, lakes, and groundwater are collectively referred to as “source water,” and it is the raw water that supply our wells and municipal drinking water systems (Emerson & Jesperson, 1998). Protection of source water within our watersheds is therefore vital for continued human and ecological survival.

Humans have settled near water sources for millennia. For much of this time, however, society’s dependence on freshwater has increased significantly. The Food and Agriculture Organization of the United Nations reported that global freshwater withdrawal increased from “less than 600 km^3 [cubic kilometers] per year in 1900 to almost 4000 km^3 per year in 2010,” and that “water withdrawal has increased 1.7 times faster than population over the last century” (United Nations, 2014a).

Human activities can have an effect on surface and groundwater systems in several ways, such as groundwater pumping (that diverts groundwater flow from reaching surface water), groundwater withdrawals that exceed natural rates of recapture, urbanization and land use changes (that alter groundwater recharge rates and surface run-off), changes in thermal stream temperatures, and point-source and non-point source contamination in source waters (Weber et al., 2017; Granneman & Van Stempvoort, 2016; Veldkamp et al., 2016). The interconnectedness of surface and groundwater has become more evident in recent years. One particular example of this ‘single-resource’ recognition arose from the Walkerton tragedy in Ontario, in the year 2000 that led to the formation of source water protection in Ontario (see Section 3.2), which resulted in the formation of the province’s *Clean Water Act*, introduced in 2006 (Ministry of the Environment and Climate Change, 2014). As human civilizations have developed and expanded over time (starting most notably with the Industrial Revolution), the increased demand for natural resources has correspondingly increased the need to introduce legislation and monitoring programs to further protect water resources.

Accordingly, Garda et al. describe that source water protection vis-à-vis water monitoring provides a way to understand surface and groundwater interactions, and it helps to assess the state of aquatic ecosystems (2017). Protecting water at its source is considered by the Auditor General of Ontario as “the first line of defense in a multi-barrier approach to protecting Ontario’s drinking water,” and its purpose is to ensure the long-term supply of the sources of drinking water in the province, and to reduce health risks and future costs by effectively managing and protecting drinking water systems (Ministry of the Environment and Climate Change, 2014, 408).

There are two main sources of drinking water; namely, surface water and groundwater. Recent studies suggest that surface and groundwater can be considered a single resource due to their interactions and thus that groundwater can be equally vulnerable to impacts as surface water (Granneman & Van Stempvoort, 2016; Lefebvre et al., 2015). Groundwater, defined as “any water that lies in aquifers beneath the land surface” (Oskin, 2015), represents about one-third of the world’s freshwater and contributes to maintaining the water-level flow into rivers, lakes and wetlands (Hansen et al., 2018). During drier months, when there is little direct recharge of surface waters from rainfall, groundwater provides the base flow into surface waters (Kenda et al., 2018; Hansen et al., 2018). Surface water, defined as “water on the surface of the earth in the form of lakes, rivers, wetlands, and reservoirs” (Orlova & Branfreun, 2014) interacts with groundwater to maintain the flow regulation of hydrologic processes (Kleidon et al., 2014). Studies have quantified the importance of a functioning hydrologic cycle, defined as “the continuous movement of water on, above, and below the surface of the earth,” to maintain the recharge-discharge processes of surface and groundwater (Daily et al., 1997). Studies have also shown that changes in the hydrologic process can cause significant impacts to water availability at regional and global scales (Kleidon et al., 2014; Back et al., 2013). Further, recent studies have quantified that the movement of groundwater to surface water "will inherently have an effect on surface water quality," and that groundwater contaminants (i.e., road salt, nutrients, industrial compounds, petroleum hydrocarbons, and a variety of other contaminants) can adversely impact surface water quality in its interconnected water channels (Granneman & Van Stempvoort, 2016, 12; Lefebvre et al., 2015). The rate at which the hydrologic cycle (or "water cycle") renews or replenishes freshwater resources; in effect, determines the availability of freshwater for human use (Engelman & LeRoy, 1993, 56).

One of the key differences between surface and groundwater is that groundwater moves at a much slower rate than surface water. This is because groundwater experiences far more friction as it moves through the small spaces in soil, sand and rock (Provencher, 1992). Although groundwater moves at a much slower rate compared with surface water, groundwater has become a large supporter for many societies around the world; and in some areas, it is the primary source of water for municipal, industrial, agricultural and urban use (Weber et al., 2017; Bruce et al., 2017; Jakeman et al., 2016). For this reason, groundwater plays an important role in the management and sustainability of water resources.

Large quantities of clean freshwater are stored in underground "aquifers" (defined by Provencher (1992) as geologic formations of soil, sand and rocks (4)) and is usually easy to access with groundwater well and pump technologies. This groundwater is often available "on-site" and is filtered by natural processes (such as different layers of soil) and it is therefore typically inexpensive to treat for human consumption compared to surface water (Pfeiffer & Lin, 2012). This makes groundwater a reliable source of water because it can provide users with on-demand water when they need it, and it is less expensive to treat for consumption compared to surface water. It is therefore not surprising that industrial, commercial and domestic use of groundwater is the preferred source of water; however, paradoxically, this has led to rigorous and unsustainable groundwater withdrawal in many areas around the world (see Section 3.1 for examples).

General consensus amongst researchers is that, in some watersheds, large quantities of current water withdrawal comes from water resources that are effectively non-renewable. For example, groundwater aquifers with very slow recharge rates or groundwater systems that cannot be recharged when over-pumped can make the resource "non-renewable" (Wada et al., 2010; Gleick & Palaniappan, 2010). For this reason, it becomes increasingly important to understand the effects of over-pumping groundwater resources; which, in turn, can cause a 'ripple effect' on its nearby surface water bodies.

A 2018 report by the United States Geological Survey (USGS) describes that when water withdrawal from a groundwater aquifer far exceeds the natural rate of recharge, groundwater is quickly depleted by lowering of the water table (resulting in reduction of water in streams and lakes), land subsidence and aquifer compaction, increased costs for the user, increased salinization, the deterioration of water quality, and a depletion of overall groundwater resources (USGS, 2018). Moreover, in cases when groundwater aquifers become contaminated with pollutants that make the water unusable, many researchers argue that the adverse effects carry over to surface water bodies and impact freshwater ecosystems and the biodiversity within them (Granneman & Van Stempvoort, 2016; Gleick & Palaniappan, 2010; Falke et al., 2010).

Past cases of unsustainable water use have been studied and found to demonstrate the impact of excessive groundwater pumping. For example, in the Central Valley of California, excessive groundwater pumping has caused significant drawdowns, aquifer-system compaction, and subsidence (Faunt et al., 2015). About eighty percent of land subsidence, defined as "the gradual setting and lowering of the earth's surface" in the United States can be directly attributed to groundwater withdrawal (Falke et al., 2010). In the state of Wisconsin, United States, excessive groundwater pumping reduced the stream flows of surrounding surface water resources resulting in the drying up of streams and supported ecosystems (Wanamaker, 2018). Recent studies have also found that global groundwater depletion rates have reached an all-time high (Russo & Lall, 2017; Gleeson & Richter, 2017).

Due to the hidden nature of groundwater, it becomes increasingly important to understand how this water moves through the hydrologic cycle to provide the necessary stock of freshwater for humans and ecosystems. Hydrologic fluxes, or "movements of water through the hydrologic cycle," are considered by researchers as imperative to understanding water availability (Good et al., 2015, 176; Kleidon et al., 2014; Kornelsen & Coulibaly, 2014; Engelman & LeRoy, 1993). The hydrologic cycle (see Figure 3) is an important natural deliverance system of freshwater to supply the needs of human and ecological systems. It is our dependence on the water cycle where humans extract water for agriculture, industry and energy, municipal use (e.g., drinking water), and it maintains the environmental flow regimes for local and regional ecosystems (Good et al, 2015).

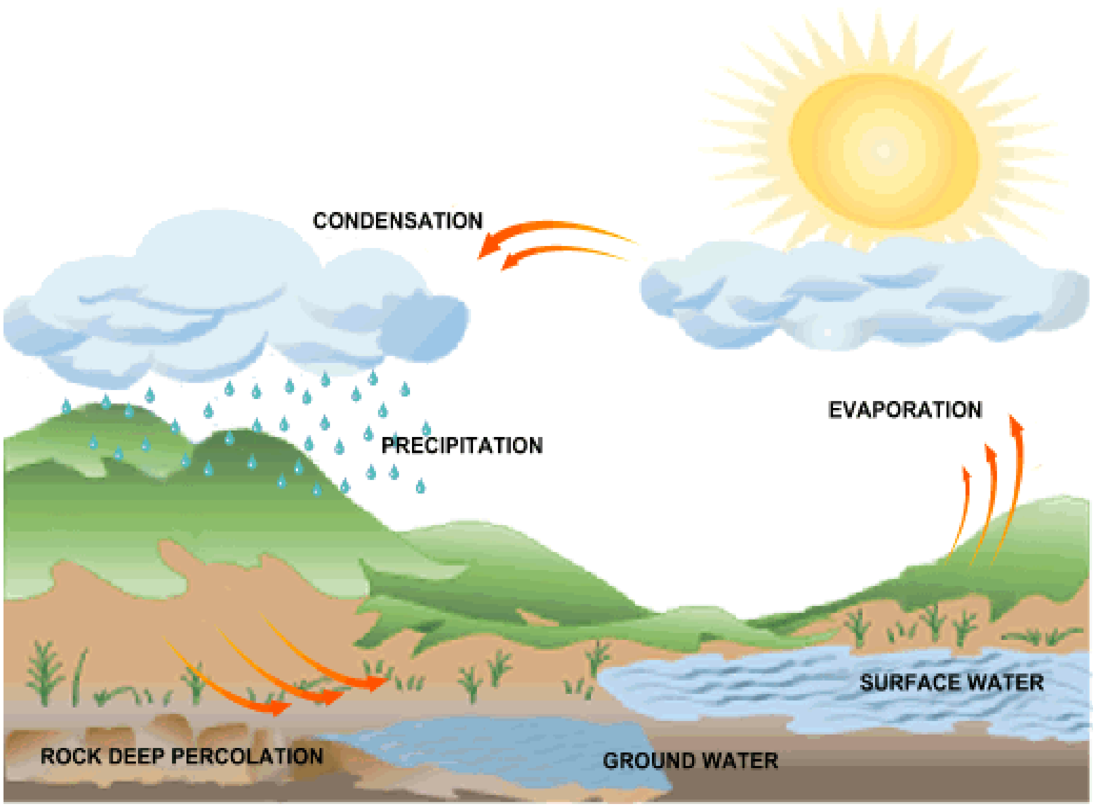

Figure 3: The Hydrologic Cycle (Source: Southeast Texas Water, 2019)

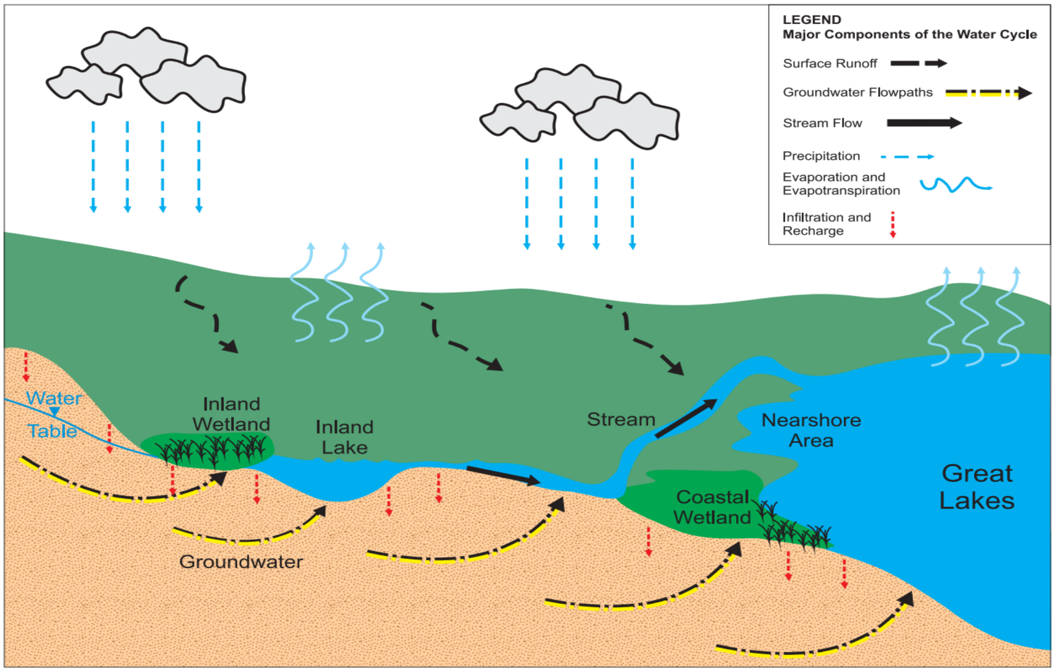

Figure 4: Schematic of groundwater flow through Wetland, Stream and Lake Ecosystems (Source: Granneman & Van Stempvoort, 2016)

To appreciate the importance of protecting water at its source, it is helpful to understand the ways in which water is collected and diverted into surface and groundwater systems. Illustrated in the above Figures (3 and 4) is the hydrologic cycle; the endless circulation of water from the atmosphere to the earth and back to the atmosphere. Its natural process involves evaporation (when the sun heats up the molecules of a water body evaporate into the atmosphere), transpiration (plants/vegetation give off water vapor into the atmosphere), condensation (as water vapor rises, it cools and condenses), precipitation (clouds with condensed water molecules fall in the form of rain, snow, etc.), percolation (some precipitation seeps into porous soil and cracks in rocks to settle in aquifers), and surface run-off (precipitation flows over the surface of land and into nearby water bodies) (Findlay, 2004).

To elucidate surface and groundwater interactions, the concept of "base flow" (defined by Kornelsen & Coulibaly (2014) as "the contribution of groundwater discharge to overall flow of the water body") is highlighted in the literature (1). Groundwater is mobile in underground aquifers and flows towards discharge points at the surface near water bodies or wetlands (Oskin, 2015; Kornelsen & Coulibaly, 2014). Since the temperature of groundwater is usually lower than the surface (i.e., less exposure to sunlight), it is commonly accepted amongst researchers that groundwater discharge into streams provides a critical temperature regulation function, which is vital for productive and sustainable habitats and to maintain water quality (Kornelsen & Coulibaly, 2014; Gleick & Palaniappan, 2010). In addition to precipitation and surface run-off that replenish surface water bodies, this groundwater discharge (see Figure 4) is also essential to the stream flows of various creeks, rivers and lakes (Granneman & Van Stempvoort, 2016; Kleidon et al., 2014). As a result, general consensus amongst researchers is that to achieve sustainable water use, human extractions of water must be less than or equivalent to the natural recharge-discharge processes of the hydrologic cycle to maintain an equilibrium (Oskin, 2015; Kleidon et al., 2014).

2.6 Defining "Sustainability"

It is becoming increasingly clear that we must not only manage our water resources for today's social, economic and environmental needs, but we must also keep our resources unimpaired to ensure a sufficient supply for future needs. It also becomes increasingly important to recognize that today's decisions of water use may compromise the natural systems that support life on Earth for future generations. For this reason, the concept of "sustainability" or "sustainable development" is increasingly viewed in the academic literature as a vital management philosophy for all of our environment and resources (Morelli, 2011; Callicott & Mumford, 1997; Foy, 1990). Members of various professions offer different meanings to the term "sustainability," and thus, there is no universally accepted definition in the literature. It is defined in various ways and for specific purposes, depending on the context in which it serves.

For example, Callicott & Mumford (1997) develop the meaning of the term within the context of "ecological sustainability," serving as a suitable concept for conservation biologists. In *Ecological Sustainability as a Conservation Concept*, the authors apply an ecological definition of sustainability that connects ecosystem services and human needs, further expressed by the authors as "meeting human needs without compromising the health of ecosystems"

(Callicott & Mumford, 1997, 32). From an economic standpoint, the term "sustainability" has a radically different viewpoint from ecological sustainability. For example, in *Economic Sustainability and the Preservation of Environmental Assets*, Foy explains that "the core requirement of sustainability is that current economic activities should not result in an excessive burden on future generations" (Foy, 1990). In contrast of the different ecological and economic standpoints of the term "sustainability," ecologists will seek to preserve environmental assets in *physical* terms, whereas economists will seek to preserve environmental assets in *financial* terms. However, both standpoints of the concept are similar in that they have a shared ideology; that is, maintaining an 'equilibrium' so that the human needs of today do not jeopardize the ability of future generations to meet their own needs.

Sustainability is also defined in broader terms of the environment; more specifically, "environmental sustainability," defined by Morelli (2011) as "a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity" (5). Broadly speaking, "environmental sustainability" can be viewed as adding depth to the conventional definition of "sustainable development;" that is, "meeting the needs of the current generation without compromising the ability of future generations to meet their own needs" (Morelli, 2011, 5). Among the various definitions of sustainability, a common theme presents itself where we must think and act in a responsible way; such that today's decisions in resource management do not endanger the requirements of future generations.

In Canada, the federal government discuss that to manage water in a "sustainable way" we need to "[1] develop a better understanding of the physical, chemical, and biological components of aquatic ecosystems; [2] improve our knowledge about how atmospheric and terrestrial changes impact water quality and quantity; and [3] we need to apply this knowledge appropriately to anticipate and prevent environmental degradation from occurring" (Environment and Climate Change Canada, 2013a).

For the purposes of this research, I will adopt the view of sustainable development in terms of meeting the human and ecological needs of today without compromising the ability of future generations (both humans and ecosystems) to meet their own needs. The concepts of sustainability and sustainable development certainly hold their place in water resource management initiatives. The long-term goals of protecting our water resources emphasize water withdrawals to be consistent with or less than what can be replenished naturally through the hydrologic cycle (Oskin, 2015; Kleidon et al., 2014). It is also necessary to extract water for human sustenance and continued economic growth; however, it is equally necessary that we understand the rate at which water is recycled through the hydrologic cycle to ensure that the amount withdrawn is at an equilibrium. It is our ability to maintain this equilibrium that will define our ability to use water sustainably, in addition to protecting its quality and availability for all other uses of water.

2.7 Volume and Accessibility of Freshwater

Since their beginning, human civilizations have settled near streams, rivers, and lakes that provide potable water for consumption and all other uses. In many ways, vast quantities of freshwater have supported the advancement of human societies. For example, dating as far back as 8,000 BC, at the end of the last ice age, small bands of hunters and gatherers settled next to large rivers to maintain a sufficient supply of water for domestic use and as farming developed for irrigation (Etim, 2018). All the same, from the Seine River in Paris to Lake Texcoco in Mexico City, population growth and distribution have been closely linked to the availability of freshwater for millennia (Hamoumy, 2019). Today, we continue to rely on the hydrologic cycle for water supplies that support a variety of social, cultural, economic, and life-support services. In particular, these life-support services require clean freshwater for humans and wildlife to consume. For the purposes of this research, it is important to emphasize that what is normally measured when it comes to water consumption is ‘freshwater’ consumption.

Accordingly, only a tiny fraction of Earth’s water abundance consists of liquid water that is fresh enough to drink, grow crops, and satisfy other human and ecological needs. There is a major distinction between the total resource, and its availability and accessibility to serve the needs of the former. Of the total volume of water on the planet (an estimated 1,386,000,000 km^3), only 2.5 percent is fresh, with two-thirds of that locked in glaciers and ice caps that are, in effect, inaccessible to humans. Of the freshwater that is accessible to humans, merely 0.77 percent of the world's water is held in lakes, rivers, wetlands, underground aquifers, soil pores, plant life and the atmosphere (McDonald et al., 2011; Rogers, 2008). Accordingly, even though the majority of Earth's surface is comprised of water (about 70 percent), less than one percent of this water is made available for consumption. In maintaining this small supply of potable water for humans and wildlife, precipitation on land is of particular importance. An estimated 110,000 km^3 of water is made available annually through the hydrologic cycle and constitutes the total global renewable freshwater supply (Good et al., 2015).

Human demands for freshwater have increased rapidly in recent decades as a result of population growth and its corresponding higher levels of material consumption (Debaere & Kurzendoerfer, 2019; Shaikh, 2017; Gleeson & Richter, 2017), with estimates of withdrawals or extractions of water from the environment "having more than tripled since 1950" (Debaere & Kurzendoerfer, 2019, 155).

Most of the world's total renewable freshwater supply can be found in Brazil, Russia, the United States, Canada, and China, respectively (Misachi, 2018). Evidently, there is an uneven distribution of water resources around the world. Only a few countries are freshwater-rich, while others remain faced with high levels of water stress and increased scarcity of water resources. Even so, many of the aforementioned countries are experiencing significant drawdowns of water resources, primarily due to over-taking and contamination (a few cases are discussed in Section 3.1). Although Canada ranks fourth in total global renewable freshwater supply (Misachi, 2018), 18 to 20 percent of the available global surface freshwater can be found in southern Ontario; most of which is located in the Great Lakes (Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014).

The growing and competing demand for industrial, agricultural, municipal, and recreational water has made potable water a scarce resource in many areas around the world (Gleeson & Richter, 2017; Mekonnen & Hoekstra, 2016). Severe water shortages have already affected some countries, regions, and municipalities. For example, Engelman & LeRoy (1993) categorized countries with less than 1,700 m^3 (cubic meters) per capita, less than 1,000 m^3 per capita, and less than 500 m^3 per capita as facing water stress, chronic (moderate) water scarcity, and absolute (severe) water scarcity, respectively (Engelman & LeRoy, 1993, 56). Over the last few decades, studies have demonstrated increasing trends of water scarcity based on the aforementioned categories of water stress and have found increasing threats to the sustainable development of society. For example, 71 percent of the human population (about 4.3 billion people) reportedly live under conditions of "moderate to severe" water scarcity for at least one month of every year (Mekonnen & Hoekstra, 2016). Studies have also quantified that water-scarce countries grew from seven in 1955 to twenty in 1990, and the number of water-scarce countries are projected to increase to thirty-five by the year 2025 (Elkiran & Turkman, 2008). Additionally, the United Nations' Sustainable Development Goal 6 Synthesis Report, 2018, on Water and Sanitation, reported that more than two billion people live in countries experiencing high levels of annual water stress (United Nations, 2018). Today, 27 countries are short of water, a quarter of the world's population has no safe water, 46 percent have no proper sanitation, and every year four million children die of waterborne diseases (Postel, 2014).

Recent studies suggest that increasing human populations are not only stressing the volume and sustainability of the existing supply of freshwater, but they are also placing these supplies at a greater risk of contamination (Gleeson & Richter, 2017; Richey et al., 2015). The result is increased global "freshwater scarcity," defined as "the inability of water resources to meet water demands" (Howell, 2013). Water scarcity is unanimously considered among the current literature as one of the most important global risks for modern society (Veldkamp et al., 2016; Mekonnen & Hoekstra, 2016; Gosling & Arnell, 2013). Unfortunately, warnings of water scarcity do not come as a surprise to most. The United Nations have been warning us of water shortages by the year 2050 for years; if not, for decades. In 2001, the United Nations Population Fund warned that "the world will begin to run out of freshwater by 2050" (Shaikh, 2017). As we approach the year 2020, these warnings are becoming more and more of a concern, and there is a general consensus amongst researchers to suggest that water scarcity conditions are increasing faster than previous estimates (Weber et al., 2017; Veldkamp et al., 2016; Jakeman et al., 2016).

Freshwater availability changed during human history as a result of increasing drainage and diversions for agriculture and industry, as well as rapid urban development (Petersen et al., 2019; Doll & Zhang, 2010). Despite its apparent scarcity, it is of fundamental importance for every form of life and its availability remains threatened by various human pressures. Adding to the many existing human pressures on the quality, volume, and accessibility of Earth's water resources, is anthropogenic (or human-induced) climate change.

Since the Industrial Revolution, studies have demonstrated a significant increase in greenhouse gas emissions, consequently increasing the heat-trapping capability (via the 'greenhouse effect') of Earth's atmosphere (Tietenberg & Lewis, 2016; Admiraal et al., 2015; IPCC, 2013). According to the Intergovernmental Panel on Climate Change (IPCC), National Research Council, "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia," and that "it is extremely likely that human influence has been the dominant cause of the observed warming" (IPCC, 2013, 4). As the earth warms, the consequences are expected to affect both humans and ecosystems at local, regional, national, and global scales. Although the literature suggests that climate change impacts can considerably affect many other earthly functions (e.g., melting polar ice caps and its corresponding rising sea levels, increased natural disasters, warming ocean temperatures, etc.) (Nerem et al., 2018), the focus of this paper is on freshwater ecosystems. In this respect, recent studies suggest that climate change is likely to be a centerpiece in depleting global, national, and municipal water supplies; in addition to the number and variation of species that thrive within freshwater environments.

There is a general consensus amongst current researchers to suggest that climate change is impacting (and likely to further impact) freshwater ecosystems not only by changing temperatures but also by changing "water flow regimes" (defined by Doll & Zhang (2010) as "the pattern of flow variability to include long-term annual and monthly means, statistical low and high flows, daily to inter-annual variability, and the timing of flows" (784)). These flow regimes can influence other characteristics of freshwater ecosystems that affect the health of organisms, water quality, and water temperature (Granneman & Van Stempvoort, 2016; Doll & Zhang, 2010). It is therefore important to recognize that climate change puts additional stress on freshwater environments that are already heavily stressed by other human pressures on freshwater ecosystems (e.g., over-exploitation, water pollution, habitat destruction/degradation and invasive species). Research on climate change impacts and related adaptation to water demand is still very limited; however, with impacts to water resources reaching unprecedented levels and with increased concerns of global water scarcity, it is imperative that we competently manage the water resources we have left.

3.0 CASE STUDIES

The previous chapter identified the significance of freshwater for human and ecological survival, and provided a general overview of its volume, uneven global distribution and accessibility. Additionally, the chapter introduced the increasing concerns of deteriorating water quality and quantity around much of the world; with emphasis placed on worsening global water scarcity and increasing concerns of climate change impacts likely to exacerbate human pressures on water resources.

This chapter will provide specific case studies from the current literature that reflect the ways in which freshwater is managed around the world, and in areas where there is (or was) an abundant supply of freshwater for drinking supply needs. The case of the Walkerton tragedy and its subsequent Inquiry, and its influence on source water protection legislation in southern Ontario will also be presented.

Although there are a wide variety of related cases available in the literature, it would be impossible to address them all in this paper. Instead, only a select few cases are reviewed to represent the overall context for global source water depletion. Further, the following cases represent, by example, water depletion in regions (and nations) where freshwater is considered abundant (refer to Section 2.7 on *Volume and Accessibility*).

3.1 Global Examples of Source Water Depletion

3.1.1 High Plains Aquifer, United States

The High Plains (HP) aquifer is one of the largest freshwater groundwater systems in the world, covering eight States and encompassing over 450,000 km^2 (square kilometers) in area (Strassberg et al., 2009). The HP aquifer is the most intensely used aquifer in the United States, responsible for nearly two-thirds of the country's total groundwater extraction, and for providing drinking water to approximately 2.3 million people (Fienen & Arshad, 2016). Groundwater age dating of the HP aquifer indicates that some of the "fossil water" was recharged as long as 13,000 years ago, and a study by Scanlon et al. (2012) estimated that, between 1950 and 2015, the amount of water in the aquifer decreased by approximately 6.4 trillion gallons, representing an average loss of 300,000 acre-feet per year, and that the ratio of rates of extraction to natural recharge was found to be ten times greater (Scanlon et al., 2012). Moreover, between 2011 and 2015 alone, the water available in the HP aquifer decreased by 3.2 million acre-feet; representing an approximate decline of 800,000 acre-feet per year (Gultch, 2017). This not only indicates that intensive groundwater over-taking continues to persist in the region, but it represents a significant increase in water withdrawal compared with previous decades.

The over-taking of groundwater in the southern HP aquifer has resulted in significant declines in water levels, with some areas having dropped 100 feet in less than twenty years (James & Reilly, 2015). The primary concern is that extractions of groundwater have far exceeded natural rates of recapture in the HP region. Taking upward of 13,000 years to replenish to its volume prior to being tapped, coupled with its significant drawdowns over several decades, is indicative of a depleting resource on a human timescale. The result is substantial economic damages in addition to a reduced availability of potable water for the millions of people that depend on the HP aquifer.

Furthermore, as a direct consequence to the depleting HP aquifer, is a significant drawdown in surface water availability in the region. Recent studies indicate that over-pumping in the HP aquifer "has dried up 358 miles of nearby surface rivers and streams across a 200-square mile area," which also has a direct impact on the disappearing fish species in the region (i.e., minnows and catfish that had evolved to endure periodic droughts) (Gultch, 2017). As a result, the recurrent over-taking of groundwater in the HP aquifer and its corresponding water level reductions in nearby surface waters, and disappearing fish species, can serve as an indicator for researchers that the ecological impacts may be reaching a tipping point. Even so, groundwater exploitation continues to persist in the region to serve agricultural, industrial and domestic needs. The availability of water to support the future needs of the region, however, are threatened. Water depletion in the HP aquifer is so significant that Haacker et al. (2016) describe that "if current rates of decline continue, much of the Southern High Plains and parts of the Central High Plains will have insufficient water for irrigation [and drinking supply] within the next 20 to 30 years" (231). Over time, evidence of over-taking groundwater in the HP aquifer will become more prevalent in the lives of groups and individuals within the region that depend on this resource.

3.1.2 North China Plain, North-Eastern China

In China, there has been a significant trend towards an increased dependency on groundwater over the last 50 years. As a result, aquifers of the North China Plain (NCP) have experienced groundwater over-taking for agricultural, industrial and domestic use since the 1970s (Fienen & Arshad, 2016; Feng et al., 2013). Studies have demonstrated significant impacts from the intensive over-exploitation of groundwater reservoirs in the NCP, including decreases in aquifer storage (causing land subsidence), ground fissuring, seawater intrusion, water quality degradation and its corresponding surface water declines, and pollution of shallow and deep aquifers (Fienen & Arshad, 2016; Shi et al., 2011). Over-taking of groundwater in the NCP has resulted in depletion of its groundwater reserves, and the Ministry of Water Resources (MWR) of the People's Republic of China reported an overall decrease of over eight billion m^3 in groundwater reserves between 2014-2015 alone (Hu, 2015). Due to the intensive over-taking of groundwater, studies have found that a cluster of shallow and deep groundwater depression cones have formed ("depression cones" are defined by Shi et al. (2011) as "lowering of the water table [in a cone shape around the well] when the pumping rate exceeds the rate of water flowing into an aquifer") in some areas of the cities of Tianjin, Cangzhou, Hengshui and Dezhou. The study found that the depression cones have declined the water table by more than twenty meters, with some aquifers having been compacted and are permanently unable to recharge (Shi et al., 2011, 3). The example of over-taking groundwater in the NCP serves as a valuable lesson to the rest of the world. That is, when groundwater is exploited at an uncontrolled and unsustainable rate, the effect is groundwater depletion. The knowledge and understanding derived from this example (and the example of the HP aquifer) should promote more proactive water management regimes that balance groundwater extraction for human uses with natural rates of recharge.

3.1.3 Cape Town, South Africa

As echoed in the United Nations' Sustainable Development Goal (SDG) 6, sufficient quality and availability of water is vital for human survival, sustaining ecosystem services, and for economic productivity (United Nations, 2018). More recently, the importance of SDG 6 was emphasized in Cape Town, South Africa. In January 2018, the city faced a severe water crisis and had to resort to extreme water rationing (including the need to import water) to avoid a complete water supply shutdown for its four million inhabitants (Maxmen, 2018). The gravity of water issues in the Cape Town water crisis were a combination of droughts exacerbated by climate change and poorly structured water resource management regimes (Maxmen, 2018). In modern history, no city in the developed world has ever run out of freshwater to this extent. In review of the recent water crisis in Cape Town, and with an understanding of human influence on global freshwater scarcity, it is reasonable to presume that no city, province/state or country is truly exempt from water scarcity.

3.2 The Walkerton Inquiry: The Dawn of Source Water Protection in Ontario

"*The first barrier to the contamination of drinking water involves protecting the sources of drinking water*" - Justice Dennis O'Connor, Walkerton Inquiry, 2002

In May 2000, the Province of Ontario experienced one of the most tragic public health events in modern history. Two types of bacteria known to be considerably hazardous to human health; namely, *Escherichia coli 0157:H7* and *Campylobacter jejuni*, contaminated the drinking water supply in Walkerton, Ontario. The resulting impacts were substantial, with a recorded seven deaths, 27 people diagnosed with acute kidney failure, and over 2,000 people that fell severely ill from the contaminated water supply (Prudham, 2004; Holme, 2003). *Escherichia coli 0157:H7* (henceforth known as "E. coli") discovered in the Walkerton drinking water supply produced substantial public outcry and reactive government responses, including a public inquiry into the circumstances surrounding these events (Gloubeman, 2001).

In the aftermath of Walkerton, Ontarians and Canadians quickly began to doubt the safety of their drinking water. Following the contamination event, Justice Dennis O'Connor (the Associate Chief Justice of Ontario at the time) led an inquiry into the events at Walkerton, which produced a two-part report detailing the events, along with a series of recommendations to ensure the future safety of Ontario’s drinking water (Mukhammadiev, 2014). Part I of the Walkerton Commission of Inquiry highlighted improper operating practices by the Walkerton Public Utilities Commission, in addition to regulatory and compliance shortcomings by the Government of Ontario. The resulting economic damage inflicted a total cost of between $64.5 and $155 million (Mukhammadiev, 2014). In Part II of the report, the Commission recommended that Ontario residents be guaranteed by legislation that their tap water is safe. To ensure its safety, Part II of the report required the Government of Ontario to allocate $329 million towards water management initiatives, and it required the Ontario Ministry of the Environment to establish new policies to oversee water safety; later becoming the *Clean Water Act* in 2006 (Mukhammadiev, 2014; Prudham, 2004).

