Bulk Water Pricing Framework to Foster Sustainable Water Management in Ontario

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Amidst rising concerns for sustainability of water resources, the province of Ontario has placed a temporary moratorium expiring on January 1, 2019 on bulk groundwater extraction by new water bottlers while considering broader reforms in water management policies. Given the projected impacts of climate change, coupled with population and economic growth, episodes of water scarcity are expected to rise in Ontario. Even though measures for sustainable water management are slowly gaining momentum, Ontario's economy is likely to remain water-intensive with a burgeoning water demand. Therefore, to assure sustainability of water resources, proactive policies need to be developed that can effectively communicate water scarcity and change the consumption behavior of all water-using sectors.

Bulk water pricing is an effective economic instrument to manage demand, incentivize use-efficiency and conservation by signaling to users the economic value of water. However, current water extraction charges imposed on few industrial sectors are very small, and hence insufficient not only to foster sustainable water use but also to recover the costs of various resource management initiatives undertaken by the Province of Ontario. To overcome the deficiency in current charges, this research investigates global and provincial best practices in order to design efficient bulk water-pricing framework based on actual resource costs that can effectively signal water risks, improve water use-efficiency, and reduce water demand of self-supplied extractive water users.

As an output of this research, a bulk water extraction charge calculator is designed starting from cost-recovery principles and based on public water resource management initiatives. Major federal and provincial investments in various quality and quantity management programs are considered along with volumetric data on water intake by different sectors to derive an average volumetric base price for Ontario. Moreover, to reflect spatial and temporal water source vulnerabilities along with sector specific risks, price multipliers have been integrated to provide price differentiation and policy flexibility within a unified framework.

Given the moratorium placed and ongoing provincial review on water policies refueling the interest in economic instruments, this research provides a regionally tailored dynamic bulk water pricing framework that can fund future water management initiatives while triggering the transition of Ontario into a more water-efficient economy.

Acknowledgment

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I would also like to thank my family and friends for providing relentless support throughout this rather interesting learning experience where I decided to step out of the comfort of my disciplinary confines. I am especially grateful to Vasundhara Saravade for the much-needed philosophical discussions and for being an extraordinary friend amidst the range of emotions experienced in this academic tenure. I am deeply thankful for the support and encouragement received from my cohort that has been the prime impetus behind the completion of this program.

Dedication

This thesis is dedicated to my family and to the flowing *River* carrying wisdom in the depths of *her* waters inspiring me to continue this meandering yet introspective journey.

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1.0 Introduction

As echoed in Sustainable Development Goal (SDG) 6, sufficient availability and quality of water is crucial for human survival, sustaining vital natural ecosystems, and economic productivity (UN, 2015). The gravity of SDG 6 was most recently realized in Cape Town. In January 2018, the city faced a severe water crisis and had to resort to extreme water rationing to avoid a complete water supply shut down (Maxmen, 2018). Water crises, such as in Cape Town, are a culmination of droughts exacerbated by climate change as well as grave lapses in water management. In addition to the criticality of water as a social and ecological resource, all economic sectors rely on significant amount of water as a material input. Thus, in addition to social and environmental repercussions, any lapses in water management can have huge economic implications as well making water a core component of sustainable development (Russo, Alfredo, & Fisher, 2014; UN-Water, 2013).

The objective hence of sustainable water management is to assure that all social, economic and ecological water demands of current and future generations are fulfilled while sustaining the productivity (quality and quantity) of water resources (Russo et al., 2014). Even though repercussions of water scarcity are evident, the drive towards sustainable water management has been rather reactionary. Contrary to common belief, freshwater is in fact a temporally "finite" resource that can be depleted if anthropogenic extractions exceed natural rate of recharge by precipitation. Given the threats posed by climate change on water availability coupled with growing anthropogenic demands, no city, province, or country is truly immune to water scarcity (AghaKouchak, Feldman, Hoerling, Huxman, & Lund, 2015).

In the Canadian context, the province of Ontario is surrounded by the bountiful Great Lakes with many regional freshwater sources owing to which many industries have flourished over the years. However, there is huge variability of water availability and quality within regional sub-watersheds that continue to pose serious threats to water sustainability (Bakker & Cook, 2011). It is unanimously agreed that the Great Lakes basin is a crucial economic hub for not only the province of Ontario but also nationally. The Great Lakes and their numerous equally productive natural ecosystems have been a central part of the heritage of Ontario that cater to the spiritual, recreational, and cultural needs of individual residents as well as economic trade and commercial activities (Steinman et al., 2017).

About 33% of the entire population of Canada resides within the Great Lakes basin and the region contributes about 40% to the overall national economic activity with a 25% share to Canada's agriculture sector and 75% share to the manufacturing sector (Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014). As evident from aforementioned statistics, the Great Lakes region is a booming social, ecological, and economic hub for Canada, hosting water-reliant domestic and industrial sectors that are expected to grow in the future. However, the increasing pressure on existing water resources and the rising water intensity of Ontario's economy is generally overlooked owing to the "myth of water abundance" that continues to persist in the region (Bakker & Cook, 2011).

1.1 Challenging the Myth of Water Abundance within the Abundant Great Lakes

Even though the Great Lakes constitute about 20% of the available global freshwater, the annual rate of natural replenishment by precipitation and surface run-off is in fact less than 1%, which constitutes the "renewable" component of Great Lakes thus making the region susceptible to anthropogenic over-extraction (Environment Canada & Ontario Ministry of the

Environment and Climate Change, 2014). According to a recent study on freshwater availability for all watersheds (drainage regions) across Canada, the Great Lakes drainage region had the highest amount of water abstracted, amounting to more than 40% of the total water yield (renewable recharge), making the region highly water stressed during the summer (as depicted in Figure 1). Even though Ontario experiences higher precipitation as compared to the drier Canadian Prairie regions, the region is equally water stressed due to significantly higher water demand especially in the industrialized and populous Southern Ontario (Statistics Canada, 2017).

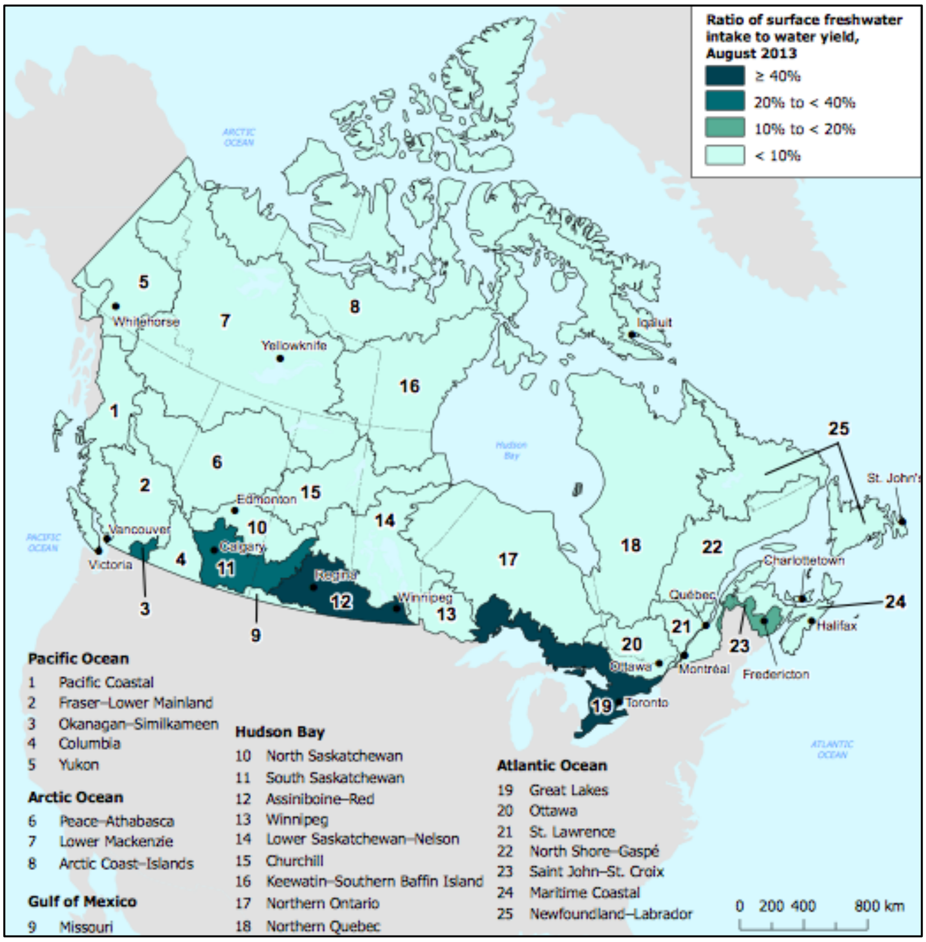

Figure 1: Surface Freshwater Intake to Yield in Canada, August 2013
Source: Statistics Canada (2017)

From a hydrological perspective given the impact of climate change, another pertinent cause of concern is the permanent recession of glaciers where the melt waters constitute a non-renewable supply of freshwater that cannot be sustained in the future thereby making the actual renewable water yield in the Great Lakes region much lower. Moreover, Southern Ontario is projected to be vulnerable to more droughts due to increasing average temperatures under various greenhouse gas emission scenarios. With increasing surface temperatures, more water is lost from water and land sources due to evaporation thus resulting in lower lake levels and increased need of land irrigation. With these hydrological factors under consideration, the rate of replenishment of water in various sources is highly uncertain in the present and future (Maghrebi, Nalley, Laurent, & Atkinson, 2015). Thus, even in the midst of the Great Lakes, zooming at the inland sub-watershed level there are prevailing threats of temporal and spatial water scarcity with anthropogenic extractive water demands directly competing with environmental water demands. Minimum environmental in-stream flows need to be maintained not only to sustain the productivity of natural ecosystems and waste assimilation capacity of water bodies but also required to maintain water levels for water navigation, in-stream fisheries, sporting and recreational activities. Thus, in addition to anthropogenic extractive water demands, the demand for in-stream environmental flows is an equally important consideration for understanding water availability holistically. Therefore, in the context of Ontario, the 40% threshold of extraction of renewable water supply is considered to be representative of high water stress in the region (Bonsal et al., 2011; de Loë & Kreutzwiser, 2000; Statistics Canada, 2017).

Water scarcity is a rather nuanced construct that is not only contingent on quantity of water available to fulfill both human and ecological demands but also includes the necessary quality of various water resources for present and future generations (Liu, Liu, & Yang, 2016; van Vliet, Flörke, & Wada, 2017). Reduced stream flows during extended dry periods not only result in insufficient water quantity for different users including sensitive ecosystems but also result in highly degraded water quality of streams due to insufficient dilution of contaminants. Moreover, in certain cases even if sufficient quantity of water is available but the quality of water is impaired due to highly toxic contaminants thereby rendering the water resource unfit for use. (Bonsal et al., 2011; Morris, Mohapatra, & Mitchell, 2008). Thus, scarcity is a multidimensional construct where both the quantity and the quality of water resources can be compromised failing to meet the local water demands. Given that water resources are equally vital to sustain ecosystems that need a minimum quantity and quality to thrive, water scarcity can have huge environmental implications as well. Thus, sustainability of water resources is not only limited to ensuring sufficient quantity of water but also preserving the quality of water resources that can be safely used in-stream or economically treated by different water extractive sectors.

1.2 Hydrological Context of Surface Water and Groundwater Resources in Ontario

Alarmingly, water availability issues continue to be masked by the "myth of water abundance" in Ontario. Thus, it becomes particularly important to understand the spatial and temporal facets of scarcity with a regional lens to understand these subtle nuances of different water sources like surface and groundwater, their hydrological interactions, impacts of climate change and anthropogenic pressures, as well as the added complexity of water quality at the sub-watershed level (Bakker & Cook, 2011). Delving deeper at the sub-watershed level, inland water users in Ontario rely on both "finite" groundwater aquifers and local surface water sources like streams, creeks, small lakes, and rivers. Many municipalities, rural domestic users, agricultural users as well as industrial sectors like beverage manufacturing rely exclusively on groundwater sources for water supply (Grannemann & Van Stempvoort, 2016). In fact, groundwater sources become an important aspect of overall water availability in the region since surface water and groundwater sources are hydrologically connected. The impact of decreased water quantity and quality of one type of source can have adverse ripple effects on other connected water bodies thus making groundwater a key water resource (Mohapatra & Mitchell, 2009; Nowlan, 2007).

To elucidate groundwater – surface water interactions, the concept of base-flow is generally highlighted in literature. Groundwater is mobile underground and flows towards discharge points at the surface near water bodies or wetlands. Since the temperature of groundwater is relatively lower than surface water, groundwater discharge into streams provides an important temperature regulation function that is crucial for productive aquatic habitats (refer to Figure 2 for visual representation of the overall hydrological cycle). Thus, in addition to precipitation and run-off that replenish surface water bodies, this groundwater discharge also contributes to the stream flow of various creeks, rivers, tributaries or sometimes directly to lakes. This contribution of groundwater discharge to overall flow of the water body is quantified volumetrically as "Base-flow" (Grannemann & Van Stempvoort, 2016; Kornelsen & Coulibaly, 2014). These base-flows are especially pertinent in the summer, when in absence of regular precipitation, this groundwater discharge becomes the major contributor to maintain flow in surface water bodies (Maghrebi, Nalley, Laurent, & Atkinson, 2015).

In the context of the Great Lakes basin, groundwater base-flow contributes about 40 to 75% water to various tributaries resulting in about 20 to 40% of the total water flow into the Great Lakes (Kornelsen & Coulibaly, 2014). Moreover, given the significant contribution of groundwater in terms of quantity in various water sources across the region, the quality of groundwater also impacts the overall quality of surface water bodies. Hence contamination of groundwater sources due to infiltration of toxic chemicals or hazardous wastes indirectly impacts the surface water where contaminated groundwater ultimately discharges (Grannemann & Van Stempvoort, 2016; Howard & Gerber, 2018). Thus, the benefits of protecting and sustaining the quality and quantity of groundwater are also reflected in surface water sources, making surface water and groundwater resources mutually dependent and equally important from a resource management perspective.