The Walkerton Inquiry confirmed the cause of the outbreak stemmed from manure that had been applied to a field in close proximity to a municipal well that was supplying water to the town’s water treatment and distribution system (O’Connor, 2002). The well’s groundwater was surrounded by fractured bedrock, and a routine manure application in April 2000 was followed by significant rainfall, thus flushing E. coli into the wells’ groundwater (O’Connor, 2002). The Inquiry highlighted the events leading up to the tragedy as regulatory shortcomings, technological deficits, insufficient training and knowledge, privatization of water testing, budget cuts to the Ontario Ministry of the Environment, and human negligence (Mukhammadiev, 2014; Prudham, 2004). In the case of Walkerton, multiple public utility and management failures, coupled with privatized water testing allowed the system to go unchecked as the community drank the contaminated water for several days (O’ Connor, 2002).

The contamination event at Walkerton was deeply tragic and unfortunate. The crisis; however, did prompt invaluable changes to Ontario’s water management regime, wherein the events that took place at Walkerton are described by de Loe & Kreutzwiser (2007) as a “catalyst for change in water governance in Ontario and other parts of Canada [that] cannot be overstated” (94). In review of the comprehensive inquiry following these events, recommendations by the Walkerton Commission of Inquiry stated the need to restructure and improve the Province of Ontario’s long neglected and poorly structured water management regulations (Prudham, 2004).

The recommendations following the event included new source water protections, training requirements, water quality standards and monitoring, greater funding for water-related research, vastly more public engagement in water governance processes, and a renewed recognition of water's connections to public and environmental health (Cote et al., 2017).

By extension of these new water management regulations was the introduction of the *Clean Water Act*, passed in 2006, as part of a multi-barrier approach (MBA) to drinking water safety and is centered on protecting water at its source (see Figure 5 for a visual representation of the MBA to source water protection). The MBA is designed to sufficiently and reliably ensure the quality and quantity of sources of municipal drinking water, such as lakes, rivers and groundwater (Ministry of the Environment and Climate Change, 2014). The steps of the MBA include the following: (1) protecting water at its source; (2) robust water treatments; (3) monitoring and inspecting; (4) laboratory analysis of the treated water; (5) distribution; and (6) supply to the end-user (O'Connor, 2002). Each step to the MBA is intended to incrementally reduce health risks of water use and consumption.

In many ways, the new legislation that emerged from the Walkerton Inquiry represent a "next generation" environmental policy (defined by Plummer et al. (2010) as "policy development in response to a crisis [that] can advance progress on the issue") (Plummer et al., 2010, 3). This is exactly what happened with Walkerton; new policy had developed in response to the crisis to advance progress on drinking water safety. In review of the contamination events at Walkerton, a critical point in how we view the significance of competent and extensive water resource management emerged. It is, however, important to highlight that the events at Walkerton illustrate the consequences of acting after-the-fact, rather than making proactive decisions under conditions of uncertainty.

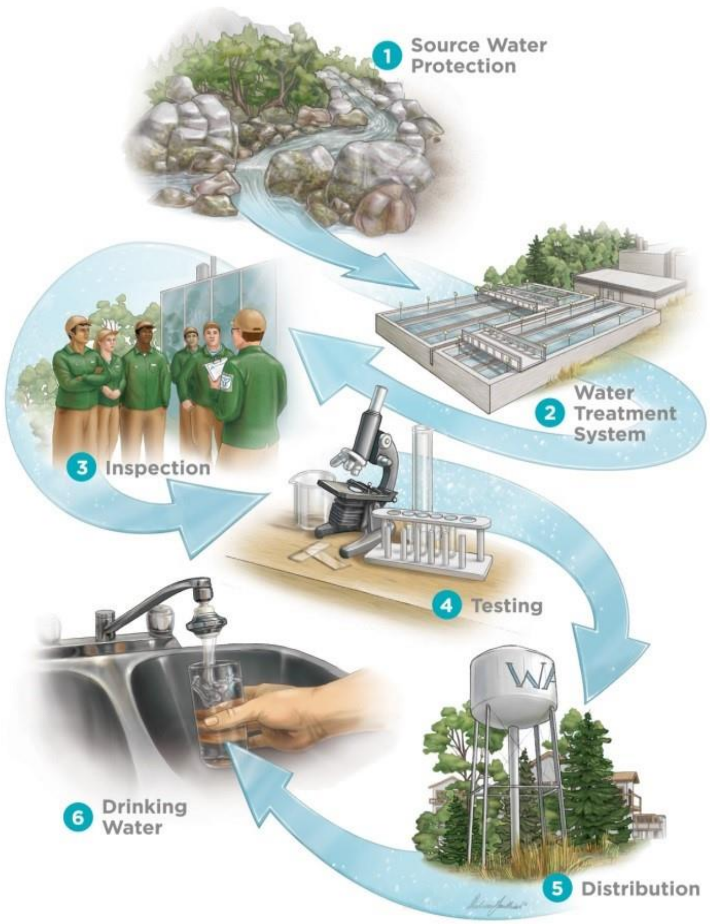

Figure 5: Multi-Barrier Approach to Source Water Protection (Source: International Joint Commission, 2019)

4.0 CURRENT STATE OF FRESHWATER IN SOUTHERN ONTARIO

4.1 Ontario's Source Waters

While global freshwater resources are experiencing unprecedented strain, Ontario is one such location that is often viewed as largely abundant in this valuable resource. With about 250,000 lakes and over 500,000 kilometers of rivers and streams, and vast networks of groundwater resources, Ontario has one of the most abundant supplies of freshwater resources in the world (Ministry of the Environment and Climate Change, 2014). Ontario borders on four of the five Great Lakes, which is the source of drinking water for over 75 percent of the population of the province. The remaining population sources its water predominantly from groundwater (ibid).

4.2 Significance of the Great Lakes and the Oak Ridges Moraine

Within southern Ontario, there is a recognition of two major networks of water systems, both of which are environmentally sensitive, interconnected among various water channels and are economically significant. The Great Lakes and the Oak Ridges Moraine (ORM) are known for their tremendous value for human and ecological provisions, as the following will illustrate.

4.2.1 The Great Lakes

The Province of Ontario is surrounded by the bountiful Great Lakes with a variety of local freshwater sources that are the underpinning for industrial, community and economic prosperity. The Great Lakes and their interconnected inland waterways and groundwater networks supply drinking water for its communities, they cater to traditional and cultural use, they provide healthy ecosystems for recreation and tourism, and they provide habitat for a diverse number of species (Ontario Ministry of the Environment, Conservation and Parks, 2018a).

The Great Lakes Basin is not only a critical economic hub for Ontario, but also for Canada. Approximately 33 percent of Canada's entire population resides within the Great Lakes Basin and the region contributes about 40 percent to the total national economic activity; with a

25 percent share to the Canadian agriculture sector and 75 percent to the manufacturing sector (Ontario Ministry of the Environment and Climate Change, 2016). The Great Lakes consist of five interconnecting large lakes (Superior, Michigan, Huron, Erie, and Ontario), one small lake (Lake St. Clair), four connecting channels, and the St. Lawrence Seaway (Hands & Komar, 2018). Together, they form the largest surface freshwater system in the world, holding nearly one-fifth of the earth's surface freshwater, and are easily spotted from space as they cover 16,000 kilometers of shoreline and serve as a drain for more than 200,000 square miles of land (see Figure 6) (ibid). Moreover, the Great Lakes watershed is home to a wide variety of terrestrial and aquatic species, such as the gray wolf, moose and bald eagle, and fish species such as Lake Whitefish, walleye and trout (Steinman et al., 2017).

For many years, the Great Lakes have been threatened by multiple anthropogenic disruptions, including pollution, climate change, invasive species, sulfide mining, and other industrial and commercial activities (Ontario Ministry of the Environment, Conservation and Parks, 2018a; Horachek et al., 2015). These human pressures on the Great Lakes have prompted a variety of transboundary agreements between Canada and the United States, such as the *Great Lakes Action Plan*, the *Great Lakes Water Quality Agreement*, the *Great Lakes Protection Act*, and numerous other legislations designed to protect the valuable Great Lakes from contamination and environmental degradation. Details are discussed in Section 4.4.

Figure 6: NASA Visible Earth: The Great Lakes (Source: NASA Earth Observatory, 2010)

4.2.2 The Oak Ridges Moraine

The ORM is a glacial remnant formed approximately 12,000 years ago, shaping significant geologic and hydrologic features that support a wide variety of interconnected surface and groundwater networks, and it provides habitat for over 470 types of plants and 81 wildlife species; many of which are threatened or endangered (i.e., the Jefferson Salamander, Wood Thrush, and the Ovenbird) (TRCA, 2019a). The ORM is the largest glacial remnant in Ontario and acts as a vital groundwater recharge-discharge area for approximately 65 waterways (Furberg & Ban, 2008).

Figure 7 demonstrates the location of the ORM, which spans 160 kilometers from the Niagara Escarpment in the West to the headwaters of the Trent River in the East, and 18 percent of the Greater Toronto Area (GTA) is entrenched in the ORM (TRCA, 2019a). Crossing 32 municipalities and four districts, the ORM provides drinking water for over 250,000 people, and its land cover includes water, forest, golf courses, agriculture, low-density built-up, high-density built-up, construction sites, parks, grass and fields (Molnar et al., 2012; Furberg & Ban, 2008). The ORM is a natural feature of enormous importance to Ontario with unique ecological functions and processes related to water (e.g., forests and parks provide land cover for filtration, infiltration and water cycle regulation, and rivers support with flood control), and the ORM has been informally labelled "the rain barrel of southern Ontario" (Environmental Commissioner of Ontario, 2015).

For a number of years, the urban growth trend has expanded towards and onto the ORM, and natural hydrologic features are threatened by agriculture (i.e., nitrogen and phosphorus pollution), nearby golf courses extracting large quantities of water, residential and commercial development that pose risks of water pollution and erosion, and land conversion to impermeable surfaces that increase run-off to water sources, fragment the landscape, and increase risks of erosion (Molnar et al., 2012; Furberg & Ban, 2008). With a variety of human pressures on the ORM, the *Oak Ridges Moraine Conservation Plan* was introduced in 2002, set out in O. Reg. 140/02 under the *Oak Ridges Moraine Conservation Act*, 2001 (Ministry of Municipal Affairs, 2017). The purpose of the *Plan* is to "protect the Moraine's ecological and hydrological features and functions," by collaborating with provincial ministers, ministries and agencies, municipalities, landowners and other stakeholders (Ministry of Municipal Affairs, 2017, 3).

Figure 7: Map of the Oak Ridges Moraine area (in green) – Land use designation map (Source: Einstein, 2005)

4.3 Ontario's Water Use by Sector

Before highlighting the existing regulatory frameworks used for water resource management initiatives (particularly protecting water at source) in Ontario, it is important to first underline the water use trends by various sectors in the province. Analyzing the trends in water demand can help design specific strategies for sectors that require the most attention for demand reduction. Including all water takings for all uses except for hydroelectric power generation, the Organization for Economic Development and Co-operation (OECD) reported that Canadians use the fourth most water per capita of 28 nations profiled, withdrawing about 1,000 m^3 of water per capita, with Ontarians using even more, at about 1,745 m^3 per capita in 2011 (OECD, 2016).

In 2001, municipal water supply accounted for about 38 percent of total water consumption in Ontario, compared to 28 percent for industrial manufacturing, 20 percent for agriculture, 3.9 percent for golf courses, 3.4 percent for industrial mining, 3.35 percent for thermal power generation (which is the largest sector of water withdrawal), and rural residential consuming about 3.17 percent (de Loe et al., 2001). It is important to recognize that many of Ontario's largest urban centers, such as Toronto, Hamilton and London, receive their water supply from the Great Lakes Basin. In contrast, agriculture is dispersed throughout the province and withdraws water from a variety of smaller sources (e.g., smaller lakes, rivers or groundwater reserves). As a result, agriculture is typically in competition for these limited supplies with other rural water users, including municipalities, self-supplied domestic users, rural commercial and industrial users, and golf courses (Shortt et al., 2004; Kreutzwiser et al., 2004).

4.3.1 Municipal Water Trends

Municipal water demand is considered inclusive of all sectors (i.e., residential, industrial and commercial) that are connected to a municipally treated water supply system. Municipal water use in Canada dropped from a profuse 343 liters per capita in 1999 to 251 liters per capita in 2011; with much of this decline in municipal water consumption being owed to various provincial and municipal initiatives such as water metering, tariffs, efficient plumbing, municipal water conservation programs, water efficiency standards in the Ontario Building Code, and water rebates (Environment Canada, 2011). However, the municipal water demand is still considerably high in Ontario, such that data from Statistics Canada's *Survey of Drinking Water Plants*, in 2013, found that Ontarians took an average of 200 liters of water per capita for municipal use (Statistics Canada, 2013). Trends in municipal water use in Ontario show a considerable decline in overall consumption over the last two decades. However, municipal water demand remains considerably higher than its global counterparts (Canada's Ecofiscal Commission, 2017), and there remains room for improvement in overall conservation and water efficiency measures (Environmental Commissioner of Ontario, 2017).

4.3.2 Agricultural Water Trends

Statistics Canada's *Agriculture Water Survey* is conducted annually to gather information on water use, irrigation methods and practices, and sources and quality of water used for agricultural purposes (Statistics Canada, 2018). Results from the *Agriculture Water Survey* indicate that irrigation volumes closely correspond with precipitation patterns; wherein lower precipitation in the region subsequently increases the water demand of the agricultural sector. For example, in 2011, results from the *Agriculture Water Survey* indicated a decrease in the number of farms with irrigated crops from 1,990 in 2007 to 995 in 2010, with a 40 percent increase in water use being owed to a particularly dry growing season in southern Ontario in 2007, wherein the south-east portion of the province received 85 percent less precipitation than normal rates (Statistics Canada, 2011). According to the results from the 2016 *Agriculture Water Survey*, the volume of water used in Ontario for irrigation in 2016 was about five times greater than the volume recorded for 2014 (Statistics Canada, 2016). The Ontario *Low Flow Maps* published by the Ministry of Natural Resources and Forestry attribute this increased demand to a particularly dry summer in 2016 with an extended period of low precipitation (Ontario Ministry of Natural Resources and Forestry, 2016). The issues surrounding agricultural water demand is therefore rooted in farmers relying on irrigation during the drier months; wherein periods of low precipitation also increase water demand from municipal, industrial and thermal power generation sectors. Consequently, conflicts of equitable water allocation can occur among various sectors during the drier months.

4.3.3 Industrial Water Trends

Industrial water use includes water extracted by various economic sectors, such as manufacturing, mining and quarrying, water bottling, thermal power generation, and oil and gas extraction. Given that industrial water consumption accounts for approximately 35 percent of the province's total water consumption, the industrial sector inflicts significant pressure on Ontario's water resources (de Loe et al., 2001). Industrial uses of freshwater are vital for Ontario's economy, and thus they are a 'necessary evil' in terms of water consumption for industrial growth and economic prosperity, in addition to their subsequent strains on local water resources. Nonetheless, industrial water demand in Ontario continuous to grow, and Statistics Canada (2014) reported that thermal power generation accounts for about 86 percent of the annual water withdrawn; therefore, imposing significant pressure on local water resources (Statistics Canada, 2014). Even though most of the water used by power generation is discharged post-treatment and is returned to the original source, van Vliet et al. suggest that in cases of insufficient water availability (i.e., periods of drought or higher temperatures in the region), power generation could be hindered; therefore raising concerns of energy security (2016). As a result, competent and proactive measures that ensure sustainable water use can be economically beneficial for all industrial sectors by ensuring continuous production.

Industrial water users extract raw water directly from the source (i.e., surface or groundwater) and the water withdrawn is pumped and treated to be used for their specific purposes. For example, water is used either directly as part of a product (i.e., food, beverage or water bottling) or in power generation it is commonly used for the purposes of cooling or steam production (Rubin, 2017; Renzetti et al., 2015). For self-supplied domestic water users that are not connected to a municipal supply system, they withdraw water from their local groundwater wells (refer to Section 5.6). However, there are concerns reflecting the impacts of the lucrative water-bottling industry on self-supplied domestic users regarding the quantity of water, in addition to a lack of regulatory water testing for contamination (Bruce et al., 2017; Grannemann & Van Stempvoort, 2016). Many of the industrial water-bottling facilities are located near self-supplied domestic water users (outside of the boundaries of a municipally treated water supply system), and high capacity groundwater pumping can cause aquifer drawdowns and have been a source of conflict with self-supplied water users in the past (Morris et al., 2008; Shortt et al., 2004). As Ontario's water-intensive industry continues to grow, the competing demand for local water resources is likely to increase among various industrial sectors, in addition to all other users of water (i.e., agricultural and municipal sectors).

4.4 Existing Water Resource Management Initiatives in Ontario

The following section will discuss the current status of source water protection in Ontario through detailing a few of the most notable legislations for protecting Ontario's watersheds and its encompassing surface and groundwater sources. It would be an impossible undertaking to list all provincial legislations, programs and plans surrounding water management in Ontario; and thus, a select few are emphasized.

4.4.1 Ontario's Safe Drinking Water Act

The *Safe Drinking Water Act*, 2002, O. Reg. 170/03, was prompted by Justice O'Connor's *Recommendation 67* in the Part II Report of the Walkerton Inquiry, which expressively called upon the province to enact the *Safe Drinking Water Act* (Canadian Environmental Law Association, 2002). The *Act* has set forth a number of important measures to protect drinking water consumers, including the following: "mandatory use of licensed and accredited laboratories for drinking water testing; mandatory duty to report adverse test results; certification of all operators of drinking water systems; licensing regime for drinking water systems; broad Ministry of the Environment inspection power and the creation of the Chief Inspector; strong prohibitions and penalties; and statutory standard of care upon managers of drinking water systems" (Ministry of the Environment, Conservation and Parks, 2019). The *Act* is predicated on sufficient and reliable processes under the MBA to ensure drinking water safety.

Effective July 1, 2018, amendments to the *Safe Drinking Water Act* require the owners of municipal drinking water systems within Source Protection Areas, under the *Clean Water Act*, to identify and map vulnerable areas around new and expanding drinking water systems. Under the amendment, the owners can only apply for a permit once they have confirmation from the Source Protection Authority (i.e., Conservation Authority) that vulnerable areas have been appropriately identified, and owners of new and expanding drinking water systems cannot provide water to the public until the local Source Protection Plan has been approved and updated by the Ministry of the Environment, Conservation and Parks (Environmental Registry of Ontario, 2018). In effect, a decentralized and collaborative effort between the owners of new and expanding municipal drinking water systems (that are required to identify and map vulnerable areas), Source Protection Authorities (that are required to review and confirm the areas mapped), and the Ministry of the Environment, Conservation and Parks (the permit issuer) is established to better protect drinking water before it is provided to the public.

4.4.2 Ontario's Source Water Protection Plans

As outlined in the *Clean Water Act*, 2006 (established in response to the contamination event in Walkerton), the premise of source water protection is based on the "multi-barrier approach" to ensure sustainable and safe drinking water starting with the protection of all water sources (Ministry of the Environment and Climate Change, 2014). Source water protection involves a collaborative provincial initiative between the Ministry of the Environment, Conservation and Parks (MECP), the Ministry of Natural Resources and Forestry (MNRF), and individual municipalities and Conservation Authorities. The premise of the MBA is to increase its water management regimes to be proactive (i.e., pre-waterborne illness events) opposed to acting in a reactive nature (i.e., post-waterborne illness events) (Ministry of the Environment and Climate Change, 2014). Source water protection is therefore designed to more holistically approach water protection of all sources by acting in a proactive nature when dealing with uncertainty.

An important recommendation made by Justice O'Connor following the events at Walkerton was that "the precautionary principle should be used as the basis for standard setting" (Lindgren, 2003, 18). To act in a proactive nature can be best suited when dealing with uncertainty, and protecting the sources of drinking water would also mean protecting the biodiversity flourishing within freshwater environments. Effectively, Garda et al. describe that source water protection—involving water monitoring and other interconnected activities—provides a way to better understand surface and groundwater interactions, and it can also be helpful in assessing the state of aquatic ecosystems (2017). As a result, the introduction of source water protection in Ontario is a considerable improvement from the water management regimes prior to the tragedy at Walkerton. Not only does source water protection provide a more holistic approach to safeguarding water sources for human supply needs (i.e., though the MBA), but it also promotes biodiversity conservation in freshwater environments.

Although it was not developed in direct response to the Walkerton Inquiry, the *Nutrient Management Act*, 2002, is also important in the protection of source water. The objective of the *Act*, as stated by the Office of the Auditor General, is "to manage nutrients (including manure, fertilizer, compost, and sewage and pulp and paper bio-solids) in ways that will better protect the environment, including source water" (Ministry of the Environment and Climate Change, 2014, 408). Accordingly, the focus of the *Nutrient Management Act* is predicated on reducing nutrient concentration from various agricultural, sewage treatment and other industrial wastes that are discharged into water bodies, such as the Great Lakes and their interconnected water systems.

Studies have quantified many of these nutrients (i.e., nitrogen and phosphorus) in water bodies in the Great Lakes, and have found that these nutrients are a major cause of algal blooms (i.e., blue-green algae) that degrade ecological health and can be fatal for aquatic life; thus, disrupting fisheries and increasing costs associated with water treatment (Bingham et al., 2015). Moreover, O'Geen et al. (2010) describe that unlike industrial pollution (which is typically considered a "point source" of pollution), nutrient pollution produced by agricultural activities is typically a source of "non-point" pollution, meaning it is difficult to trace because of pesticides, pathogens, and other nutrients that run-off into water sources (2). As a result, since the effluent from agricultural activities is difficult to monitor and control, the province has introduced regulations, through the *Nutrient Management Act*, that focus on practical studies on nutrient transport, policy research (i.e., through case study research), awareness and stewardship programs for farmers, upgrades to wastewater treatment facilities, and monitoring programs funded by both the provincial and federal governments (Ontario Ministry of the Environment, Conservation and Parks, 2018a; Ontario Ministry of the Environment and Climate Change, 2016).

Under the *Clean Water Act*, 36 Source Protection Areas based on sub-watershed boundaries are identified in Ontario; 35 of which are within the Great Lakes Basin (Ministry of the Environment and Climate Change, 2014). Under Section 28 Regulations of the *Conservation Authorities Act*, individual Conservation Authorities are responsible for preparing and implementing individual Source Protection Plans in Ontario (Conservation Ontario, 2018). Accordingly, the Conservation Authorities regulate development, expansion, and other activities in or adjacent to river or stream valleys, and they are tasked with water/flow supply monitoring, ecosystem health monitoring, and other water stewardship programs at the sub-watershed level (Conservation Ontario, 2013). Under the source water protection initiative and centered at providing safe and reliable drinking water supply for present and future generations, individual Conservation Authorities are required to conduct extensive scientific assessments of threats to water quality and quantity at local scales (Ministry of the Environment and Climate Change, 2014). Once accepted by the MECP, plans set out by individual Conservation Authorities are designed to ensure that all of their respective water sources (i.e., surface and groundwater) in the region are scientifically monitored and assessed to identify and reduce any potential threats or vulnerabilities, such as contamination, over-taking or drought (Canadian Environmental Law Association, 2012).

Using the local data obtained by the individual Conservation Authorities, assessments of surface and groundwater are carried out in three stages or "tiers" assigning "Water Quantity Stress," and they are predominantly focused on assessing surface and groundwater interactions and their seasonal vulnerabilities, and variability of water supply. For example, under Tier 1 analysis (considered "low stress"), detailed "water budgets" are carried out for individual sub-watersheds where a record of current water demand (based on withdrawals by sector), actual water taking records (reported through the *Permit to Take Water* program), and hydrologic assessments are quantified under the *Clean Water Act* (Ministry of the Environment and Climate Change, 2014). These "water budgets" look at the volume of water that enters a watershed, how much is stored, and the volume that leaves the watershed over time (Keller, 2018). This information can be useful in that it determines the amount of water available for human uses, while conjunctively ensuring that there is enough water remaining for natural hydrologic processes (i.e., to maintain healthy rivers, streams, aquifers and lakes).

The assignment of “Tier 2” (considered “moderate stress”) and “Tier 3” (considered “high stress”) water budgets of surface and groundwater assessments undergo more comprehensive assessments in cases where there is a severe threat to a municipal supply system (Ministry of the Environment and Climate Change, 2014). These source water protection initiatives can also be carried out through various water quality and quantity monitoring programs; some of which are addressed in the following section.

4.4.3 Water Quantity and Quality Monitoring Programs

For the Province of Ontario to monitor its surface and groundwater quality and availability and their respective water flows and interactions, there are a few notable programs, standards, and conservation efforts in place. Particularly, these programs include the *National Hydrometric Program* (NHP), the *Freshwater Quality Monitoring and Surveillance* (FWQMS) program, and the *Provincial Groundwater Monitoring Network* (PGMN). The Government of Canada has developed and implemented the NHP, which is designed to monitor and record data on water levels, velocity and movement, and flows of various surface water sources across Canada (Environment Canada, 2018a). The NHP is designed to explicitly monitor water *quantity*, whereas the FWQMS is designed as a water *quality* initiative under Environment Canada to ensure ecosystem integrity of various water sources across the country (Environment Canada, 2017). At the provincial level, under both the NHP and the FWQMS, there are approximately 576 surface water quantity monitoring stations dispersed throughout Ontario, in addition to 187 surface water quality stations across the province that record and register data that is publicly accessible through Environment Canada’s websites (Environment Canada, 2018a; Environment Canada, 2017).

While the NHP and FWQMS programs focus on surface water quality and quantity; across Ontario, under the PGMN, there are currently 489 monitoring wells that have been installed and are monitored for groundwater quality and quantity (Government of Ontario, 2019a). In the Great Lakes Basin alone, there are 358 provincial groundwater monitoring wells under the PGMN (on the Canadian border) and 1,759 monitoring wells under the USGS National Water Information System (on the United States border); which collectively monitor the Great Lakes' groundwater networks (see Figure 8). However, Granneman & Van Stempvoort (2016) describe that these monitoring wells (both in Canada and the United States) are very deep; and thus, it is both expensive and difficult to conduct groundwater quality surveys and only a few types of contaminants are often analyzed.

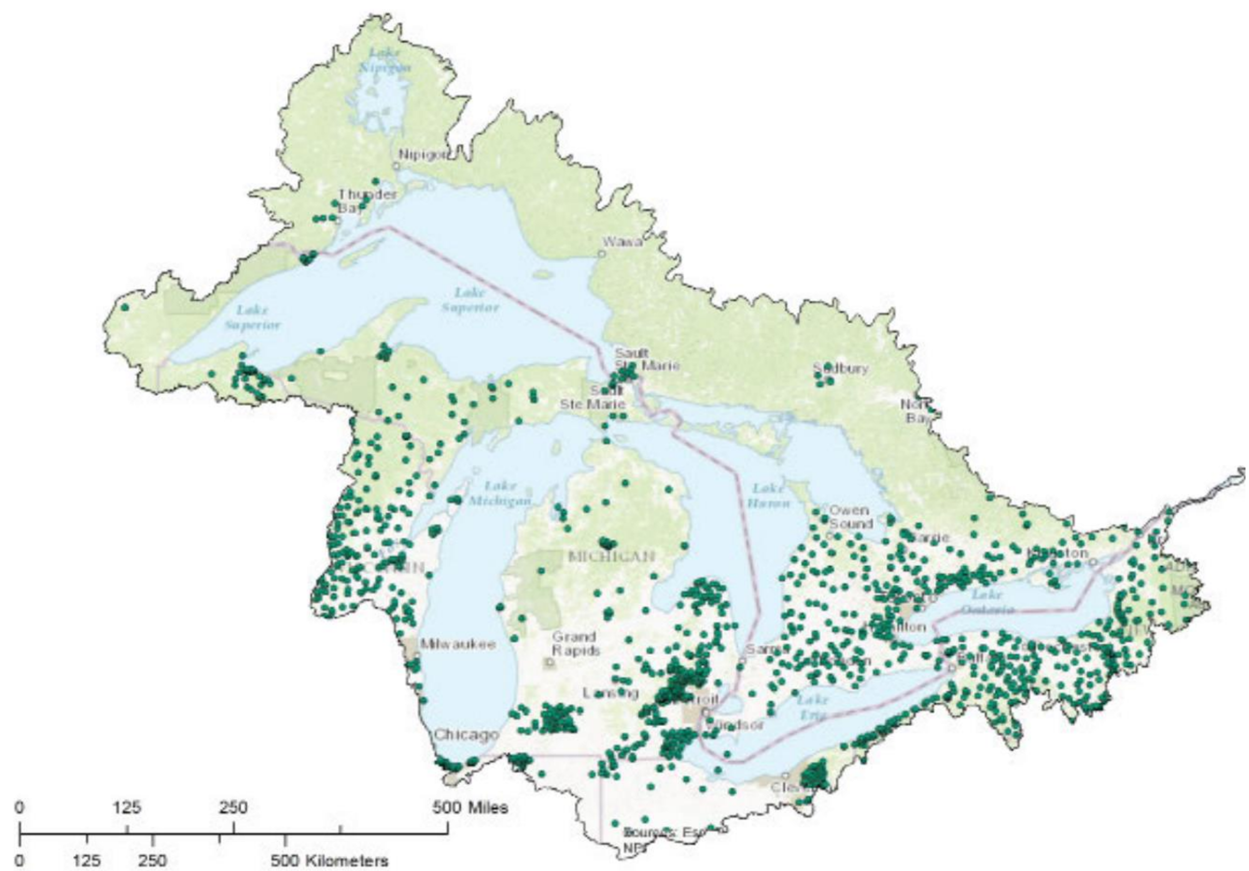

Figure 8: Locations of Monitoring Wells in the Great Lakes Basin (Source: Granneman & Van Stempvoort, 2016)

The data obtained from these water monitoring programs (NHP, FWQMS and PGMN) are vital to understanding the current state of water quality and quantity of both surface and groundwater sources, and they provide baseline data for the province and can be an indicator for potential drought conditions or water contamination. A detailed map of the PGMN can be found on the Government of Ontario's website; specifying the locations and data for both public and private wells that have been tagged and listed (Government of Ontario, 2019a). These programs provide baseline data for the province's *Low Water Response Program* (discussed in the following section) through real-time monitoring data to assist with technical assessments that are useful for water management and planning activities (Conservation Ontario, 2018).

4.4.4 Ontario's Low Water Response Program

Historically, Ontario has been pressured with droughts marked by prolonged dry periods with little precipitation, thus initiating Ontario's *Low Water Response Program* (LWRP) in 1999/2000—a program funded by the MNRF with application by various Conservation Authorities (Ontario Ministry of Natural Resources, 2010). The droughts experienced in southwestern Ontario occurring from the 1960s into the late 1980s prompted water conflicts that eventually led to the formation of the LWRP (Long Point Region Conservation Authority, 2018). The program is predicated on a decentralized effort to involve various Conservation Authorities, provincial ministries and local municipalities, in addition to a specified Low Water Response Team (WRT) comprised of various representatives of the aforementioned groups. Its purpose is to collaboratively approach water management in critical times of drought (Long Point Region Conservation Authority, 2018). According to the MNRF, there are three levels of low water conditions, including (1) the first indication of a potential water supply problem, wherein the WRT asks those with permits to take water to voluntarily reduce their water use by 10 percent; (2) a potentially serious problem, wherein the WRT asks all permit holders to voluntarily reduce their water use by 20 percent; and (3) water supply fails to meet demand, wherein the WRT impose mandatory use restrictions on all permit holders (Ontario Ministry of Natural Resources and Forestry, 2016).

It is, however, important to emphasize that the LWRP is designed to be 'reactive' and not 'proactive,' and the WRT does not possess any legislative authority; thus, restrictions on water-taking are only enforced with the onset of drought (Ontario Ministry of Natural Resources, 2009). Moreover, these programs are predicated on voluntary efforts and responses, and are not enforced by regulation (Durley et al., 2003). Evidently, the current LWRP has room for improvement by more long-term conservation approaches and proactive measures to encourage competent and sustainable extraction of water resources. Emphasis on the drought periods experienced in the province in previous decades can be further expressed by the WRTs to engage with local stakeholders about the potential impacts to water resources from drought, and how to better prepare for future drought scenarios. Further emphasis can be placed on potential climate change impacts on sub-watersheds and local water sources, and its potential for intensification of drought within the province (refer to Section 5.8).

4.4.5 Great Lakes Action Plan

In recent decades, given the significance of the Great Lakes region and its transboundary water-sharing agreements between Canada and the United States, many water quality agreements have been undertaken to protect the Lakes from contamination and over-taking. Historically, the Great Lakes and other interconnected water systems in the region have undergone many water quality issues arising from agricultural run-off, chemical spills, industrial discharge, untreated municipal sewage and various other contamination events (Ontario Ministry of the Environment, Conservation and Parks, 2018a). Some of the key contamination events include an abandoned mine in Deloro, Ontario, that contaminated surface and groundwater with radioactive and harmful metallic wastes in 1979 (Noble, 2015). Similarly, toxic chemical leaks from a fuel storage facility in Smithville, Ontario, from 1985 into 1989, and a chemical plant in Elmira, Ontario, in 1989, contaminated the local aquifers and surface water bodies with polychlorinated biphenyl (PCB), trichlorobenzene (TCB) and trichloroethylene (TCE); harmful and carcinogenic substances (O'Neill et al., 2001).