With urban growth, increased agricultural production, and industrial activities groundwater resources are increasingly being used to supplement water demands in the region. Many municipalities have also relied on groundwater sources for municipal water supply and households not connected to municipal systems rely exclusively on their private domestic wells. The controversial water bottling industry predominantly uses groundwater sources to extract and treat water that is bottled and sold. Thus, groundwater serves as a reliable and convenient on location source of water for various sectors instead of raw surface water being piped and pumped from distant sources (Howard & Gerber, 2018; Nowlan, 2007). Contrary to surface water sources, groundwater present in aquifers is indeed finite since the recharge of aquifers is an extremely slow process spanning to many human lifetimes so groundwater can be considered as a non-renewable source of water with all possibility of permanent depletion (Maghrebi et al., 2015; Mohapatra & Mitchell, 2009).

Excessive groundwater pumping by various sectors and users in the region can cause hydraulic disturbances during dry seasons. When high volume of groundwater is pumped, the water table lowers thus causing "flow reversals" where the direction of naturally flowing groundwater (towards surface water) is reversed and captured leading to reduced base-flows to surrounding streams as well as drying up of wetlands otherwise fed by naturally flowing groundwater (Howard & Gerber, 2018; Morris et al., 2008). For instance, in the state of Wisconsin, United States (regionally in the Lake Michigan basin), excessive groundwater pumping reduced the stream flows of surrounding surface water resources resulting in drying up of streams and supported ecosystems as visually depicted in Figure 3. Albeit at small rates, the extent of water capture was significant enough to permanently capture water from Lake Michigan (instead of it naturally flowing into the lake) thereby highlighting the cumulative impact of anthropogenic water pumping on permanently altering the natural hydraulic landscape of a region (Morris et al., 2008; Reeves, 2010).

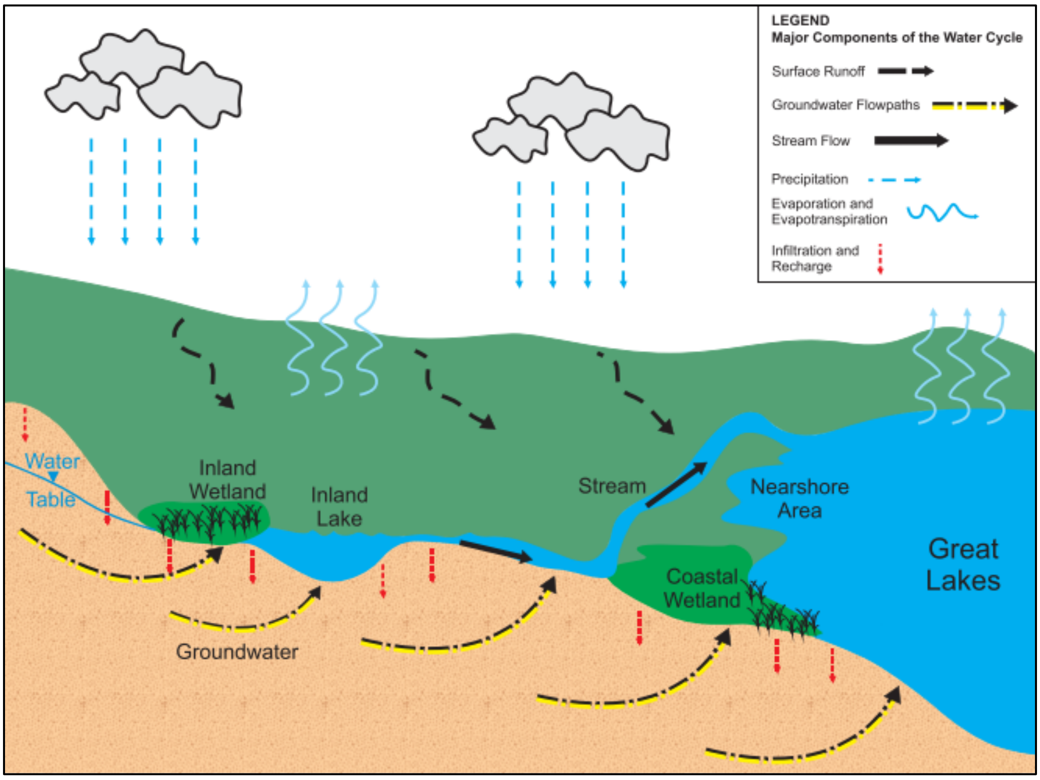

Figure 2: Overall Hydrological Cycle with Surface water - Groundwater Interactions
Source: Grannemann & Van Stempvoort (2016)

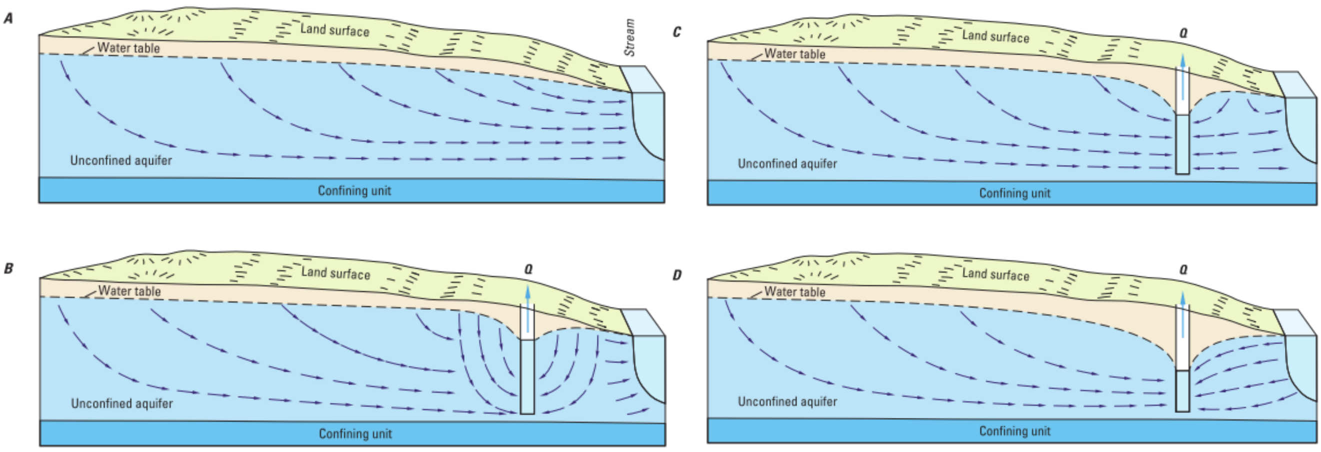

Figure 3: Impacts of High Capacity Groundwater Pumping on Surrounding Stream Flows
Source: Barlow & Leake (USGS Survey Circular 1376) (2012)

Scenario A: Normal hydrological case with no anthropogenic water pumping
Scenarios B through D: Various stages of groundwater pumping with increasing Q (volumetric flow rate of groundwater pumped) resulting in stream capture or flow reversals from surrounding streams or other surface water bodies.

Summer and early fall in south-western Ontario are not only marked by excessive water demand due to increased agricultural irrigation, power generation, and residential use but also decreased water availability during periods of low precipitation hence resulting in competition and hence conflicts among various domestic, agricultural, and industrial users (Morris et al., 2008). Thus, in addition to uncertain water supply during summers marked by reduced water levels in wells and dried up creeks, increased water demand also poses significant temporal threat to equitable water allocation among competing users (Bonsal et al., 2011; Gabriel & Kreutzwiser, 1993). Moreover, the sub-watersheds in Ontario also lose the highest amount of water naturally by evaporation from both land and regional water sources (evapotranspiration) as compared to other regions in Canada. This water loss by evaporation is expected to increase further with increased surface temperatures and reduced ice cover owing to the impacts of climate change. These increased water losses from land and vegetation is an important consideration for potential increase in water demand for agriculture requiring more frequent irrigation for retaining soil moisture (Bonsal et al., 2011; Maghrebi et al., 2015). Thus, considering the current and future state of water resources in the region, the myth of water abundance is rather challenged from uncertainty in freshwater supply as well as growing anthropogenic demands especially in Southern Ontario.

1.3 Burgeoning Water Demand and Inefficient Water Use in Ontario

The overall volume of freshwater extracted and residential water 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 50-100 L/day/person to fulfill all basic human and residential needs (Howard & Bartram, 2003). Owing to various provincial and municipal initiatives including metering, tariff revisions, technology innovation, rebates on water efficient plumbing, awareness, and stewardship programs, the residential water use in Canada dropped from a copious 343L/day/capita in 1999 to 251 L/day/capita in 2011. However, the residential water demand is still considerably high as compared to global counterparts and there lies much more scope for improvement in overall conservation and water efficiency measures (Bruneau, Dupont, & Renzetti, 2013; Environment Canada, 2011a).

From the perspective of overall water use by different sectors, "Water Productivity" is a common indicator used to compare the efficiency of water use for different countries. It is numerically defined as the GDP (in constant US dollars) per total volume of freshwater extracted for a country ($\$/m^3$ of freshwater extracted) for all water use sectors. While an economy composed of natural resource driven industrial and agriculture sectors is expected to have lower water productivity, countries that are naturally water abundant have also been found to be inefficient in utilizing water resources. Thus, countries like Canada with economies driven by industrial and agriculture production and are relatively water abundant tend to use water rather inefficiently (Canada's Ecofiscal Commission, 2014; Debaere, 2014).

Canada has one of the lowest water productivity indices as compared to other OECD countries with maximum volume of freshwater extraction by the industrial sector (including thermal power generation). Australia, a naturally arid country similar to Canada in terms of composition of the economy has significantly improved its water productivity over the years while Canada continues to be water intensive. This intensity or low productivity in water use has been attributed to the perception of abundance of water in Canada that leads to water being an underpriced and hence an inefficiently used resource (Canada's Ecofiscal Commission, 2014;

Cantin, Shrubsole, & Aït-Ouyahia, 2005; Debaere, 2014; World Bank, 2018). Since Ontario is the industrial and population hub of Canada surrounded by the water rich Great Lakes, Ontario's economy has followed similar trends of high-water intensity. Hence concerns over sustainable use due to burgeoning demand and variable freshwater availability in the region have been gaining traction (Morris et al., 2008; Ontario Ministry of Environment and Climate Change, 2007; Statistics Canada, 2017).

Academic research and analysis specifically on industrial water use over time has concluded that the current water consumption behavior by diverse industrial sectors is inefficient and hence is a key sector for tackling potential threats to water security in the region (Bruneau et al., 2013; Renzetti, 2007; Renzetti & Dupont, 2015). With uncertainties in supply and increasing competing demands, episodes of conflicts among domestic and industrial users continue to surface and grow (Morris et al., 2008; Shifflett, 2014). Evidently, regional and temporal water scarcity is prevalent across Ontario and is expected to increase as the province grows in a climatically uncertain future. However, at the regulatory level, the water allocation and drought management initiatives like the Low Water Response Program (discussed in detail in Section 2.4), the province of Ontario follows a rather reactionary approach to water management.

Rather than proactively incentivizing water conservation and use-efficiency to adapt to a climatically uncertain future, the first line of defense after an event of drought or low flows is the voluntary reduction in use by self-supplied water users (Kreutzwiser, de Loë, Durley, & Priddle, 2004). The reliance on managing a low flow or drought situation temporarily rather than preventing the occurrence of the same is a major impediment reflecting the current and looming water threats in the region (Disch, Kay, & Mortsch, 2012; Kreutzwiser et al., 2004). Thus, this brings to fore serious deficiencies in current water management policies to effectively communicate water risks and manage demand of different sectors so as to ensure sustainable use of water resources (Bakker & Cook, 2011; Disch, Kay, & Mortsch, 2012; Kreutzwiser et al., 2004).

Before delving into the existing regulatory frameworks used for water resource management in Ontario, an in-depth analysis of the water use trends by various sectors at the granular provincial scale is required. Analyzing the trends in water demand from a sector-segregated perspective for Ontario can help design specific strategies for sectors that need the most intervention for demand reduction.

1.4 Water Use Trends by Various Sectors in Ontario

- ***Agricultural Irrigation and Livestock Water Demand in Ontario:*** As compared to Canadian agricultural hubs like Alberta, Manitoba, and Saskatchewan (Prairie provinces) as well as British Columbia, Ontario follows these regions in the amount of water used for agriculture (Statistics Canada, 2016). Since Ontario experiences higher precipitation as compared to the drier western provinces of Canada, the irrigation water demand in Ontario is relatively lower as compared to other provinces. Nonetheless, as observed from the Statistics Canada's Agriculture Water Survey results, the irrigation volumes correspond closely with the precipitation patterns and if precipitation in the region is projected to be uncertain then agriculture water demand is expected rise as well (de Loë, Kreutzwiser, & Ivey, 2001; Weber & Cutlac, 2017).

According to the Statistics Canada Agriculture Water Survey for the province of Ontario, the volume of water used for irrigation in the year 2016 was about 5 times higher than the volume recorded for the year 2014. As observed from the Ontario Low Flow Response Maps published by Ontario Ministry of Natural Resources and Forestry, 2016 happened to be a particularly dry year marked by an extended period of low precipitation during summer (Ontario ministry of Natural Resources and Forestry, 2016; Statistics Canada, 2016c). The complexity of agricultural water demand stems from the reliance of farmers on irrigation solely during drier months which also coincide with increased withdrawals due to higher residential and power generation demand. However, unlike manufacturing sectors agricultural production is seasonally and spatially sensitive and cannot be stalled or altered based on periods or regions of higher water availability.