These contamination events have had many adverse impacts on the quality of both surface and groundwater in the Great Lakes Basin, thus leading to the formation of the *Great Lakes Action Plan*, 1989, which remains an ongoing initiative in part with the *Canada-United States Water Quality Agreement*, 1972, to restore and protect water sources of the contaminated sites (Environment Canada, 2018b). Under the *Great Lakes Water Quality Agreement*, Environment Canada identified seven "severely contaminated" sites within Ontario, typically referred to as "Areas of Concern [AOCs]," on the Canadian side of the Great Lakes Basin, whereas 22 AOCs are identified in the United States (see Figure 9) (Environment Canada, 2014). Notably, four of the seven AOCs in Canada are concentrated in the region of Lake Ontario, with three other AOCs present on the edges of Lake Superior; thus reflecting the magnitude of industrial, commercial, and other intensive and potentially environmentally harmful sectors present within two of the Great Lakes in Canada.

Figure 9: Canadian and United States "Areas of Concern" in the Great Lakes Basin (Source: Environment Canada, 2014)

These AOC sites, as shown in the above Figure (Figure 9), represent the many areas that are under federal and provincial responsibility, and they will continue to reflect the extent of environmental costs associated with industrial contamination (Environment Canada, 2014). The long-term economic costs, extensive remediation and restoration activities required by Canadian-United States transboundary agreements serve as a valuable lesson in how quickly and significantly contamination can spread into and across our water resources. Industrial, commercial, agricultural, chemical, and various other water-using industries are a continuous potential threat to the Great Lakes and its interconnected water systems. Given these events and how effortlessly contaminated water can travel through groundwater and its interconnected surface water channels, it becomes increasingly important to use this knowledge to proactively protect Ontario's water sources, and to extend this protection to sub-watersheds and all its interconnected water systems.

4.4.6 Ontario's Permit to Take Water (PTTW) Program

The *Ontario Water Resources Act*, 1990, which originally passed in 1961, provides the regulatory framework to safeguard the sustainable and competent use of water resources within the province (CELA, 2012). Under the aforementioned *Act*, the MECP is responsible for issuing and enforcing permits that allow water users to extract a certain volume of water from the environment (Ontario Ministry of the Environment, Conservation and Parks, 2017). It is commonly accepted among the literature that human extractions of water must be less than or equivalent to natural rates of recharge in hydrologic processes to sustainably manage water resources (Gleick & Palaniappan, 2010; Kenny, 2006). In effect, the issuing and enforcement of PTTWs in Ontario needs to be both efficient and equitable to ensure that water needs of the users are fulfilled while also maintaining water flows for environmental needs.

Under Section 34 of the *Ontario Water Resources Act* is the PTTW program, whereby users extracting more than 50,000 liters of water per day (from either surface or groundwater) directly from the source, require a permit and are required to adhere to the regulations of the permit (i.e., restrictions during different low flow conditions) (Ontario Ministry of the Environment, Conservation and Parks, 2017). All sectors including municipal water suppliers, manufacturing, mining, oil and gas, thermal and hydroelectric power generation, commercial, industrial, and agricultural extracting more than 50,000 liters of water per day are therefore required to obtain a permit (Ontario Ministry of the Environment, Conservation and Parks, 2017). No provincial permits are required for water takings under the 50,000-liter threshold, such as private wells for individual residences. In review of the *Low Water Response Program*, permit holders are required to adhere to the restrictions of reduced water flow during periods of drought; however, in the case of a drought the province relies mostly on voluntary compliance to provide relief to water stress in the region, unless the assignment of a high stress (Tier 3) indicator takes effect (Ontario Ministry of Natural Resources, 2009; Durley et al., 2003).

Once a permit has been approved, under Regulation O. Reg 387/04, *Water Taking Regulation*, permit holders are required, by law, to adhere to the mandatory monitoring and reporting stipulations set out in their PTTW, and to report their daily water takings to the MECP's *Water Taking and Reporting System* (Ontario Ministry of the Environment, Conservation and Parks, 2017). The permits are designed to continuously monitor water level data collected by various sectors, which in turn is beneficial to the government in tracking long-term trends or alerting them of high or low-level water conditions in addition to the province's own water quantity and quality monitoring programs (ibid).

Effective January 1, 2009, under Regulation O. Reg. 450/07 of the *Ontario Water Resources Act*, the province introduced a water conservation charge of $3.71 per million liters of water extracted by sectors that are "phase one" industrial or commercial water users (i.e., water-bottling facilities, beverage manufacturing facilities, fruit and vegetables canning facilities, ready-mix concrete manufacturers, agricultural chemical manufacturing facilities, non-metallic mineral product manufacturing facilities, and other inorganic chemical manufacturing facilities) that withdraw significant amounts of water that is not returned to the local watershed (Province of Ontario, 2009). After paying an initial permit fee of $750 for low- or medium-risk water takings, or $3,000 for those that are considered a high risk to cause an adverse environmental impact, effective as of August 1, 2017, those with permits to take water must pay an additional $500 for every million liters for a total of $503.71 per million liters of water withdrawn (Ministry of the Environment, Conservation and Parks, 2018). This new charge was introduced as an initiative by the province to promote water conservation and efficiency. As imposed on high consumptive industrial water users, the new charges also serve to recover the costs of various water management initiatives undertaken by the province and to supplement funds for future initiatives (Ministry of the Environment, Conservation and Parks, 2018; Renzetti & Dupont, 2017). Section 5.6 provides further discussion into the PTTW program.

5.0 CHALLENGES FOR MANAGING FRESHWATER IN ONTARIO

5.1 Introduction

Following the contamination event at Walkerton, protecting Ontario's water at source through source water protection plans (and other legislation) is a broad and well-entrenched initiative to safeguard drinking water quality and public health. Under the *Clean Water Act*, source water protection is one of the most comprehensive water protection programs in Canada, and possibly in the world. There are copious statutes and policies in place to protect water sources for present and future use, in addition to preserving the freshwater ecosystems that produce the necessary stock of water resources. However, like with anything human, there is always room for improvement. This is especially true when humans exploit non-renewable stocks of freshwater (i.e., groundwater) under conditions of low precipitation—such as in times of drought and reduced water flows—in addition to increasing global freshwater scarcity that further emphasize the increasing value of this resource. From a resource management and ecosystem services perspective, there are gaps in what is protected under the source water protection initiative in Ontario to account for current and emerging threats, as the following sections will illustrate.

The most notable challenges to managing freshwater in Ontario include reductions in government funding to provincial environmental agencies, rapid urban expansion in the GTA and its associated land use change, federal contaminated sites in the GTA, illegal contaminated soil dumping in the ORM, groundwater over-taking, surface water contamination of micro-plastics, projected climate change impacts on southern Ontario's water resources, water contamination on First Nations reserves, the Canadian "myth of water abundance," and the environmental implications of *Bill 108, More Homes, More Choice Act*. These contemporary challenges are further discussed in the sections below, and they represent current gaps in source water protection; which, to elucidate, involves procedures that "ensure the long-term sustainability of the sources of drinking water in the province; reduce health risks and potential future costs by effectively managing and protecting drinking water sources in accordance with related legislation; and reliably measure and report on its performance" (Ministry of the Environment and Climate Change, 2014, 409).

5.2 Reductions in Government Funding to Provincial Environmental Agencies

In Canada, protecting surface and groundwater resources and monitoring for ecosystem health has historically been the responsibility of municipal, provincial/territorial and federal governments. However, reductions in funding for many environmental ministries and departments has correspondingly reduced the quality and consistency of monitoring; thus, resulting in the fragmentation of monitoring data (Garda et al., 2017). Accordingly, reduced funding hinders governments' abilities to adequately assess water quality and quantity, identify and reduce threats to aquatic ecosystem health, update programs and policies to address current and emerging threats, and sufficiently and stringently enforce regulations (ibid). The result is an increased reliance on the public, citizen scientists, non-governmental organizations, volunteers, and various environmental groups to copiously and individually support the province in protecting its water sources and ecosystem integrity. Although the decentralization of tasks and responsibilities can be more proactive, efficient, more inclusive and overall more reliable for managing our water resources, there are concerns reflecting the enforcement capacity of the government on certain water-intensive sectors (i.e., the water-bottling industry) (Griswold, 2017; Bruce et al., 2017). The laws stipulated by various legislations and regulations are predominantly developed to ensure that environmental standards are met and adhered to, such as by citizens, industry and various other water-using sectors that pose potential risks to the environment. Without adequate enforcement of these laws, one is left to wonder: what is the purpose of legislation to start with, and what are the repercussions if these laws are not enforced?

In Ontario, reductions in government funding for provincial environmental agencies (i.e., the MECP and the MNRF) means that they cannot adequately study, monitor, enforce and protect its water resources in greater logistic scale. A particular example of the impacts of provincial budget cuts to environmental ministries was outlined by the Walkerton Inquiry, wherein "budget reductions made it less likely that the MOE [Ontario Ministry of the Environment] would have identified both the need for continuous monitors at Well 5 [the contaminated well] and the improper operating practices of the Walkerton Public Utilities Commission" (Lindgren, 2003, 8).

Despite the events that led up to the tragedy at Walkerton, including contributions from budget reductions to the MECP (previously referred to as the MOE), provincial budget cuts continue to affect the Ministry. For example, in 2006, the MOE retained only about "one-third of one percent" (about 0.36 percent) of the total provincial budget for its funding operations (Environmental Commissioner of Ontario, 2006, 3). More recently, in 2017-2018, the MECP was allocated $764 million dollars, whereas the newly introduced provincial budgets for 2019-2020, introduced on April 11, 2019 under the Ford Administration, revealed that the Ministry will have $631.2 million dollars in funding to allocate towards environmental protection (Ontario Nonprofit Network, 2019). The reduced funding for the MECP between 2017-2018 and 2019-2020 represents a reduction of approximately $132.8 million dollars (or a decline of about 17.5 percent), respectively. This reduction in funding is likely to hinder the Ministry's ability to develop effective policies to address emerging environmental threats to the province, it is likely to even further limit the enforcement capacity of the Ministry, and it is likely to impede on the quality of environmentally proactive plans, programs and research studies undertaken by the province. The newly introduced 2019-2020 provincial budgets have been increasingly criticized among various environmental groups, citizen scientists and the public; being slated by Greenpeace Canada as "the most anti-environmental budget in Ontario since the deadly tainted-water disaster in Walkerton" (Firempong, 2019).

5.3 Rapid Urban Expansion in the Greater Toronto Area

Urbanization, defined by Wang et al. (2015) as "the absorption of less developed areas, such as agricultural and forest land, by built-up areas, such as residential and commercial land" has become a growing global occurrence (1). Many urban areas are hubs for population growth, economic development, industrialization and transportation development, and urbanization is increasing considerably in the developed world (Vaz & Arsanjani, 2015). This is particularly true in southern Ontario. Rapid urban expansion in southern Ontario and in the GTA, in particular, has resulted from significant economic growth and growing migration (see Figure 10 for population trends between 1850 and 2011). This growth is so significant that southern Ontario holds approximately one-third of the population of Canada; about 12.7 million people of the total 37 million Canadians (Statistics Canada, 2017). This region, named the "Golden Horseshoe" due to its shape (see Figure 11), has been identified as the "fastest growing region in North America" (Cadieux et al., 2013). The continued growth in the Golden Horseshoe is expected to increase significantly, wherein the Ministry of Infrastructures expressed through the *Places to Grow Act* that the region's population is projected to increase to 13.48 million by 2041 (Vaz & Arsanjani, 2015).

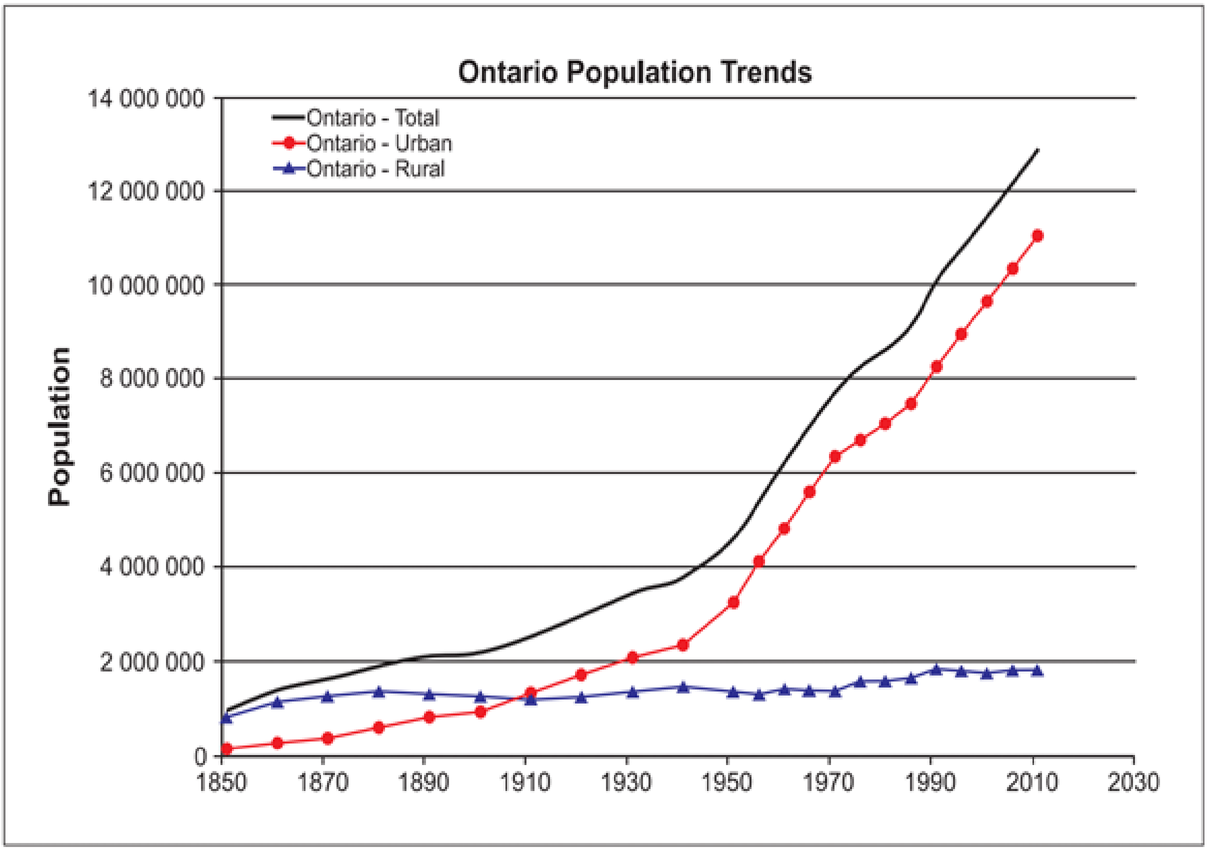

Figure 10: Population Trends for Ontario, Canada (Source: Statistics Canada, 2011)

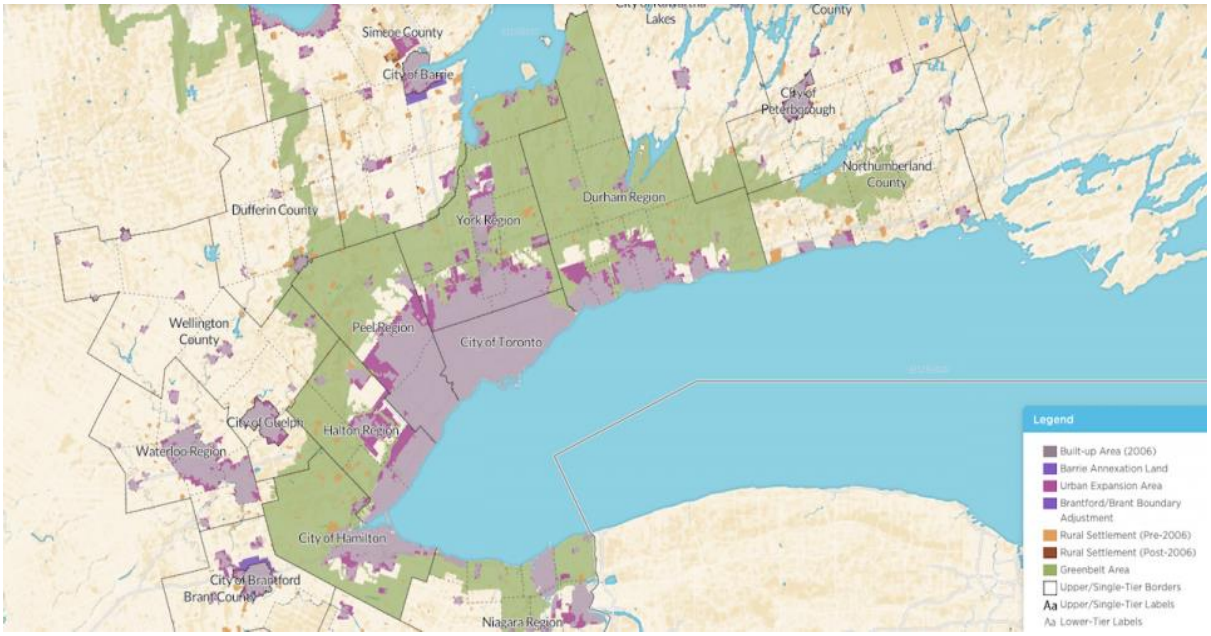

Figure 11: Map of the Greater Golden Horseshoe Area (Source: Urban Toronto, 2016)

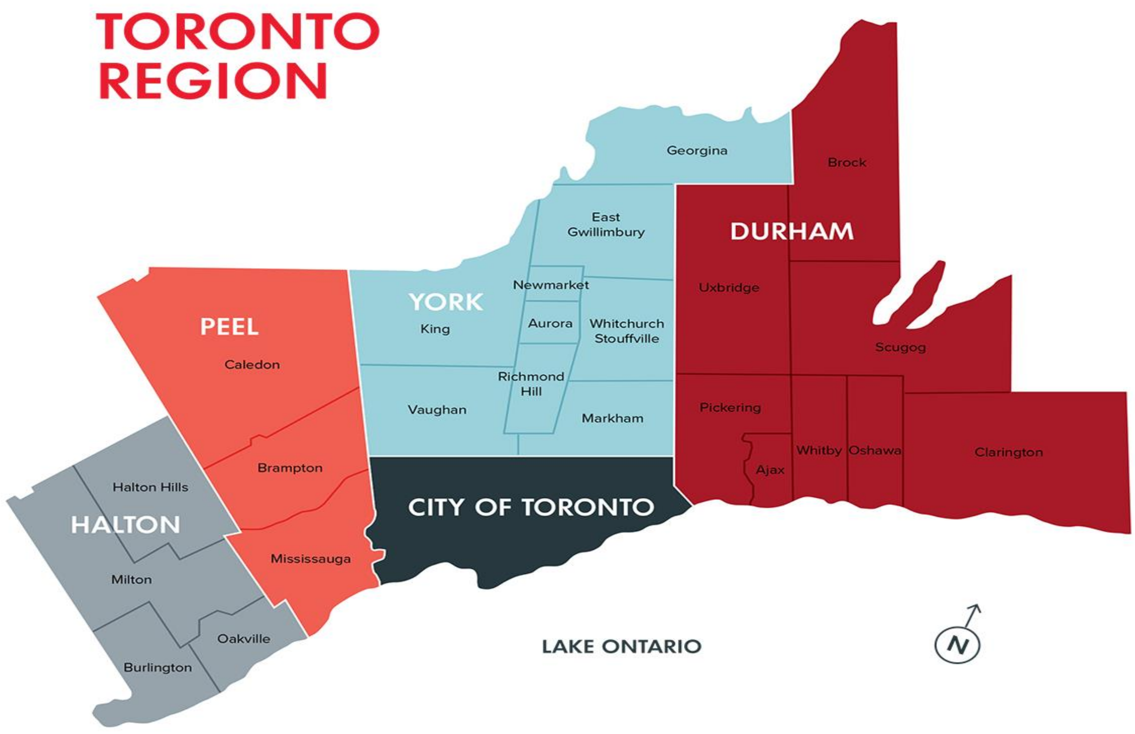

Figure 12: Map of the Greater Toronto Area (GTA) to include the City of Toronto and the four municipalities of Durham, Halton, Peel and York (Source: Toronto Global, 2019)

The GTA is the most populous metropolitan area in Canada, which includes the City of Toronto and four regional municipalities (Durham, Halton, Peel and York) (Furberg & Ban, 2008, 131). The above Figure (Figure 12) illustrates where the City of Toronto and the four municipalities are situated, to collectively form the GTA. The GTA holds a population of over 6 million inhabitants, and projections of population growth in the GTA are expected to increase by an additional 2.8 million residents by 2041 (Ontario Ministry of Finance, 2016). The rate at which urbanization is growing and expanding in the GTA poses particular concern to the surrounding natural environments and watershed areas that produce the stock of necessary water. While urban regions remain essential for economic prosperity for its urban cores (Nijkamp & Kourtit, 2013), they pose significant environmental challenges, resulting in loss of biodiversity, environmental degradation and increased pressures on water resources (Vaz & Arsanjani, 2015). In effect, urban expansion is studied to have a positive effect on the local economy; however, it is typically coupled with adverse environmental impacts by influencing "ecosystem imbalances," as reflected in changes in water quality and declining forest land (Wang et al., 2015, 1).

Over the last few decades, rapid urban expansion and population growth in the GTA have typically occurred at the rural-urban fringe boundary (refer to Figure 13). Studies of urban sprawl have identified major land use change through different "cover classes" in the area, including low-density built-up (residential areas), high-density built-up (including roads and industrial areas), construction sites, agriculture, forest, golf courses, parks/pasture, and water (Furberg & Ban, 2008, 132). A 2012 study by Furberg & Ban found that urban growth patterns showed significant development from 1985 to 2005, where Durham Regional Municipality's urban areas grew by 53 percent (79 km^2); Peel grew by 60 percent (181 km^2); York by 108 percent (234 km^2); and Toronto by 1 percent (10 km^2) (Furberg & Ban, 2012).

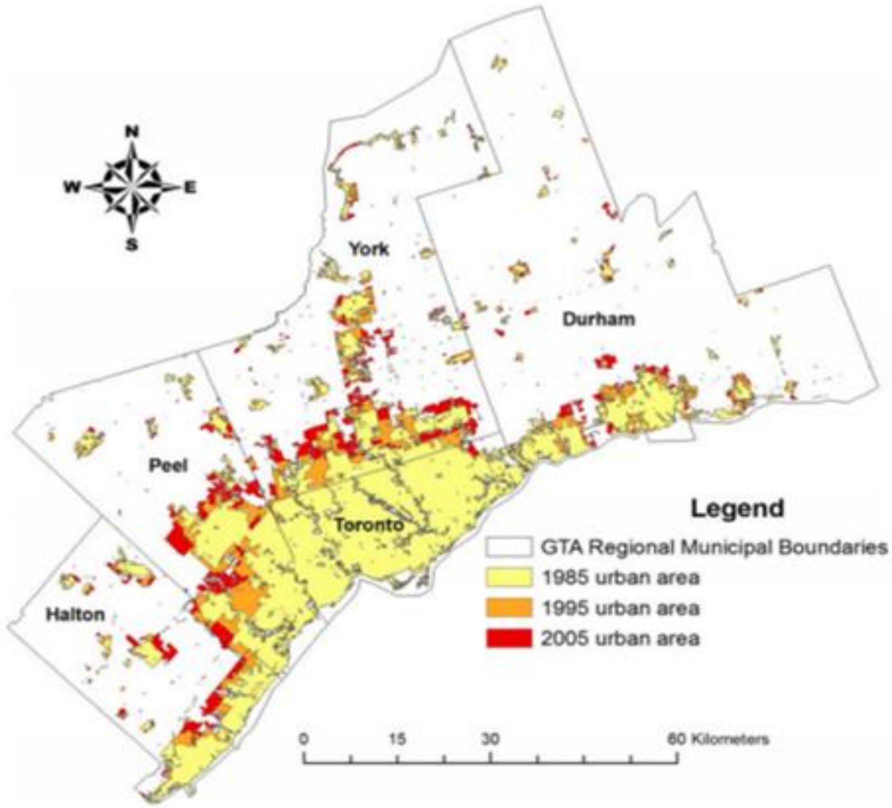

Figure 13: Urban Sprawl in the GTA between 1985 and 2005 (Source: Furberg & Ban, 2012)

The type of land cover in a watershed affects the levels of evapotranspiration to the atmosphere, percolation and recharge to groundwater aquifers, run-off to surface water bodies, and it also influences base flows and critical stream thermal temperatures (Granneman & Van Stempvoort, 2016; Takala et al., 2016). As a result, the type of land cover ultimately influences natural hydrologic processes; which, in turn, determine the state of freshwater ecosystems and their respective ecosystem services.

Coupled with urban expansion and its associated land use change is more extensive cover by impermeable surfaces (such as concrete, asphalt and roofs), that correspondingly alters the extent and composition of forests, grasslands, wetlands and other ecosystems (Nelson et al., 2011). With fewer ecosystem services provided by soil and vegetation, such as water filtration and protection against erosion, water quality and quantity can become compromised. For example, studies have found that land use change to impervious surfaces typically increase storm water run-off, reduce water quality, degrade and destroy aquatic and terrestrial habitats, and diminish the interconnectedness of streams, rivers and other natural landscapes (Barnes et al., 2015). Habitat fragmentation and the introduction of impervious surfaces therefore limit the benefits derived from ecosystem services; ultimately reducing the quality and quantity of water resources.

Moreover, urban areas use large volumes of polluting substances, given their occurrence in the manufacture, import, export, store, and transport of various industrial and chemical materials; some of which may inevitably contaminate urban sources of freshwater (see Figure 14 for examples of urban-sourced pollutants) (Granneman & Van Stempvoort, 2016). Throughout the Great Lakes Basin, urban groundwater is contaminated by a variety of urban-sourced pollutants that are likely to enter the Great Lakes in an estimated “100-year timeframe,” either directly through surface water discharge, or indirectly through drainage systems and interconnected rivers and streams (Granneman & Van Stempvoort, 2016, 54).

In addition to fissures in the foundations of old urban infrastructure that allow access for pollutants to enter groundwater networks, large urban areas (like the GTA) that have vast quantities of impermeable surfaces also require a variety of roads and highways for transport. In the winter months, chemicals that are associated with road de-icing (i.e., chloride/salt) for the numerous roads and highways represent a serious threat to urban surface and groundwater quality. For example, a 2000 survey of 23 springs in the GTA recorded high chloride contamination levels of salt, resulting from the winter application of road de-icing salt, ranging from <2 to >1200 mg/L (milligrams per liter) (Williams et al., 2000). A 2013 study found that 50 percent of salt applied to roads and highways in the GTA enters the subsurface, subsequently increasing the salinity of groundwater and receiving streams (Perera et al., 2013).

High concentrations of chloride in water systems pose particular concerns for many aquatic species. For example, Granneman & Van Stempvoort (2016) describe that “chloride concentrations above 250 mg/L in the base flow can be chronically toxic for many freshwater species” (49). The 2000 study by Williams et al. found maximum concentrations of chloride in the GTA to be much higher than the threshold specified by Grannemann & Van Stempvoort. Further, studies have quantified increasing chloride contamination in the Great Lakes, which is attributed to the groundwater inputs (and inputs from a variety of interconnected waterways) of chloride through discharge streams that flow to the Great Lakes (Chapra et al., 2009). Moreover, increased chloride concentrations correspondingly increase the costs associated with water treatment. Consequently, chloride contamination of freshwater sources adds further pressures on both human and ecological systems. It is therefore important to address the use of salt for road de-icing within urban areas, and to better understand the cumulative impacts it may have on aquatic ecosystems and water quality.

As the GTA grows and urban sprawl continues, major problems related to surface and groundwater are expected to intensify. This is especially true given the projections of future population growth in the GTA, wherein increased populations is likely to increase the development of built-up areas; thus, correspondingly increasing the extent of impermeable surfaces. As urban centers develop and expand, urban-sourced pollutants will subsequently increase in scale across southern Ontario. For this reason, it becomes increasingly important to account for cumulative environmental impacts in today's land use decisions. Accordingly, this includes better understanding anthropogenic disruptions of natural systems that provide the necessary water purification, water quality, and water quantity that supply the needs of humans and ecosystems.

With the GTA's population expected to grow by a near 50 percent over the next two decades (Ontario Ministry of Finance, 2016), it is logical to expect further continuation of urban sprawl and an increase in land use change. Consequently, this is likely to decrease the natural land cover (e.g., forests and grasslands) that support ecosystem services, and increase the amount of urban-sourced pollutants that enter the GTA's groundwater systems and ultimately into the Great Lakes. As emphasized in chapter 2, it becomes increasingly important to protect our watersheds that provide vital ecosystem services that are necessary for the region to thrive. It is equally important to make informed land use decisions today to account for environmental impacts, where remediation is significantly more costly, environmentally damaging and long-term when compared with prevention.

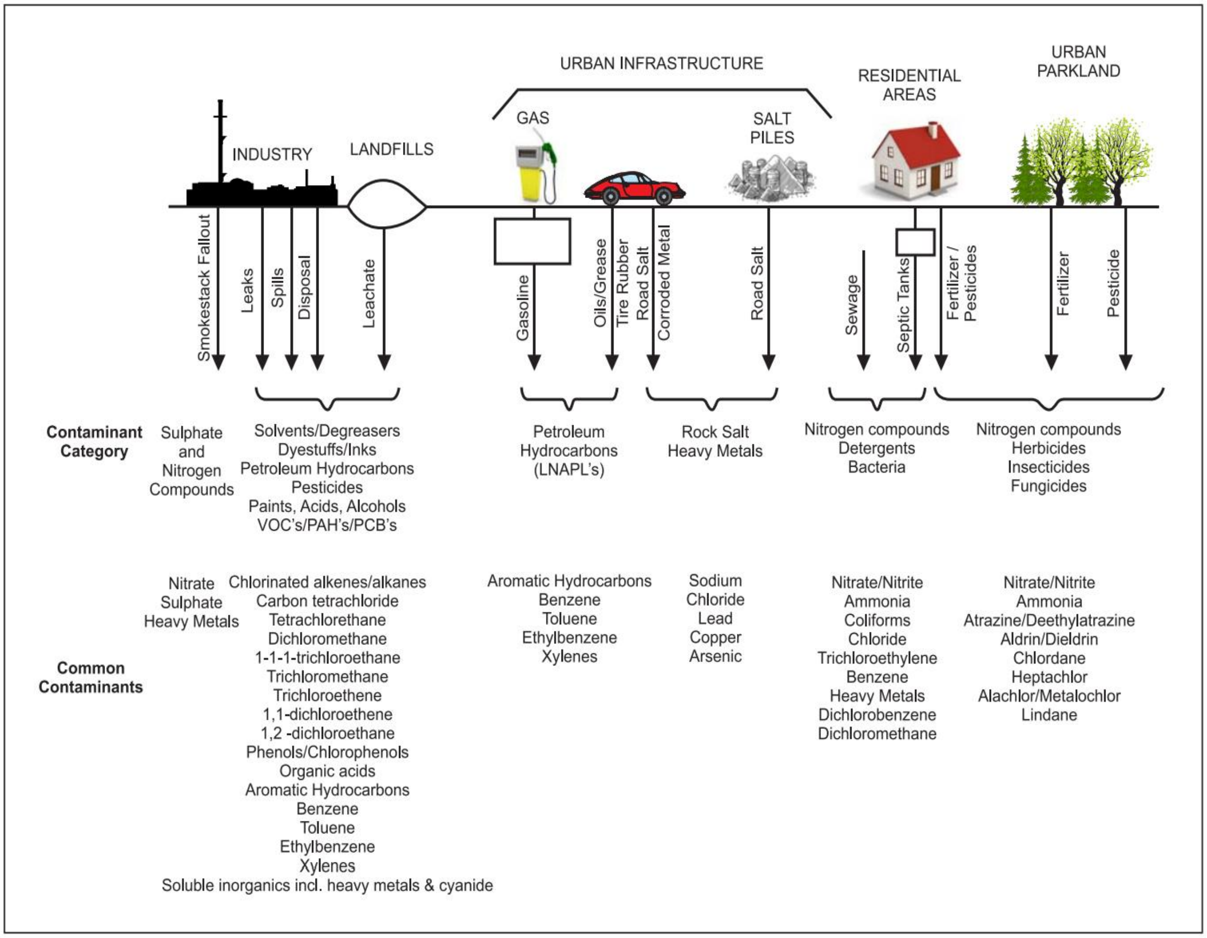

Figure 14: Common Urban Groundwater Contaminants (Source: Granneman & Van Stempvoort, 2016)

5.4 Federal Contaminated Sites in the Greater Toronto Area

According to the definition adopted by the federal government of Canada, a "contaminated site" is "one at which substances occur at concentrations [that are] [1] above background levels [normally occurring] and pose or are likely to pose an immediate or long-term hazard to human health or the environment, or [2] exceeding levels specified in policies and regulations" (Treasury Board of Canada Secretariat, 2019). In other words, the key determination for including a contaminated site in the government's inventory is that there is a concentration of a particular designated substance in the soil, air, groundwater, sediment, or surface water that exceeds the expected levels stipulated in regulations. It is reasonable to expect that the premise of developing "exceedance levels" of specific substances is based on the potential for these substances to be harmful to water quality and ecosystems. The accepted levels set out by regulations must be designed for the specific intent to control contaminant levels so that they are equal to or lower than the critical threshold. Accordingly, anything beyond these levels—considered "exceedances"—in such natural features including soil, groundwater, surface water, sediment, air, or other sources can potentially harm humans and the environment.