Agricultural sector thus has been a prime focus area for water management initiatives not only due to the temporal and spatial dependence on water withdrawal during low flow seasons but also due to the impact of nonpoint water pollution caused by fertilizer and pesticide application (de Loë et al., 2001; Morris et al., 2008; OECD, 2013; Weber & Cutlac, 2017). The contamination events related to phosphorus loadings resulting in algal blooms as well as manure run-off resulting in E. Coli contamination of drinking wells have been the impetus behind many agriculture water stewardship programs constituted by the province (Bakker & Cook, 2011; Mitchell, 2017). The difficulty in monitoring seasonal water use as well as quality of run-off water necessitates the use of more collaborative and voluntary stewardship programs as a means to regulate water demand and pollution (OECD, 2017; Renzetti & Dupont, 2015).

The recent Statistics Canada Agriculture Water Survey (from 2010 to 2016 biennially) provides a database of irrigation volumes, techniques, crop type, and number of farms irrigated for different provinces. However these estimates along with the historical data on irrigation water use are limited in their accuracy due to the lack of continuous monitoring and reporting in the sector (Morris et al., 2008; Statistics Canada, 2016c; Weber & Cutlac, 2017). Moreover, there is no such survey that accounts for water used for rearing livestock and in Ontario the livestock sector is exempt from requiring a permit to take water. In the absence of such records the most pertinent study carried out in Ontario to estimate the volume of water used for agricultural irrigation and livestock is by de Loë, Kreutzwiser & Ivey (2001). The study arrives at an extensive list of water use coefficients based on the type of crop and livestock that can be used to calculate the total volume of water used based on the crop/livestock information provided by the census of Agriculture database. However, the study carried out in 2001, has not been updated since to reflect any technological changes in irrigation in the past 17 years that may change the coefficients considerably (de Loë et al., 2001).

The Great Lakes Regional Water Use database is an additional source of gathering water use data by sector for the Great Lakes-Ottawa-St Lawrence region in the province of Ontario. The database is maintained by the Great Lakes Commission (under the Canada-US joint commission requirements) and provides water withdrawal data in daily volumetric rates (million liters/day). Even though the database has water withdrawal data by sector, unlike Statistics Canada, the methodology for data collection and estimations are not reported in detail (Great Lakes Commission, 2012; Vandierendonck & Mitchell, 1997). Therefore for the purposes of this research this database is used only for secondary comparison of trends or for sectors that are completely unavailable in Statistics Canada e.g. livestock. Unlike agricultural irrigation that varies seasonally and is contingent on precipitation, livestock water demand is assumed to remain constant over the year. Thus, for the purposes of this research daily volumetric flow rates for the livestock sector are converted into annual rates, assuming that the water is withdrawn for 365 days/year.

In the context of Ontario, the agriculture and livestock sectors are not major extractors of water as compared to industrial and residential sectors. However, the water quality issues due to pollution and the highly consumptive use of water (about 85% of the water is consumed or evaporated hence not returned to the original source) by these sectors make them a key area for water management policies. Since agricultural production is extremely sensitive to water availability especially in the summer, many of the water conflicts during periods of low flow are centered around agricultural and industrial permit holders (Morris et al., 2008; Ontario Ministry of Natural Resources, 2014; Weber & Cutlac, 2017). Given the future projections of increased demand of water-intensive produce from water scarce countries, agricultural water demand is expected to rise across Canada. Therefore proactive water management strategies for water efficient and environmentally friendly practices like drip irrigation and nutrient management are much needed for these sectors (NRTEE, 2011; Rubin, 2017).

- ***Municipal Water Demand in Ontario:*** Municipal water demand is inclusive of all sectors (residential, industrial, commercial) that are connected to municipally treated water supply. Water extracted by various municipal treatment plants is treated to drinking water quality standards and then supplied to residences, commercial, institutional, and industrial facilities that are connected to these municipal systems. Both groundwater and surface water sources are used for municipal supply with certain municipalities like Guelph relying predominantly on groundwater sources (Bruneau et al., 2013; de Loë, Kreutzwiser, & Neufeld, 2005). Post the Walkerton contamination tragedy in 2000, under the Clean Water Act, 2006 many initiatives (including the source protection program) have been undertaken to ensure sustainable and high quality water treatment and supply. There have been many water conservation programs as well as voluntary stewardship programs directed at efficient water use in various municipalities (de Loë & Berg, 2006; de Loë et al., 2005; Ontario Ministry of the Environment, 2007).

According to the 2009 Municipal Water Use survey, for about 91% of the metered residential sector, the average per capita water use in Ontario was 225 L/day/person compared to Canada's per capita residential water use of 343 L/day/person in the year 1999. The biennial municipal survey results for 2015 show a reduction in residential per capita water use to about 201 L/day/person (Environment Canada, 2011b; Statistics Canada, 2016). This improvement in residential water demand is attributed to increasing awareness regarding water use, water efficient plumbing fixtures, improved metering, municipal water conservation and efficiency rebate programs, per capita use reduction targets (e.g. City of Guelph target of 157 L/person/day by 2038) and the use of variable volumetric water tariff structures like increasing block rates to incentivize conservation that have been used by different municipalities across Ontario (Environmental Commissioner of Ontario, 2016). Municipalities have relied on a mix of voluntary, regulatory, as well as economic instruments like variable pricing tariff structures that have regulated the exceedingly high water demand of residential sectors to some extent (Bruneau et al., 2013).

However, the industrial and commercial sectors connected to municipal systems have not been entirely subjected to similar initiatives or stringent regulatory measures like increasing block rate tariffs. On the contrary to improve economic competitiveness by attracting more industrial firms in region, commercial and industrial sectors are offered a declining block rate for water tariffs in some municipal regions like Toronto thus dis-incentivizing water conservation. Each municipal region in Ontario has designed their own water tariff schemes and water sustainability objectives thus making municipal water pricing and use highly variable across the province (City of Toronto, 2015, Canada's Ecofiscal Commission, 2017).

Even though the majority of industrial water users are self-supplied and do not rely on municipal water supply for production needs, from an equity perspective, charging low prices for municipal water that is supplied to industrial sectors is antithetical to water sustainability goals as well as conservation efforts of residential water users. Moreover, from the perspective of financial sustainability, even though there is no charge for water extraction for the purposes of municipal supply, the tariffs imposed on users for the "service" of supplying treated water is only sufficient to recover partial costs of operations and maintenance of the aging water treatment and supply infrastructure (Bruneau et al., 2013; Renzetti & Dupont, 2015; Renzetti & Kushner, 2004). Given the significant investments made by the province for source water protection and other water monitoring initiatives that ensures high quality and sustainability of water sources, there is a dire need for equitably recovering the costs of water resource management along with municipal water tariffs from all high volume water users (Environmental Commissioner of Ontario, 2016; Brandes, Stinchcombe, & Renzetti, 2010).

- ***Self-Supplied (Bulk) Domestic Water Demand in Ontario:*** About 15% of the total population in Ontario (mostly in the rural parts of Northern Ontario) are not connected to municipal supply systems and rely on self-supplied water sources like groundwater wells for their water needs. The volume of water extracted for self-supplied domestic water use has been estimated based on the methodology used by Vandierendonck and Mitchell (1997). The study uses the average per capita water demand for rural users of 159 L/day/person and estimates the population not served by municipal supply systems using the Municipal Drinking Water Plants Survey and Census data (Total population of Ontario – Population served by municipal systems), thereby calculating the volume of self-supplied domestic water demand (Vandierendonck & Mitchell, 1997). The same methodology has been used by various conservation authorities in their water demand estimated for the technical assessment reports for Source Water Protection Plans and can be used for the purposes of this study as well.

  Even though self-supplied domestic water demand is considerably lower than municipal water demand, the cumulative impact of multiple water takings in a drought sensitive area needs to be factored. An important consideration for self-supplied domestic water users is the quality and quantity assurance of water sources as well as regular testing for contamination (Grannemann & Van Stempvoort, 2016). High capacity groundwater pumping by industrial users especially water bottlers, dewatering operations, or large scale agricultural can cause drawdown of water level in domestic wells and have been a source of conflict in the past (Morris et al., 2008). Even in the case of extreme contamination events like chemical spills or infiltration of water contaminated by blue-green toxic algae many domestic wells have to be abandoned thus disrupting the sole source of water supply for these users (Bingham, Sinha, & Lupi, 2015; Environment and Climate Change Canada & Ontario Ministry of the Environment and Climate Change, 2018; Grannemann & Van Stempvoort, 2016). While self-supplied domestic users do not need a permit to extract water, the impact of other water use sectors and conflicts due to potential draw down of water levels of domestic wells needs to be factored and prioritized in water allocation decisions.

- ***Self-Supplied Industrial, Commercial, and Institutional Water Demand in Ontario:*** Industrial, commercial, and institutional water users extract raw or bulk water directly from the source and the water withdrawn (intake water) is treated and pumped by these users privately to be used for different processes. Water is used either directly as part of the production as process water, where it becomes a part of the product (in the case of food, beverage, or water bottling) or for purposes of cooling or steam production. The volume of water entering the facility is partially consumed in various processes and the remaining wastewater (laden with other process chemicals) is discharged as effluent either into surface water bodies or municipal sewers after adequate treatment (as prescribed by regulations). Commercial and institutional water demand comes predominantly from businesses, hospitals, schools, other larger establishments etc. that have their own water treatment facilities instead of municipal supply connections (Bruneau et al., 2013; Bruneau & Renzetti, 2010).

Industrial water use includes water extracted by various economic sectors like manufacturing, mining and quarrying, oil and gas extraction, and thermal power generation (fossil-fuel and nuclear) that use water as a production material input (process, cooling, or steam generation). Industrial water demand in Ontario continues to grow and is intricately linked to the economic output thus highlighting the high water intensity of production (Renzetti, 2015). Thermal power generation accounts for nearly 85% of the annual water extracted in the region and the sector poses significant pressure on local water resources (Statistics Canada, 2014d). Even though water extracted for thermal power generation is returned to the original source (at an altered quality/temperature), in case of insufficient water availability or higher water temperatures in the region, power generation has to be stalled thereby raising concerns for energy security (van Vliet, Sheffield, Wiberg, & Wood, 2016). Thus, various water quantity management initiatives that ensure sustainability and productivity of water sources benefit all industrial sectors economically by sustaining continuous production (Renzetti & Dupont, 1999; Rivers & Groves, 2013).

As a major hub for manufacturing and thermal power generation, sustainability of water resources by apt policy measures is crucial for the prosperity and growth of Ontario. While there has been significant focus on managing water demand of other sectors, industrial water users have been outside the water policy radar (Renzetti, 2017). As a sector that commercially benefits from using water as an economic resource and has evidently been inefficient in its water use, the emphasis on using economic instruments to curb industrial water demand is warranted. Nonetheless, dynamic pricing models should be designed to differentiate high water consumption users from low consumption to maintain equity while recovering the costs of water management that benefits all water extractors (Canadian Council of Ministers of the Environment, 2015; Renzetti, 2007, 2017).

1.5 *The Need for Sustainable and Efficient Water Use in Ontario*

According to climate projections (based on current carbon emissions), many regions in Southern Ontario are estimated to encounter more than 45 days of above 30°C temperature in the year 2080. These projections are harbinger of more frequent and severe droughts in the region followed by extreme precipitation events hence water availability in Ontario is likely to be highly uncertain both temporally and spatially (Prairie Climate Centre, 2018; Grannemann & Van Stempvoort, 2016). Droughts across the globe have severely damaged ecosystems as well as disrupted food production, energy generation, and industrial operations as witnessed in countries across the globe (AghaKouchak et al., 2015). In extreme cases, droughts have been a source of political conflict and civil unrest, threatening the very core of human wellbeing (World Economic Forum, 2017; World Bank, 2016). Given the past and future propensity of Ontario to experiencing water availability and quality issues, water supply will remain uncertain amidst climate change as well as population and economic growth. Thus, in order to build a sustainable, climate-resilient and prosperous economy, proactive measures for sustainable water management are necessitated for Ontario.

As many parts of the globe reel under water scarcity, Ontario is considered to be a prime trade-friendly location for water dependent industries and agriculture (Rubin, 2017). Even though bulk water is not exported directly, production of most goods consumes significant quantities of water. Thus, "virtual water" embedded in these products is traded internationally to water-scarce countries. (Debaere, 2014; Ercin et al., 2013). When this embedded water or "virtual water" in various products is quantified, it is found that countries that are considered to be water abundant like Canada tend to export products whose production/manufacturing indeed utilize copious amounts of water from local resources rather inefficiently thus making the economy highly water intensive. As global demand for these products is projected to increase, the pressure on domestic water resources will consequently increase for provinces like Ontario perceived to be water-abundant (Debaere, 2014; Ercin, Mekonnen, & Hoekstra, 2013). However, given the uncertainty in local water supply in Ontario as well as the burgeoning water demands due inefficient water use and low water productivity of various sectors is a major threat to the sustainability of local water resources.

Unlike other material resources used for production, water is an underpriced resource in Ontario thus there is neither a check on the growing water demand nor the reflection of regional water supply risks to end users. In absence of adequate price signals the use of an economically significant resource like water continues to be undervalued with growing risks of overconsumption. While countries like Australia, Israel, China, and most European Union countries are taking measures to ensure productivity of local water resources by progressing towards a water efficient economy, Canada and Ontario are yet to show significant improvements in sustainable use of water resources (Canada's Ecofiscal Commission, 2014; Rubin, 2017). Given the economic forecast due to the increasing demand posed by water-scarce countries, water is indeed as a key resource for Ontario's economy. Thus, to capitalize on this economic opportunity, existing water threats must be mitigated by means of proactive demand management measures and move towards water-efficient practices in all sectors (Rubin, 2017).

In order to suggest pertinent and practical measures for effective water demand management, it is first critical to gain an understanding of the current regulatory frameworks ongoing water management initiatives, as well as areas in need of policy reform in the province of Ontario. The following sections provide a theoretical foundation of various policy instruments that are employed for efficient water management followed by the detailed analysis of current water policy frameworks, various water management initiatives, and gaps that need to be addressed to promote sustainable water use in Ontario.

2.0 Literature Review

2.1 Policy Instruments for Efficient Water Resource Management

The use of publicly governed natural resources like water with significant social, economic, and environmental implications need to be managed and regulated with a mix of policy instruments. The complexity of water stems from its unique identity as a social-economic-ecological resource, wherein drinking water is a human right but economic use by industries makes it an economic resource (Hanemann, 2006; OECD, 2013). Thus, the demand of water needs to be managed for very diverse sectors ranging from households, commercial and industrial sectors, power generation, agriculture and livestock as well as the along with the in-stream water users. Since a certain minimum amount of water is crucial to sustain vitality of ecosystems (environmental uses) as well as in-stream uses of water like navigation, recreational activities, fisheries, hydroelectric power generation, and waste assimilation, allocation and extraction of water resources by other sectors needs to monitored and regulated by public authorities by means of effective water policies (Dupont & Adamowicz, 2017; Mitchell, 2017).

Given the growing demands of various users and uncertain supply of water resources, efficient use of water and conservation are the underlying objective of various policies for sustainable water resource management (European Environment Agency, 2013; OECD, 2013). Traditionally there are three main types of policy approaches that are employed for environmental management including water resource management.

1. ***Command and Control Approach***: These conventional prescriptive regulations are based on enforced restrictions imposed by governing public authorities on the use of natural resources and limits of pollution based on human health/ environmental impacts. Although the command and control approach is more popularly known for prescribing permissible limits for contaminants for pollution control, permits/licensing for water allocation as well as seasonal water use restrictions are also included in the overall approach for water resource management (European Environment Agency, 2017; OECD, 2013). Monitoring and enforcing compliance to these set regulations form an important aspect of this approach, wherein penalties are imposed on users failing to comply. However, implementing these regulatory framework as well as ensuring enforcement and compliance requires significant financial and human resources thus registering high administrative costs for the governing authorities. Thus, it is acknowledged that command and control approaches are more suited towards pollution based policies and use restrictions in a more reactive setting wherein outcomes can be achieved with significant costs borne by the regulator (Finney, 2013; Harrington & Morgenstern, 2004; OECD, 2013).
2. ***Economic Instruments***: A core principle that has been identified for sustainable water management is the recognition of the true value of water resources (Bithas, Kollimenakis, Maroulis, & Stylianidou, 2014). Economic instruments are based on the economic theory of using price signals for demand management of scarce resources by signaling not only the value of the resource but also the risks of availability to bring about a change in consumption behavior of users. When a resource is underpriced, there is a risk of overconsumption due to the misconception of excess supply (European Environment Agency, 2013). Thus, users have no financial incentive to be efficient in their use or invest in

practices for conservation. To correct this consumption behavior proactively, water pricing is increasingly being employed in overall water policy portfolio both for signaling sustainable water use and recovery of costs of water management initiatives (Bruneau et al., 2013; Renzetti, 2007).

Water abstraction charges based on cost recovery pricing principles is one of the commonly used economic instruments for water management in addition to purely market based approaches like setting up water markets and trading of water rights (OECD, 2013). Water markets and trading are popular economic instruments used globally and also in the province of Alberta, Canada. However in the Canadian context, the institutional and legal frameworks required to design and implement these markets as well as monitoring subsequent transactions makes water markets and trading an inherently complex and cost-intensive task (Cantin, Shrubsole, & Aït-Ouyahia, 2005). Thus, considering the existing regulatory framework for water management and allocation in the Province of Ontario, the scope of this study is limited to publicly administered bulk water charges that may be a more practically and contextually relevant choice of economic instrument.

In the past two decades, water pricing has become a popular economic instrument used globally to complement policies for efficient and sustainable use of water resources (Cantin et al., 2005). As emphasized in Article 9 of the European Union Water Framework directive, water pricing culminating in the form of an abstraction charge or water resource fee is an effective economic instrument used for water demand management as well as a means to recover costs incurred by public authorities to manage and allocate water resources (European Environment Agency, 2013; OECD, 2013). Even in the Canadian context, water extraction charges or fees were recognized and championed as pertinent water policy instruments for managing water demand for all use sectors in the 1987 Federal Water Policy designed by the Government of Canada (Cantin et al., 2005).

3. ***Voluntary Stewardship or Compliance***: In a voluntary, self-regulation based approach, softer measures in the form of stewardship or awareness programs undertaken by different sectors are also gaining momentum for promoting sustainable water use. Given the regulatory, economic, and reputational risks associated with water scarcity, many industries are taking voluntary steps to improve their water performance and proactive voluntary compliance for water use efficiency and conservation (Christ & Burritt, 2017; Lambooy, 2011). An important bottom-up firm level approach, these initiatives are slowing gaining traction but are more limited to areas where the threats to water resources are more prevalent and water resources are already scarce (Martinez, 2015). In Ontario these stewardship programs are already in effect for agricultural sectors wherein farmers are engaged in initiatives focused on nutrient management (prevention of phosphorus/nitrogen pollution) and other water quality management techniques (NRTEE, 2011; Weber & Cutlac, 2017).

Environmental eco-labeling, water awareness campaigns, voluntary initiatives like Alliance for Water Stewardship Standards, CDP Water Program, CERES Water Risk Disclosure, CEO Water Mandate, Global Reporting Initiatives are all pertinent examples of voluntary approaches for sustainable water management (Burritt & Christ, 2017). These programs are crucial for overall participatory water governance measures and also serve as important complements to regulatory initiatives as seen in the case of residential water demand reduction (NRTEE, 2011). However, from a policy perspective it is very challenging to measure and monitor the effectiveness of such initiatives to manage and reduce industrial water demand at the macro scale to bring about a change in consumption behavior of firms in all industrial sub-sectors (European Environment Agency, 2017).

As concluded by research focused on various environmental policies, economic instruments serve as an cost effective and efficient policy instruments that not only reveal the value of water resources but also signal conservation to different end users (Bithas et al., 2014; Harrington & Morgenstern, 2004). As a complementary mix of policy instruments, in addition to the conventional command and control style of regulatory instruments as well voluntary stewardship initiatives, economic instruments like pricing are being considered as an important and indispensable part of various resource and environmental policies. These economic instruments also serve to financially sustain regulatory and voluntary initiatives that need sufficient resources for planning, monitoring, and implementation (Harrington & Morgenstern, 2004). Thus, for the context of Ontario this study explores economic policy instruments like water pricing that can complement existing regulatory framework and voluntary initiatives undertaken by various sectors for a holistic sustainable water management framework (Canada's Ecofiscal Commission, 2014; European Environment Agency, 2013; Finney, 2013)

2.2 Economic Instruments for Sustainable Water Management

Bulk Water Pricing refers to assigning a monetary value to raw water that is extracted and used by diverse sectors as a resource (European Environment Agency, 2013). Based on the ***economic theory for pricing***, monetary signals like prices can effectively change consumption behavior and hence manage demand of a scarce resource by reflecting its true value (de Gispert, 2004; Hanemann, 2006). The response to change in price is measured through the concept of *"price elasticity of water demand", which measures the change in water demand when the price changes by a unit* (Griffin, 2016). Thus, pricing becomes pertinent as a viable demand management strategy if industrial sectors exhibit a (negative) price elasticity (Griffin, 2016). Globally, as compared to other use sectors, industrial water demand is found to be more responsive (high negative price elasticity) to water prices thus making it an apt policy instrument for demand management. Moreover, prices are set such that the user faces full social, economic, and environmental costs arising from water abstraction, use, and discharge (Mysiak & Gómez, 2015; Renzetti, 2005).

Since water is both a social (public) good as defined by the Rio Principles and an economic good (used by industrial sectors as a material input for production) defined by Dublin Principles, pricing water in the absence of competitive markets requires a different approach than regular private goods (Dinar, Pochat, & Albiac-Murillo, 2015; Hanemann, 2006). At the very outset, pricing water to arrive at an extraction charge is in no means indicative of privatization of water resources that continue to be governed and regulated under public jurisdiction. Instead water pricing is a pertinent policy instrument used to reflect the value of water resources as well as sensitivity of different watersheds. Thus, pricing for sustainable water management is not only limited to arriving at apt resource costs but also to effectively change consumption behavior of diverse end-use sectors (de Gispert, 2004; Dinar et al., 2015; Lant, 2004). An efficient water price ensures resource cost-recovery, demand reduction, improved use-efficiency, water conservation and signals spatial and temporal water risks to the end use sectors (European Environment Agency, 2013).

It has been established that there is spatial and temporal scarcity at the sub-watershed level across Ontario. Given the multitude of uncertainties posed on productivity of local water resources, water pricing can be an effective policy instrument for water demand management (NRTEE, 2011; Renzetti & Dupont, 2017; Rivers & Groves, 2013). Underpricing water is not only a consequence of undervaluing the services that the resource provides but also a function of policy failures (European Environment Agency, 2013). Even though water is used a material input in industries, it is practically free of charge as compared to other inputs like energy, material, and labor. Thus, there is no economic rationale to invest in technologies that are water efficient or produce less waste. As economic theory would predict - if a scarce resource is underpriced i.e. there is a failure to reflect full costs and benefits to the consumers, there will be overconsumption and hence unsustainable extraction (Griffin, 2016).

2.3 Establishing the Efficacy of Bulk Water Pricing to Manage Water Demand in Ontario

In the context of Ontario, water policies fail to fully utilize economic instruments like pricing to reduce the growing water demand and have been under much academic scrutiny (Canada's Ecofiscal Commission, 2014; Renzetti, 2005). The rationale for using water pricing as a tool to change consumption behavior is bolstered by the economic theory of pricing for demand management (Griffin, 2016; Olmstead, 2010). However, the extent of the impact of water prices on water demand as measured by price elasticity of demand varies across industrial sub-sectors (Dupont & Renzetti, 2001; NRTEE, 2011). Even though industrial sectors are major abstractors of water, there are limited quantitative studies based on impact of bulk water prices on industrial water demand at the regional sub-watershed level (NRTEE, 2011; Rivers & Groves, 2013). Nonetheless, existing published literature at provincial, national, and international level is sufficient to provide a thorough insight into pertinent research methods, conclusions, as well as remaining academic gaps.

In the Canadian context, providing a sound rationale for using economic instruments like pricing to manage industrial water demand, Dupont and Renzetti (2001) have statistically estimated the price elasticity of intake water in manufacturing industries. Using an econometric KLEM model and water data from Statistics Canada, it was concluded that water intake by industries was indeed sensitive to increase in water prices. The price elasticity of the manufacturing sector for intake self-supplied water was statistically determined to be in the range of -0.79 to -0.81 with wide variance between individual sub-sectors. Even though, actual water prices during the analysis period were insufficient to bring significant water use-efficiency thus indicating underpricing, the results of the simulation established the pertinence of water abstraction charges to reduce water intake in different manufacturing sub-sectors (Dupont & Renzetti, 2001). However, arriving at a price that effectively reduces intake by virtue of improved efficiency and conservation needs to be established further.

An important feature of industrial water use is the capacity of firms to recirculate water to be more water efficient thus justifying the sensitivity (price elasticity) and capacity of industrial sectors to alter water consumption behavior with price signals. The decision of manufacturing firms in Canada to recirculate water and hence reduce water demand is investigated by Bruneau and Renzetti (2014) using a Heckmann decision-making model. Water intake prices along with the scale of operation and type of sector were found to be factors influencing increased recirculation. Thus, by increasing bulk water prices, not only is industrial water demand estimated to decrease but also firms are incentivized to be more efficient by recirculating water (Bruneau & Renzetti, 2014). Conversely, by underpricing water, industries remain water inefficient and distorting any conservation gains made by initiatives undertaken other water-use sectors (Bruneau, Dupont, & Renzetti, 2013; Renzetti & Dupont, 1999).

From a price elasticity perspective, industrial water demand is indeed sensitive to water intake prices thus establishing the rationale for using water pricing as an effective tool to reduce consumption and incentivize use-efficiency. However, to arrive at optimal water prices, impacts of different prices on water demand, economic performance, and overall provincial economy are simulated and analyzed. Such assessment-based studies are necessary to alleviate concerns of adverse economic impacts thus building the business case for water sustainability stronger (NRTEE, 2011; Rivers & Groves, 2013). One of the earlier econometric studies using a partial and general equilibrium model by Dupont and Renzetti (1999) simulated the impact of different water permit pricing structures (flat and uniform volumetric) on all water use sectors in Ontario. It was concluded that as compared to a flat fee (volume independent), a volumetric charge ($/volume) significantly reduces water demand thus having a stronger conservation signal with minor impact on total costs. Although this study is limited by the lack of disaggregated data for industrial sub-sectors, it does provide statistical evidence for efficacy of different water pricing schemes.

More recently, Rivers & Groves (2013) also analyzed the impact of different pricing scenarios on all water use sectors (including residential, agricultural, industrial, and power generation) in Canada using a Computable General Equilibrium simulation model. By imposing an abstraction charge of $13/ million liters, the simulation revealed a 25% decrease in water intake with a negligible overall GDP loss. However, the impact on individual sub-sectors is variable with water-intensive sub-sectors experiencing a maximum GDP loss of 0.4%. Thus, depending on the provincial sub-sector economic profiles as well as initial price of water, the impacts of proposed prices will vary. The results consistently point towards the efficacy of pricing schemes for demand management, conservation, and use efficiency without major impacts on economic productivity. However, owing to lack of regional data at the time, authors address limitations of nationally aggregated analysis in capturing regional variability in water supply and demand. Nonetheless, the current econometric literature is sufficient to highlight the tendency of industrial sectors to react to bulk water extraction charges and change their consumption behavior (NRTEE, 2011; Rivers & Groves, 2013).