The federal policy framework for addressing "contaminated sites" is governed by the Treasury Board *Policy on the Management of Real Property*, 2006, and is focused on reducing and eliminating contaminated sites listed on the Federal Contaminated Sites Inventory (FCSI) (Government of Ontario, 2016a). The Treasury Board of Canada Secretariat has a federal profile of all listed contaminated sites (see Figures 15 and 16 for examples), and although the details of each is available through their website (i.e., specific individual site name, site number and reporting branch), there is no information regarding the actual type of contaminant in the site areas. The Treasury Board of Canada Secretariat has a list of all various contaminants classified under the "Contaminants and Media" overall profile, including petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), BTEX (benzene, toluene, ethylbenzene, and xylene), metal, metalloid and organometallic, microorganisms, polychlorinated biphenyl (PCBs), pesticides, halogenated hydrocarbons, isotopes, energetics, biological/chemical warfare agents, and other physical/chemical agents (i.e., pH, temperature, dissolved solids, turbidity, etc.) (Treasury Board of Canada Secretariat, 2019). According to the most current information on their website, in Ontario there are currently 680 sites that are "high priority for action," 1,680 sites that are "medium priority for action," and 1,243 sites that are "low priority for action" (ibid).

Although each type of the aforementioned contaminants is identified and mapped within the Province of Ontario under the FCSI, there are no details presented by the Treasury Board of Canada Secretariat on their specific contaminant, concentrations, or sources of contamination. Moreover, there are no concerns issued by the government regarding the proximity to water bodies (i.e., the surrounding Great Lakes of Lake Ontario, Lake Huron and Lake Erie) that are within reach of these contaminated sites. Nor does the government issue concerns or specifics on their website about how these contaminants are contained within their particular contaminated area; and thus, no assurances are made in terms of the potential exposure of these contaminants to surface water bodies, groundwater, or other pathways through soil and sediments. The severity of this concern is rooted in their proximity to prime agricultural land, source waters and human settlements; as is visually obtained through the map on the Treasury Board of Canada Secretariat's website (Treasury Board of Canada Secretariat, 2019).

Moreover, the government fails to inform the public on the potentially hazardous substances that are present within the FCSI. Although there is an identification of the locations of contaminated sites and an overall profile of what these contaminants are, there is no information on what these designated substances can inflict on human and ecological health. Sources from external research (outside the Treasury Board of Canada Secretariat) suggest that many of these contaminants can have serious and sometimes fatal properties if consumed by humans or exposed to freshwater ecosystems. For example, PHC and BTEX compounds have been independently associated with human health effects; with acute effects ranging from headaches, fatigue and dizziness, to chronic exposure that can impair the immune system and decrease white blood cell count (Kponee et al., 2015). Moreover, the presence of trichloroethylene (TCE), benzene or vinyl chloride in water is particularly hazardous to water quality, human health and ecosystem integrity.

For example, TCE is a chemical substance typically associated with equipment degreasers at automotive repair facilities and industrial activities, and is also a breakdown product of perchloroethylene, a dry-cleaning chemical. Exposure of this contaminant can cause kidney cancer, non-hodgkin lymphoma and cardiac defects in humans, while its carcinogenic properties can also be catastrophic to freshwater organisms when spoiled through channels of freshwater systems (Agency for Toxic Substances and Disease Registry, 2017). Consequently, coupled with increased human populations is a likely increase in industrial, commercial, agricultural, chemical, and municipal contamination. As a result, it becomes increasingly important to address these "contaminated sites" to reduce the potential impact of contaminants through various pathways in the soil, sediment, groundwater, surface water, or other conduits for contamination and cross-contamination. It also becomes increasingly important to develop and implement policies that prevent or actively mitigate these impacts. The *Policy on the Management of Real Property* is developed as a guide for remediating contaminated sites in a “financially responsible” and “cost-effective” way; however, it is founded on guiding remediation by best practice and there is no stringent policy framework to enforce immediate mitigation of contaminants (Government of Ontario, 2016a). As we have learned from various case studies, proactive resource management is significantly more beneficial and preferred to reactive resource management.

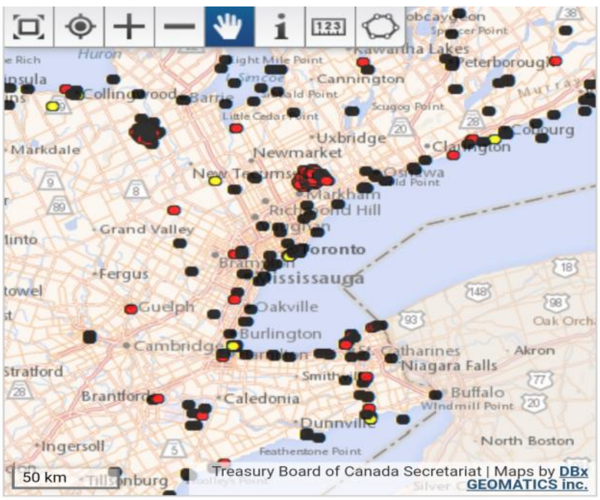

Figure 15: Federal Contaminated Sites
Western Lake Ontario

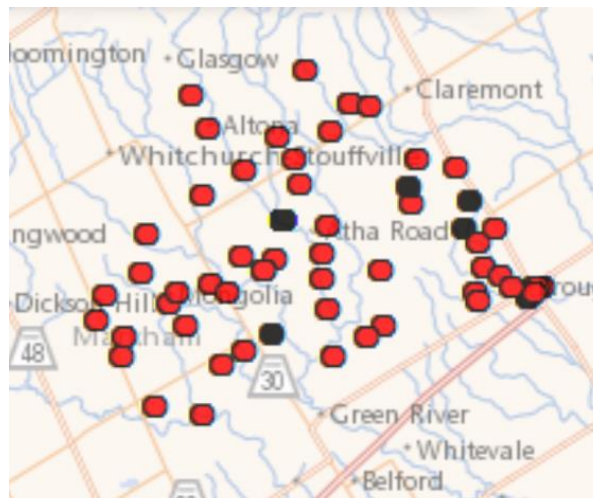

Figure 16: Federal Contaminated Sites
Markham, Ontario

The above figures illustrate, by example, the listed contaminated sites on the Treasury Board of Canada Secretariat’s website (red = active, yellow = potential threat, black = no longer active). Many of the identified sites are listed as “no longer active” which demonstrates a significant reduction in the overall number of contaminated sites in the specific example shown in Figure 15 near the west portion of Lake Ontario. However, a significant cluster of contaminated sites (as shown in Figure 16) are currently active in an area south of Newmarket and north of Markham. Notably, these contaminated sites are situated near a variety of inland freshwater channels in several regions, including Glasgow, Whitchurch-Stouffville, Markham, and Mongolia. Their proximity to inland water systems raises concerns of potential contaminants impacting the local water quality and ecosystem health, in addition to their ability to cross-contaminate by transferring along the interconnected water systems.

5.5 Contaminated Soil Dumping in the Oak Ridges Moraine

The ORM is unanimously known as an environmentally sensitive region that provides necessary natural benefits to humans and ecosystems alike. In recent years; however, there have been a growing number of environmental experts and citizen groups that have raised concerns regarding soil movement from construction sites in the GTA (see Figure 17) to locations on or near the ORM (see Figure 18). These concerns are rooted in "contaminated soils" being transported from construction sites in and around the City of Toronto and dumped into old quarries that are within the boundaries of the ORM (Queen, 2017; Garfinkel, 2016; Welsh, 2014). For example, in 2014, a *Toronto Star* report revealed that the province does not track the movement of construction fill that is contaminated with dangerous heavy metals and petroleum hydrocarbons (Welsh, 2014). According to Welsh, thousands of tonnes of contaminated soil taken to farmland in the ORM from downtown condominium projects were "accidentally" discovered by neighbours who reported bad odors from soil that is "supposed to be clean" (Welsh, 2014). Moreover, the *Toronto Star* interviewed the executive director of the Ontario Waste Management Association, Rob Cook, who said that "at a time when excavation projects have spiked, there is a dramatic drop in the number of trucks taking the dirt to the special landfill sites that can safely manage toxins; thus leading to the potential for large amounts of contaminated soil being improperly managed" (Welsh, 2014). The insufficient monitoring and controlling of hazardous soil material is highlighted, meaning that the provincial government is not enforcing its legislation in allowing the ORM to be potentially contaminated. The *Toronto Star* also interviewed the Environment Minister at the time, Glen Murray, who said that "better controls are needed to deal with this serious issue that [for Murray] is at the top of environmental and economic concerns in Ontario" (Welsh, 2014). Despite the Minister's recognition of the illegal dumping of contaminated soils in the ORM, it remains a contemporary issue.

According to the Environmental Commissioner of Ontario, when soil is determined to be "contaminated" it is regulated as "waste" under the *Environmental Protection Act*, and there are clearly outlined disposal methods (i.e., proper disposal facilities for the contaminated soil) (2015). Dumping contaminated soil at these facilities proves to be at a much higher cost compared with dumping “clean” soil material; or soils that are tested and approved by a certified laboratory to be under the limits or exceedances as stipulated by the Ontario government regulations. The Environmental Protection Agency describe that treatment approaches to contaminated soil include the following: “flushing contaminants out of the soil using water, chemical solvents, or air; destroying the contaminants by incineration; encouraging natural organisms in the soil to break them down; or adding material to the soil to encapsulate the contaminants and prevent them from spreading” (Pegex, 2014). Although no exact numbers of contaminated soil disposal costs in Ontario can be found in the literature, the process described is relatively extensive; and thus, it is logical to assume that it is costly. It is also logical to see how at a time when excavation projects have boomed, it is difficult to track the trucks that are hauling contaminated soils, and improperly and illegally disposing of these soils. However, this is no excuse for the government, especially when the environmentally sensitive and ecologically vital ORM is at risk from contamination.

More recently, in 2016, an article by *Ontario Nature* reported that despite the many years of environmental criticism of the soil dumping in the ORM, contaminated soil (particularly petroleum hydrocarbons and heavy metals) from old industrial sites in the GTA continue to be dumped into a formal gravel pit in the Durham region (refer to Figure 18). The article also addresses that the dumping site is on a groundwater recharge area with some areas described as having fissures in the rock; and thus, the likelihood of contaminants leeching into the groundwater supply is high (Garfinkel, 2016). A major concern is that there are no existing government reports, studies, or apparent enforcement of regulation on the impacts of contaminated soil dumping in the ORM. Even more recently, a 2017 article by *York Region* reported that contaminated soil continues to be dumped in the ORM, even though it is managed under a number of legislations, including the *Aggregate Resources Act*, which applies in cases where fill is dumped into quarry pits as part of site remediation (Queen, 2017). A major issue that is noted by *York Region’s* article is that specific to soil dumping, it is governed by “strong provincial framework,” however the article discusses that if the provincial push is for more underground soil excavation from more intensive transit and condominium development, then those projects will generate excess soil that must "find a new home" (Queen, 2017). In effect, growing concerns arise among various media outlets regarding the ineffective enforcement capacity of the province. This is especially true when contaminated soil continues to be dumped in the ORM.

Figure 17: Excavation site in the GTA where soil was removed and transported to the ORM (Source: Ontario Nature, 2016)

The *Toronto Star*, *Ontario Nature* and *York Region* investigations revealed many troubling facts to include the lack of transparency between the province and the public, the lack of contaminated soil tracking, regulation, research studies, and provincial enforcement of soil dumping in the ORM. The dumping of contaminated soils is particularly troublesome near the ORM for local surface and groundwater sources—especially when considering the potential cumulative effects on the local ecosystems and drinking water quality. There is much uncertainty in when the effects of these cumulative soil dumping activities in the ORM will be observed;

including its water resources and species (specifically those listed as endangered) that thrive within the ecologically vital and sensitive ORM.

Figure 18: Area of gravel pit where contaminated soil is dumped (Source: Vanessa Lu of the *Toronto Star*, 2014)

5.6 Groundwater: Reliance and Over-taking

In Ontario, small municipalities and individuals are particularly reliant on groundwater resources; such include Waterloo, Guelph, and Kitchener, whose municipal systems draw directly from aquifers (TRCA, 2018). In southern Ontario, not all municipalities are located within a close enough proximity to a surface water resource and are thus dependent on groundwater to support their daily needs. Instead of fitting extensive and costly pipelines to transfer water from the large wastewater treatment facilities within the GTA, it is often more reliable and cost-effective for communities that are far from a municipal water supply system to withdraw their water from groundwater sources (Ministry of the Environment and Climate Change, 2014). For this reason, more than 25 percent of Ontario's population relies on groundwater, representing approximately 3.5 million residents, as their primary source of water (see Figure 19). In addition to the residential needs of groundwater as their primary source, groundwater also serves as a source of water supply for agricultural, industrial and institutional operations (Bruce et al., 2017). Considering the dependency of the aforementioned sectors on groundwater sources in Ontario, it is also important to elucidate that on a human timescale, groundwater is effectively a non-renewable and "finite" resource because of its slow recharge rates (Gleick & Palaniappan, 2010). In southern Ontario, the rate of recharge is highly variable and dependent on the source of the aquifer, ranging from 10 years to upward of 10,000 years (Khader, 2017).

Moreover, just as there is a question of the volume of groundwater that can be extracted due to the varying rates of recharge in Ontario, there is also a question of timing (e.g., with the onset of drought). In southern Ontario, summer and early fall are typically marked by decreased water availability during periods of low precipitation; and thus, increased conflicts can occur among various agricultural, domestic and industrial users (Morris et al., 2008; Shortt et al., 2004). Further, the sub-watersheds in the southern region of Ontario also lose the highest amount of water naturally by evaporation when compared to other regions in Canada (Maghrebi et al., 2015). The result is a reduction in water level that correspondingly reduces the amount of surface and groundwater available for extraction. With these hydrologic factors under consideration, groundwater quantity and groundwater management remain a major challenge in southern Ontario, which this section will address.

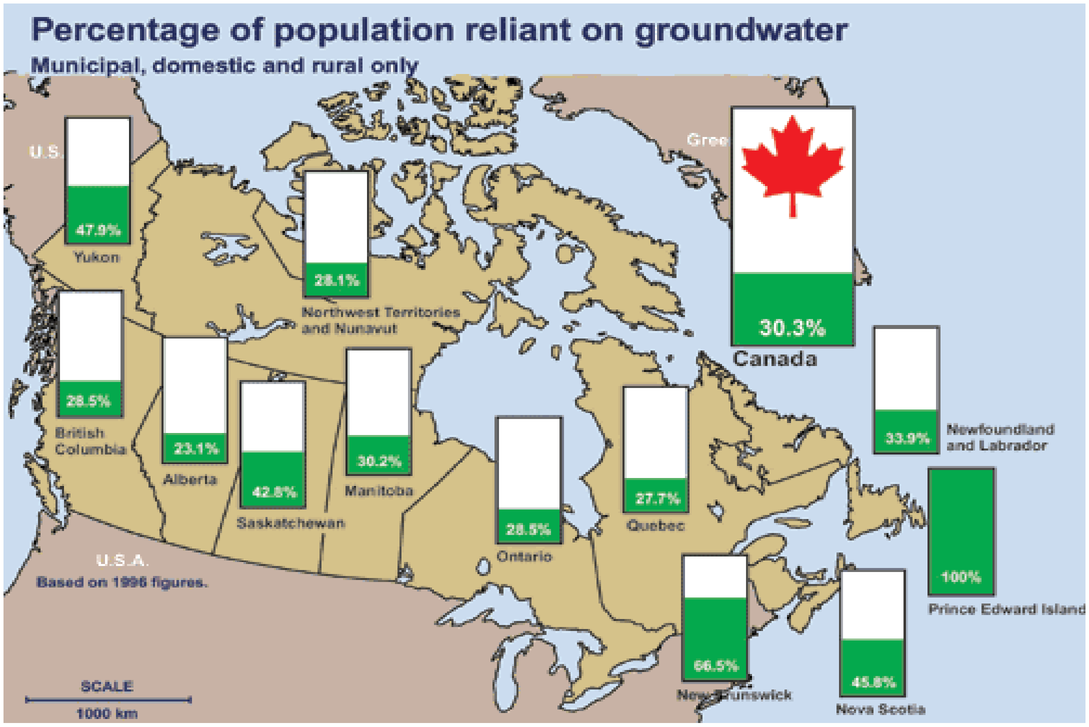

Figure 19: Percentage of Provincial Populations that are Reliant on Groundwater (Source: Environment and Climate Change Canada, 2016)

In 2010, the Canadian Council of Ministers of the Environment (CCME) surveyed and reported on the views of 104 Canadian groundwater regulators, consultants, researchers, and users regarding the knowledge and knowledge gaps of linking surface and groundwater for the purposes of groundwater management (CCME, 2010, 1). It is the only survey of its kind in Canada, and it was revealed that there are significant knowledge gaps among those interviewed. In particular these include knowledge gaps on groundwater quality, mapping and characterization, monitoring, sustainability, and understanding the linkage between surface and groundwater (CCME, 2010, 4-6). The survey also revealed that there are significant challenges to the interpretation, implementation, enforcement and compliance of regulations, in addition to the lack of funding for provincial ministries and a lack of recognition of the value of groundwater as a resource (CCME, 2010, 11). Although the survey is nation-wide, it discovered that generally, Canadian professionals in the field of groundwater-related resource management do not fully understand the mechanisms of groundwater management and the difficulties that surround it. The results of the survey demonstrate the uncertainty and complexity of managing groundwater in a knowledgeable and responsible way, thus posing particular challenges for its sustainable use.

Due to its hidden nature, groundwater cannot be visually observed in the same way as surface water. Poor groundwater quality can have devastating implications, and we have seen issues of groundwater contamination before. For example, the infamous Love Canal in Niagara Falls, United States, was one of the first recognized sites of groundwater contamination in the 1960s. The United States Environmental Protection Agency (USEPA) became aware of the impacts of groundwater contamination when decades of chemical dumping in the Love Canal resulted in toxic leeches through various soil and sediments and into the groundwater, ultimately pouring into residential zones and consequently degrading various forest, vegetation and soils (USEPA, 1979). By the early 1970s there were 800 homes and 250 apartments in the region, and complaints of odors exploded among the residents; thus prompting the New York Department of Health to conduct an investigation that later found hazardous chemicals (i.e., pesticides and dioxin) as a serious threat to human health. The results of contamination were significant, wherein many children born between 1974 and 1978 had birth defects, and miscarriage rates had increased 300 percent in the same period. The contamination event at Love Canal was so impactful that it established the very first Environmental Protection Agency's "superfund" project (USEPA, 1979).

In addition to Walkerton, the example of the infamous Love Canal should never be forgotten and should serve as a reminder of what can result from incompetent source water management, poor regulations, and inadequate enforcement of those regulations. In Ontario, recent measures to protect groundwater from contamination have been, for the most part, quite successful. Since Walkerton, source water protection under the *Clean Water Act* has been at the forefront of safeguarding water sources from contamination that could ultimately infiltrate the drinking supply. As a result, high praise should ultimately be given to the accomplishments of source water protection plans (and other legislation, such as the *Nutrient Management Act*) in Ontario.

Despite the successes of the *Clean Water Act* and its robust source water protection initiative, there are considerable concerns rooted in groundwater over-taking and groundwater quantity within southern Ontario. Among many conflicts over competing water uses (i.e., domestic, agricultural and industrial), the recent controversy over water-taking by the lucrative water-bottling industry (i.e., Nestlé Canada) across southern Ontario has triggered profuse public outrage. In recent years, issues of groundwater over-taking have predominantly centered on the millions (if not billions) of liters of water per day that Nestlé Canada extracts from various aquifers across southern Ontario. For example, watersheds in the City of Guelph, the Township of Centre Wellington, and the Town of Elora, Ontario, are such locations that have triggered significant public upset over Nestlé Canada's extraction of large quantities of groundwater (Butler, 2017; Bruce et al., 2017).

In Ontario, the extraction of water for bottling comprises about one percent of total groundwater withdrawals (Rutherford, 2004). This amount may not seem to be a great deal in the grand scheme of total water withdrawal in the province. However, the main reason why water-bottling has become such a concern is because bottled water is entirely consumptive; meaning that unlike water used for other sectors (i.e., power generation and domestic use), all of the water extracted by the bottled water industry is not returned to the local ecosystem from which it was taken (Rutherford, 2004). Bruce et al. (2017) suggest that this is likely to interfere with the ability of the aquifer to recharge; however, the lack of available data in Ontario (i.e., no systematic inventory and data keeping of groundwater levels) makes it difficult to find reliable information about overall trends in groundwater levels in the province (2). Nonetheless, the literature confirms that excessive groundwater pumping can cause hydrologic disturbances during dry seasons (Gleick & Palaniappan, 2010), and that southern Ontario has experienced increased frequency and intensity of drought in recent years (Sutherland, 2016). Despite the onset of drought, Nestlé Canada continues to extract large quantities of water annually at little cost to the corporate giant (i.e., $3.71 per million liters per day) (Butler, 2017).

Furthermore, effective January 1, 2017, under the *Ontario Water Resources Act* (O. Reg. 463/16), the Province of Ontario authorized a two-year moratorium that prohibits new PTTWs to be issued by the MECP for bottling purposes. Prior permit holders, however, can continue extraction if their permit was issued prior to December 16, 2016 (Ministry of the Environment, Conservation and Parks, 2018; Government of Ontario, 2016b). Before the implementation of the moratorium, in the summer of 2016, the Township of Centre Wellington was outbid by Nestlé Canada for water-taking rights to a local water supply well (Jones, 2017). The purchase of this well gained international attention because of the province's difficulties in conserving water supply during drought, and Nestlé Canada's ability to financially obtain water rights from domestic users (ibid). The Township of Centre Wellington soon became an area of interest among various environmentalists and policymakers who were seeking to change provincial regulations of the PTTW program. For example, many Canadians and environmental groups (i.e., the Council of Canadians and Wellington Water Watchers) argued that the inability of the Township to secure rights to its own supply of drinking water demonstrates the inability of the MECP to protect municipalities' access to water from multi-national companies (Bruce et al., 2017; Jones, 2017; Council of Canadian Academies, 2009).

Despite the extensive international attention over the rights to a supply well in the Township, Nestlé Canada continues to run its intensive water-taking operations on expired permits, as allowed by the provincial government. For example, in 2017, the MECP allowed bottled water companies to withdraw up to 7.6 million liters of groundwater per day on expired permits in Wellington County, and Nestlé Canada's permits and water-taking locations in Aberfoyle, Ontario, and Erin, Ontario allow the multi-national company to extract up to 4.7 million liters of water per day (Butler, 2017).

Available data on active PTTWs within Ontario can be found on the Government of Ontario's website (see Figure 20), which also details the permit number, permit holder name, purpose, source type, and maximum liters per day that can be withdrawn (Government of Ontario, 2019b). The database, however, does not record the amount of water actually extracted and used by each permit holder (i.e., users taking more than the maximum), nor does it describe whether the amount of water varied over time (i.e., users taking less than the maximum). According to the database, Nestlé Canada maintains eleven water-taking permits in Wellington County for the purposes of water-bottling. Collectively, these permits allow a maximum extraction of 22,067,000 liters per day, with nine of these permits allowing year-round access

(Government of Ontario, 2019b; Bruce et al., 2017). Accordingly, even though the PTTW program is predicated on ensuring that water needs of the users are fulfilled while also maintaining flows for environmental needs (Ontario Ministry of the Environment, Conservation and Parks, 2017), there are various discrepancies and inconsistencies surrounding the integrity of the program. This is particularly true when bottled water companies continue to extract the maximum allowable amount of water during times of drought; and perhaps, even more than the maximum.

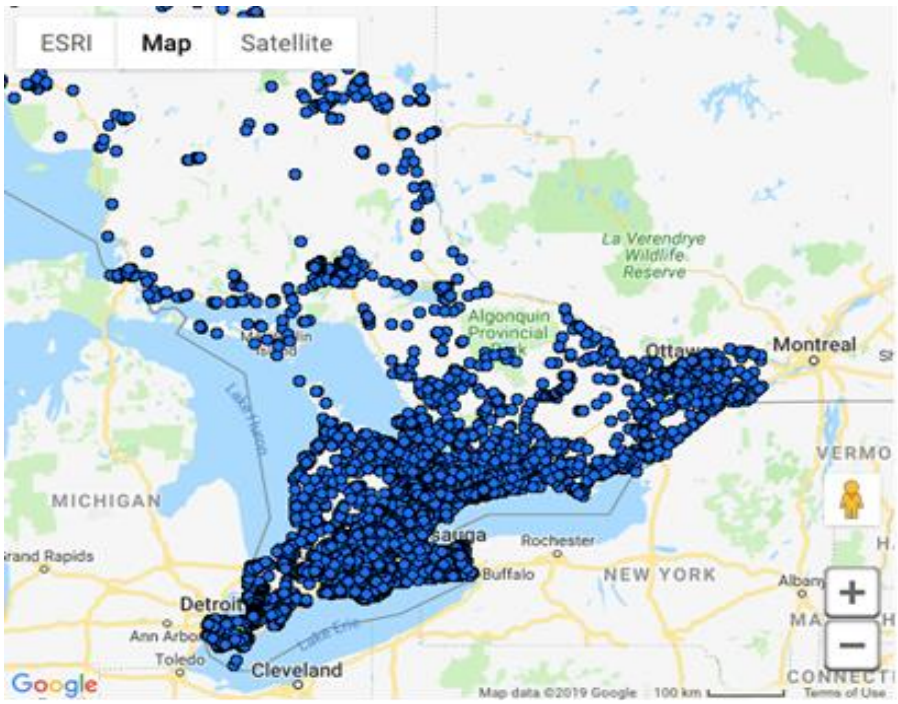

Figure 20: Maps – Permits to Take Water (Source: Government of Ontario, 2019b)

In addition to source water over-taking and loopholes in provincial regulations surrounding the PTTW program and its year-round water-taking access, there are concerns reflecting the MECP's ability to recover fees owed to the government by various permit holders. For example, from the most current available information, in 2014, there were over 6,000 permit holders taking water in Ontario, and the MECP only recovers "about $200,000 of the $9.5 million direct annual program costs attributed to water-taking by industrial and commercial users" under the PTTW program (Ministry of the Environment and Climate Change, 2014, 412).

As a result, not only does the provincial government lose money on its annual program costs in maintaining the PTTW program, but water-taking corporations are also not being enforced by the province to pay fees owed to the government. Although the fees may be collected in time, currently the permit holders are extracting water at little to no cost. Both the Province of Ontario and its citizens are therefore the ultimate ‘losers’ of the PTTW program; particularly the smaller municipalities that no longer have access to their local groundwater supplies.

Moreover, the charges associated with the MECPs permits to take water have been widely criticized for being insufficient. In 2016, these insufficient charges were acknowledged by the Minister of the Environment and Climate Change at the time, Glen Murray, who indicated that water costs under the PTTW program are too low, and that water is unfairly priced and the province needs to “revamp its decades-old regulations around commercial water use” (Butler, 2016). Despite this recognition of underpriced water by the Minister in 2016, it remains a contemporary issue.

It is commonly accepted among the literature that in free markets, increases in the scarcity of a resource will incrementally and subsequently increase its relative market price (Henckens et al., 2016; Farley et al., 2015). However, in Ontario this is not the case. Water pricing in Ontario does not reflect its true value, and consequently households and industry are paying very little for water withdrawal and consumption. This is also true across Canada as a whole, which can be observed by comparing water pricing and consumption trends to its global counterparts (see Figure 24 in Section 5.10). Water use has been regulated insufficiently, and this is particularly true for industrial sectors where water remains to be an underpriced and therefore over-extracted resource (Environmental Commissioner of Ontario, 2015; Klamar, 2015). This is especially challenging for Ontario in ensuring sustainable water use to account for future water demand, wherein climate change, urbanization, and various other factors are likely to hinder the quantity of water available for withdrawal and consumption.

Not only are there concerns reflected in the highly controversial PTTW program, but bottled water companies are also a contributor to plastic pollution. Although plastic pollution is beyond the scope of this paper, with the exception of micro-plastics in the Great Lakes (discussed in the following section), it is estimated that Nestlé Canada produced "more than 3 billion plastic bottles in Aberfoyle, Ontario [alone] since their permit expired in 2016" (Calzavara, 2019). Considering the current and future state of water resources in southern Ontario, the 'myth of water abundance' is challenged from uncertainty in freshwater supply in addition to growing and competing demands for this resource. As long as water is considered as a free, unregulated, and abundant commodity in Ontario, there will likely be dire socioeconomic and environmental implications of future water use if the PTTW program is not corrected to properly value water resources.

The Government of Ontario has extended the moratorium of water-bottling permits to January 1, 2020, and the MECP plans to "review the province's water taking policies, programs and science tools to ensure that vital water resources are adequately protected and sustainably used" (Government of Ontario, 2019b). It is critical that within this time, the MECP develop water pricing to sufficiently reflect the value of water, and to develop policies that limit the amount of water that can be extracted during times of drought and low precipitation. However, while the moratorium for water-bottling permits has been extended, permit holders prior to December 16, 2016, continue to extract large quantities of source water. Consequently, the more time it takes the province to reform its policies and issue new regulations, companies like Nestlé Canada will continue to exploit Ontario's water resources; at little cost, in times of drought, and at unsustainable rates.

5.7 Surface Water Contamination: Micro-Plastics in the Great Lakes

Ontario's surface water resources have long been impacted by contamination from agricultural, industrial, commercial, chemical, institutional, and various other sectors (Ontario Ministry of the Environment, Conservation and Parks, 2018). Many of these sectors have been targeted by increased legislation with the aim to reduce the potential for contamination (i.e., the *Nutrient Management Act*), and also by introducing transboundary agreements (i.e., the *Great Lakes Protection Act*) to remediate AOCs and improve the overall water quality of the Great Lakes (Ministry of the Environment and Climate Change, 2014).

There is, however, an emerging threat to Ontario's surface water resources that is not being addressed in current policy and regulation. Among the multiple human pressures on aquatic ecosystems, the accumulation of plastic debris in freshwater environments is largely underrepresented in the academic literature. In recent years, studies into plastic contamination has gained traction and is relatively well-understood in marine (ocean) environments. However, in freshwater environments, its impacts remain understudied and virtually undefined; wherein less than four percent of microplastics-related studies are reportedly associated with freshwater ecosystems (Li et al., 2018). The fact that we know micro-plastics are present in our freshwater ecosystems, and are doing very little about it, is deeply concerning. It is therefore critical that we address concerns over the volume and concentration of plastics—in particular, "micro-plastics" and its associated micro-fibers, beads, fragments, nurdles and foam—where recent studies have documented an increasing occurrence of micro-plastics in the Great Lakes (Driedger et al., 2015; Eriksen et al., 2014). It also becomes a critical point to address micro-plastic contamination in drinking water supply, where a growing number of researchers are turning to the possibility of micro-plastics present in drinking water consumables; post-treatment at wastewater treatment facilities (Pivokonsky et al., 2018; Anderson et al., 2016; Driedger et al., 2015). For this reason, the reliability of the current MBA to source water protection is threatened by emerging concerns of micro-plastic contamination.

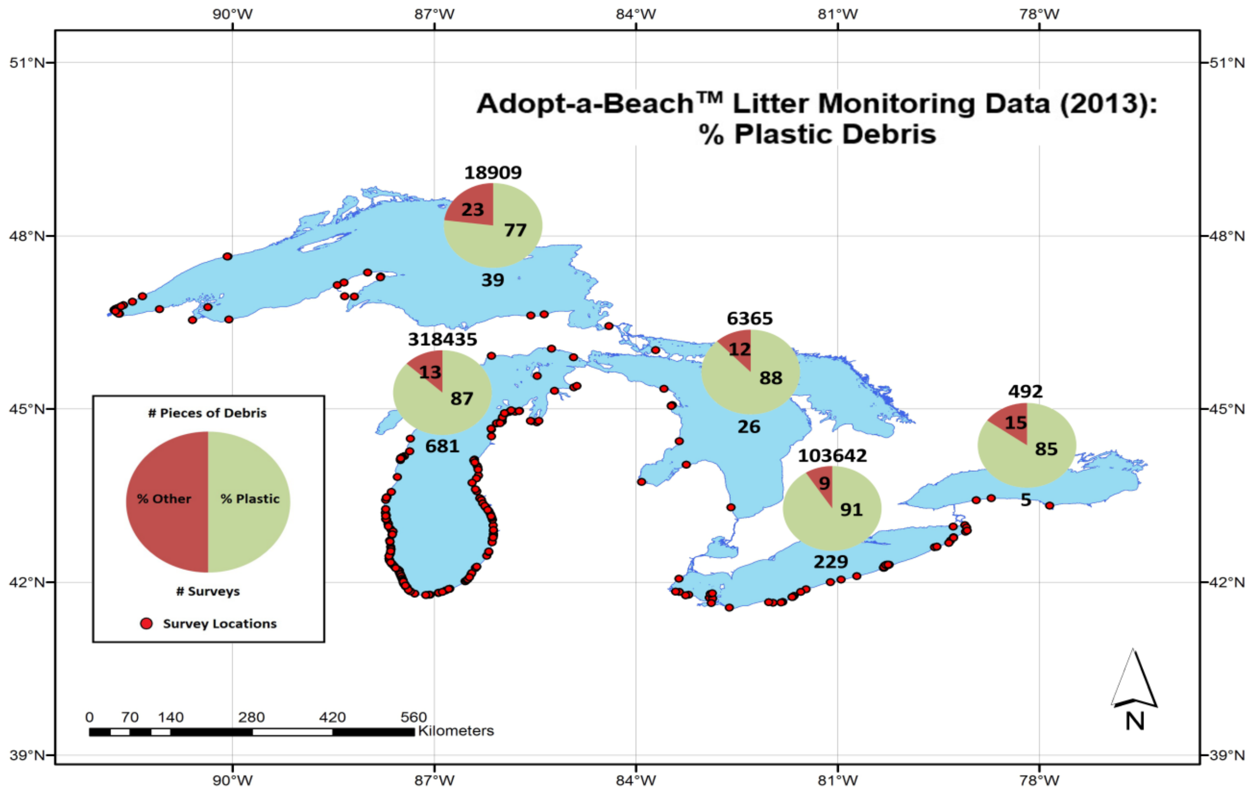

Figure 21: Locations and Percentages of Plastic Litter for the Great Lakes (Source: Driedger, 2013)

"Micro-plastics" refer to plastic particles that are less than 5 mm (milometers) in size (Anderson et al., 2016), and the main sources of plastic pollution are from landfills, industrial waste, careless disposal of consumer products and skin care cleansers (i.e., polypropylene that are flushed into wastewater after use), and storm water and agricultural run-off (Dris et al., 2015; Eriksen et al., 2014). A variety of micro-plastics are also broken down from larger plastic debris, and Figure 21 displays the results from a 2013 study that mapped plastic debris along the beaches of the Great Lakes, with the highest concentrations found in Lake Michigan and Lake Erie, respectively (Driedger, 2013). These plastic debris also have the capacity to transfer through the different channels of the Great Lakes, thus making the interconnected Lakes susceptible to one another. Moreover, recent studies suggest that wastewater treatment plants (WWTPs) are also a large source of micro-plastics because they are not required to monitor micro-plastics in effluent, and many WWTPs in the Great Lakes region are not equipped with micro-filtration or micro-screens; thus ironically acting as a secondary source through wastewater effluent (Dreidger et al., 2015).

Although the occurrence of micro-plastics in freshwater environments is underrepresented in the literature, there are a few studies that have documented their presence in the Great Lakes. For example, a 2014-2015 study published by the USGS found that in the Great Lakes, "plastic particles were found in all 107 analyzed samples, and 72 percent were less than a millimeter in size" (Baldwin et al., 2016, 4). Moreover, a 2015 study found that of all the Great Lakes, the highest concentration of micro-plastics was observed in Lake Michigan, where more than two dozen fish were studied and micro-plastics were found in each subject (Driedger et al., 2015). These small plastic fragments are often mistakenly ingested as food by fish and other aquatic life, which can cause abrasions or blockages that can lead to starvation (ibid). Further, micro-plastics pose negative consequences for ecosystem processes, such as decomposition and nutrient cycling, and present risks for food web dynamics through the bioaccumulation of micro-plastics in lower trophic levels that transfer up the food chain (Horton et al., 2017). Not only are the fish affected by micro-plastics, but humans that consume fish with micro-plastics are also ingesting these particles. However, research studies have yet to quantify this as an occurrence in freshwater environments.

In 2018, the Government of Ontario acknowledged that they are aware of micro-plastics contamination in the Great Lakes, when the Ontario Minister's Annual Report on Drinking Water, 2018, revealed that monitoring and studies in Lake Ontario and Lake Erie "have found a variety of micro-plastics in lakes, streams, wastewater, sand/sediment and species of fish," and that "the ministry will analyze micro-plastics in drinking water as well as the effectiveness of treatment methods to remove micro-plastics in drinking water systems" (Ontario Ministry of the Environment, Conservation and Parks, 2018). The Government of Ontario therefore acknowledges the occurrence of micro-plastics in the Great Lakes, in addition to their potential to enter the drinking water supply. Studies into micro-plastics entering our consumables; however, is largely understudied and unknown at this current point in time. Some researchers argue that Canadian and United States wastewater treatment regulations make no provision for micro-plastic debris, and that future research should include a thorough review of current micro-plastic removal efficiencies of WWTPs surrounding the Great Lakes region (Driedger et al., 2015; Eriksen et al., 2014). It therefore becomes increasingly critical to address issues of micro-plastics in the Great Lakes (and ultimately in our drinking water supply) to be proactive in maintaining the quality of water supply for both humans and ecosystems. Evidently, further research is required to obtain a better understanding of micro-plastics and their sources, policy gaps, and impacts to humans and freshwater ecosystems.

5.8 Projected Climate Change Impacts on Southern Ontario's Water Sources

Centered on historic baseline assessments, summer and early fall in southern Ontario are typically marked by decreased water availability during naturally occurring periods of increased evapotranspiration and its corresponding low precipitation (Sutherland, 2016; Morris et al., 2008). Lower precipitation subsequently results in a reduction in water levels that affect both surface and groundwater availability. Consequently, coupled with the already uncertain water supply during these seasons (i.e., reduced water levels in drier months), there is a corresponding increase in water demand among various domestic, industrial and agricultural water users, therefore posing a threat to equitable water allocation and distribution among users (Bonsal et al., 2011; Morris et al., 2008; Shortt et al., 2004).

In the Canadian context, the sub-watersheds in the Province of Ontario lose the highest amount of water naturally by evaporation during the summer months as compared to other Canadian provinces (Bonsal et al., 2011). Further exacerbating the vulnerability of Ontario's water quantity in the summer months, various greenhouse gas scenarios are projecting that southern Ontario is particularly susceptible to an increase in both the frequency and intensity of droughts due to increasing mean temperatures (McDermid et al., 2015; Wang et al., 2014). With increasing surface temperatures, more volumes of water sources are lost due to evaporation; thus lowering lake and groundwater levels. Changes to the hydrologic cycle will likely include alterations in the timing, rate, and volume of water that recharges groundwater systems. This will subsequently have a 'ripple effect' on surface water resources, wherein the quality and availability of surface and groundwater for drinking supply and maintaining valued ecosystems (i.e., cold water fish in streams) will also likely be affected by changes in thermal temperature

(Grannemann & Van Stempvoort, 2016). With these hydrologic factors under consideration, changes to the rate of water replenishment (i.e., recharge-discharge) between surface and groundwater levels across the province are likely to affect humans and ecosystems.

The projections of future climate change for the Province of Ontario pose serious concerns regarding the quality and availability of future water resources. Warming is projected across the entire province throughout the 21st century, with the greatest increase (as anticipated by various climate scenarios) projected to be upwards of 10.3 degrees Celsius by 2080 (McDermid et al., 2015). Across the province, warming is projected to increase winter temperatures ranging from 1.1 to 3.9 degrees Celsius, and in the summer periods warming is projected to increase temperatures ranging from 1.2 to 9.8 degrees Celsius by 2080 (McDermid et al., 2015). Moreover, Wang et al. (2014) predict a likely raise in mean temperature in Ontario to 6 to 8 degrees Celsius by the end of the century (7). These projections are indicative of more frequent and intense droughts in the region that illustrate a threat to future water quality and availability.

The literature suggests that temperature is one of the most important drivers in maintaining healthy aquatic ecosystems (Maghrebi et al., 2015), and that species are physiologically adapted to specific thermal temperatures such that "the availability of suitable thermal habitat has an influence on their growth, survival, timing of reproductive events and distribution" (Grannemann & Van Stempvoort, 2016, 40). Accordingly, changes to water temperature from climate change will not only affect humans by a lesser supply of potable water, but it will also impact freshwater organisms that depend on specific thermal temperatures for their survival.

In addition to the projected mean temperature increases in southern Ontario, studies have quantified its corresponding impacts on changes in total precipitation. By 2080, more precipitation is projected in the winter (i.e., upwards of 158 mm from historic mean levels) and less precipitation is projected in the summer (i.e., with a range of 69 to 48 mm *less* precipitation than historic baseline levels across the province) (McDermid et al., 2015). The imbalance of precipitation levels indicates increased snowfall and flooding in the winter, and decreased rain in the summer months; when water resources are already stressed by naturally occurring dry periods with low precipitation. Moreover, hotter mean temperatures is likely to increase water demand among domestic, industrial, agricultural, and various other sectors, in response to the increased temperatures and reduced water availability.

Changes in mean temperature and precipitation levels are not the only factors of climate change that are likely to impact source water quality and availability. Within the GTA, the Toronto and Region Conservation Authority (TRCA) discuss that changes in climate are also likely to affect water quality and quantity, in addition to wastewater infrastructure. Accordingly, the TRCA describe that at times of extreme precipitation events, heavy rain can force wastewater to enter rivers and streams, it can damage infrastructure, erode stream and river banks, and flush polluting substances (e.g., oil, lawn fertilizers and animal waste) into waterways (TRCA, 2019b, para. 9). In contrast, at times of little amounts of precipitation, the TRCA discuss that warmer water temperatures and increased evapotranspiration in the Great Lakes and other various interconnected water bodies may allow new waterborne pathogens to move northward or existing ones to flourish (TRCA, 2019b). The introduction of new waterborne pathogens is particularly worrisome, and Moreira & Bondelind (2016) emphasize that the occurrence of waterborne disease outbreak may have significant impacts for drinking water, and that due to climate change and its increased potential for waterborne disease outbreak, “drinking water treatment plants are likely to face increased uncertainty in safeguarding the quality of its water” (83).

In review of the overall projected climate change scenarios in Ontario, there appears to be an imbalance in the projected levels of precipitation, such that the winter seasons are projected to receive an excess amount of precipitation, whereas in the summer (drier) months there is an anticipated lesser amount of precipitation. In either case, the adverse effects of climate change on freshwater systems can aggravate the impacts of other human stressors, such as population growth, continuous and growing economic activity, urban expansion and its associated land use change, surface water contamination, and over-taking of groundwater.

Globally, water demand is likely to grow in the coming decades, primarily due to climate change, population growth and its corresponding increased demand for water to serve the growing human needs for drinking, irrigation and the economy. Climate change impacts, such as higher mean terrestrial and aquatic temperatures, and increased precipitation variability, are predicted to impact southern Ontario. Given the past, current and future susceptibility of southern Ontario to experience water quality and quantity issues, water supply is likely to remain uncertain amidst climate change, population growth, and various other pressures.

5.9 Water Contamination on First Nations Reserves

There is nothing more important than clean and safe drinking water, and the events at Walkerton, Ontario emphasized this importance. Following the Walkerton tragedy, Justice O'Connor identified First Nations in Ontario as "having some of the poorest quality of water in the province" (O'Connor, 2002). Even though the Walkerton Inquiry sparked a generational shift in how the province safeguards its citizens from drinking water contamination, many First Nations communities remain threatened today with poor water quality and water standards. These concerns are echoed by a wide variety of environmental groups, such as the Council of Canadians (see Figure 22), who say that "the lack of clean, safe drinking water in First Nations is one of the greatest violations of the UN-recognized human rights to water and sanitation" (Council of Canadians, 2019).

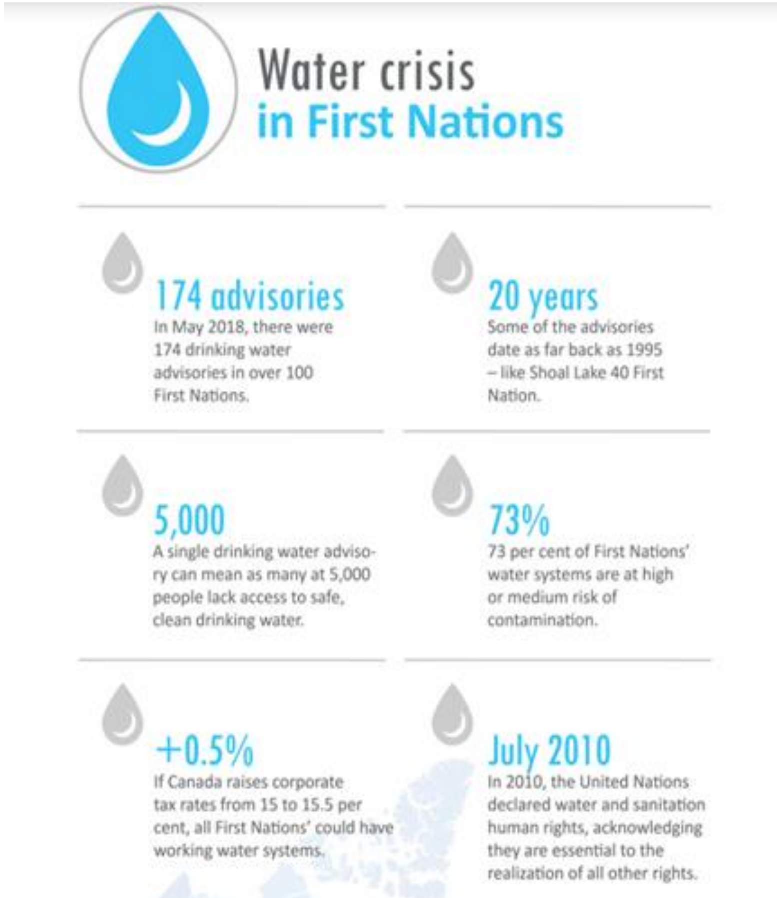

Figure 22: Water Crisis in First Nations (Source: Council of Canadians, 2019)

In 2011, of the 77 wastewater treatment systems that serve 67 First Nations communities in Ontario, 28 were categorized as "high overall risk," 38 were categorized as "medium overall risk," and 11 were categorized as "low overall risk" (Burnside, 2011). Many First Nations communities in Ontario (in particular, 105 out of 133) are located outside the boundaries of a Source Protection Area; and thus, they are exempt from regulations stipulated under the *Clean Water Act* (Burnside, 2011). As of 2016, drinking water advisories—or, notices that alert communities when their water is not safe to drink—were highly concentrated in Canada's First Nations communities, to the extent that in 134 water systems (90 of which were in Ontario), drinking water advisories were issued in 85 First Nations reserves (Human Rights Watch, 2016). In response to the ample number of drinking water advisories that were issued to First Nations communities, the Human Rights Watch (an international non-governmental organization) conducted a study into the water quality at 6 First Nations reserves in Ontario; namely, Six Nations of the Grand River, Batchewana, Shoal Lake 40, Grassy Narrows and Neskantaga (see Figure 23 for reserve locations). Their study found seriously harmful contaminants in drinking water, including chloroform, E. coli, cancer-causing trihalomethanes, and uranium (Human Rights Watch, 2016).

Many non-governmental organizations and environmental groups attribute the poor drinking water quality in First Nations reserves to the lack of regulations on water quality on First Nations reserves, continuous under-funding and inconsistent budgeting for water system costs (i.e., operation and maintenance costs), lack of support for household water and wastewater systems, worsening conditions of source water due to increased industrial pollution, and a lack of capacity and support from the provincial and federal governments for water operators (Council of Canadians, 2019; Human Rights Watch, 2016). Many challenges face the First Nations communities in Ontario; people that are environmental advocates and are spiritually and culturally connected to water, air, land, and all things ecological. Moreover, all First Nations, all Ontarians, all Canadians, and all people of the world require access to clean and safe drinking water for survival. The right to sanitary water should entitle everyone; however, decades of failure to fulfill the rights to water and sanitation have caused significant harm to First Nations communities, and they reflect poorly on the world's perception of the Government of Ontario in safeguarding its citizens from poor water quality and standards.

Figure 23: First Nations Communities that were studied by Human Rights Watch for Water Quality (Source: Human Rights Watch, 2016)

5.10 The Canadian "Myth of Water Abundance"

Various regions around the world are experiencing growing concerns of freshwater scarcity due to extreme human pressures of contamination and over-taking, and further exacerbating these pressures is anthropogenic climate change (Gleeson et al., 2017; Richey et al., 2015). Ontario is no different from the rest of the world in that it exerts a variety of human pressures on its water systems, and climate change (as a global issue) is likely to further impact our ability to manage these resources. There is, however, a key difference in terms of the volume and accessibility of Ontario's freshwater compared with the rest of the world; where Ontario is the envy of the world with its 'abundance' of this valuable resource. The Province of Ontario has copious legislation echoed by the *Clean Water Act* and a variety of other statutes designed to protect and sustain the sources of freshwater within the province. Even so, increasing demands on Ontario's existing water resources, contamination, and unsustainable water exploitation remain a current threat to the province and are often overlooked; owing to the 'myth of water abundance' that continues to persist in the region. For many Canadians, water is the underpinning of our national identity and we take great pride in Canada as having one of the world's largest supplies of freshwater on the planet. This view has been echoed by the Government of Canada, who have relayed to the public that "Canada may be considered a freshwater-rich country" (Natural Resources Canada, 2017). As a result, many Canadians and Ontarians believe that a quarter of the world's freshwater supply is found in Canada, ultimately adding to the perception that Canada has a near unlimited supply of this valuable resource. However, this abundance is more myth than reality, as the following will illustrate.

Canadians are often told by their politicians and media outlets that we have ample amounts of freshwater within our lakes. One reason for this perception is that we have abundant places for water to collect, such as in the depressions left by receding glaciers from thousands of years ago, that can be visually observed in abundance across the country (Schindler, 2006). In Ontario, most of these depressions are apparent in the Great Lakes, in various swaths of wetlands and smaller lakes within Algonquin Provincial Park, the ORM, and many other bodies of water that are entrenched within provincial boundaries (Schindler, 2006). However, having more Basins to catch rain does not mean that the province receives more precipitation. This is also true across Canada as a whole. In fact, when compared to its global counterparts, Canada gleans on average much lower annual volumes of precipitation. The Food and Agriculture Organization (FAO) of the United Nations report that Canada receives about 537 mm of precipitation per year; which, when compared to its global counterparts, is ranked 134th out of 177 (from highest to lowest in annual precipitation volume) (United Nations, 2014b). Contrary to common belief, Canada's annual rate of precipitation is much less than when compared to most other countries. On a global scale, the fact that Canada is above average in the amount of freshwater resources, but below average in the amount of annual precipitation, further emphasizes the importance of protecting freshwater resources within the country. Moreover, many of the depressions that have allowed for freshwater to collect were a result of receding glaciers; and thus, if we contaminate our freshwater systems, or extract more than can replenished by natural processes, our 'abundant' supplies of freshwater can be depleted.

The myth of water abundance can be attributed to the fact that Canada holds approximately seven percent of the world's renewable supply of freshwater, but only 0.50 percent of the world's population (Warren, 2016; Klamar, 2015). Even though the Great Lakes constitute 18 to 20 percent of the available global freshwater, the annual rate of natural replenishment by precipitation and surface run-off is in fact less than one percent which constitutes the 'renewable' component of the Great Lakes (Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014); thus, making the region susceptible to anthropogenic over-taking. Moreover, Canada's water is not equally distributed, such that the majority of Canada's population lives in the southern portion of the country (i.e., southern Ontario), but "60 percent of the country's renewable water drains to the north," and therefore access to water resources is limited (Klamar, 2016, para. 5). Canadians also do not realize that, globally, freshwater is a scare natural resource that is also becoming scarcer every day.

The 'myth of water abundance' perceived by Canadians can also be viewed through statistics in municipal water use. Analyzing municipal water use in Canada compared to global trends is reflective of the general population; and thus, other sectors (i.e., industry and agriculture) have no influence on measuring how citizens of Canada perceive the abundance of water within the country. By this example, we can observe how Canadians (generally) view water as an abundant resource. For example, the overall volume of freshwater extracted and used for municipal use per capita in Canada is one of the highest when compared to other OECD countries (Canada's Ecofiscal Commission, 2017). According to the World Health Organization, the average per capita requirement of water is within 50 to 100 liters per person/per day, to fulfill all basic human and residential needs (Howard & Bartram, 2003). The municipal water use in Ontario, Canada, as of 2013, is measured at 200 liters per person/per day (Statistics Canada, 2013). Accordingly, the amount of municipal water consumption is two to four times greater in Ontario than what is required to fulfill all basic human and residential needs.

Contributing to the high volumes of municipal water consumption in Ontario is also reflected in water pricing for municipalities; wherein water is exceptionally underpriced, and it is therefore an undervalued resource that lacks effective market pricing mechanisms (Wood, 2014). As shown in Figure 24, countries with lower water prices generally consume more water.

Various academic papers have also concluded that by underpricing water, both the value of the resource is overlooked and there is a failure of signaling the looming threats of water resources to users; thereby resulting in over-taking, wastage, and ultimately conflicts among users that is likely to worsen in future years (Renzetti, 2017, Bruneau et al., 2013).

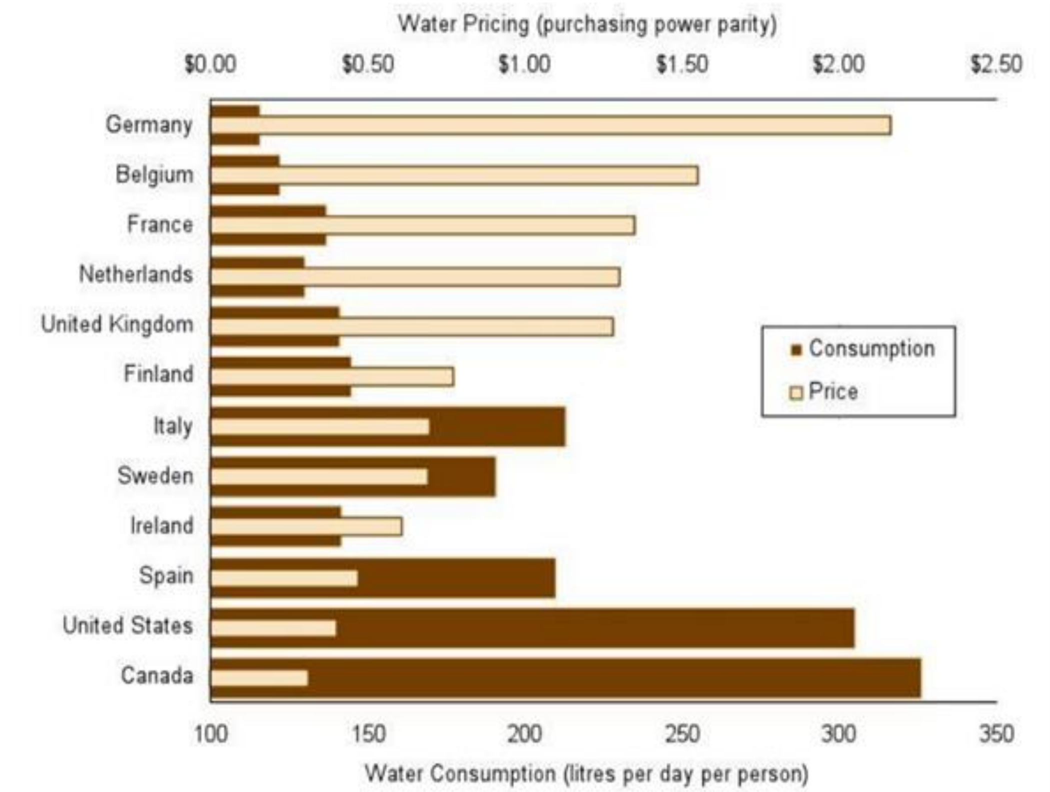

Figure 24: Municipal Water Consumption (liters per day per person) and Water Pricing (purchasing power parity) by Country (Source: Bruce et al., 2017)

In addition to Canada's overall highly consumptive municipal water use, industrial water-taking in the country is predicated on the perception that Canada is in excess supply of water resources. For example, in 2009, industry was Canada's largest water user, using 30.6 billion cubic meters (Conference Board of Canada, 2013). As many parts of the world are experiencing growing concerns of freshwater scarcity, Ontario is one such location that is considered to be a major "trade-friendly" location for water-dependent industries and agriculture (Rubin, 2017). Although water in bulk is not directly exported, its use in the production of goods (i.e., bottled water and agriculture) consume significant quantities of water (ibid). As a result, some researchers suggest that “virtual water” embedded in these products is traded internationally to water-scarce countries (Debaere, 2014; Konikow & Kendy, 2005, 319), and it is estimated that about twenty percent of water consumption in the world relates to the production of export goods (Ercin et al., 2013). As global demand for these products is estimated to increase with growing human populations, a growing concern among the literature is that the pressure on domestic water resources will likely, and consequently, increase for regions (like Ontario) to be perceived as water-abundant (Debaere, 2014; Ercin et al., 2013).

This perception is widely known in Canada; a country that is unanimously viewed as “water-rich” as it possesses 18 to 20 percent of the world’s surface freshwater and has many of the largest lakes and rivers (Environment and Climate Change Canada, 2013b). Canada’s supposed water abundance is more myth than reality, propagated by politicians and the media, which enables governments to ignore the need for water policy, water conservation, and efficient water pricing for all sectors (especially residential and industrial use, and underpricing water that contributes to Canadians’ perception of water abundance) (Schindler, 2006). Nonetheless, Canada’s water resources face a myriad of threats arising from population growth, urban expansion and land use change, natural resource-based developments, looming implications of climate change, a growing reliance on large-scale irrigation, industrial and commercial over-taking of source water, surface water contamination, and a legacy of past laws and regulations that are unable to adequately address these new challenges. Many of these challenges have been illustrated throughout this paper. These challenges also indicate that the dependency on water for human survival should serve as a reminder to Canadians, and that the perception of water abundance in Canada can no longer be overlooked.

Accordingly, to ensure the sustainability of Ontario’s limited stocks of freshwater resources, we must proactively manage and protect our water systems in all we do. This would mean that we must sufficiently value water for what it is and charge accordingly for its withdrawal and consumption. A change in how Canadian citizens view the availability of freshwater resources in Ontario must also be changed to improve overall water efficiency and sustainability at the municipal, provincial, and national scale.

5.11 Environmental Implications of *Bill 108, More Homes, More Choice Act*

Premier Doug Ford's government has produced a long and extensively growing list of 'losers' that have emerged since Doug Ford's "open for business" proclamation when Ford attempted to "open the door to greenbelt development" through *Bill 66, The Restoring Ontario's Competitiveness Act* (Winfield, 2019). According to Mark Winfield's article, *Doug Ford's Ontario: Who Wins, and What Does it Mean for Ontario's Future?*, developers of urban sprawl in low-density built-up development on farmland is targeted by the Ford regime, and prior to Ford's election as premier, comments were made by Ford about opening "a big chunk" of the protected Greenbelt of farms and forest land cover in the City of Toronto and other urban regions of southern Ontario to urban development (Winfield, 2019). In terms of the "open for business" campaign of the Ford Administration, and within the scope of this paper, the 'losers' are clearly the watersheds and sub-watersheds that encompass vital source waters and maintain valued freshwater ecosystems. Although Bill 66 did not pass its second reading, a new Bill surfaced; one that still promotes development of the Greenbelt and has substantial implications for environmental degradation.

On June 6, 2019, the Government of Ontario passed comprehensive legislative changes to Ontario's planning and development regime through *Bill 108, More Homes, More Choice Act*. The new legislation is centered on increasing affordable housing in Ontario, and it affects 13 *Acts* and has several municipal implications. Confining these legislative changes to the scope of this paper, Bill 108 has enacted changes to the *Conservation Authorities Act*, *Endangered Species Act*, *Environmental Assessment Act*, *Environmental Protection Act*, and the *Planning Act* (Clark, 2019). Changes to the aforementioned *Acts* cannot be discussed in length, because the effects of these changes are largely unknown.

Although the full effects of Bill 108 have yet to be seen, various law and real estate firms (i.e., Borden Ladner Gervais and Miller Thompson) and non-governmental organizations (i.e., Environmental Defence and Water Canada) have critically examined and dissected the legislative changes made by *Bill 108, More Homes, More Choice Act*. For example, Miller Thompson suggest that the new Bill "speeds up the process" of urban development by adjusting many prohibitions stipulated in various *Acts*, including the *Endangered Species Act* and the *Planning Act*, by restricting the number of appeals that can be brought forth by third parties (Tang, 2019). Moreover, Environmental Defence and Water Canada suggest that Bill 108 fulfills most of the demands submitted by the Ontario Home Builders Association. For example, Environmental Defence describe some of the key changes contained within the legislation, which include the following: "i) Bill 108 will restore Ontario Municipal Board rules which allow override of planning decisions made by democratically elected municipal government; ii) Bill 108 removes previous restrictions on urban boundary expansions meaning urban sprawl will again dominate new development; iii) Bill 108 proposes to amalgamate and cap development charges, depriving municipalities of needed funds for parks, community centres and libraries; iv) Bill 108 includes a new mechanism that will allow developers to pay a fee to avoid protecting the habitat of species-at-risk, and will allow for reduced protection if the species exists somewhere else in the world; [and] v) Bill 108 will reduce the scope of Conservation Authority activities and allow the Ministry of the Environment, Conservation and Parks to decide areas in watersheds that can be developed, which will enable urban sprawl development in natural areas" (Environmental Defence, 2019, para. 3). Each of these changes are anticipated to profoundly impact environmental protection of watersheds, freshwater ecosystems, water quality and quantity within the province.

The details of source water protection (refer to Section 4.4) under the *Clean Water Act* clearly highlight the need for decentralization and collaboration of water management regimes to include the MECP, the MNRF, individual Conservation Authorities and localized municipalities to ensure clean and safe drinking water for Ontarians, in addition to assessing the state of aquatic ecosystems. For example, soon after the proclamation of the *Clean Water Act*, Source Protection Committees were developed; comprised of representatives from local municipalities for a "more diverse assessment of existing and potential threats to water sources," that is vital to ensuring sustainable water use and for identifying various threats to aquatic ecosystems, watersheds and water resources. Moreover, the initiative was also added by Justice O'Connor's recommendations following the Walkerton Inquiry as a proactive measure to ensure another

Walkerton incident does not reoccur (Ontario Ministry of the Environment and Climate Change, 2014, 408).

Bill 108, however, proposes to disassemble the collaboration of the aforementioned groups, and to instead reinstate centralized decision-making under the authority of the MECP (Environmental Defence, 2019, para. 3). The authoritarian decision-making process was noted in Part II of the Walkerton Inquiry as a contributing factor to the events at Walkerton to start with, and Justice O'Connor suggested that "to ensure that local considerations are fully taken into account…source protection planning should be done at a local (watershed) level…[and] conservation authorities should coordinate the plans' local development," and that once draft plans are developed at the watershed level they would then be subject to MOE approval (Lindgren, 2003, 14). It is therefore essential to include various stakeholders when developing source protection plans to ensure the highest degree of source water protection. The legislative changes made by Bill 108 seriously threaten the integrity of watershed protection, and ultimately source water protection within the province.

Moreover, with reduced provincial funding to the MECP (refer to Section 5.2) it is likely that the Ministry cannot adequately allocate its resources to protect the most environmentally sensitive watersheds, and competently ensure the protection of watersheds that may be vulnerable to development activities. In effect, the results of these legislative changes are likely to roll back environmental protection of watersheds and their encompassing surface and groundwater resources.

Furthermore, Bill 108 is predicated on expanding urban areas for new housing, particularly in protected areas such as the Greenbelt. In tandem with these development changes is the ability of Bill 108 to bypass stringent regulations in the *Endangered Species Act*, thus allowing urban developers to pay a fee to sidestep species listed as "endangered," and to continue developing their habitat area (Environmental Defence, 2019; Shipowick & Butler, 2019). For example, Subsection 9 (1) of the *Endangered Species Act*, 2007, currently sets out prohibitions that apply to a species once they are listed on the *Species at Risk* in Ontario as threatened or endangered. The new legislature changes subsection 9, giving the Minister (of the

Ministry of Municipal Affairs and Housing) the power to limit the prohibitions of developing in areas with endangered species in various ways (i.e., indicating that prohibitions may not apply, limiting to a geographic area where they apply, or if they only apply to the species at a certain stage of development) (Clark, 2019, ii). The result is centralized decision-making by the Minister without objection by a third party; thus, posing a considerable threat to endangered species.

The implications of these legislative changes to various *Acts* are likely to be extreme. The sensitive habitat for these species is vital not only for that particular species, but also for maintaining the ecological functions of that particular ecosystem. As this paper has illustrated, urban development poses particular concerns to water quality and availability, in addition to aquatic species that depend on their respective forest cover and water systems. Further development into protected watersheds is likely to have a significant impact on the Greenbelt and other environmentally sensitive areas; although the extent of these impacts is largely unknown at this time. Some environmental groups, such as Environmental Defence, have taken proactive measures to inform the public of their opposition to Doug Ford's "open for business" campaign (see Figure 25).

When dealing with uncertainty, we must act in a proactive nature. An important recommendation made by Justice O'Connor following the events at Walkerton was that "the precautionary principle should be used as the basis for standard setting" (Lindgren, 2003, 18). Without certainty of how Bill 108 will impact the environment, we must be careful and highly critical of all development activities in the province's protected watersheds. Subsequently this should involve more public awareness and scrutiny of particular developments. It is therefore important that as citizens of Ontario; we take action against Bill 108 and its environmental implications on degrading watersheds and their encompassing source waters and aquatic species. The recent introduction of Bill 108 to Ontario's Provincial plan is likely to roll back environmental protection and facilitate urban sprawl at the request of developers; subsequently worsening the quality of environmental standards both in practice and in legislation. Although little is known about the full extent of the new legislation at this time, it is projected by various institutions to hinder Ontario's progress in sustainable development (Environmental Defence, 2019; Shipowick & Butler, 2019; Tang, 2019).