For residential water demand, similar studies to estimate price elasticity have been conducted but the value varies considerably across regions and are applicable for the total municipal water supply prices. It has been found that the initial price of water determines the elasticity therefore, if the price is higher the reduction in demand or elasticity is found to be high as well (Renzetti & Dupont, 1999). While price elasticity estimates for residential water demand in Canada vary from -0.2 to -0.6, recent econometric studies on residential water demand estimate a medium value of -0.22 (Canada's Ecofiscal Commission, 2017; Renzetti, Brandes, Dupont, MacIntyre-Morris, & Stinchcombe, 2015). While the residential sector is sensitive to water prices, factors like household income, water conservation programs, water-efficient plumbing rebate schemes, and voluntary/mandatory use-restrictions for lawn irrigation or car-washing influence residential water demand as well making the sector more nuanced than the self-supplied industrial sector (Bruneau et al., 2013; Renzetti et al., 2015). Nonetheless, studies at the federal and provincial levels have shown elastic response of water demand to varying extents by all use-sectors to change in water prices.

While the magnitude of elasticity varies with regional and sector specific factors including the original water price, the efficacy of economic instruments like pricing can be established for effective demand management to complement existing regulation based or voluntary initiatives (Brouwer & Pearce, 2005; Griffin, 2016). While the efficacy of various economic instruments like bulk water pricing has been established for efficient water demand management especially in the self-supplied industrial sectors, it is equally important to understand the current regulatory framework for water allocation and use in Ontario. The regulatory framework as well as various water resource management initiatives undertaken by the provincial government can lend useful insights on current water policies and their gaps that need to be addressed using well-designed, efficient, and dynamic bulk water pricing schemes.

2.4 Regulatory Framework for Water Resource Management in Ontario

2.4.1 Overview of the Ontario Permit to Take Water Program

Water resources in Canada are publicly governed under the jurisdiction of individual provinces with minimum federal involvement (except for fisheries, navigation, federal lands, and internationally shared waters), wherein provincially both Ministry of Environment and Climate Change (MOECC)[1] and Ministry of Natural Resources and Forestry (MNRF) are tasked with different aspects of water management (Bakker & Cook, 2011). However, the province of Ontario and especially the Great Lakes Basin is unique in its institutional setup pertaining to governance of water resources due to the bi-national commitments (Canada-United States) for trans-boundary sharing of the Great Lakes requiring collaboration of the Federal Government, Province of Ontario, and the bi-national International Joint Commission tasked with addressing issues pertaining to water resources in the basin. Thus, the water management initiatives designed by the Province of Ontario need to align with the tripartite commitments of the Canada-US-Ontario Agreements on the sustainability and quality of the Great Lakes basin (Bakker & Cook, 2011; Johns, 2017).

The Ontario Water Resources Act, 1990 (passed originally in 1961) provides the regulatory framework to ensure water resources within Ontario are efficiently and sustainably used. Water allocation among different users is administered by the Ontario Ministry of Environment that permits water users to extract a certain volume of water for various purposes. (Kreutzwiser et al., 2004). Equitable regulatory frameworks for water allocation become an important aspect for sustainable management of water resources given the compounding pressures of anthropogenic demand as well as uncertainties posed by climate change. As intensity and frequency of extreme weather events like droughts increase in the region, water allocation among competing users' needs to be both efficient and equitable to ensure that water needs of all users are fulfilled year round while maintaining minimum flows for in-stream and environmental needs (Morris et al., 2008; Vandierendonck & Mitchell, 1997).

As outlined in Section 34 of the Ontario Water Resources Act, the key policy approach used to manage water allocation among various end users as well as managing necessary flows for a productive environment is the "Permit to Take Water (PTTW) Program". The most recent regulation governing water taking and transfers in Ontario is Regulation 387/04 that further ensures all water taking activities fulfill compliance with the standards prescribed in Great Lakes - St. Lawrence River Basin Sustainable Water Resources Agreement under the bi-national commitments of trans-boundary water sharing and due consideration is given to maintain the ecological health of all water resources within the basin (Province of Ontario, 2004; Ontario Ministry of the Environment and Climate Change, 2012).

The PTTW program is managed by the Ministry of Environment and Climate Change, wherein users extracting more than 50,000 Liters/day of water (surface water and

[1]As of July 2018, the Ontario Ministry of Environment and Climate Change has been renamed to the Ontario Ministry of Environment, Conservation and Parks (MECP).

groundwater) directly from the source require a permit and are required to adhere to the requirements of the permit (use-restrictions during various low flow conditions). Thus, all sectors including municipal water suppliers, manufacturing, mining, oil & gas extraction, thermal and hydroelectric power generation, commercial & institutional, agriculture, construction extracting more than 50,000 Liters of water/day are required to obtain a water permit. However, water extraction for the purposes of self-supplied domestic use, livestock/poultry watering, firefighting/other emergency services, wetland conservation or water diversions for construction purposes does not require any permit. Moreover these permits are applicable to users extracting bulk/raw water directly from the source (self-supplied users) and do not include users obtaining their supply from municipal systems (Province of Ontario, 2004).

In order to apply for the water extraction permit, a charge varying from $750 to $3000 is conferred on users depending on the category of environmental risk of proposed water taking as outlined in the MOECC water taking guidelines. Use sectors like agriculture, aquaculture, wetlands, and wildlife conservation are exempt from this administrative fee but do require a permit for their operations. Moreover, under Regulation O. Reg 387/04 permit holders are also required to record and report their daily water taking volume to the MOECC's "Water Taking and Reporting System" on an annual basis (Ontario Ministry of Environment and Climate Change, 2014b). Review of these permit applications is a multi-tiered process where the MOECC is responsible to ensure that the proposed water taking does not adversely impact the productivity water resources in the region and there is equitable allocation among all water users. The impact of these water takings on the ecological health and flows necessary for environmental needs to be scientifically assessed especially for low seasonal flows so as to avoid future conflicts among users.

In line with the Low Flow Response Plan discussed in detail in Section 2.4.3, permit holders are instructed to adhere to the use restrictions during periods of seasonal low flows in the region. Depending on the level of intensity of the drought, measures ranging from voluntary to mandatory restrictions may be imposed on permit holders who are expected to comply with the imposed restrictions (Durley, Loë, & Kreutzwiser, 2003; Kreutzwiser et al., 2004; Roth & Murray, 2014). Thus, the province primarily relies on voluntary compliance as well as command and control type restrictions to manage demand rather reactively during periods of low water flows in the region. The compliance and monitoring of these restrictions have been widely debated and while this approach can temporarily provide relief to water stress in the region but lacks in bringing about a widespread change in the consumption behavior of all water users (Kreutzwiser et al., 2004).

In addition to the existing flat one time administrative fee imposed on all permit applicants, starting January 1st, 2009 under regulation 450/07 of the Water Resources Act, the province of Ontario introduced a volumetric charge primarily introduced as a "Water Conservation Charge" of $3.71/million liters of water extracted by high consumptive water use industrial sectors (majority of the water extracted is incorporated in the final product and not returned as wastewater to watershed). These sectors liable for volumetric charges were water bottling, beverage manufacturing, fruit and vegetable canning/pickling, ready-mix concrete manufacturing, non-metallic product manufacturing, pesticide, fertilizer, other water consumptive agricultural chemical manufacturing, and other inorganic chemical manufacturing (Province of Ontario, 2007). The rationale behind this quantity based conservation charge stems from the overarching objective of incentivizing water conservation and use efficiency by various sectors. Given the significantly high water demand as well as uncertainty due to temporal and spatial water scarcity in the region, economic instruments like water charges supplement existing water management regulations for sustainable water use (Ontario Ministry of the Environment, 2007). This economic policy instrument was administered to achieve two main objectives. First, a conservation charge serves as a price signal to users to reflect the value of a scarce provincially managed resource (European Environment Agency, 2013; Ontario Ministry of the Environment, 2007). When volume based charges are imposed on users as seen in the case of metered residential water users, industries are incentivized economically to invest in more water efficient processes and incorporate measures for overall water conservation thereby reducing overall water demand (Bruneau, Dupont, & Renzetti, 2013).

Second, based on the beneficiary or user pays principles, these charges serve to recover the costs of various water management initiatives undertaken by the Government and currently funded by general tax revenues (Renzetti, 2017; Vander Ploeg, 2011). These charges as imposed on high water consumption industrial users allow an earmarked revenue stream that not only recover the general funds used for managing water resources that benefit the users but also to supplement the funds for future initiatives (Ontario Ministry of the Environment, 2007). Thus, this regulatory charge was foreseen as a payment imposed on private commercial/industrial sectors for using/extracting a well-managed and value added resource for the purposes of profit making (Canadian Council of Ministers of the Environment, 2015; OECD, 2017).

Even though the rationale for these water conservation charges is based on sound economic principles, the magnitude of charges fixed at $3.71/million liters and imposed on few use-sectors has been under much academic and public scrutiny. These charges are criticized to be extremely low to reflect the true value of water resources, signal the impending risks of water quantity and quality thus fail not only to bring about any significant change in consumption behavior of high water users but also to recover the costs of various provincial water management programs (Environmental Commissioner of Ontario, 2014; Renzetti, 2007, 2017). Many academic papers have emphasized the inefficacy of these current charges to successfully reduce industrial water demand and failure to incentivize water use efficiency. Thus, there has been a huge push towards revising these charges and using more dynamic pricing mechanisms that not only reflect regional water risks but also recover full costs of water resource management (Bruneau, Renzetti, & Villeneuve, 2010; Renzetti, 2005, 2017; Rivers & Groves, 2013).

2.4.2 Water Rental Charges for Hydroelectric Power Generating Stations

In addition to the water charges imposed on self-supplied water users under the PTTW program, there is a separate water rental charge imposed on hydroelectric power generation under a different regulation of the Electricity Act. Hydroelectric power generation is an in-stream (non-extractive) user of water resources and it accounts for about 23% of Ontario's total installed power generating capacity in Ontario (Ontario's Independent Electricity Systems Operator, 2018a). According to the Ontario Electricity Act of 1998, hydroelectric power generating stations are required to pay an annual "water rental charge" to the Ministry of Finance for using provincial water resources for the purposes of power generation. Even though the sector is exempt from the water taking charge under the Water Resources Act since it is categorized as a very low water consumption sector, under the Electricity Act, this water rental charge is imposed solely for the in-stream "use" of provincial water resources.

Currently this charge, in addition to property taxes, is a part of the "Gross Revenue Charge" imposed fixed at 9.5% of the gross revenue generated by all hydropower stations annually and the charge is collected as general provincial revenue or royalty (Ontario Ministry of Environment, 2007; Ontario Ministry of Finance, 2016). According to the Public Accounts of Ontario published by the Ministry of Finance the revenue/royalty collected under the "water rental charge" from various hydroelectricity generating stations was about $124 Million for the year 2016 (Ontario Ministry of Finance, 2016). Given the rationale for charging hydropower stations a fixed percentage of their revenues as a royalty for using provincial water resources, from an equity perspective the MOECC should also be charging other industrial sectors for water extraction and use. Not only are other sectors more water consumptive but also use water as an economic resource for generating commercial profits.

The imposition of this water rental charge by the Ministry of Finance on hydropower but exempting other sectors including thermal power generation (accounting for about 68.5% of electricity generated in Ontario in 2016) seems to be inequitable and misaligned. Moreover, since the water rental charges collected are not earmarked for water management and a part of the general revenue, various water management initiatives are not entirely funded by these charges (Ontario Ministry of the Environment, 2007; Renzetti & Dupont, 1999; Statistics Canada, 2016). These water rental charges can be earmarked specifically for water management initiatives and other sectors including thermal power generation need to be charged for extracting provincial water resources under the PTTW and water charges program of the MOECC as well. This will allow more sources of revenue to be generated that can be recycled into future tax credit programs for water efficient users in addition to recovering costs of water programs undertaken by the province of Ontario (Rivers & Groves, 2013).

2.4.3 Water Resource Management Initiatives in Ontario

As part of the broader Canada–United States Great Lakes Water Quality Agreement (GLWQA) signed in 1972 and the Canada–Ontario Agreement (COA) on Great Lakes Water Quality and Ecosystem Health, many federal and provincial initiatives (through cost-sharing agreements) have been undertaken in the region. With the objective to restore and maintain the ecological health and productivity of the Great Lakes basin, these initiatives include technical studies, assessments, monitoring and evaluation, governance and engagement programs, as well as implementation of cleanup/remediation/restoration projects. These initiatives form a critical part of the overall water resource management in the province and have been funded jointly over the years by the Federal and Provincial Government (Bingham, Sinha, & Lupi, 2015; Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014; Environment and Climate Change Canada, 2017). The detailed costs and funding of these initiatives have been gathered as described in Section 5.2.1 and tabulated in Appendix 11.1 and 11.2. The major ongoing initiatives that focus on ensuring the sustainability of water resources in the Great Lakes basin are discussed below:

Great Lakes Action Plan and Sediment Remediation Plan: In the last few decades, given the economic significance of the Great Lakes region as well as trans-boundary water sharing agreements between Canada, the province of Ontario, and the United States, many water quality management activities have been undertaken in the basin. Given the past industrialization activities, the Great Lakes as well as other surface water bodies in the region have borne many water quality issues arising from agricultural run-off, industrial pollution, chemical spills, untreated municipal sewage and other contamination accidents. These quality issues pose significant social, economic, and environmental threats to the region, which need to be jointly managed by the Federal and provincial government along with the grassroots level support from municipalities via the conservation authorities at the sub-watershed level (Environment

Canada & Ontario Ministry of the Environment and Climate Change, 2014; Environment and Climate Change Canada, 2017).