Figure 25: Anti-Bill 108 Sign Located on Highway 400 (Source: Environmental Defence, 2019)

6.0 DISCUSSION: INTERVIEW RESPONSES

Ontario has what the rest of the world needs in terms of access to large volumes of freshwater. We have seen how the rest of the world has allowed deterioration of its freshwater environments, yet we are allowing similar human activities to occur right under our noses here in southern Ontario. Increased human pressures on our water resources, in conjunction with the 'myth of water abundance' that continues to persist in Ontario (and Canada as a whole), is cause for concern regarding the sustainable use and management of this valuable resource. Undoubtedly, there are a variety of comprehensive policies in place to protect and sustain our water resources in the province; many of which represent some of the best legislations compared to the rest of the world. However, there are a variety of data gaps and loopholes in current practice and legislation that need to be addressed to better protect the province's water resources. This is particularly true given the projections of uncertain freshwater availability under various greenhouse gas scenarios within southern Ontario, in addition to uncertain climate change impacts around much of the world.

Four members of a diverse group of environmental professionals were interviewed (by myself, the researcher) for the purposes of this paper (see "Primary Source Materials" under "References" on page 141). The open-ended questionnaire used as a baseline for the interviews can be found in the Appendices, along with the Informed Consent Form that was sent to each of the interviewees. The participants provided many diverse perspectives on where they believe Ontario's water management regimes are in terms of the quality of source water protection and water management initiatives. A common theme among the participants is that the *Clean Water Act* sets out an effective framework for protecting safe and clean municipal drinking water sources, but there remains a variety of issues in maintaining the integrity of the *Clean Water Act* and various other water management initiatives within the province. In response to Question 1 of the questionnaire, Interviewees 1-4 all acknowledged major improvements made in drinking water protection in Ontario since the Walkerton tragedy in 2000. However, Interviewees 3 and 4 both emphasized weak policy surrounding the *Permit to Take Water* (PTTW) program as a contemporary issue. For example, Interviewee 3 responded with "the permit to take water program represents a win for bottled water companies; the permits are woefully inadequate where they extract water for pennies on the dollar, although they pay more for water now than they used to, it [water] remains an extremely undervalued and thus insignificant resource." Furthermore, Interviewee 4 responded with "the government has not completed a proper inventory of freshwater resources in decades, and thus do not know where the resources are that they need to protect," continuing to say, "this is exampled by the number of bottled water companies that continue to withdraw significant volumes of fresh clean groundwater that belongs to the people of Ontario." The implications of the responses from both Interviewees 3 and 4 indicate that there is a need to update legislation to address, in particular, the industrial and commercial permit holders for bottled water extraction.

When I asked participants about their views on the general public's understanding of issues in maintaining southern Ontario's freshwater sources, Interviewees 1-4 all agreed that the public do not understand enough, wherein Interviewee 1 replied with "Water issues appear to be more restricted to those directly involved, such as members of the Ministry [MECP] or independent researchers," and Interviewees 2 and 3 shared the belief that most people simply accept the fact that they turn on the tap and water is there, and that they are not paying much for it. Interviewee 4 responded by saying "the public only know what they are told by their government and the media…as such, the people don't know the emerging crisis…they probably don't even know about the damage bottled water companies are doing, otherwise they might actually stop buying water bottles." Interviewee 3 also shared insight into inadequate media coverage of First Nations, saying that "Many First Nations communities don't have access to clean drinking water in Ontario, which is criminal in today's world," continuing to say, "the public also do not understand groundwater since it can't be seen, which is another reason for why it is taken for granted." The hidden nature of groundwater poses a particular challenge to sufficiently managing our groundwater resources. Unlike surface water sources that can be seen and used recreationally, groundwater is generally uncommonly seen among the public due to its subsurface characteristics (i.e., several feet below Earth's surface).

In terms of raising awareness of freshwater issues in Ontario, and when I asked participants who should ultimately be responsible for relaying current and emerging threats to the province's water sources to the public, Interviewee 1 responded with "It is [and should remain] the government's responsibility to clearly outline current and future threats to our water resources. I think the government could simply make anniversary announcements of events that took place, such as Walkerton or Hagersville fire that impacted groundwater quality." The events at Walkerton represented a generational shift in how Ontario views its source water, and anniversary announcements of the crisis that occurred in May 2000, may serve as a reminder of what could happen if we do not properly and proactively manage our water resources. Interviewees 3 and 4 had a similar response to Interviewee 1. For example, Interviewee 4 said that "it should be the elected officials that have been given the job to look after existing and future generations of their people…if they are not advising the people of the crisis…they are not doing their job," and Interviewee 3 responded with "the media or the government is not doing their job. The media tends to be reactionary, so it should be the responsibility of the government and NGOs to keep these issues at the forefront of public awareness." Interviewee 3 also suggested that NGOs should have a role in relaying water resource threats to the public, whereas Interviewee 2 replied with "Raising awareness needs to be coupled with tangible actions and outcomes. We need to find ways to motivate people to change their behaviors to overcome the challenge of cognitive dissonance," continuing to say "I think much greater impact can be achieved by changing industrial practices, which will require targeted messages and newer policies." Interestingly, Interviewee 2 goes beyond public awareness and hones in on the challenge of changing the behaviors that are ultimately at the root of current and emerging threats to our water sources (i.e., climate change, urbanization, material consumption, water over-consumption and over-taking, etc.). Our behaviors and mindset of how freshwater is viewed in Ontario may be an underlying factor for why human pressures continue to threaten our water sources.

When I asked the participants if they believe adequate legislation is in place for protecting source water in Ontario, Interviewees 1, 2 and 3 commonly agreed that the legislative framework is there and is comprehensive. However, Interviewee 4 responded with "Provincial legislation is outdated and thus does not incorporate current issues. Micro-plastics is an example, where their introduction was not contemplated when existing legislation was enacted. Further, some legislation, such as the *Clean Water Act*, was a knee-jerk response to a tragic issue [Walkerton] and [the *Act*] requires updates." Interestingly, Interviewee 4 had a radically different response from the others, such that the person disagrees that current legislation is adequate to address emerging source water issues within Ontario. More importantly, Interviewee 4 stressed that the *Clean Water Act* was a "knee-jerk response" to Walkerton; and in terms of being more proactive than reactionary, perhaps an update in current legislation may be required to address emerging threats to our water resources before reactionary measures are required.

When I asked participants if they think legislation is being appropriately enforced by the government, the responses varied between "yes" and "no". However, all Interviewees (1-4) addressed significant concerns over the enforcement capacity of the province. For example, Interviewee 1 responded with "government funding [for the MECP] has always lacked and continues to be reduced. The permit to take water program has many wondering whether the government is actually enforcing the regulations, retrieving the fees owed to the government and to its citizens, and monitoring how much water is actually taken from the environment." Furthermore, Interviewee 2 replied with "the key for me is in implementation, and I look forward to seeing how well source protection plans are implemented over the next few years." Interviewees 3 and 4 both shared "yes" and "no" responses to my question. For example, Interviewee 4 replied with "yes, but only in rare cases where the abuse has been obvious and significant. The watchdogs of freshwater in the province [MECP] are short-staffed and their budgets get cut regularly…so they really have to be reactive rather than proactive, meaning they only have staff to respond to big issues." Additionally, Interviewee 3 coincides with the participant views of Interviewee 4 in saying that "generally yes, the enforcement is there, but there is no question that enforcement is not nearly as robust as it should be. The larger municipalities, such as in the GTA, do a great job at enforcing strict regulations. The smaller municipalities [however] are much less able to adequately provide training, maintenance and performance. The provincial budget [for the MECP] is less than one-third of one percent. Increasing the [current] budget will make the agency more proactive and enforce a much broader and more responsible regime of policy." There is a common agreement among the participants that the enforcement capacity (particularly in smaller municipalities outside the GTA) is generally very weak, and as a result the smaller municipalities are easily targeted by industries (i.e., bottled water) as a consequence to the lack of enforcement of government regulation in these areas.

Further, I asked participants if they think wastewater treatment plants (WWTPs) are adequate and sufficient, in addition to their views on micro-plastics in source water (and drinking water supply) in the Great Lakes (in particular). Interviewee 1 implied slight concerns over micro-plastics in drinking supply systems, Interviewee 3 implied that they are not too concerned, whereas Interviewees 2 and 4 were strongly concerned with micro-plastics. For example, Interviewee 1 said "I am a little concerned [with micro-plastics] because of their potential to enter drinking water supply systems. I think they [WWTPs] can do more; the compliance list can include more parameters and they can upgrade their systems to micro-filtrate." Interviewee 3 responded with "I think the current treatment is very good, and WWTPs do this very well. I am not particularly concerned with micro-plastics [in our drinking water supply], I have yet to see if they are a legitimate threat, but I don't think the science is there yet to have a sound understanding of its impacts. I do think it needs to be further explored before jumping to conclusions." On the contrary, Interviewee 2 responded to my question by saying "Yes, I am concerned about micro-plastics in our water supply, as well as [in] our food. I don't think our wastewater treatment plants, which have been designed and built many years ago, are capable of removing novel materials such as micro-plastics." Interviewee 2 was not the only participant to view WWTPs as being outdated, wherein Interviewee 4 responded to my question by saying "Our wastewater treatment plants were designed to old technology…there are many impurities such as pharmaceuticals and micro-plastics that were never contemplated when the plants were designed and thus are not treated…so they pass right through to the natural environment and/or drinking water." The diverse responses to this question demonstrate just how emerging of a threat micro-plastics are for our water sources and ultimately our drinking water supply. The Interviewees conveyed an incremental change from "not concerned" to "very concerned," thus indicating a need for further research into micro-plastics contamination; both in our water sources and in our drinking supply. The results from participant interviews indicate that more studies and legislative provisions to micro-plastics and micro-debris in WWTPs may be required. Moreover, recent studies have already shown that there are insufficient policies in place to prevent micro-plastics from entering drinking water supply in WWTPs (i.e., WWTPs are not required by legislation to filter micro-plastics in Ontario) (Driedger et al., 2015; Eriksen et al., 2014). Evidently, further research into micro-plastics and the capabilities of WWTPs to filter these particles requires further research.

I also asked the Interviewees how knowledgeable we are (generally) about the science of the hydrologic cycle. The purpose behind this question was to see how environmental professionals view our knowledge on the hydrologic connectivity between surface and groundwater, and whether we understand enough about how the water cycle affects the availability of water and at different times of the year (i.e., at times of high or low precipitation). Moreover, delving deeper into hydrologic functions, the purpose behind my question was to see if we know enough about the hydrologic cycle to prepare us for future climate changes. The responses varied from “we do not know enough” to “yes we have a good understanding.” For example, Interviewee 1 replied with “No, I think they make the hydrologic cycle seem simpler than it really is. After all, meteorologists can barely predict tomorrow’s weather.” I found the last part of this quote to be very interesting. Even with today’s technologies and knowledge of the hydrologic cycle, there is always the possibility that the integrity of the water cycle can be compromised by climate instability, thus making predictions for future water availability (i.e., rate and volume) much more difficult. This is especially true when an industry-driven economy withdraws significant amounts of water that is not returned to the local watershed (i.e., bottled water), despite the onset of drought. With that said, Interviewee 2 replied to this question with “I think we do know a lot, but we certainly do not know everything. But with what we do know about the hydrologic cycle and drinking water threats, we can apply that knowledge to protect the quantity and quality of our drinking water sources. With what we don’t know, we may wish to act cautiously and exercise the principle of precaution. I would say climate change is one of those unknowns, especially on how climate change can impact the quantity and quality [of] local surface water and groundwater.” Additionally, Interviewee 4 expressed both “yes” and “no” responses, saying that “yes because the science of the hydrologic cycle has been well known for several decades, but no because we don’t know how climate change will change this. Also, no because true sustainability means that we should be taking only what can be replaced by nature…we don’t have current research on how much water can be taken and what rates it gets replenished.” Thus, Interviewees 2 and 4 share similar thoughts on our understanding of the hydrologic cycle, and particularly how we do not adequately understand how climate change is likely to impact hydrologic functions. However, Interviewee 3 had a different perspective, saying that “yes I think Ontario has a good base understanding of the hydrologic cycle; we know a lot about our surface water sources and different soil types are relatively well understood, and we have also mapped most of the largest aquifers within the province.” General consensus among the participants is that the hydrologic cycle; currently, is well understood. However, there are concerns among a few participants reflecting our inability to fully understand how climate change will impact hydrologic processes within the province. Thus, there is a need for further research into the potential effects of climate change on our water resources, ultimately affecting water availability for future withdrawal and consumption.

When I asked participants which water sources they think are most threatened and/or vulnerable within southern Ontario, some responses were more general (i.e., Interviewee 1 said “all of them are threatened due to climate change impacts, and continued pollution and groundwater withdrawal”), and Interviewee 4 coincides with the response from Interviewee 1, saying that “Drinking supplies are under threat and [are] vulnerable from so many different sources because nobody is paying attention to the many issues.” Furthermore, Interviewee 3 was more specific in saying that “Small municipality aquifers are the most at risk; the large ones [municipalities] have robust water treatments, [but] the smaller aquifers are more susceptible to contamination and over-extraction. More so than surface waters, groundwater systems are most threatened by [water level] drawdowns by bottled water corporations, and we need to be more careful with industrial water extraction. In some areas the recharge rate is very slow, and in other areas such as near the Great Lakes, are quickly recharged.”

I also asked the participants about their knowledge of illegal soil dumping in the ORM, and if they were at all concerned about the potential impacts on the reported contaminated soil dumping activities. Interviewee 2 replied that they were unaware that this was happening in the ORM but did mention that "illegal dumping has [sadly] been a perennial problem." However, Interviewees 1, 3 and 4 indicated that they were all aware of the issue. Interviewee 1, for example, responded with "Yes I have been aware of the dumping and I am not surprised by your question. However, I am surprised that it continues to happen. We have yet to see the impacts of this dumping. Maybe we'll see them tomorrow, or maybe we'll see them in 10 years. This is why I think it is an ongoing process." Interviewee 1 indicates that the dumping of contaminated soil in the ORM continues to occur because we have yet to see the effects, whereas Interviewee 3 replied to my question with "Yes this [dumping] doesn't surprise me at all. There is well-entrenched Brownfield policy in the province that strictly regulates where soil from development sites can go. Again, the enforcement of these regulations is very weak and comes back to the [lack of] funding for the Ministry [MECP]. There is of course the potential for contaminants to leak into the Moraine [ORM] if the liners are not properly containing the soil material, or if there are fractures in the limestone. We do need to be more responsible about the dumping, especially in such an environmentally sensitive area." Given the ecological significance of the ORM, it is surprising that the lack of enforcement on the regulations designed to protect the ORM persists as a current issue; one that ultimately needs to be addressed more critically. Furthermore, Interviewee 4 responded to my question with "This is illegal and should not be occurring. However, it does not surprise me…the Ministry [MECP] has very few staff available to watch for these things. Perhaps a hot line would be a good idea so that the general public can inform the Ministry if they see things [like the dumping] happening. But, first we have to inform the general public what is good and what is bad. They can't call the hot line to report illegal dumping unless they know that this is wrong." Interviewee 4 provided a potential solution to the problem. As this paper has illustrated, the neighboring residences in the ORM were the first to report the illegal dumping based on "bad odours" in areas where contaminated soil dumping occurred (Welsh, 2014). It should not be the public's responsibility to discover the illegal dumping. In the case that this does happen; however, the public should be better informed of what is good and what is bad for soil dumping, and can therefore act as the 'watchdogs' at times when the Ministry (MECP) cannot adequately do its part because of its continuous budget cuts.

The legislative changes brought forth by the Government of Ontario in Bill 108, first introduced on May 2, 2019 (City of Toronto, 2019), were also consulted with the various participants. Interviewees 1 and 3 were unfamiliar with the new legislation, whereas Interviewees 2 and 4 had some knowledge of Bill 108 and demonstrated concerns with its environmental implications. For example, Interviewee 2 replied with "I am concerned with Bill 108 because of its sweeping changes to the planning process. It remains to be seen how these changes will be implemented and what impacts they will actually have." In addition to the concerns of Interviewee 2, my question on the new legislation prompted a political perspective by Interviewee 4 to say that "Yes [I am concerned], electing Doug Ford, given his lack of care for the environment, means that the public that elected him has no idea of what he is like or that we have any environmental issues. That Bill will have significant implications for the environment…Mother Earth is definitely the loser from that Bill." Interviewee 4 demonstrated a dismay for the premier of Ontario, in addition to the lack of environmental support from the public that contributed to the new legislation by voting in Doug Ford by majority in the latest provincial political election. More importantly, Interviewee 4 targeted the public who ultimately voted in the premier of Ontario; thus, tying into the behaviors of the general public (discussed in Question 2) in demonstrating the lack of public awareness of environmental issues.

Overall, the interviews were pivotal in generating many aspects of my research. Going beyond the context of the questionnaire, several of the participants addressed many areas of concern, such as federal contaminated sites in the GTA, reductions in government funding to provincial environmental ministries, urban expansion, the myth of water abundance, and groundwater over-taking (particularly in smaller municipalities with less government enforcement). As a result of my discussions with various environmental professionals, many of their comments have been brought forth by this paper to represent some of the most current and emerging threats to water resources in southern Ontario.

7.0 CONCLUSIONS AND FUTURE STUDY

Water is both a unique and scarce natural resource that is vital for human and ecological survival. However, as this paper has illustrated, freshwater environments are some of the most threatened ecosystems in the world. Surface and groundwater systems are exposed to increasing and unprecedented threats from anthropogenic stressors that degrade water quality and reduce water availability (Veldkamp et al., 2016; Faunt et al., 2015). Although the causes of these threats are often known, this knowledge has done little to mitigate or eliminate these threats, and it is commonly accepted amongst researchers that, if the degradation of freshwater ecosystems continues to persist at the current rate, the opportunity to protect and conserve these systems may vanish along with many of the species that depend on them (Garda et al., 2017; Gleeson et al., 2017).

Given the looming threat of uncertain global supply, deteriorating water quality and increasing demand, sustainable water management should become a primary global objective. This is emphasized through the United Nations Sustainable Development Goal 6, which identifies access to safe and clean freshwater as a basic human right (United Nations, 2018). In Ontario, over the years sustainable and efficient water use has been resonated in a variety of policy and regulatory frameworks, such as the *Clean Water Act* and its robust source water protection initiative. Similar comprehensive legislation is most often not available or poorly implemented in many areas around the world. However, much can be learned from increased global water scarcity and depleting groundwater reserves and its conjunctive surface water levels. Ontario has the opportunity to become a global leader in sustainable water management.

Despite Ontario’s copious legislative progression in protecting water at its source to ensure a sustainable supply of potable water, there remains a significant number of threats to the province’s water sources. Namely, these threats include MECP budget cuts, urban expansion and land use change, micro-plastic contamination, groundwater over-exploitation, contaminated water supply on First Nations reserves, looming climate change threats, public fallacies of water abundance, under-valued and underpriced water resources, and emerging provincial-wide policies that threaten watersheds and their encompassing source waters and ecosystems. We now know that there are various threats to protecting source water in southern Ontario, and we need to better understand the natural resource in our watersheds (and sub-watersheds) to account for new and emerging threats to water quality and quantity. We must be proactive in land use and water management decision-making to avoid another Walkerton tragedy, and we need the public to be more aware of how valuable freshwater is in terms of ensuring the future survival of humanity and the earth.

The Government of Ontario does not have the money (and funding) to adequately test and monitor all of its extensive water systems. Moreover, budget cuts to the MECP hinder the governments' ability to enforce the variety of legislations designed to ensure the long-term protection of the environment. Through population growth and urban expansion, we have altered the natural ecosystems of southern Ontario by introducing impervious surfaces that are known to degrade watersheds and their encompassing surface and groundwater systems. Further, coupled with urban sprawl is an increase in urban-sourced pollutants that ultimately enter surface and groundwater networks in the GTA; thus, even further compromising water quality. We must act carefully and critically in making land use decisions, such that we ensure the remaining water resources are unimpaired by impending urban sprawl and increased built-up areas.

With the approval of the provincial government, Ontario is allowing bottled water companies to extract groundwater at little to no cost and in times of drought. This is particularly worrisome provided that we know this water is not returned to the local watershed, we know that water-bottling is strictly for-profit, we know that recharge rates of aquifers can be very slow, and we also know that over-taking groundwater can result in permanent depletion. It is therefore imperative that we establish a more comprehensive and critical assessment of the *Permit to Take Water* program in the province, and we need to adequately price water for its true value; that is, a scare natural resource that is growing scarcer every day.

This paper has illustrated that it is necessary to extract water for human sustenance and for economic growth; however, it is equally necessary that we understand the rate at which water is recycled through the hydrologic cycle to ensure that the amount withdrawn is at an equilibrium. For humans to use water sustainably, we must maintain this equilibrium while conjunctively ensuring that the water needs of today are fulfilled without compromising the water needs of future generations.

We need to better understand the impacts of micro-plastics on freshwater ecosystems and their ability to enter drinking water supply post-treatment at wastewater treatment plants. We need updated scientific studies and new policies to address the occurrence and impacts of micro-plastics in the Great Lakes and ultimately in our drinking supply. We must also conduct more studies into potential climate change impacts on the hydrologic cycle within southern Ontario and better prepare for future climate scenarios. Climate change is a significant threat to the province's supply of freshwater that is likely to hinder the future availability of water resources for withdrawal and consumption; concerns of which are already an occurrence within the province (e.g., during the drier months).

Moreover, as this paper has illustrated, and as outlined through the Walkerton example, we must act in a proactive nature to ensure sustainable water use in the province. Acting after-the-fact is significantly more consequential and incompetent compared with proactive measures. The consequences of this are reflected through the example of Walkerton, and in many other areas around the world that are impacted with source water contamination and deterioration. For this reason, watershed protection must address the interconnection of hydrologic processes, water use trends, and land use planning. Any activity that has the potential to impact water quality and quantity in southern Ontario (i.e., permits to take water) should require careful attention and close scrutiny. The intersection between land use management and water management should be clearly outlined and understood if the principles of sustainable development are to be preserved for current and future generations of Ontarians.

8.0 LIMITATIONS OF RESEARCH

Despite the opportunities afforded by this Major Paper, I acknowledge that there are various limitations to the research. The first and foremost is the number of participants involved in the research. The participants shared insightful experiences and knowledge on source water protection in Ontario, but there is a need to better understand the perceptions and experiences of a more diverse group of professionals to delve deeper into the underlying issues of sustaining the quality and quantity of Ontario's water resources for potable supply. Interviews with private, public, government, non-governmental, and scientific institutions will likely produce a more detailed understanding of the issues and challenges of protecting Ontario's sources of freshwater. Further, interviews across a wider range of professionals, such as biologists, hydrologists, geologists, economists, politicians, engineers, and many other related occupations can help to better assess the issues in more detail and work equitably to develop viable solutions. Interviews with the public may also provide valuable insight into the issues and challenges of maintaining safe and clean drinking water, and the public can be engaged to uncover more on the 'myth of water abundance' that continues to persist within Ontario (and Canada as a whole).

My original intention for this research was to also visit areas in southern Ontario that are impacted by groundwater over-taking (i.e., Township of Centre Wellington, Aberfoyle, and Arkell), and other issues of protecting water at its source (i.e., if allowed access, visit WWTPs and observe plastics around Lake Ontario, and potentially micro-plastics in wastewater effluent). Time constraints for the paper and physical constraints due to a recent surgery prohibited site visits and the opportunity to obtain a more in-depth understanding of the occurrence and emergence of source water issues across southern Ontario.

Second, a more in-depth overview of source water depletion at local, provincial/state, national, and global scales is limited by the time and space afforded for this paper. Detailed historical accounts of source water depletion in Ontario would allow us to identify points of progression or regression in the province's history of managing its source water supplies. These historical trends are not limited to southern Ontario and they can also be reviewed in nations around the world. Understanding how different countries react to freshwater depletion or contamination will likely help us to identify the underlying impacts and responses, and they can help shape a global framework for legislative responses to these issues (i.e., an international guideline for addressing freshwater issues). Although solutions are likely to vary for any given municipality, province/state or country, an historical dataset of past cases and their legislative/reactionary responses is likely to provide at least some baseline information that can be relatable or useful in the event of source water depletion or deterioration. Moreover, the complexities of ecosystem interactions and interconnectedness were not included in this paper despite a brief overview. A more in-depth analysis of complex ecosystem interconnectedness will likely provide a more informed understanding of the complexities of the deteriorating water availability and quality that affect more than just human populations.

This Major Paper is not only important for the discussion of resource management and ecosystem services in southern Ontario, but it is also relevant because of contemporary global concerns over declining freshwater availability; particularly in consideration of the unforeseen and uncertain impacts of global climate change on our freshwater resources. As this paper has emphasized, the world can no longer afford to ignore the significant and widespread deterioration and depletion of freshwater resources and ecosystems. Growing concerns over the future quality and quantity of freshwater will remain a significant global environmental issue, especially as concerns of climate change are likely to exacerbate the many existing human pressures on water resources. Only when we follow the path to take proactive and preventative measures, as opposed to reactionary measures (e.g., remediation or compensation) will the Province of Ontario serve as an example to the rest of the world in creating a more sustainable regime for water management.

Ontario, evidently, has the capacity to be a global leader in water resource management. Current legislation and policy within the province represent some of the best in the world, but the enforcement capacity of the MECP is weakened by persistent reductions in provincial funding; therefore, weakening the integrity of legislation. There are endless opportunities for the province to demonstrate its global leadership in freshwater management through competent enforcement, practice, environmental planning (i.e., land use and watershed planning), valuing water for what it is (i.e., a scarce natural resource), and increased public awareness of these issues. For this reason, Ontarians and Canadians can no longer overlook the abundance of water in Canada. We must change our views on the availability of freshwater that is at the foundation of our very existence. Accordingly, this means a renewed appreciation for freshwater and its contributions to sustaining life. If we maintain on our current course, the impacts of freshwater depletion will likely be catastrophic and irreversible, and freshwater will not be in the quantity needed to serve the world's growing human populations and economies. Nor will freshwater be able to sustain the many species that rely on this valuable resource for their very existence.

9.0 REFERENCES

Adamowicz, W. L., & Olewiler, N. (2016). Helping markets get prices right: Natural capital, ecosystem services, and sustainability. *Canadian Public Policy*, 42(1), S32–S38.

Addink, J.W. & Addink, S. (2008). Management of peak water use. *United States Patent*, 8 January 2008. Retrieved from https://patentimages.storage.googleapis.com/f3/62/52/5bad05149950f2/US7317972.pdf

Admiraal, A.K., Hof, A.F., Elzen, M.G.J., & Vuuren, D.P. (2015). Costs and benefits of differences in the timing of greenhouse gas emissions reductions. *Springer Science and Business Media*. 8 March 2015, pp.1165-1179.

Agency for Toxic Substances and Disease Registry (2017). ATSDR Assessment of the Evidence for the Drinking Water Contaminants at Camp Lejeune and Specific Cancers and Other Diseases. *ATSDR*, January 2017. Retrieved from https://www.atsdr.cdc.gov/sites/lejeune/docs/ATSDR_summary_of_the_evidence_for_causality_TCE_PCE_508.pdf

Amigues, J.P., Favard, P., Gaudet, G., & Moreaux, M. (1998). On the Optimal Order of Natural Resource Use When the Capacity of the Inexhaustible Substitute Is Limited. *Journal of Economic Theory*. Volume 80, Issue 1, May 1998, p.153-170.

Anderson, J.C., Park, B.J., & Palace, V.P. (2016). Microplastics in aquatic environments: Implications for Canadian Ecosystems. *Environmental Pollution*, vol. 218, November 2016, pp. 269-280. Retrieved from https://www.sciencedirect.com/science/article/pii/S0269749116305620

Austen, M., Hattam, C., & Borger, T. (2015). Ecosystem services and benefits from marine ecosystems. In T. P. Crowe & C. L. J. Frid (Eds.), Marine Ecosystems: Human Impacts on Biodiversity, Functioning and Services. *Cambridge University Press: United Kingdom*.

Back, L., Russ, K., Liu, Z., Inoue, K., & Zhang, J. (2013). Global hydrological cycle response to rapid and slow global warming. *American Meteorological Society*, 15 November 2013, pp. 8781-8786. Retrieved from http://aos.wisc.edu/~zliu/publications/13-JCLI_GlobalWarmingFastSlow_Backetal.pdf

Baldwin, A.K., Corsi, S.R., & Mason, S.A. (2016). Plastic Debris in 29 Great Lakes Tributaries: Relations to Watershed Attributes and Hydrology. *American Chemical Society*, 14 September 2016. pp. 10377-10385. Retrieved from https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b02917

Ball, P. (2007). Water: The Molecule of Life: An Interview with Philip Ball. *National Aeronautics and Space Administration*, 30 November 2007. Retrieved from https://www.nasa.gov/vision/universe/solarsystem/Water:_Molecule_of_Life.html

Barnes, K.B., Morgan, J.M., & Roberge, M.C. (2015). Impervious Surfaces and the Quality of Natural and Built Environments. *Department of Geography and Environmental Planning at Towson University, Maryland*. Retrieved from https://tigerweb.towson.edu/morgan/files/impervious_surfaces.pdf

Bingham, M., Sinha, S.K., & Lupi, F. (2015). Economic benefits of reducing harmful algal blooms in Lake Erie. *Environmental Consulting & Technology, Inc*., 66. Retrieved from http://ijc.org/files/tinymce/uploaded/Publications/Economic-Benefits-Due-toReduction-in-HABs-October-2015.pdf

Bonsal, B.R., Wheaton, E.E., Chipanshi, A.C., Lin, C., Sauchyn, D.J., & Wen, L. (2011). Drought Research in Canada: A Review. *Atmosphere-Ocean*, 49(4), pp. 303-319. Retrieved from https://doi.org/10.1080/07055900.2011.555103

Brown, S.P.A. & Wolk, D. (2000). Natural Resource Scarcity and Technological Change. *Federal Reserve Bank of Dallas*. Retrieved from https://ideas.repec.org/a/fip/fedder/y2000iq1p2-13.

Bruce, K., Chemeris, A., Kapitan, K., & Sirrs, L. (2017). Bottled water and groundwater in Ontario: Can free market environmentalism resolve the emerging conflicts? *Ontario Agriculture College*, Volume 9, Issue 2.

Brueckert K. (2017). Groups accuse Nestlé, Centre Wellington of 'backroom deal' to privatize water. *Canadian Broadcasting Corporation*. Retrieved from http://www.cbc.ca/news/canada/kitchenerwaterloo/nestle-centre-wellington-accused-denybackroom-deals-1.3920539

Bruneau, J., Dupont, D., & Renzetti, S. (2013). Economic Instruments, Innovation, and Efficient Water Use. *Canadian Public Policy/Analyse de Politiques*, 39, S11-S22. Retrieved from http://www.jstor.org/stable/23594768

Burnside, N. (2011). National Assessment of First Nations Water and Wastewater Systems—National Roll-Up Report. *Department of Indian and Northern Affairs*: Ottawa, ON, Canada.