These contamination events have had adverse impacts on quality of both surface and groundwater sources alike rendering the sources unfit for use thus creating a quality driven scarcity of water. Since 1989, the Great Lakes Action Plan is an ongoing initiative that is focused on fulfilling the international commitments of the Canada-US Water Quality Agreement (1972) to restore the environmental quality and overall protection of water sources around these sites. Environment Canada under the Great Lakes Water Quality Agreement identified 17 severely contaminated or degraded sites or "Areas of Concern" in Canada (including 5 shared bi-nationally) in the Great Lakes Basin. These sites as depicted in Figure 4 had to be technically assessed, monitored, remediated and restored in order to assure the productivity and ecological integrity of various connected surface and groundwater sources in the Great Lakes basin. Due to the dense network of tributaries, creeks, and rivers spread across the Great Lakes basin, these mobile water pollutants can originate from inland water sources and impact other connected sources including the Great Lakes (Environment Canada, 2014a). With federal, provincial, and municipal investments many of these sites have either been recovered or are under recovery. The Randle Reef Remediation Project at the Hamilton Harbor has been a major restoration initiative undertaken to manage the ecosystem degradation caused by years of industrialization and major public investments have been directed towards this site in particular (Environment Canada, 2017).

Figure 4: Canadian and U.S. Areas of Concern in the Great Lakes Basin
Source: Environment Canada (2014a)

There have also been some key regional instances considered to be extreme events of industrial contamination that have directly affected water resources and have been remediated with provincial funding. These contaminated sites are financially a liability of the province and are funded by general tax revenues in public interest of safeguarding land and water resources. Some of the key contamination events that have directly impacted local water resources include an abandoned mine in Deloro that contaminated surface and groundwater sources with radioactive and other harmful metallic wastes in 1979. Similar events include toxic chemical leaks from a fuel storage facility in Smithville (1985/89) as well as a chemical plant in Elmira (1989) contaminating the local aquifer (Auditor General of Ontario, 2004; 2015). Under the remediation liability, the province has spent significant financial resources in both remediation of such sites as well as building infrastructure for using alternate sources of water (e.g. water pipeline from nearby sources). Many such sites are under the federal and provincial responsibility and they continue to reflect the magnitude of environmental costs of industrial contamination that is currently borne by the province through general tax revenues (Auditor General of Ontario, 2014).

Great Lakes Nutrient Initiative and Agricultural Stewardship Initiative: In addition to remediation of sites with industrial contamination, many water quality management programs have focused on reducing nutrient (nitrogen and phosphorus) concentration from various agricultural, sewage treatment, and industrial wastes discharged directly into the Great Lakes or transported via local tributaries/streams. Excessive nutrient loadings in water bodies have been the major cause of algal blooms in the Great Lakes that degrade ecological health due to excessive eutrophication, which is fatal for aquatic life, hinder recreational activities, disrupts fisheries, and increase costs of water treatment. In addition to algal blooms that are classified as "nuisance" or non-toxic, there is a toxic strain of cyanobacteria or blue-green algae. The toxic blue-green algae if left untreated in water is a major human health hazard affecting animals alike thus requiring significant water treatment before use (Bingham et al., 2015; Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014; Weber & Cutlac, 2017). Thus, in order to avoid severe social, economic, and environmental impacts of these algal blooms the government has invested significantly to assure the nutrient quality of the Great Lakes region is balanced.

Unlike industrial pollution that can be considered as a point source of pollution traceable to a facility, nutrient pollution arising from agricultural practices is difficult to trace (non-point source of pollution). Agricultural pollution is mainly caused by over-application of pesticides, manure, fertilizers that can enter the local water sources along with irrigation water or precipitation (run-offs). Since effluent water from agricultural and livestock farms is difficult to monitor or control, preventative actions are better suited in this context. Nutrient management initiatives thus include technical studies on nutrient transport, policy research, awareness and stewardship programs for farmers on fertilizer use, wastewater treatment plant upgrades, and monitoring programs funded both by federal and provincial governments (Ontario Ministry of Environment and Climate Change, 2016; Environment and Climate Change Canada, 2017, 2018).

Groundwater Geoscience Program: Federally instituted Groundwater Geoscience Program (commenced in 2002) is a part of the larger Geological Survey of Canada. It is primarily implemented by Natural Resources Canada to monitor and assess all the aquifer systems across Canada in order to gain a better scientific understanding of groundwater resources. The data collected is compiled and managed as part of the Groundwater Information Network consisting of geological mapping, hydrogeological assessments, as well as groundwater modeling for the 30 aquifers across Canada (including 5 in Ontario). This database and program is foreseen as a key information repository for assessing and understanding groundwater science across provinces that can be a critical part of overall management of water resources (Natural Resources Canada, 2013). As highlighted in many studies and reports focusing on sustainability of water resources in Ontario, the lack of groundwater and aquifer assessments are seen as a major knowledge gap in understanding the groundwater-surface water interactions as well as cumulative impacts of groundwater takings on overall regional water sustainability (Grannemann & Van Stempvoort, 2016; Mohapatra & Mitchell, 2009; Nowlan, 2007). With the projected completion of the inventory and mapping for all aquifers in 2025, this program is a key resource management initiative complementing the provincial groundwater programs and assessing the anthropogenic impacts of groundwater extraction in the future (Natural Resources Canada, 2013).

Provincial Water Resource Management Initiatives

Major incidents like the drinking water contamination due to pathogens from manure run-offs in Walkerton (year 2000) have triggered (reactively) many provincial initiatives and regulations focused on assuring safe quality and quantity of water resources in Ontario (Bakker & Cook, 2011; Mitchell, 2017). These programs under the Ontario Water Resources Act is funded by the Government through the Ministry of Environment and Climate Change, Ministry of Natural Resources and Forestry along with implementation support from individual municipalities as well as Conservation Authorities of Ontario (Durley et al., 2003).

Ontario Low Water Response Program

Given the historic propensity of Ontario to witness droughts marked by extended dry periods with little or no precipitation, the Ontario Low Water Response Program was established by the province in 1999 and funded through the Ministry of Natural Resources and Forestry with implementation support primarily from the conservation authorities (Disch et al., 2012; Kreutzwiser et al., 2004). Though severe droughts were experienced in Southwestern Ontario periodically from 1960s into late 80s, the water conflicts post the 1998 drought triggered the formation of the Low Water Response Program (Gabriel & Kreutzwiser, 1993; Mohapatra & Mitchell, 2009).

This program was designed primarily to be collaborative and participatory in nature wherein a Low Water Response Team composed of representatives from various provincial ministries, conservation authorities, municipalities, as well as water users would be responsible for coordinated action for drought management. Thus, this decentralized program is based on a more collaborative governance approach for planning and management of droughts involving all stakeholders (Durley et al., 2003; Gabriel & Kreutzwiser, 1993; Mohapatra & Mitchell, 2009). However, these programs are rather reactive, wherein restrictions are imposed only with the onset of drought that may be highly variable year to year with varying level of compliance among different sectors. Moreover with less severe dry conditions, these programs rely on voluntary restrictions rather than legally enforced regulations (Durley et al., 2003; Horbulyk, 2017; Roth & Murray, 2014). Thus, the current low water response program needs to be supplemented by more long-term conservation and proactive measures to incentivize water efficient behavior of all use sectors rather than voluntary compliance (Kreutzwiser et al., 2004).

There are 3 levels of low water conditions that are categorized based on the volume of flow in local streams during conditions of low precipitation. Flows of various streams are continuously monitored by various conservation authorities as well as the MNRF and the designated Low Flow Response Team is tasked with declaring the appropriate water condition level for the region. Based on the level declared, necessary response measures are undertaken by various sectors that may range from voluntary to mandatory use restrictions and prioritizing certain users over others (e.g. hospitals, firefighting, residential except lawn irrigation). Complying to these actions are required to be followed by all permit holders while monitoring this compliance may not be as straightforward (Durley et al., 2003; Kreutzwiser et al., 2004; Roth & Murray, 2014). The three levels of low water conditions and expected response from water users are described in Table 1 (Grand River Conservation Authority, 2018; Roth & Murray, 2014):

Table 1: Low Flow Condition Levels and Response

Low Water Condition Level	Triggering Flow/ Precipitation Conditions	Expected Action and Response from Water Users and Permit Holders
I	Stream flow < 70% of normal summer flow OR Precipitation < 80% of the average	10% voluntary reduction in water use
II	Stream flow < 50% of normal summer flow OR Precipitation < 60% of the average	MOECC sends letters to all permit holders to voluntarily to reduce water use by 20%
III	Stream flow < 30% of normal summer flow OR Precipitation < 40% of the average	Production disruptions and reduced environmental flows anticipated. Mandatory use restrictions on all permit holders is imposed

Typical low water flow conditions map published by the Ministry of Natural Resources and Forestry depicting various levels is given below in Figure 5 for Ontario (August 2016):

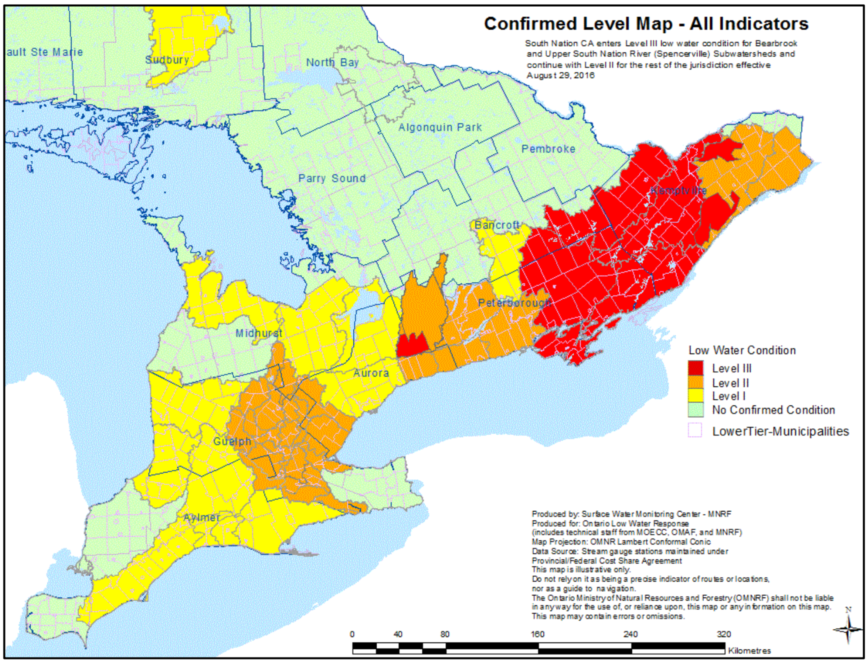

Figure 5: Low Water Conditions for Ontario in August 2016
Source: Ontario Ministry of Natural Resources and Forestry (2016)

Ontario Source Water Protection Assessment and Plans

As outlined in the Clean Water Act, 2006 (constituted 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. Under this collaborative provincial initiative between Ministry of Environment and Climate Change, Ministry of Natural Resources and Forestry, individual municipalities and Conservation Authorities, 36 Source Protection Areas based on sub-watershed boundaries were identified and grouped into 19 Source Protection Regions covering municipal regions in Ontario (35 conservation authorities are within the Great Lakes basin). Conservation Authorities in Ontario have been involved with various land, water, biodiversity, and natural hazards management initiatives at the sub-watershed level and are thoroughly equipped with regional expertise regarding water resource management (Conservation Ontario, 2018; Ontario Ministry of Environment and Climate Change, 2014a).

Under the provincial directive, conservation authorities have not only been tasked with preparing and implementing the Source Protection Plans but also other water management initiatives like the low water response program, flow/water supply monitoring, ecological health monitoring and other water stewardship programs at the sub-watershed scale. Under the Source Water Protection initiative, extensive scientific assessment of threats to water quantity and quality have been undertaken for water resources by individual conservation authorities to arrive at policies and plans centered at sustainable and safe drinking water supply for present and future generations (Auditor General of Ontario, 2014; de Loë, Kreutzwiser, & Neufeld, 2005). These plans accepted by the Ministry of Environment and Climate Change ensure all water resources (surface water and groundwater) in the region are scientifically monitored and assessed to mitigate any potential threats and vulnerabilities.

As a precursor to arriving at these plans, various technical assessments have been carried out by individual conservation authorities for proactive identification of vulnerable areas and threats due to over-extraction and contamination. Using regional data and scientific modeling techniques, these assessments (carried out in three stages or tiers of complexity/details) have quantified various risks based on surface-groundwater interactions, seasonal vulnerabilities, as well as supply variability under various drought scenarios. For Tier 1 analysis, detailed ***"water budgets"*** are carried out for individual sub-watersheds wherein an inventory of current water demand (based on water withdrawals by sectors) and source yields is tabulated based on water monitoring data, actual water taking records (under the PTTW programs) of permitted users, and hydrological assessments based on the methodology defined by the Technical Rules defined under the Clean Water Act.

Water quantity stress is assigned based on the maintaining minimum environmental flows at all times while accounting for all water withdrawals in the region with keen emphasis on highly consumptive uses that remove water from a source (e.g. aquifer) and do not return to the same source (e.g. groundwater returned to surface water body). Another threat that is identified for water quantity is the reduced rate of water recharge for aquifers due to impervious surface development arising from urbanization and land use changes (Ontario Ministry of Environment and Climate Change, 2017c; Lake Erie Region Source Protection Committee, 2015). The stress thus assigned as outlined in Table 2 is based on % of water demand of the total renewable supply of water for the source (recharge for aquifers or run-off/ precipitation for surface water).

Table 2: Water Quantity Stress Assignment

Water Quantity Stress Assignment	Surface Water	Groundwater	
	Maximum Monthly % Water Demand	Average Annual % Water Demand	Maximum Monthly % Water Demand
Significant	> 50%	> 25%	> 50%
Moderate	20-50%	> 10%	> 25%
Low	<20%	0 – 10%	0 – 25%

The regions of high and moderate surface and groundwater stress identified in tier 1 assessments are then further investigated with more detailed modeling and granular scenarios for tier 2 and tier 3 assessments such that municipal supply systems under water quantity and quality threat can be ascertained. Even though the objective of the program is ensuring sustainable and protected drinking water supply by identifying specific municipal water systems under threat, technical assessment tier 1 reports have extremely pertinent information of individual water sources within sub-watersheds (Ontario Ministry of Environment and Climate Change, 2017c). With future plans to integrate these assessments in future water taking permits by users, sensitive watersheds thus identified can be protected from over-extraction. These programs not only benefit municipal water users but also other self-supplied use sectors reliant on these resources by identifying regions with potentially low water availability thus avoiding future production shutdowns.

Given the moratorium in place for groundwater extraction for water bottlers, these sub-watershed level initiatives should also be considered a vital part of the overall water resource management by the province (Conservation Ontario, 2016). These approved technical assessment reports and source protection plans are publicly available on the websites of individual conservation authorities and serve as a key resource for obtaining information on water stress for various sub-watersheds in the region. Thus, future water taking permits and allocations can be based on information provided in these reports by classifying various regions within sub-watersheds according to their water quantity stress levels.

Water Quantity and Quality Monitoring Programs

In order to monitor surface water flows, the federal government has developed and funded the ***National Hydrometric Program*** (NHP) that monitors and records data on the water levels, velocities, and volumetric flows of various surface water sources across Canada. In addition to water quantity monitoring, the ***Freshwater Quality Monitoring Program*** (FQMP) is a key water quality initiative undertaken by Environment Canada to ensure ecological integrity of various water resources across Canada. Under the NHP and FQMP, there are about 576 water quantity monitoring stations in Ontario along with 187 water quality stations recording and registering data that is publicly accessible through their website. This hydrometric data on water level, flows, and velocities has been used for various water management programs and policies (Environment and Climate Change Canada, 2014b, 2015).

At the provincial scale, with keen focus on groundwater monitoring, there are about 489 wells that are monitored for water quality and quantity in the region under the ***Provincial***

Groundwater Monitoring Network. In addition to groundwater monitoring, there are about 1129 surface water monitoring stations set up by the province and various conservation authorities across various sub-watersheds (Conservation Ontario, 2013). The data (quantity and quality) collected from these stations is an integral part of the various source protection, water quantity/drought management programs. The water flow triggers for the Low Flow Response Plan is primarily based on the real-time monitoring data obtained from these stations that are equipped with state-of-art equipment and technology. Since monitoring is an important part of various technical assessments as well as water management and planning activities, the federal and provincial government continues to invest and bolster its monitoring programs (Shifflett, 2014; Etienne, 2014).

2.5 Addressing Gaps in Water Management and Water Extraction Charges

Even though the rationale of applying charges for extraction and use of water resources is in line with economic demand management principles, the charge itself and implementation of the charges has been widely criticized for being insufficient. The per capita water extraction and water-intensity of Ontario's economy even post the PTTW conservation charges remains one of the highest among OECD countries (Environment and Climate Change, Canada, 2016). According to the Industrial Water Use statistics, the manufacturing sector in Ontario extracted about *1.4 Billion* m^3 *(1* m^3*= 1000 Liters)* of bulk water in 2013. The permit charges paid for this substantial abstraction volume was a meager *0.00005%* of the total production expenses for the manufacturing sector in 2013.

Majority of the costs associated with water in various manufacturing sub-sectors stem from operation and maintenance costs of the pumping infrastructure, intake/discharge treatment, and municipal fees paid for potable water. The actual license/permit fees paid for the extraction of bulk water or the price of the resource itself is a meager fraction of these water costs in Ontario (Statistics Canada, 2014). These permit charges based solely on recovering administrative costs of managing the PTTW program are imposed on only few industrial sectors (1% of the total permit holders) and found to be extremely low to effectively signal water scarcity, improve use-efficiency, and water conservation. Thus, contrary to their desired function, current bulk water prices and provincial water policies are largely deficient in materializing the objectives of sustainable water management and use (Environmental Commissioner of Ontario, 2015; Renzetti, 2017, Auditor General of Ontario, 2014).

According to Regulation 450/07 defined in the Ontario Water Resources Act, water charges for commercial and industrial users need to be reviewed every 5 years but the charges have remained the same in the last decade. Moreover, contrary to the original Water Conservation Charges Proposal, other medium consumptive use industrial sectors have not yet been phased in to pay volumetric water charges. Thus, the majority of the industrial sectors currently only pay the one-time flat application fee for the amount of water extracted and used (Environmental Commissioner of Ontario, 2014; Ontario Environment and Climate Change, 2007). Given the burgeoning water-intensity of the industrial sector and uncertainty in supply to satiate social, economic, and environmental uses, proactive reforms in current water pricing policy need to be devised for effective water demand management in Ontario (Canada's Ecofiscal Commission, 2014; Mohapatra & Mitchell, 2009; Morris et al., 2008).

The extensive water management initiatives discussed in Section 2.4.3 are a critical part of the overall water resource management that are funded by the federal and provincial governments through general tax revenues while all water use sectors are beneficiaries of these programs (Auditor General of Ontario, 2014). It has also been highlighted that these water resource assessments for source protection began in 2009 using water withdrawal data and hydrological information that will have to be continuously updated as scientific understanding on surface and groundwater interactions as well as forecasting models improve (Grannemann & Van Stempvoort, 2016; Kornelsen & Coulibaly, 2014). Thus, even with the Source Protection Plans approved by the MOECC, technical assessments of sub-watersheds for water quality and quantity can be anticipated as an ongoing initiative as part of managing sustainability of water resources in Ontario. Thus, the province and municipalities will continue to invest in various technical studies and source management programs to ensure sustainable supply and safe quality of water within local watersheds.

The current permit fees and volumetric charges imposed on few industrial sectors recover approximately $200,000 annually. At the very least, when costs attributable only to PTTW program and water quantity management ($17.5 Million annually) are considered these charges fall short of full cost recovery (Environmental Commissioner of Ontario, 2015; Ontario Ministry of Environment and Climate Change, 2017b). Therefore, if costs for all water management initiatives are accounted which are much higher than the partial costs considered for the current PTTW charges, these charges would need significant revision. Instead of a financially sustainable water resource management program funded equitably by all water use sectors (as beneficiaries) by earmarked revenues, the initiatives in Ontario rely on the common pool of tax revenue (Environmental Commissioner of Ontario, 2015; Ontario Ministry of Environment and Climate Change, 2017b). Given the investments and expenses incurred, from an economic standpoint, bulk water is a valuable resource yet provided nearly free of cost to industries that affect both water availability and quality of water. Thus the current provincial charges are not only insufficient in recovering costs incurred for water resource management but also fail to signal the risks and value of water resources to industrial users so as to encourage efficient water use (Environmental Commissioner of Ontario, 2015; Renzetti & Dupont, 2017).

In addition to the inadequacy of these conservation charges to curb excessive water demand and recover costs of resource protection and management, the PTTW program has also drawn criticism for over-allocation. Since charges are not differentiated based on total volume to be extracted, water users take permits for much higher volumes than actual water extracted and reported to the MOECC. Moreover, the volumetric charges are calculated on actual volume of water used and reported instead of permitted volume, thus there is no incentive for users to apply for permits closer to their actual requirements (Kreutzwiser et al., 2004). Water use has been regulated insufficiently especially for industrial sectors and water for these sectors remains to be an underpriced and hence over-extracted resource (Environmental Commissioner of Ontario, 2015).

As long as water is considered as a free, unregulated, abundant utility, there is no “business case” for water sustainability thus reinforcing chances of another impending “tragedy of the commons” (Debaere, 2014; Martinez, 2015). Therefore, it becomes pertinent to reform current water policies and use apt economic instruments to reflect the value of water resources and incentivize industries to invest in water efficient and environmentally benign technologies (Bruneau et al., 2013). Even though the PTTW program provides a basic regulatory framework for implementing water allocation and demand management initiatives, it needs significant reforms both in designing efficient water pricing framework as well as integrating the scientific sub-watershed assessments.

2.6 Significance and Implications of Research

Among many conflicts over competing water uses (domestic, agricultural, and industrial), the recent controversy over water taking by the water bottling corporation Nestlé in Guelph has been the impetus in triggering much needed reform in the PTTW program (Water Canada, 2016). Responding to the concerns of the residents of the environmental impact of water taking by bottlers in drought prone regions, the MOECC has imposed a moratorium on new water bottling permits till January 1, 2019 via Regulation O. Reg. 463/16 under the Ontario Water Resources Act, 1990. In addition to the moratorium, via Regulation O. Reg. 176/17, the province has also increased the volumetric charges for current permit holders in the water bottling sector to $503.71/million liters (Ontario Ministry of Environment and Climate Change, 2017a,d).

The ministry after acknowledging the insufficiency of current water charges for water bottlers, is also reviewing and considering policy reforms directed at overall sustainable management of water resources (Ontario Ministry of Environment and Climate Change, 2017b,d). However, issues pertaining to sustainability of water resources in the region go beyond water bottling and need to be addressed more holistically rather than focusing on individual sectors in a piecemeal manner (Water Canada, 2016).

In order to tread the path of sustainable development, looming threats on water resources across Ontario need to be mitigated by effectively managing water demand. Many industrial users have capitalized on valuable water resources in Ontario making lucrative gains whilst local aquifers and watersheds bear brunt of these abstractions (NRTEE, 2011; Renzetti, 2007). While the province continues to design plans and programs to ensure sustainability of water resources, use by different self-supplied sectors continues to be highly inefficient thus exposing deficiencies in current policies to manage water sustainably (Bakker & Cook, 2011; Renzetti & Dupont, 2017; Environmental Commissioner of Ontario, 2015). The value of water and impending risks on water resources need to be effectively signaled such that Ontario can proactively transition towards a more water efficient and water secure economy.

Given the moratorium in place, this provides a unique opportunity for actively exploring more efficient, robust, and dynamic pricing framework that can overcome the identified shortcomings in current water charges that can be equitably distributed among all water use sectors. Since the institutional setup for these charges already exists, this study will provide an objectively designed pricing tool that can integrate within the existing water management system. By arriving at a comprehensive bulk water pricing framework that is reflective of actual resource costs and regional water conditions, both cost recovery and water sustainability objectives can be realized (Rivers & Groves, 2013).

Pricing municipal water reflecting the economic costs of supply and treatment, as a “service” is fairly intuitive, where capital, operational and maintenance costs can be evaluated rather objectively. However, pricing bulk water to reflect the economic value of the “resource” itself is much more dynamic, involving ecological and hydrological economic assessments at the watershed level (European Environment Agency, 2013; Lant, 2004). While it has been established that current bulk water prices and policies in Ontario fail to incentivize sustainable water use, the larger question of operationalizing pricing principles into an efficient and dynamic bulk water pricing scheme largely remains unexplored in academic literature (Renzetti, 2007; Renzetti & Dupont, 2017). Therefore, based on identified gaps for effective water demand management, current academic and policy literature will be analyzed to extract global best practices that can be adapted to arrive at an efficient and dynamic bulk water pricing framework for Ontario.

3.0 Research Objective and Questions

The overarching objective of this study is to arrive at a dynamic sub-watershed based bulk water pricing framework that can effectively incentivize water use-efficiency and conservation of all water use sectors so as to transform Ontario into a more water-efficient economy.

Given the research objective, the study aims to address following questions:

RQ.1 What best practices are used to design bulk water pricing framework for sustainable water management globally and provincially within Canada?

RQ.2 Based on the best practices identified, how can a dynamically efficient bulk water pricing framework be designed integrating spatial and temporal considerations of water availability for Ontario?

4.0 Best Practices for Pricing Bulk Water Extraction

To gain a deeper understanding on how bulk water pricing and subsequently extraction charges can be designed for Ontario, a global and provincial scan of pricing practices is undertaken to address the first research question of the study. Article 9 of European Water Framework Directive (WFD) serves as a global model for introducing resource and environment costs as part of full cost pricing for the use of water resources (OECD, 2013, 2017). Tailored at the sub-watershed scale, member states need to account not only for the opportunity costs of abstracting water (resource costs) but also costs arising from degradation in water quality due to effluents discharged into water bodies (environmental costs). Moreover, OECD countries like Israel and Australia, once grappling with water scarcity have also effectively employed economic instruments like pricing to efficiently allocate water, reduce freshwater demand, promote water reuse, as well as induce technology innovation for water efficient products as well as processes in the industrial sector. Thus, globally there is a growing momentum towards employing full capacity of pricing instruments to realize sustainable water management objectives (Dinar et al., 2015; OECD, 2013).

While economic instruments like pricing are championed to be pertinent tools for effective water demand management, the methodology for designing efficient pricing schemes that cater to objectives of equity, economic efficiency, and environmental sustainability is highly nuanced and varies considerably across the globe (European Environment Agency, 2013; OECD, 2013). Even within Canada due to the decentralized institutional setup for water governance, there are multiple approaches and models followed by provinces for allocating water and designing bulk water extraction charges (Bakker & Cook, 2011). These best practices will provide a sound theoretical foundation with relevant practical examples that will help inform the final design of the pricing framework for Ontario.

Moreover, the Canadian Council of Ministers of the Environment published a policy paper in the year 2015 that outlines current practices across Canadian provinces and future recommendations for efficient water pricing. Thus, available global and Canadian literature can provide pertinent guiding principles for redesigning bulk water extraction charges framework for the context of Ontario.