Butler, C (2016). Ontario water isn't being priced fairly, says Environment Minister Glen Murray. *Canadian Broadcasting Corporation*, 18 October 2016. Retrieved from https://www.cbc.ca/news/canada/kitchener-waterloo/guelph-aberfoyle-new-rules-water-environment-glen-murray-1.3809763

Butler, C. (2017). Ontario allowing bottled water companies to take 7.6M litres a day on expired permits. *Canadian Broadcasting Corporation*, 26 November 2017. Retrieved from https://www.cbc.ca/news/canada/toronto/ontario-water-bottling-1.4420158

Cadieux, K.V., Taylor, L.E., Buncec, M.F. (2013). Landscape ideology in the Greater Golden Horseshoe Greenbelt Plan: Negotiating material landscapes and abstract ideals in the city's countryside. *Journal of Rural Studies*, 32, 307-319. http://dx.doi.org/10.1016/j.jrurstud.2013.07.005

Callicott, J.B. & Mumford, K. (1997). Ecological Sustainability as a Conservation Concept. *Conservation Biology*, 11(1), 1997, pp. 32-40. Retrieved from https://www.sierraforestlegacy.org/Resources/Community/Sustainability/SY_CallicottMumford1997.pdf

Calzavara, M. (2019). Nestle just took its billionth litre. *The Council of Canadians*, 4 June 2019. Retrieved from https://canadians.org/blog/nestle-just-took-its-billionth-litre

Canada's Ecofiscal Commission (2017). Only the Pipes Should be Hidden: Best Practices for Pricing and Improving Municipal Water and Wastewater Services. September 2017. Retrieved from http://ecofiscal.ca/wp-content/uploads/2017/09/Ecofiscal-Commission-Report-Only-the-Pipes-Should-be-Hidden-FINAL-Sept-26-2017.pdf

Canadian Council of Ministers of the Environment (2010). Review and Assessment of Canadian Groundwater Resources, Management, Current Research Mechanisms and Priorities. *CCME*, 2010. Retrieved from https://www.ccme.ca/files/Resources/water/groundwater/gw_phase1_smry_en_1.1.pdf

Canadian Environmental Law Association (2002). Ontario Passes Safe Drinking Water Act. *CELA*, 2002, vol. 27, no. 3-4, July – December 2002. Retrieved from https://www.cela.ca/article/safe-drinking-water-act/ontario-passes-safe-drinking-water-act

Canadian Environmental Law Association (2012). Fact Sheet: What is the provincial legal structure around water in Ontario? *CELA*, 2012. Retrieved from https://www.cela.ca/sites/cela.ca/files/FactSheet-DrinkingWaterLegislation2012.pdf

Chapra, S.C., Dove, A., Rockwell, D.C. (2009). Great Lakes chloride trends: long-term mass balance and loading analysis. *Journal of Great Lakes Research*, 35(2), pp. 272–284

City of Toronto (2019). Proposed Bill 108 (More Homes, More Choice Act, 2019) and the Housing Supply Action Plan – Preliminary City Comments: Report for Action CC7.3. *City of Toronto*, 14 May 2019. Retrieved from https://www.toronto.ca/legdocs/mmis/2019/cc/bgrd/backgroundfile-133165.pdf

Clark, S. (2019). An Act to amend various statutes with respect to housing, other development and various other matters. *Minister of Municipal Affairs and Housing*. 2 May 2019. Retrieved from https://www.ola.org/sites/default/files/node-files/bill/document/pdf/2019/2019-05/b108_e.pdf

Comte, L. & Olden, J.D. (2017). Climatic vulnerability of the world's freshwater and marine fishes. *Nature Climate Change*, 13 September 2017, Retrieved from https://www.sciencedaily.com/releases/2017/09/170913192938.htm

Conference Board of Canada (2013). Water Withdrawals: International Ranking. *CBC Aeric Inc.*, January 2013. Retrieved from https://www.conferenceboard.ca/hcp/Details/Environment/water-consumption.aspx

Council of Canadian Academies (2009). The sustainable management of groundwater in Canada: report of the expert panel on groundwater. *Council of Canadian Academies*. Retrieved from http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/groundwater/(2009-05-11)%20gw%20report.pdf

Council of Canadians (2019). Safe Water for First Nations. *Council of Canadians*, February 2019. Retrieved from https://canadians.org/fn-water

Conservation Ontario (2013). Conservation Ontario Annual Report 2013: Driving Innovation. *Conservation Ontario*. Retrieved from https://conservationontario.ca/resources/?tx_fefiles_files%5Bcategory%5D=7&tx_fefiles_files%5Baction%5D=list&tx_fefiles_files%5Bcontroller%5D=File&cHash=e6494db8f96ead7f7b7d0165bfef3224

Conservation Ontario (2016). Conservation Ontario Submission on the "Proposed Permit to Take Water Moratorium". *Conservation Ontario*. Retrieved from http://conservationontario.ca/resources/?tx_fefiles_files%5Bfile%5D=305&tx_fefiles_files%5Baction%5D=show&tx_fefiles_files%5Bcontroller%5D=File&cHash=6e77af21b2d5e3a0717c5c7bd065e1d6

Conservation Ontario (2018). Source Protection Plans and Resources. *Conservation Ontario*. Retrieved from https://conservationontario.ca/conservation-authorities/source-water-protection/source-protection-plans-and-resources/

Cote, S.A., Ross, H.C., David, K., & Wolfe, S.E. (2017). Walkerton revisited: how our psychological defenses may influence responses to water crises. *Ecology and Society*, 22(3). Retrieved from https://www.ecologyandsociety.org/vol22/iss3/art32/

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Llmburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, Vol. 387, 15 May 1997, pp. 253-260. Retrieved from https://groups.nceas.ucsb.edu/ma-eco-tradeoffs/documents/valuation-reprints-and-resources/Costanza%20et%20al%20-%20The%20value%20of%20the%20world2019s%20ecosystem%20services%20and%20natural%20capital.pdf/view

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., & Turner, R.K. (2014). Changes in global value of ecosystem services. *Global Environmental Change*, Volume 26, May 2014, pp. 152-158.

Daily, G.C., Postel, S., & Carpenter, S. (1997). Chapter 11: Freshwater Ecosystem Services in Nature's Services – Societal Dependence on Natural Ecosystems. *The Center for Resource Economics*. Retrieved from https://books.google.ca/books?hl=en&lr=&id=QYJSziDfTjEC&oi=fnd&pg=PA195&dq=what+is+freshwater&ots=YgyRIRHXAo&sig=iptgFtZJf7THE7XdXP7S6SWnxWQ#v=onepage&q=what%20is%20freshwater&f=false

Davies, J.M. & Mazumder, A. (2003). Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. *Journal of Environmental Management*, Volume 68, pp. 273-286. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.335.9334&rep=rep1&type=pdf

De Loe, R., Kreutzwiser, R. & Ivey, J. (2001). Agricultural Water Use in Ontario. *Canadian Water Resources Journal*, 26(1), pp. 17-42. Retrieved from https://doi.org/10.4296/cwrj2601017

De Loe, R. & Kreutzwiser, R. (2007). Challenging the status quo: the evolution of water governance in Canada. *UBC Press*, Vancouver, British Columbia, Canada, pp. 85-104 in Eau Canada: the future of Canada's water.

Debaere, P. (2014). The Global Economics of Water: Is Water a Source of Comparative Advantage? *American Economic Journal: Applied Economics* 2014, 6(2): pp. 32-48. Retrieved from https://www.darden.virginia.edu/uploadedFiles/Darden_Web/Content/Faculty_Research/Directory/DebaereAEJ.pdf

Debaere, P. & Kurzendoerfer, A. (2019). Decomposing US Water Withdrawal since 1950. *Association for Environmental and Resource Economics,* vol. 4, no. 1, 27 June 2019. Retrieved from https://www.journals.uchicago.edu/doi/pdfplus/10.1086/689833

Dodds, W.K. (2002). Ecology: Concepts and Environmental Applications. *Division of Biology at Kansas State University.* Retrieved from https://books.google.ca/books?hl=en&lr=&id=3OR0102I7n4C&oi=fnd&pg=PP1&dq=why+is+fresh+water+important&ots=WUfOZN50Kf&sig=ah7_oMadbhpYWHceYehjh_dXCP0#v=onepage&q=why%20is%20fresh%20water%20important&f=false

Doll, P. & Zhang, J. (2010). Impact of climate change on freshwater ecosystems: a global-scale analysis of ecologically relevant river flow alterations. *Hydrology and Earth System Sciences*, 21 May 2010, vol. 14, pp. 783-799. Retrieved from https://www.hydrol-earth-syst-sci.net/14/783/2010/hess-14-783-2010.pdf

Driedger, A.G.J., Durr, H.H., Mitchell, K., & Cappellen, P.V. (2015). Plastic debris in the Laurentian Great Lakes. *Journal of Great Lakes Research*, vol. 41, issue 1, March 2015, pp. 9-19. Retrieved from https://www.sciencedirect.com/science/article/pii/S0380133015000064

Dris, R., Imhof, H., Sanchez, W., Gasperi, J, Tassin, B., & Laforsche, C. (2015). Beyond the ocean: Contamination of freshwater ecosystems with (micro-) plastic particles. *Journal of Environmental Chemistry*, 12(5), 539-550.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z. (2005). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews*, Vol. 81, Issue 2. Retrieved from https://www.cambridge.org/core/journals/biological-reviews/article/freshwater-biodiversity-importance-threats-status-and-conservation-challenges/96AA265E3D88C95FB802E7A73CCB4332

Durley, J.L., Loe, R., & Kruetzwiser, R. (2003). Drought Contingency Planning and Implementation at the Local Level in Ontario. *Canadian Water Resources Journal*, 28(1), pp. 21-52. Retrieved from https://www.tandfonline.com/doi/pdf/10.4296/cwrj2801021?needAccess=true

Einstein, N. (2005). A map showing the Oak Ridges Moraine in southern Ontario. Wikipedia Commons, 27 May 2005. Retrieved from https://commons.wikimedia.org/wiki/File:Oak_Ridges_Moraine_map.png

Elkiran, G. & Turkman, A. (2008). Water Scarcity Impacts on Northern Cyprus and Alternative Mitigation Strategies. Chapter from book, *Environmental Problems of Central Asia and their Economic, Social and Security Impacts* (NATO Science for Peace and Security Series), January 2008, pp. 241-250. Retrieved from https://www.researchgate.net/publication/226463979_Water_Scarcity_Impacts_On_Northern_Cyprus_And_Alternative_Mitigation_Strategies

Emerson, H. & Jesperson, K. (1998). Safe Drinking Water Act: States Must Assess Source Water. *Drinking Water News for America's Small Communities*, Vol. 7, Issue 1. Retrieved from http://www.nesc.wvu.edu/pdf/DW/publications/ontap/newsletter/OTNsp98.pdf

Engelman, R. & LeRoy, P. (1993). Sustaining water. Population and the future of renewable water supplies. *Population Action International, Population and Environment Program*, 1993. 56 p. Retrieved from https://www.popline.org/node/331603

Environmental Commissioner of Ontario (2006). Public Opinion Research: Evaluating the Provincial Budget's Allocation to the Ministry of the Environment: Summary Report. *Corporate Research Associates Inc.*, August 2006. Retrieved from http://docs.assets.eco.on.ca/reports/other-publications/2006/2006-MOE-Budget-Allocation.pdf

Environmental Commissioner of Ontario (2012). Waiting for a Change: The Oak Ridges Moraine Conservation Plan. Losing Our Touch, ECO Annual Report, 2011-12. Toronto, ON: *Environmental Commissioner of Ontario*, pp. 84-89.

Environmental Commissioner of Ontario (2015). Small Things Matter: Annual Report 2014/2015. *Government of Ontario*. Retrieved from http://docs.assets.eco.on.ca/reports/environmental-protection/2014-2015/2014_2015-AR.pdf

Environmental Commissioner of Ontario (2017). Chapter 5: Water Conservation in Annual Energy Conservation Progress Report – 2016/2017.

Environment and Climate Change Canada (2013a). The importance of surface water data. Federal *Government of Canada*. Retrieved from https://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=1CC21B07-1

Environment and Climate Change Canada (2013b). Water in Canada: Is Canada "water-rich" country? Government of Canada, Last Updated 22 July 2013. Retrieved from https://www.canada.ca/en/environment-climate-change/services/water-overview/publications/water-in-canada.html

Environment and Climate Change Canada (2016). Map - Percentage of population reliant on groundwater: municipal, domestic and rural only. Retrieved from https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/groundwater.html

Environment Canada (2011). 2011 Municipal Water Use Report – Municipal Water Use. *Environment Canada*. Retrieved from https://www.ec.gc.ca/doc/publications/eau-water/COM1454/survey1-eng.htm

Environment Canada (2014). Great Lakes: Areas of Concern. *Government of Canada*. Retrieved from https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/areas-concern.html

Environment Canada & Ontario Ministry of the Environment and Climate Change (2014). Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, 2014. Retrieved from http://publications.gc.ca/collections/collection_2014/ec/En164-51-2014-eng.pdf

Environment Canada (2017). Overview of freshwater quality monitoring and surveillance. *Environment and Climate Change Canada*. Last Updated 15 August 2017. Retrieved from https://www.canada.ca/en/environment-climate-change/services/freshwater-quality-monitoring/overview.html

Environment Canada (2018a). Water level and flow. *Government of Canada*. Retrieved from https://wateroffice.ec.gc.ca/

Environment Canada (2018b). Great Lakes Action Plan. *Government of Canada*. Retrieved from https://ec.gc.ca/grandslacs-greatlakes/default.asp?lang=En&n=DF30B51A-1&wbdisable=true

Environmental Defence (2019). Analysis shows that Ontario's Bill 108 gives the development industry most of what it asked for. *Environmental Defence*, 31 May 2019. Retrieved from https://environmentaldefence.ca/2019/05/31/analysis-shows-that-ontarios-bill-108-gives-the-development-industry-most-of-what-it-asked-for/

Environmental Registry of Ontario (2018). Establishment of a regulation under the Safe Drinking Water Act, 2002. *Government of Ontario*. Retrieved from https://ero.ontario.ca/notice/013-1840

Ercin, A.E., Mekonnen, M.M., & Hoekstra, A.Y. (2013). Sustainability of national consumption from a water resources perspective: The case study for France. *Ecological Economics* 88 (2013), pp. 133-147. Retrieved from https://waterfootprint.org/media/downloads/Ercin-et-al-2013.pdf

Eriksen, M., Mason, S., Box, C., Zellers, A., Edwards, W., Farley, H., & Amato, S. (2014). Microplastic pollution in the surface waters of the Laurentian Great Lakes. E*lsevier in Marine Pollution Bulletin*, Vol. 77 (2013) pp. 177-182.

Etim, J. (2018). Settlement: Definition, Types, Hierarchy and History of First Human Settlement. *JotScroll Forum*, 15 Feb 2018. Retrieved from http://www.jotscroll.com/forums/3/posts/202/settlement-first-human-settlement-definition-types-hierarchy.html

Falke, J.A., Fausch, K.D., Magelky, R., Aldred, A., Durnford, D.S., Riley, L.K., & Oad, R. (2010). The role of groundwater pumping and drought in shaping ecological futures for stream fishes in a dryland river basin of the western Great Plains, USA. *Ecohydrology*, Volume 4, Issue 5, pp. 682-697. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1002/eco.158

Falkenmark, M. & Rockstrom, J. (2004). Balancing Water for Humans and Nature: The New Approach in Ecohydrology. First published by *Earthscan* in the UK and USA in 2004. Retrieved from https://books.google.ca/books?hl=en&lr=&id=vkhtiv8xRAcC&oi=fnd&pg=PR11&dq=Water+is+always+on+the+move+in+the+hydrologic+cycle.+It+is+the+very+foundation+for+all+biological+life+on+Earth,+and+the+basic+link+between+the+biosphere+and+the+anthroposphere&ots=t0Dg00rkOm&sig=8jwGr-C1B2UfK5W7ZvEXdFCqZog#v=onepage&q=Water%20is%20always%20on%20the%20move%20in%20the%20hydrologic%20cycle.%20It%20is%20the%20very%20foundation%20for%20all%20biological%20life%20on%20Earth%2C%20and%20the%20basic%20link%20between%20the%20biosphere%20and%20the%20anthroposphere&f=false

Farber, S. C., Costanza, R., & Wilson, M. A. (2002). Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, 41(3), 375-392

Farley, J. (2008). The role of prices in conserving critical natural capital. *Conservation Biology*, 22(6), 1399-1408.

Farley, J., Filho, A.S., Burke, M., & Farr, M. (2015). Extending market allocation to ecosystem services: Moral and practical implications on a full and unequal planet. *Ecological Economics*, Vol. 117, September 2015, pp. 244-252.

Faunt, C.C., Sneed, M., Traum, J., & Brandt, J.T. (2015). Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeology Journal*. May 2016, Volume 24, Issue 3, pp. 775-684. Retrieved from https://link.springer.com/content/pdf/10.1007%2Fs10040-015-1339-x.pdf

Feng, W., Zhong, M., Lemoine, J.M., Biancale, R. Hsu, H.T., & Xia, J. (2013). Evaluation of groundwater depletion in North China using the Gravity Recovery and Climate Experiment (GRACE) data and ground-based measurement. *Water Resources Research*, 12 March 2013. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/wrcr.20192

Fienen, M.N., & Arshad, M. (2016). The International Scale of the Groundwater Issue. *Integrated Groundwater Management*, 2016. Retrieved from https://link.springer.com/content/pdf/10.1007%2F978-3-319-23576-9_2.pdf

Findlay, R. (2004). The Source Water Protection Primer. Pollution Probe, May 2004. Retrieved from https://www.sourcewater.ca/en/how-it-works/resources/Documents/Publications_Primer.pdf

Firempong, J. (2019). Premier Ford's 2019 budget is "the most anti-environmental budget in Ontario" since Walkerton. *Greenpeace Canada*, 11 April 2019. Retrieved from https://www.greenpeace.org/canada/en/press-release/8386/premier-fords-2019-budget-is-the-most-anti-environmental-budget-in-ontario-since-walkerton/

Foy, G.E. (1990). Economic Sustainability and the Preservation of Environmental Assets. *Journal of Environmental Management*, 14(8), 1990, pp. 771-778.

Furberg, D. & Ban, Y. (2008). SATELLITE MONITORING OF URBAN SPRAWL AND ASSESSING THE IMPACT OF LAND COVER CHANGES IN THE GREATER TORONTO AREA. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. xxxvii. Retrieved from https://www.researchgate.net/profile/Yifang_Ban/publication/239814892_Satellite_Monitoring_of_Urban_Sprawl_and_Assessing_the_Impact_of_Land_Cover_Changes_in_the_Greater_Toronto_Area/links/5449147a0cf244fe9ea216d1/Satellite-Monitoring-of-Urban-Sprawl-and-Assessing-the-Impact-of-Land-Cover-Changes-in-the-Greater-Toronto-Area.pdf

Furberg, D., & Ban, Y. (2012). Satellite monitoring of urban sprawl and assessment of its potential environmental impact in the Greater Toronto Area between 1985 and 2005. *Environmental Management*, 50(6), 1068-1088.

Garda, C., Castleden, H., & Conrad, C. (2017). Monitoring, Restoration, and Source Water Protection: Canadian Community-Based Environmental Organizations' Efforts towards Improving Aquatic Ecosystem Health. *Water Journal*, Vol. 9, pp. 1-22. Retrieved from https://www.mdpi.com/2073-4441/9/3/212

Garfinkel, J. (2016). Contaminated soil on moraine: Greenbelt and Oak Ridges Moraine. *Ontario Nature*, 16 March 2016. Retrieved from https://ontarionature.org/contaminated-soil-dumped-on-oak-ridges-moraine/

Gleeson, T. & Richter, B. (2017). How much groundwater can we pump and protect environmental flows through time? Presumptive standards for conjunctive management of aquifers and rivers. *River Resource Applications*. Retrieved from https://onlinelibrary.wiley.com/doi/epdf/10.1002/rra.3185

Gleick, P.H. & Palaniappan, M. (2010). Peak water limits to freshwater withdrawal and use. *Proceedings of the National Academy of Sciences of the United States of America*, 22 June 2010, 107(25), pp. 11155-11162. Retrieved from https://www.pnas.org/content/107/25/11155

Gloubeman, S. (2001). Walkerton Water and Complex Adaptive Systems. *Hospital Quarterly*, vol. 4, no. 4, pp. 28-31, 2001. Retrieved from https://pdfs.semanticscholar.org/f064/18b2108fd20ceb9d3afcae41670a1a95d0de.pdf

Good, S.P., Noone, D., & Bowen, G. (2015). Hydrologic connectivity constrains partitioning of global terrestrial water fluxes. *Science*, 10 July 2015, vol. 349, Issue 6244, pp. 175-177. Retrieved from https://science.sciencemag.org/content/349/6244/175

Gosling, S.N., & Arnell, N.W. (2013). A global assessment of the impact of climate change on water scarcity. *Climatic Change in Springer Netherlands*, 17 August 2013, Volume 134, Issue 3, pp. 371-385. Retrieved from https://link.springer.com/article/10.1007/s10584-013-0853-x

Government of Ontario (2016a). Federal contaminated sites policy framework. *Government of Canada*, Last Updated 10 March 2016. Retrieved from https://www.canada.ca/en/environment-climate-change/services/federal-contaminated-sites/policy-framework.html

Government of Ontario (2016b). O.Reg. 463/16 (Ontario Water Resources Act, R.S.O. 1990, c. O.40): Taking ground water to produce bottled water. Toronto (ON): Queen’s Printer for Ontario. Retrieved from https://www.ontario.ca/laws/regulation/r16463

Government of Ontario (2019a). Map: Provincial Groundwater Monitoring Network. *Ontario Ministry of Environment and Climate Change*. Retrieved from https://www.ontario.ca/environment-and-energy/map-provincial-groundwater-monitoring-network

Government of Ontario (2019b). Map: permits to take water. *Ontario Ministry of Environment and Climate Change*. Retrieved from https://www.ontario.ca/environment-and-energy/map-permits-take-water

Grand River Conservation Authority (2015). Approved Source Protection Plan for the Grand River Source Protection Area within the Lake Erie Source Protection Region. *Grand River Conservation Authority*, 26 November 2015. Retrieved from https://www.sourcewater.ca/en/source-protection-areas/resources/Documents/Grand/GRSPP_V1_Title-pages_s51_Edits_clean.pdf

Grannemann, N.G., Hunt, R.J., Nicholas, J.R., Reilly, T.E., & Winter, T.C. (2016). The Importance of Ground Water in the Great Lakes Region. *United States Geological Survey*. Retrieved from https://water.usgs.gov/ogw/pubs/WRI004008/WRIR_00-4008.pdf

Grannemann, G. & Van Stempvoort, D. (2016). Groundwater Science Relevant to the Great Lakes Water Quality Agreement: A Status Report. Retrieved from https://binational.net//wpcontent/uploads/2016/05/GW-Report-final-EN.pdf

Griswold, E. (2017). Ontario government has taken sides against the bottled water industry. *The Toronto Star*, 10 April 2017. Retrieved from https://www.thestar.com/opinion/commentary/2017/04/10/ontario-government-has-taken-sides-against-the-bottled-water-industry.html

Groot, R.D., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Bratt, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., & van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Journal of Marine and Freshwater Research, Ecosystem Services* 1 (2012), pp. 50-61. Retrieved form https://reader.elsevier.com/reader/sd/pii/S2212041612000101?token=AF76D833C79C460132D843722002506E941381FEFFD52BBF052B682FE387610693531E1B94F0AF525C2C05502B9ABB29

Gultch, C. (2017). High Plains Aquifer pumping is impacting surface water and native fish. *Colorado Division of Water Resources*, 9 October 2017. Retrieved from https://coyotegulch.blog/2017/10/09/high-plains-aquifer-pumping-is-impacting-surface-water-and-native-fish/

Haacker, E.M.K., Kendall, A.D., & Hyndman, D.W. (2016). Water Level Declines in the High Plains Aquifer: Predevelopment to Resource Senescence. *Groundwater*, Vol. 54, No. 2, April 2016, pp. 231-242. Retrieved from http://hydrogeology.glg.msu.edu/wordpress/wp-content/uploads/2016/08/Haacker_et_al-2016-Groundwater.pdf

Hansen, A.L., Donnelly, C., Refsgaard, J.C., & Karlsson, I.B. (2018). Simulation of nitrate reduction in groundwater – An upscaling approach from small catchments to the Baltic Sea basin. *Advances in Water Resources*, pp. 58-69. Retrieved from https://reader.elsevier.com/reader/sd/pii/S0309170817303986?token=2AFCE26657AA29EB71AE76AFE1743076A39974F4B13727044027D37AD83640AC6E83F549E87A637C28D6BFEB8DB287B7

Hamoumy, K.E. (2019). Water is without a doubt one of the most undervalued resources on earth. *Fresh Water Watch*. Retrieved from https://freshwaterwatch.thewaterhub.org/content/water-precious-resource

Hands, E.B. & Komar, P.D. (2018). Chapter 8: The Great Lakes as a Test Model for Profile Responses to Sea Level Changes in *Handbook of Coastal Processes and Erosion*.

Helm, P., Zimmer, G., Stones, M., Thibeau, J., Sims, A., Thorburn, B., Page, W. (2016). Microplastics in and entering nearshore surface waters of the lower Great Lakes. In: Abstract Submitted for the 59th Annual Conference on Great Lakes Research, *International Association for Great Lakes Research (IAGLR)*, Guelph, Ontario, June 6- 10, 2016.

Henckens, M.L.C.M., van Ierland, E.C., Driessen, P.P.J., & Worrell, E. (2016). Mineral resources: Geological scarcity, market price trends, and future generations. *Resources Policy*, Vol. 49, September 2016, pp. 102-111.

Holme, R. (2003). Drinking water contamination in Walkerton, Ontario: positive resolutions from a tragic event. *Water Science and Technology,* Volume 47, Issue 3, 1 February 2003. Retrieved from https://iwaponline.com/wst/article-abstract/47/3/1/8309

Horachek, H., Nuri, S., Ollis, N., & Kuwahata, H. (2015). Algal Blooms in the Great Lakes: Consequences, Governance and Solutions. *Student Research on Environment and Sustainability Issues*. Retrieved from https://environment.geog.ubc.ca/algal-blooms-in-the-great-lakes-consequences-governance-and-solutions/

Horton, A.A., Walton, A., Spurgeon, D.J., Lahive, E., & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment*, vol. 586, 15 May 2017, pp. 127-141. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969717302073

Howard, G. & Bartram, J. (2003). Domestic Water Quantity, Service Level and Health. *World Health Organization*, 2003. Retrieved from https://www.who.int/water_sanitation_health/diseases/WSH03.02.pdf

Howell, L. (2013). Global Risks. *2013 World Economic Forum*, Geneva, Switzerland.

Hu, Feng. (2015). Groundwater under pressure. *China Water Risk*, 14 May 2015. Retrieved from http://www.chinawaterrisk.org/resources/analysis-reviews/groundwater-under-pressure/

Human Rights Watch (2016). Make it Safe: Canada's Obligation to End the First Nations Water Crisis. *HRW*, 7 June 2016. Retrieved from https://www.hrw.org/report/2016/06/07/make-it-safe/canadas-obligation-end-first-nations-water-crisis

Intergovernmental Panel on Climate Change (2013). Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

International Joint Commission (2019). Protecting our sources of Drinking Water: Implementation of Source Protection Plans across Ontario. *Conservation Ontario*. Retrieved from https://ijc.org/en/protecting-our-sources-drinking-water-implementation-source-protection-plans-across-ontario

International Union for Conservation of Nature (2017). The IUCN Red List of Threatened Species. *IUCN*, 2017. Retrieved from https://www.iucnredlist.org/

Jacob, S.A. & Furgerson, S.P. (2012). Writing interview protocols and conducting interviews: Tips for students new to the field of qualitative research. *The Qualitative Report*, 17(42), pp. 1-10.

Jakeman, A.I., Barreteau, O., Hunt, R.J., Rinauso, J.D., Ross, A., Arshad, M., & Hamilton, S. (2016). Integrated Groundwater Management: An Overview of Concepts and Challenges. *National Centre for Groundwater Research and Training*, p. 756.

James, I. & Reilly, S. (2015). Pumped beyond limits, many U.S. aquifers in decline. *Pulitzer Center on Crisis Reporting*. Retrieved from https://www.desertsun.com/story/news/environment/2015/12/10/pumped-beyond-limits-many-us-aquifers-decline/76570380/

Jones, A. (2017). Ontario proposes to boost water bottler fee by $500 per million litres. *The Globe and Mail*, 18 January 2018. Retrieved from http://www.cbc.ca/news/canada/toronto/water-bottlefee-1.3940545

Keller, M. (2018). Guelph and Guelph/Eramosa Tier 3 Water Budget Study. *Grand River Conservation Authority*. Retrieved from https://www.sourcewater.ca/en/source-protection-areas/Guelph-and-Guelph-Eramosa-Tier-3.aspx

Kenda, K., Cerin, M., Bogataj, M., Senozetnik, M., Klemen, K, Pergar, P., Laspidou, C., & Mlademic, D. (2018). Groundwater Modelling with Machine Learning Techniques: Ljubljana polje Aquifer. *Proceedings*, 2018, Vol. 2 Issue 696. Retrieved from https://www.mdpi.com/2504-3900/2/11/697

Kenny, A. (2006). Ecosystem Services in the New York City Watershed. *Ecosystem Marketplace*.

Khader, A. (2017). A Spatial Estimation of Groundwater Recharge in Southern Ontario, Canada. *Journal of Natural Resources,* vol. 31(1), 24 January 2017. Retrieved from https://mafiadoc.com/a-spatial-estimation-of-groundwater-recharge-in-southern-ontario-_5b9524a2097c47c13c8b46a3.html

Klamar, J. (2015). Why Canada Cannot Export its Water. *Stratfor Enterprises*, 19 June 2015. Retrieved from https://worldview.stratfor.com/article/why-canada-cannot-export-its-water

Kleidon, A., Kravitz, B., & Renner, M. (2014). The hydrological sensitivity to global warming and solar engineering derived from thermodynamic constraints. *Geophysical Research Letters,* 16 December 2014. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL062589

Konikow, L.F. & Kendy, E. (2005). Groundwater Depletion: A global problem. *Journal of Hydrogeology*, 2005, 13, pp. 317-320. Retrieved from http://www.azul.bdh.org.ar/bdh3/archivos/publications/986998/Leonard_F_Konikow-Bueno.pdf

Kornelsen, K.C. & Coulibaly, P. (2014). Synthesis review on groundwater discharge to surface water in the Great Lakes Basin. *Journal of Great Lakes Research*, 40(2), pp. 247-256. Retrieved from https://doi.org/10.1016/j.jglr.2014.03.006

Kreutzwiser, R.D., de Loe, R.C., Durley, J., & Priddle, C. (2004). Water Allocation and the Permit to Take Water Program in Ontario: Challenges and Opportunities. *Canadian Water Resources Journal*, Vol. 29(2), pp. 135-146. Retrieved from https://www.tandfonline.com/doi/pdf/10.4296/cwrj135?needAccess=true

Kriebel, D., Tickner, J., Epstein, P., Lemons, J., Levins, R., Loechler, E.L., Quinn, M., Rudel, R., Schettler, T., & Stoto, M. (2001). The Precautionary Principle in Environmental Science. *Environmental Health Perspectives*, Vol. 109, No. 9, pp. 871-876, September 2001. Retrieved from https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.01109871

Kponee, K.Z., Chiger, A., Kakulu, J.I., Vorhees, D., & Heiger-Bernays, W. (2015). Petroleum contaminated water and health symptoms: a cross-sectional pilot study in a rural Nigerian community. *Environmental Health*, 2015, volume 14. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4636824/

Lefebvre, K., Barbecot, F., Larocque, M., & Gillon, M. (2015). Combining isotopic tracers (222Rn and 813C) for improved modelling of groundwater discharge to small rivers. *Hydrological Processes*, 29(12), 2814-2822. Retrieved from doi:10.1002/hyp.10405

Li, J., Liu, H., & Chen, P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Elsevier in *Water Research*, Vol. 137, pp. 362-374.

Lindgren, R.D. (2003). In the Wake of the Walkerton Tragedy: the Top 10 Questions. *Canadian Environmental Law Association*, March 2003. Retrieved from https://www.cela.ca/sites/cela.ca/files/uploads/440walkerton.pdf

Lioness, A. (2008). Semi-structured Interview. *The Sage Encyclopedia of Qualitative Research Methods*, 2008. *SAGE Publications*, 7 March 2009. Retrieved from https://sites.google.com/site/savethechildrendme/Home/semi-structured-interview

Long Point Region Conservation Authority (2018). Low Water Response Program. *LPRCA*, Ontario, 2018. Retrieved from http://www.lprca.on.ca/pages/1357673445/Low-Water-Response-Program

Loucks, D.P. & van Beek, E. (2017). Water Resource Systems Planning and Management: An Introduction to Methods, Models, and Applications. *Institute for Water Education*. Retrieved from https://books.google.ca/books?hl=en&lr=&id=stlCDwAAQBAJ&oi=fnd&pg=PR6&dq=water+management+issues&ots=oBXfTmlv3d&sig=J7s1QWDPDmetFhR-OXpS_bI4JnI#v=onepage&q=water%20management%20issues&f=false

Maghrebi, M., Nalley, D., Laurent, K.L., & Atkinson, J.F. (2015). Water quantity as a driver of change in the Great Lakes-St. Lawrence River Basin. *Journal of Great Lakes Research*, pp. 84-95. Retrieved from https://doi.org/10.1016/j.jglr.2014.12.005

Maxmen, A. (2018). As Cape Town water crisis deepens, scientists prepare for “Day Zero.” *Nature*, 554(7690), pp. 13-14. Retrieved from https://doi.org/10.1038/d41586-018-01134-x

McDermid, J., Fera, S., & Hogg, A. (2015). Climate change projections for Ontario: An updated synthesis for policymakers and planners. *Ontario Ministry of Natural Resources and Forestry, Science and Research Branch*, Peterborough, Ontario. Climate Change Research Report CCRR-44.

McDonald, R.I., Green, P., Balk, D., Fekete, B.M., Revenga, C., Todd, M., & Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences*, Apr 2011. Retrieved from https://www.pnas.org/content/108/15/6312

McLamb, E. (2013). The continuing ecological impact of the Industrial Revolution. *Ecology Communications Group*, 2013. Retrieved from http://www.ecology.com/2013/11/11/continuing-ecological-impact-industrial-revolution/

Mekonnen, M.M., & Hoekstra, A.Y. (2016). Four billion people facing severe water scarcity. *Science Advances*, vol. 2, no. 2, 12 February 20-16. Retrieved from https://advances.sciencemag.org/content/2/2/e1500323?utm_source=rss&utm_medium=rss

Ministry of the Environment and Climate Change (2014). Source Water Protection in Chapter 3: Section 3.12. *Auditor General of Ontario*, 2014. Retrieved from http://www.auditor.on.ca/en/content/annualreports/arreports/en14/312en14.pdf

Ministry of the Environment, Conservation and Parks (2018). Water taking report and charges. *Government of Ontario*. Retrieved from https://www.ontario.ca/page/water-taking-report-and-charges

Ministry of the Environment, Conservation and Parks (2019). Safe Drinking Water Act, 2002: S.O. 2002, Chapter 32. *Government of Ontario*, Last amendment: 2019, c. 7, Sched. 17, s. 157.

Ministry of Municipal Affairs (2017). Oak Ridges Moraine Conservation Plan (2017). *Queen's Printer for Ontario*, 2017, May 2017. Retrieved from http://www.mah.gov.on.ca/AssetFactory.aspx?did=18548

Misachi, J. (2018). Which Country has the Most Fresh Water? *World Atlas*, 24 September 2018. Retrieved from https://www.worldatlas.com/articles/countries-with-the-most-freshwater-resources.html

Molnar, M., Stewart, K., & Iseman, S. (2012). Watersheds of the Ontario Greenbelt. *David Suzuki Foundation.* Retrieved from https://davidsuzuki.org/wp-content/uploads/2012/05/watersheds-ontario-greenbelt-policy-options-preserve-protect-restore.pdf

Moreira, N.A., & Bondelind, M. (2016). Safe drinking water and waterborne outbreaks. *Journal of Water Health*, 2016, 15(1), pp. 83-96. Retrieved from https://iwaponline.com/jwh/article/15/1/83/28437/Safe-drinking-water-and-waterborne-outbreaks

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability*, Volume 1, Issue 1, Article 2, pp. 1-9. Retrieved from https://scholarworks.rit.edu/cgi/viewcontent.cgi?referer=https://scholar.google.ca/&httpsredir=1&article=1007&context=jes

Morris, T.J., Mohopatra, S.P., & Mitchell, A. (2008). Conflicts, costs and environmental degradation – Impacts of antiquated groundwater allocation policies in the Great Lakes Basin. *Water Policy,* 10(5), pp. 459-479. Retrieved from https://doi.org/10.2166/wp.2008.059

Mukhammadiev, R.U.B. (2014). Drinking Source Water Protection in Ontario. *Green Economy Bridging Program and Community Development at Ryerson University*, 2 July, 2014. Retrieved from https://www.slideshare.net/mukhammadievbr/drinking-source-water-protection-in-ontario-june-2014

National Aeronautics and Space Administration (2010). Great Lakes, No Clouds. *NASA Visible Earth*, 28 August 2010. Retrieved from https://visibleearth.nasa.gov/view.php?id=45615

Natural Resources Canada (2017). Water: Distribution of Water, Water Quantity, and Climate Change. *Government of Canada*, Last Updated 30 October 2017. Retrieved from https://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/selected-thematic-maps/16888

Nature Conservancy (2019). Mapping Ocean Wealth: Ecosystem Services. *Oceanwealth.org*. Retrieved from https://oceanwealth.org/ecosystem-services/

Nelson, E., Pennington, D., & Johnson, K.A. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. *Environmental and Resource Economics*, 1 January 2011, 48(2), pp. 219-242.

Nerem, R.S., Beckley, B.D., Fasullo, J.T., Hamlington, B.D., Masters, D., & Mitchum, G.T. (2018). Climate-Change--driven accelerated sea-level rise detected in the altimeter era. *Proceedings of the National Academy of Sciences of the United States of America*, 12 February 2018, 115(9), pp. 2022-2025. Retrieved from https://www.pnas.org/content/115/9/2022.short

Nijkamp, P., and Kourtit, K. (2013). The "New urban Europe": global challenges and local responses in the urban century. *European Planning Studies*, 21(3), 291-315. http://dx.doi.org/10.1080/09654313. 2012.716243

Noble, R. (2015). Historic Deloro mine returns to nature. *Canadian Mining Journal*, 1 February 2015. Retrieved from http://www.canadianminingjournal.com/features/historic-deloro-mine-returns-to-nature/

O'Connor, D. R. & Ontario Ministry of the Attorney General (2002). Report of the Walkerton Inquiry: The Events of May 2000 and Related Issues: a Summary. *Ontario Ministry of the Attorney General*.

O'Geen, A.T., Budd, R., Gan, J., Maynard, J.J., Parikh, S.J., & Dahlgren, R.A. (2010). Mitigating Nonpoint Source Pollution in Agriculture with Constructed and Restored Wetlands. *Chapter One* in *Advances in Agronomy*, Vol. 108. Retrieved from https://www.academia.edu/24297991/Mitigating_Nonpoint_Source_Pollution_in_Agriculture_with_Constructed_and_Restored_Wetlands

O'Neill, J.E., Early, T.O., Steimle, R., Wertz, W.E., Davies, K., & Kueper, B.H. (2001). Finding containment, remediation and site characterization solutions in fractured bedrock: the Smithville strategy. *Florida State University*. Retrieved from http://www.containment.fsu.edu/cd/content/pdf/373.pdf

Ontario Ministry of the Environment (2007). Water Conservation Charges Proposal, report number PIBS 6134e. Retrieved from http://www.ontla.on.ca/library/repository/mon/16000/272421.pdf

Ontario Ministry of Finance (2016). Ontario Population Projections Update. *Government of Ontario*, Fin.gov.on.ca. Retrieved from http://www.fin.gov.on.ca/en/economy/demographics/projections/

Ontario Ministry of Municipal Affairs (2006). Ontario's Greenbelt and built-up area. Retrieved from https://thereevesreport.files.wordpress.com/2014/12/f1-large.jpg

Ontario Ministry of Natural Resources (2009). Ontario Low Water Response. *Legislative Assembly of Ontario*, July 2009.

Ontario Ministry of Natural Resources (2010). Ontario Low Water Response. *OMNR*, March 2010. Retrieved from http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/Canada/2012_Provincial_Summaries/Ontario-Low-Water-Response.pdf

Ontario Ministry of Natural Resources and Forestry (2016). Low Water Response Program. *MNRF*. Retrieved from https://www.ontario.ca/page/low-water-response-program

Ontario Ministry of the Environment and Climate Change (2014). Source Water Protection. Retrieved from https://www.ontario.ca/page/source-protection

Ontario Ministry of the Environment and Climate Change (2016). Ontario's Great Lakes Strategy 2016 Progress Report. *Environment Canada*. Retrieved from https://www.ontario.ca/page/ontarios-great-lakesstrategy-2016-progress-report

Ontario Ministry of the Environment, Conservation and Parks (2017). Permits to take water. Retrieved from https://www.ontario.ca/page/permits-take-water

Ontario Ministry of the Environment, Conservation and Parks (2018a). Canada-Ontario Lake Erie Action Plan: Partnering on Achieving Phosphorous Loading Reductions to Lake Erie from Canadian Sources. *Environment Canada*. Retrieved from https://www.canada.ca/content/dam/eccc/documents/pdf/great-lakesprotection/dap/action_plan.pdf

Ontario Ministry of the Environment, Conservation and Parks (2018b). Minister's Annual Report on Drinking Water 2018. *Government of Ontario*. Retrieved from https://www.ontario.ca/page/ministers-annual-report-drinking-water-2018

Ontario Nonprofit Network (2019). Provincial Budget 2019. *ONN*. Retrieved from https://theonn.ca/our-work/our-financing/provincial-budget-2019/

Organization for Economic Cooperation and Development (2016). Abstractions of freshwater in OECD Factbook 2015-2016: Economic, Environmental and Social Statistics (Paris: *OECD Publishing*, 2016).

Orlova, J. & Branfreun, B.A. (2014). Surface Water and Groundwater Contributions to Streamflow in the James Bay Lowland, Canada. Arctic, Antarctic and Alpine Research, 1 February 2014, Volume 46, pp. 236-251. Retrieved from https://bioone.org/journals/arctic-antarctic-and-alpine-research/volume-46/issue-1/1938-4246-46.1.236/Surface-Water-and-Groundwater-Contributions-to-Streamflow-in-the-James/10.1657/1938-4246-46.1.236.full

Oskin, B. (2015). What is Groundwater? *Live Science*, 8 January 2015. Retrieved from https://www.livescience.com/39579-groundwater.html

Pegex (2014). Environmental Remediation: What you need to know about soil contamination and remediation. *Pegex Hazardous Waste Experts*, 16 April 2014. Retrieved from https://www.hazardouswasteexperts.com/what-you-need-to-know-about-soil-contamination-2/

Perera, N., Howard, K.W.F., Gharabaghi B. (2013). Groundwater chloride response in the Highland Creek watershed due to road salt application: a re-assessment after 20 years. *Journal of Hydrology*, 479(4), pp. 159–168.

Petersen, L., Heynen, M., & Pellicciotti, F. (2019). Freshwater Resources: Past, Present, Future. *International Encyclopedia of Geography*, 27 March 2019. Retrieved from https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781118786352.wbieg0712.pub2

Pfeiffer, L. & Lin, C.Y.C. (2012). Groundwater pumping and spatial externalities in agriculture. *Journal of Environmental Economics and Management*, Volume 64, Issue 1, July 2012, pp. 16-30.

Pivokonsky, M., Cermakova, L., Novotna, K., Peer, P., Cathami, T., & Janda, V. (2018). Occurrence of microplastics in raw and treated drinking water. *Science of the Total Environment*, Volume 643, m1 December 2018, pp. 1644-1651. Retrieved from https://www.sciencedirect.com/science/article/pii/S0048969718330663

Plummer, R., Velaniskis, V., de Grosbois, D., Kreutzwiser, R.D., & de Loe, R. (2010). The development of new environmental policies and processes in response to a crisis: the case of the multiple barrier approach for safe drinking water. *Environmental Science & Policy*, Volume 13, Issue 6, October 2010, pp. 535-548.

Population Reference Bureau (2018). Human Population: Future Growth. *PRB*, Washington, DC. Retrieved from http://www.prb.org/Publications/Lesson

Postel, S. & Carpenter, S. (1997). Chapter 11: Freshwater Ecosystem Services in Nature's Services: Societal Dependance on Natural Ecosystems. The Center for Resource Economics. Retrieved from https://books.google.ca/books?hl=en&lr=&id=QYJSziDfTjEC&oi=fnd&pg=PA195&dq=freshwater+drinking+supply&ots=YgxPJRHTAh&sig=B6s1Rwu0VwvKzriTM6f4DLOp96A#v=onepage&q=freshwater%20drinking%20supply&f=false

Postel, S. L., & Thompson, B. H. (2005). Watershed protection: Capturing the benefits of nature's water supply services. In Natural Resources Forum (Vol. 29, No. 2, pp. 98-108). Blackwell Publishing, Ltd.

Postel, S. L. (2014). The Last Oasis: Facing Water Scarcity. *Worldwatch Environmental Alert Series*, Routledge. Retrieved from https://www.taylorfrancis.com/books/9781315070346

Provencher, B. (1992). A private property rights regime to replenish a groundwater aquifer. *Department of Agricultural Economics at the University of Wisconsin.* Retrieved from https://tind-customer-agecon.s3.amazonaws.com/c5fd495c-fee8-4f2c-b864-da97e0994716?response-content-disposition=inline%3B%20filename%2A%3DUTF-8%27%27agecon-wisc-0345.pdf&response-content-type=application%2Fpdf&AWSAccessKeyId=AKIAXL7W7Q3XHXDVDQYS&Expires=1560812912&Signature=JtJMJFvaEk4JheamsARFt%2FsHz2w%3D

Province of Ontario (2009). Ontario Regulation 450/07 made under the Ontario Water Resources Act: Charges for Industrial and Commercial Water Users. *Government of Ontario*.

Prudham, S. (2004). Poisoning the well: neoliberalism and the contamination of municipal water in Walkerton, Ontario. *Geoforum*, Volume 35, Issue 3, May 2004, pp. 343-359. Retrieved from https://www.sciencedirect.com/science/article/pii/S0016718503001076

Queen, L. (2017). Province 'doing nothing to protect' environment from soil dumps: PSRTF. *York Region*, 16 February 2017. Retrieved from https://www.yorkregion.com/community-story/7144489-province-doing-nothing-to-protect-environment-from-soil-dumps-osrtf/

Reeves, H.W. (2010). Water Availability and Use Pilot: A Multiscale Assessment in the U.S. Great Lakes Basin. *U.S. Geological Survey Professional Paper 1778*. Retrieved from https://pubs.usgs.gov/pp/1778/pp1778_completereport.pdf

Renzetti, S., Brandes, O.M., Dupont, D.P., MacIntyre-Morris, T., & Stinchcombe, K. (2015). Using demand elasticity as an alternative approach to modelling future community water demand under a conservation-oriented pricing system: An exploratory investigation. *Canadian Water Resources Journal*, 40(1), pp. 62-70. Retreieved from https://doi.org/10.1080/07011784.2014.985508

Renzetti, S. & Dupont, D. (2017). Water Pricing in Canada. *Water Policy and Governance in Canada*, pp. 201-212. Retrieved from https://doi.org/10.1007/978-3-319-42806-2_1

Richey, A.S., Thomas, B.F., Lo, M., Reager, J.T., Famiglietti, J.S., Voss, K., Swenson, S., & Rodell, M. (2015). Quantifying renewable groundwater sources stress with GRACE. *Water Resources Research*, 16 June 2015, pp. 5217-5238. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2015WR017349

Roberts, M.E., Stewart, B.M., Tingley, D., Lucas, C., Leder-Luis, J., Gadarian, S.K., Albertson, B., & Rand, D.G. (2014). Structural Topic Models for Open-Ended Survey Responses. *American Journal of Political Science*. 6 March 2014. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/ajps.12103

Rogers, P. (2008). Facing the freshwater crisis. *Scientific American Magazine*. Retrieved from http://ohm.ecce.admu.edu.ph/wiki/pub/Main/ResearchProjects/Facing_the_Freshwater_Crisis__Scientific_American.pdf

Rubin, J. (2017). Economic Opportunities from a Changing Climate: CIGI Papers No. 118 – February 2017. *Centre for International Governance Innovation*. Retrieved from https://www.cigionline.org/sites/default/files/documents/CIGI%20Paper%20no.118web.pdf

Russo, T.A. & Lall, U. (2017). Depletion and response of deep groundwater to climate-induced pumping variability. *Nature Geoscience*, Volume 10, pp. 105-108. Retrieved from https://www.nature.com/articles/ngeo2883

Rutherford, S. (2004). Groundwater use in Canada. *West Coast Environmental Law*, November 2004. Retrieved from https://www.wcel.org/sites/default/files/publications/Groundwater%20Use%20in%20Canada.pdf

Scanlon, B.R., Faunt, C.C., Longuevergne, L., Reedy, R.C., Alley, W.M., McGuire, V.L., & McMahon, P.B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. *Proceedings of the National Academy of Sciences of the United States* *of America*, 12 June 2012, 109(4), pp. 9320-9325. Retrieved from https://www.pnas.org/content/109/24/9320

Schindler, D. (2006). The Myth of Abundant Canadian Water. *Ecology Department at the University of Alberta*, 1 March 2006. Retrieved from https://www.mchs.gsacrd.ab.ca/eteacher_download/1364/15826

Schröter, M., van der Zanden, E. H., van Oudenhoven, A. P. E., Remme, R. P., Serna-Chavez, H. M., de Groot, R. S., & Opdam, P. (2014). Ecosystem Services as a Contested Concept: A Synthesis of Critique and Counter-Arguments. *Conservation Letters*, 7(6), 514–523. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1111/conl.12091

Schwoerbel, J. (2016). Methods of hydrobiology: freshwater biology. *Pergamon Press.* Retrieved from https://books.google.ca/books?hl=en&lr=&id=pxjLBAAAQBAJ&oi=fnd&pg=PP1&dq=freshwater&ots=6nv1KQF0Ow&sig=bvYOXt2qF8kb8NtNmuR9yfgsa54#v=onepage&q=freshwater&f=false

Shaikh, A. (2017). The Bad News? The world will begin running out of water by 2050. The Good News? It is not 2050 yet. United Nations News and Commentary *Forum*, June 16 2017. Retrieved from https://www.undispatch.com/bad-news-world-will-begin-running-water-2050-good-news-not-2050-yet/

Shi, J., Wang, Z., Zhang, Z., Fei, Y., Li, Y., Zhang, F., Chen, J., & Qian, Y. (2011). Assessment of deep groundwater over-exploitation in the North China Plain. *Geoscience Frontiers*, Volume 2, Issue 4, October 2011, pp. 593-598. Retrieved from https://www.sciencedirect.com/science/article/pii/S1674987111000752

Shipowick, A., & Butler, K. (2019). Canada: Bill 108, Ontario’s More Homes, More Choice Act, 2019. *Borden Ladner Gervais*, 20 May 2019. Retrieved from http://www.mondaq.com/canada/x/806890/Building+Construction/Bill+108+Ontarios+More+Homes+More+Choice+Act+2019

Singh, G.G. (2016). Understanding and Assessing Cumulative Impacts to Coastal Ecosystem Services. *A Thesis in Resource Management and Environmental Studies at the University of British Columbia*, October 2016. Retrieved from https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0319134

Shortt, R., Caldwell, W.J., Ball, J., & Agnew, P. (2004). A Participatory Approach to Water Management: Irrigation Advisory Committees in Southern Ontario. *57th Canadian Water Resources Association Annual Congress*, June 16-18 2004, Montreal, QC, Canada. Retrieved from http://www.c-ciarn.uoguelph.ca/documents/shortt.pdf

Southeast Texas Water (2019). Water Cycle: How the earth recycles water. Retrieved from https://southeasttexaswater.com/water-facts/water-cycle/

Statistics Canada (2011). Agricultural Water Use in Canada. *Statistics Canada*. Retrieved from https://www.150.statcan.gc.ca/n1/pub/16-402-x/2011001/part-partie1-eng.htm

Statistics Canada (2013). Survey of Drinking Water Plants, 2013. *Statistics Canada*. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/150619/dq150619d-eng.htm

Statistics Canada (2017). Population size and growth in Canada: Key results from the 2016 Census. *Government of Canada*, Last Updated 30 March 2017. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/170208/dq170208a-eng.htm

Statistics Canada (2018). Agricultural Water Survey. Retrieved from https://www.statcan.gc.ca/eng/survey/agriculture/5145

Statistics Canada (2014). CANSIM Table 153-0075. Water acquisition costs in manufacturing industries, by provinces, territories and drainage regions.

Statistics Canada (2016). CANSIM Table: 153-0134. Irrigation Volume by Province and Drainage Region.

Storck, F.R., Karlsruhe, T.Z.W., Kools, S.A.E., & Rinck-Pfeiffer, S. (2015). Science Brief: Microplastics in Fresh Water Resources. *Global Water Research Coalition*, September 2015. Retrieved from https://www.frogn.kommune.no/contentassets/054b969079034ee7813a163aad2f6259/151103_storck-et-al.-2015-gwrc-science-brief-microplastics-september-20152.pdf

Steinman, A.D., Cardinale, B.J., Munns, W.R., Ogdahl, M.E., Allan, J.D., Angadi, T., Bartlett, S., Brauman, K., Byappanahalli, M., Doss, M., Dupont, D., Johns, A., Kashian, D., Lupi, F., McIntyre, P., Miller, T., Moore, M., Muenich, R.L., & nWashburn, E. (2017). Ecosystem Services in the Great Lakes. *Journal of Great Lakes Research*, Vol. 43, Issue 3, June 2017, pp. 161-168. Retrieved from https://doi.org/10.1016/j.jglr.2017.02.004

Strassberg, G., Scanlon, B.R., & Chambers, D. (2009). Evaluation of groundwater storage monitoring with the GRACE satellite: Case study of the High Plains aquifer, central United States. *Water Resources Research*, 9 May 2009. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2008WR006892

Sutherland, S. (2016). Despite rain and flooding, Southern Ontario drought worsens. *The Weather Network*, 29 July 2016. Retrieved from https://www.theweathernetwork.com/news/articles/drought-conditions-worsening-throughout-easternontario/69534

Swain, P.C. (2016). Water Resources Systems Planning & Management: Lecture Notes. *Water Resources Engineering*, 2016. Retrieved from http://www.vssut.ac.in/lecture_notes/lecture1525500606.pdf

Takala, W., Adugna, T., & Tamam, D. (2016). The effects of land use land cover change on hydrological process of Gilgel Gibe, Omo Gibe Basin, Ethiopia. *International Journal of Scientific & Engineering Research*, Vol. 7, Issue 8, August 2016, pp. 117-128. Retrieved from https://www.ijser.org/researchpaper/The-effects-of-land-use-land-cover-change-on-hydrological-process-of-Gilgel-Gibe-Omo-Gibe-Basin-Ethiopia.pdf

Tang, D. (2019). More Homes, More Choice Act, 2019: What will Bill 108 do to Ontario's Planning and Development Regime? *Miller Thompson*, 16 May 2019. Retrieved from https://www.millerthomson.com/en/publications/communiques-and-updates/real-estate-report/may-16-real-estate-report/more-homes-more-choice-act-2019-what-will-bill-108-do-to-ontarios-planning-and-development-regime/

Tietenberg, T. & Lewis, L. (2016). Environmental & Natural Resource Economics: Tenth Edition. Published 2016 by *Routledge*.

Toronto and Region Conservation Authority (2018). Groundwater. *TRCA*. Retrieved from https://trca.ca/conservation/environmental-monitoring/groundwater/

Toronto and Region Conservation Authority (2019a). Oak Ridges Corridor Conservation Reserve: An Ecological Treasure. *TRCA*. Retrieved from https://trca.ca/parks/oak-ridges-corridor-conservation-reserve/

Toronto and Region Conservation Authority (2019b). Climate Change Impacts: Local Impacts. *TRCA*. Retrieved from https://trca.ca/conservation/climate-change/climate-change-impacts/

Toronto Global (2019). Map of the Greater Toronto Area and Four Municipalities of Durham, York, Peel and Halton. Retrieved from https://torontoglobal.ca/where-to-find-us

Treasury Board of Canada Secretariat (2019). Federal Contaminated Sites Inventory. *Government of Canada*. Retrieved from https://tbs-sct.gc.ca/fcsi-rscf/home-accueil-eng.aspx

Tuck, E. (2009). Suspending damage: A letter to communities. *Harvard Educational Review*, 79(3), pp. 409-428.

United Nations (2014a). Water withdrawal and pressure on water resources. *Food and Agriculture Organization of the United Nations*, 2014. Retrieved from http://www.fao.org/nr/water/aquastat/didyouknow/index2.stm

United Nations (2014b). Precipitation – Country Rankings: Precipitation, mm per year, 2014. Food and Agriculture Organization of the United Nations, TheGlobalEconomy.com. Retrieved from https://www.theglobaleconomy.com/rankings/precipitation/

United Nations (2018). Sustainable Development Goal 6 Synthesis Report 2018 on Water and Sanitation. *The United Nations*. Retrieved from https://www.unwater.org/publication_categories/sdg-6-synthesis-report-2018-on-water-and-sanitation/

United Nations Sustainable Development (1992). United Nations Conference on Environment & Development: Rio de Janerio, Brazil, 3 to 14, 1992, Agenda 21. *United Nations Sustainable Development.* Retrieved from https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf

United States Environmental Protection Agency (1979). The Love Canal Tragedy by Eckardt C. Beck. *USEPA*, January 1979. Retrieved from https://archive.epa.gov/epa/aboutepa/love-canal-tragedy.html

United States Geological Survey (2018). Groundwater Decline and Depletion. *USGS*. Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/groundwater-decline-and-depletion?qt-science_center_objects=0#qt-science_center_objects

Urban Toronto (2016). Neptis Responds to Proposed Growth Plan Amendments: Map of Land in the Greater Golden Horseshoe. Retrieved from https://urbantoronto.ca/news/2016/05/neptis-responds-proposed-growth-plan-amendments

Van Vliet, M.T.H., Sheffield, J., Wiberg, D., & Wood, E.F. (2016). Impacts of recent drought and warm years on water resources and electricity supply worldwide. *Environmental Research Letters,* 11(12). Retrieved from https://doi.org/10.1088/1748-9326/11/12/124021

Vaz, E. & Arsanjani, J. (2015). Predicting Urban Growth of the Greater Toronto Area – Coupling a Markov Cellular Automata with Document Meta-Analysis. *Journal of Environmental Informatics.* Retrieved from https://www.geog.uni-heidelberg.de/md/chemgeo/geog/gis/markov_cellular.pdf

Veldkamp, T.I.E., Wada, Y., Aerts, J.C.J.H., & Ward, P.J. (2016). Towards a global water scarcity risk assessment framework: incorporation of probability distributions and hydro-climatic variability. *Environmental Research Letters*, 2 Feb 2016, Volume 11, No. 2. Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/11/2/024006/meta

Verhoeven, J.T.A. & Setter, T.L. (2009). Agricultural use of wetlands: opportunities and limitations. *Institute of Environmental Biology*, pp. 155-163. Retrieved from https://academic.oup.com/aob/article/105/1/155/245730

Wada, Y., van Beek, L.P.H., van Kempen, C.M., Reckman, J.W.T.M., Vasak, S., & Bierkens, M.F.P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters*. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL044571

Wanamaker, C. (2018). Geologic Hazards: What you need to know about land subsidence due to groundwater pumping. *Owlcation,* 7 March 2018. Retrieved from https://owlcation.com/stem/Geologic-Hazards-What-You-Need-to-Know-about-Groundwater-Induced-Land-Subsidence

Wang, X., Huang, G., Lin, Q., Nie, X., & Liu, J. (2014). High-resolution temperature and precipitation projections over Ontario, Canada: a coupled dynamical-statistical approach. *Quarterly Journal of the Royal Meteorological Society*, 9 July 2014. Retrieved from https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/qj.2421

Wang, L., Li, W., Wang, S., & Li, J. (2015). Examining Urban Expansion in the Greater Toronto Area using Landsat Imagery from 1974-2014. *Geomatica*, Vol. 69, No. 2, 2015, pp. 161-172. Retrieved from https://uwaterloo.ca/mobile-sensing/sites/ca.mobile-sensing/files/uploads/files/examining_urban_expansion_in_the_greater_toronto_area_using_landsat_imagery_from_1974-2014.pdf

Warren, J. (2016). Fresh water scarcity is an issue in Canada too. *Toronto Sun*, 24 September 2016. Retrieved from https://torontosun.com/2016/09/24/fresh-water-scarcity-is-an-issue-in-canada-too/wcm/c87ed2c5-bfe8-43c0-9d70-4d0389acc35d

Webber, M.E. (2016). Thirst for power: energy, water and human survival. *Energy development in Yale University Press*, 2016. Retrieved from https://books.google.ca/books?hl=en&lr=&id=65aJDQAAQBAJ&oi=fnd&pg=PP9&dq=clean+drinking+water+is+necessary+for+human+survival&ots=c3Gk9vvxwi&sig=-VpZ8O5UDzvP9lcf6jIJBT9s2gI#v=onepage&q=clean%20drinking%20water%20is%20necessary%20for%20human%20survival&f=false

Weber, M., Rinke, K., Hipsey, M.R., & Boehrer, B. (2017). Optimizing withdrawal from drinking water reservoirs to reduce downstream temperature pollution and reservoir hypoxia. *Journal of Environmental Management,* Volume 197, 15 July 2017, pp. 96-105. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301479717302189

Wellmer, F., & Sinding-Larsen, R. (2010). Non-Renewable Resource Issues: Geoscientific and Societal Challenges. *Dordrecht: Springer*.

Welsh, M. (2014). Toxic dirt dumped in Ontario's prime farmland. *The Toronto Star*, 20 October 2014. Retrieved from https://www.thestar.com/news/gta/2014/10/20/toxic_dirt_dumped_in_ontarios_prime_farmland.html

Westcott, T. (2018a). More Must be Done to Protect Ontario's Water. *Water Resources Canada*, 14 November 2018. Retrieved from https://www.watercanada.net/report-more-must-be-done-to-protect-ontarios-water/

Westcott, T. (2018b). Ontario government proposes legislation to sidestep Clean Water Act. *Water Resources Canada*. 7 December 2018. Retrieved from https://www.watercanada.net/on-gov-proposes-legislation-to-sidestep-clean-water-act/

Williams, D.D., Williams, N.E., & Cao, Y. (2000). Road salt contamination of groundwater in a major metropolitan area and development of a biological index to monitor its impact. *Water Research*, vol. 34, issue 1, 1 January 2000, pp. 127-138.

Winfield, M. (2019). Doug Ford's Ontario: Who Wins, and What Does it Mean for Ontario's Future? *National Post*, 24 February 2019. Retrieved from https://nationalpost.com/pmn/news-pmn/doug-fords-ontario-whos-winning-and-what-it-means-for-the-provinces-future

Wood, C. (2014). The Myth of Canada's Water Abundance. *The Tyee*, 5 January 2014. Retrieved from https://poliswaterproject.org/files/2017/06/2007-11-22_Tyee.pdf

World Health Organization (1993). Guidelines for Drinking Water Quality. Vol. 1: Recommendations. *WHO*, Geneva.

Primary Source Materials: Interviews

Interviewee 1: Anonymous. Senior Environmental Field Technician at a *Private Environmental Consulting Firm*. May 18, 2019. Interview conducted via email.

Interviewee 2: Lam, Sharon. Project Coordinator at *Toronto and Region Conservation Authority*. June 21, 2019. Interview conducted via email.

Interviewee 3: Anonymous. Manager and Assistant Director at *Ontario Ministry of the Environment, Conservation and Parks*. May 29, 2019. Interview conducted via telephone.

Interviewee 4: Anonymous. President and Chief Executive Officer at a *Private Environmental Consulting Firm*. June 1, 2019. Interview conducted via email.

APPENDIX A: SAMPLE QUESTIONS FOR INTERVIEWS

1. In your opinion, is the Government of Ontario doing enough to protect our drinking water resources? Please explain.

2. Do you think the public understand enough about the severity of the deterioration of our drinking water supply? Please explain.

3. Do you feel that the media is doing enough to raise awareness of the deterioration of our water supply? Who do you think should be responsible to inform the public of this situation (i.e., government, independent researchers, media, non-governmental organizations, etc.)?

4. Do you think we have appropriate legislation to protect our supply of drinking water?

5. Is this legislation being enforced?

6. Do you believe that wastewater treatment is sufficiently purifying our drinking water supply? Are you concerned about micro-plastics in our water supply?

7. Do you think we know enough about the science of drinking water (and the hydrologic cycle) to protect the resource in a sustainable way?

8. In your opinion, which water sources are most threatened and/or vulnerable in southern Ontario? Please explain.

9. Are you aware that contaminated soil from industrial sites in the Greater Toronto Area are being dumped into old gravel pits on the Oak Ridges Moraine?

10. Are you concerned with the newly introduced Bill 108 by the Ford Administration? Please explain.

11. Is there anything not discussed that you would like to bring forward?

12. Is there anyone you would recommend that I speak to about source water protection in southern Ontario? If so, please provide their contact information.

APPENDIX B: INFORMED CONSENT FORM

Date: February 19, 2019

Name of Participant: ________________________

Research Name: *Source Water Protection in Southern Ontario*

Researcher: Andrew Watters

Purpose of the Research:

The purpose of this research is to solicit feedback about Ontario's management of its clean drinking supply in order to address contemporary and emerging issues and to make the program more effective. Completing this interview will take approximately thirty minutes to one hour. There are no known risks associated with this study and your anonymity will be secured. This research like all MES Major Research will be published in YorkSpace and may be published on the FES website if nominated for the Outstanding Paper Series. This research is part of my MES Major Research.

What You Will Be Asked to Do in the Research:

Participants are expected to provide a response, to the best of their knowledge, to specific questions asked of them either through an email questionnaire or via phone call. The estimated time commitment is thirty minutes to one hour. Questions will solicit information about your role and involvement within your institution, your general knowledge/views of clean drinking water management and sustainability within southern Ontario, and your willingness to participate in enhancing the program. Questions will allow for open-ended responses.

Voluntary Participation:

Your participation in the study is completely voluntary and you may choose to stop participating at any time. You should not feel obliged to answer any material that you find objectionable or that makes you feel uncomfortable. Your decision not to volunteer will not influence the nature of any relationship you may have with the researcher(s), study staff, or York University, either now or in the future.

Legal Rights and Signatures:

I, __________________, consent to participate in an evaluation of source water protection in southern Ontario conducted by Andrew Watters. I understand the nature of this study and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent.

- I agree that my participation may be audio-recorded: Yes _______ No _______
- I agree to be identified by name: Yes ________ No ________
- I agree to be quoted by name: Yes ________ No ________
- I would like to receive a copy of the final research paper, at the following email address:

____

- I agree to allow video and/or audio, digital images or photographs in which I appear to be used in teaching, academic presentations and/or publications based on this research. I am aware that I may withdraw this consent at any time without penalty. Yes ____ No ____

____ __________________________

Participant Signature Date

____ __________________________

Researcher Signature Date

Risks and Discomforts:

We do not foresee any risks or discomfort resulting from your participation in the research. You have the right to not answer any particular questions.

Withdrawal from the Study:

You can stop participating in the study at any time, for any reason, if you so decide. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researchers, York University, or any other group associated with this project. If you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

Confidentiality:

Unless you specifically give your permission by checking the boxes above, all personal information you supply (i.e., name and contact) during the research will be held in confidence and your name will not appear in any report or publication of the research. Data will be collected via audio recording, hand-written notes, or through your email responses to the questionnaire. Your data will be safely stored on a hard drive in a locked facility and only research staff will have access to this information. The data will be retained for a period of two years. The recordings, transcript, and questionnaire responses will be safely stored in a password protected hard drive until April 1, 2021 and deleted after this date. Confidentiality will be provided to the fullest extent possible by law.

Questions about the Research?

If you have questions about the research in general or about your role in the study, please feel free to contact my Supervisor, Peter Mulvihill, either by telephone at (416) 736-5252, or by e-mail (prm@yorku.ca). This research has been reviewed and approved by the FES Research Committee, on behalf of York University, and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Office of Research Ethics, telephone (416) 736-5914 or e-mail ore@yorku.ca.