4.1 Costs under Consideration for Pricing Bulk Freshwater Extraction

Under full economic considerations in line with the economic theory of pricing, the price of water should include the full financial/ economic costs of water resource management, environmental costs of ecological damage caused by water extraction as well as resource costs arising from allocation of water to a less water-efficient water use sector. However, the interpretation, scope, and methodology used to arrive at these costs as well as extent of recovery vary significantly across countries (European Environment Agency, 2013; Mysiak & Gómez, 2015). While the interpretation of different costs associated with the extraction and use of water resources vary across countries, the first stage of designing a pricing framework is to arrive at the objectives of the pricing policy. The range of objectives of water pricing can vary from cost recovery of water management, signaling risks associated with water resources, reflecting the value of water resources, incentivizing efficient use and conservation, or maintaining ecological integrity. While multiple objectives can be achieved in a single framework, the efficacy of economic instruments like pricing is achieved only if there is change in consumption behavior of end users (OECD, 2017; Olmstead, 2010; Ward & Pulido-Velázquez, 2008).

In the case of the European Union Water Framework Directive (EU WFD), the overarching objective for water pricing policies (by recovering full environmental and resource costs of water) is to "*provide adequate incentives for users to use water resources efficiently and contribute to the* ***good ecological status*** *of the water bodies*" (European Environment Agency, 2013). According to the European and OECD water pricing strategies, the concept of "water services" is defined above and beyond just municipal water supply and treatment. In fact from the context of water resources, provisioning services include flows for hydroelectric power generation, navigation, recreation, fisheries, waste assimilation services as well as supply and storage of raw/ bulk water for industrial, agricultural, municipal purposes. Thus, raw water extraction directly from the source is also a service further enhanced by water management initiatives undertaken by public authorities that assure a certain quality and quantity at the source itself. Thus, bulk water itself is value-added resource that becomes subject to a price based on the costs and benefits associated with its extraction or use (DG ECO2, 2004; European Environment Agency, 2013; OECD, 2013).

To arrive at various pricing schemes for water resources, it is important to understand various costs that can be considered for pricing various water services. These costs are defined based on the EU WFD and OECD considerations and can be attributed to individual service under consideration e.g. bulk water abstraction/extraction (European Environment Agency, 2013; OECD, 2017). For other countries and provinces like Ontario, the extent of applicability of each cost will be contingent on the regional hydrological status of the water resources, existing water demand, existing regulatory frameworks for water allocation, and guiding water policies (DG ECO2, 2004; European Environment Agency, 2013; OECD, 2017). Nonetheless, the nuances of these costs are crucial to understand and adapt relevant principles for the context of Ontario.

1. ***Economic Costs:*** Administrative and operating costs associated with permitting, regulating, and administering various water management programs, monitoring and evaluation costs of quantity and quality of water sources, drought management programs (e.g. low water flow response programs), environmental assessments and planning initiatives. These costs

also include the capital costs of providing infrastructure to regulate/maintain flows like reservoirs as well as equipment used for monitoring the water quantity and quality in streams and wells (DG ECO2, 2004; European Environment Agency, 2013). In the extreme case of water scarcity as seen in Israel or pollution remediation of water sources, costs incurred to supplement existing sources with an alternate sources or treatment to remove contaminants are also considered (OECD, 2017).

2. ***Resource Costs:*** Seen as potential rent for the use of scarce resources, which in the case of water can be temporal or spatial scarcity arising from multitude of reasons like physical depletion of water resources (droughts), degraded quality leading to abandoning of sources, or minimum requirements for environmental flows. These resource costs or alternatively the marginal opportunity costs of using a scarce resource can be designed in two ways. First, from a resource depletion perspective, the costs incurred due to over-extraction of the resource resulting in loss of economic benefits for future water dependent sectors and users can be estimated. Second, the loss of economic value/benefits of allocating the resource to an inefficient user (instead of alternate users) resulting in depletion of the resource can be estimated and accounted. Thus, resource costs reflect the hedonic, social, and recreational value of the resource by accounting for the forgone water use opportunities by other sectors if the inefficient allocation and abstraction by one user impairs the resource for others (DG ECO2, 2004; European Environment Agency, 2013).
3. ***Environmental Costs:*** Costs associated with environmental damage hence subsequent loss of ecosystem services due to anthropogenic extraction and pollution of water resources. For instance if inadequately treated wastewater or contaminants are discharged into water bodies that impair the ecological health or ecosystem services (recreation, fisheries, productive wetlands), the remediation costs or loss of benefits can be used to arrive at the environmental cost of the proposed activity/use. Alternatively from the perspective of productivity of water resources supplying a certain quantity of water for various uses, the ecological damage caused by over-extraction (beyond the rate of natural replenishment by precipitation) can be monetized as the environmental cost. In this case the production disruption costs incurred by various industrial sectors or provision of alternate source of water due water scarcity can be accounted as environmental costs (DG ECO2, 2004; European Environment Agency, 2013; OECD, 2017).
4. ***Environmental Protection Costs:*** In many countries, significant investments are made to proactively protect water resources and hence avoid future ecological damages caused either by abstraction or pollution. From the context of cost recovery, the expenditures of these preventative measures to avoid possible environmental damage are accounted as Environmental Protection Costs. Thus, the financial costs associated with these measures as part of the larger water resource management initiatives are internalized and reflected in the water price (DG ECO2, 2004).

The different categories of costs described above are not entirely mutually exclusive and thus cannot be simply added without due consideration for double counting. Resource costs arising from inefficient allocation over time generally incorporate the environmental costs incurred due to this allocation and in certain cases there may be no environmental cost associated with a user. Different methodologies are adopted for evaluating these resource and environmental costs based on principles of economic valuation including willingness to pay surveys (contingent valuation method), replacement/ remediation cost assessments, and hedonic property pricing (willingness to pay for pristine (high quality) environment) etc. It is also important to note that in many instances water use and pollution charges are considered in a unified framework thus the costs of over-extracting and wastewater discharge attributed to a sector are internalized in these calculations (DG ECO2, 2004; OECD, 2017).

Alternatively, various river basin authorities in Spain piloted a hydro-economic modeling study for estimating resource costs associated with the services provided by water resources at the basin scale. Using simulation and optimization models, a dynamic resource cost using hydrological information for estimated water supply and user demands was estimated by simulating the benefits associated with allocating the resource to the most efficient user (Pulido-Velazquez, Andreu, Sahuquillo, & Pulido-Velazquez, 2008). In Greece, resource and environmental costs are calculated at the basin scale as well but are based on the "avoidance costs" principle wherein the loss of economic value arising from hypothetical water restrictions is estimated. To estimate environmental costs for municipal and industrial sectors, the cost of constructing wastewater treatment facilities was calculated as proxy for the environmental impact of pollution or lost economic value of waste assimilation capacity of water resources.

In this analysis, specific sector based issues e.g. inefficient wastewater treatment or pollution from agriculture/livestock sectors were identified and costs of these internalizing these externalities were estimated (DG ECO2, 2004). Thus, even within the EU, member states employ a variety of methodological approaches to arrive at resource and environmental costs. These estimates rely on many assumptions with both environmental assessment and economic valuation (cost based or benefit based) of services provided by the regional water resources at the sub-watershed or river basin level (European Environment Agency, 2013). Operationalizing and accounting for these costs necessitates a combination of environmental and ecological valuation principles that are contingent on the spatial and temporal conditions of water resources (Lant, 2004). Thus, to account for different costs, previous government reports, ecosystem valuation studies, published remediation costs, etc. will have to be referred to extract pertinent costs at the sub-watershed level if extensive primary studies have already been conducted (Renzetti, Dupont, & Bruce, 2010).

In the absence of advanced hydro-economic modeling and economic analysis of ecosystem services as well as contingent valuation surveys, economic costs can be estimated by accounting for actual costs incurred by the government for implementing various water management measures for both prevention and remediation of past contamination events (used as a proxy for environmental costs). In other words, these costs can be representative of the economic value of a well-managed and sustainable resource as a result of these publicly funded water management initiatives (DG ECO, 2004). These costs are generally computed by accounting for various expenditures/investments made by public authorities in various water quantity and quality initiatives that contribute to the overall environmental management of water resources (OECD, 2017).

4.2 Different Methodological Approaches for Pricing Water Resources

In the absence of traditional competitive markets for water (excluding the countries that have designed markets to trade water rights), pricing the services provided by water resources becomes complex. To arrive at various resource and environmental costs associated with water resources as elaborated in Section 4.1, it is necessary to calculate the economic value of the benefits provided by these resources at the regional sub-watershed scale (Getzner, 1999; Olmstead, 2010). While certain uses and benefits of water are inherently obvious e.g. extractive uses for manufacturing, municipal water supply, power generation, there are many in-stream as well as indirect services/uses of water resources that need to be valued and monetized since water allocation to one user impairs access for users downstream (Dupont & Adamowicz, 2017). Although valuing or monetizing the complete spectrum of ecosystem services provided by water resources is not always used to calculate the price for water extraction, valuation can also be extremely useful for other purposes. For instance, economic valuation of all water related ecosystem services have been proposed to help allocate sensitive water resources like groundwater among various users (Brouwer, Ordens, Pinto, & Condesso de Melo, 2018). Moreover, valuation is a key component of cost-benefit analysis that is undertaken for environmental project assessments and investments. In many cases of extreme contamination events like the Exxon Valdez oil spill ecosystem valuation provides the basis of calculating the total economic liability of damage caused that is payable by the polluting company (Canadian Council of Ministers of the Environment, 2010; Dupont & Adamowicz, 2017).

One of the major impediments in promoting sustainable use and management of water has been the lack of appropriate signals that reflect value as well as risks associated with water resources resulting in the misconception of water being an infinite and free resource that continues to be over-extracted (NRTEE, 2011). However given the temporal and spatial scarcity of water resources as well as growing competing demands among users, water policies need to be geared towards efficient allocation as well as incentivizing conservation behavior (Dupont & Renzetti, 2008). Thus, ***Total Economic Value (TEV)*** framework utilized by academia and policy makers not only classifies all possible uses and services provided by water resources but also monetizes the benefits provided by those services/uses thereby quantifying the economic contribution of these resources (Dupont & Adamowicz, 2017; Renzetti et al., 2010).

Moreover, the resource and environmental costs defined in the EU WFD suggest the use of similar frameworks to arrive at full cost pricing that is reflective of the overall economic value of water resources thereby bridging the value and price gap (European Environment Agency, 2013). As outlined in the United Nations System of Environmental and Economics Accounting, the valuation of services and goods provided by natural resources is seen as a strong foundation for championing preservation and sustainability of critical natural capital. However, before accounting for the monetary value, various categories of direct and indirect use as well as non-use/passive value of water resources are defined as follows (Canadian Council of Ministers of the Environment, 2010; Dupont & Adamowicz, 2017; Renzetti et al., 2010):

1. ***Direct use value of water resources***: These uses include the extraction of water for the purposes of drinking water (municipal supply), manufacturing, agricultural production, thermal power generation, fishing, etc. Non-consumptive (in-stream) direct uses include water flow diverted or altered for hydropower, recreational use (boating/water sports/swimming), marine transportation, tourism (lakefront and beaches), aesthetic preference for properties etc. (Renzetti et al., 2010).
2. ***Indirect use value of water resources:*** These uses include the complete portfolio of ecosystem services provided by water resources including waste/pollution assimilation, nutrient cycling, climate regulation, supportive ecological habitats for preserving biodiversity, flood control, base-flow provided by groundwater to maintain surface water stream-flows (drought recovery) as well as temperature regulation of streams and other regulating functions (Dupont & Adamowicz, 2017; Renzetti et al., 2010).
3. ***Non-use or passive value of water resources:*** These subjective values are not based on the use of water resources but on the assurance of preservation and existence of these resources for current and future use (intergenerational equity). Thus passive valuation is intrinsically driven and is contingent on individual preferences for maintaining or

protecting quality and quantity of water resources or the ecosystems supported by these resources (Renzetti et al., 2010).

The Total Economic Value of water resources is the sum of both Use and Non-Use monetary value that is estimated using economic valuation methods at different spatial scales of analysis. The economic methods used to estimate the aforementioned values of each of the different component of the TEV framework are highly variable and rely on carefully designed studies to gather relevant data dependent on available time and resources. As an alternative, secondary data from previous studies for different regions/countries can be used in a "benefits transfer" approach by acknowledging the errors due to spatial variation. Using valuation databases like Environment Canada's Environmental Valuation Reference Inventory (EVRI), access to previous valuations studies can be obtained. However, before choosing the applicable valuation method, it is crucial to determine the objective of water valuation and assessing if it is necessary to conduct a full-fledged study (Canadian Council of Ministers of the Environment, 2010; Dupont & Adamowicz, 2017).

A comprehensive study funded by the province of Ontario was undertaken to evaluate the "Economic Value of Protecting the Great Lakes" in 2010. This report provides useful insights on the various monetary values calculated for provisioning, regulating, and cultural services provided by the Great Lakes basin including the value of freshwater supply and storage. According to the report a proxy economic value of groundwater was estimated at $7/m^3 by an Environment Canada study that calculated the cost of avoiding water to be pumped from Lake Ontario via a pipeline to the town of Caledon. Hence this avoided cost of using an alternative water source was used to estimate the value of freshwater supply and storage provided by local groundwater sources. Similarly costs for some of the ecosystem services like water treatment, wastewater assimilation, and flood control, etc., can be estimated from alternate infrastructure costs or costs of avoided damage. For instance the value of water supplied by these sources as well as natural filtration functions (wetlands and natural dilution) provided can be estimated from costs of intake water treatment plants as well as avoided damage costs of illness due to drinking water contamination (Renzetti et al., 2010).

For estimating the value of bulk water used as a material input for industrial use, there are econometric studies that employ production input methods to simulate the change in overall costs borne by a sector if water intake is reduced for a given production output. The shadow price for raw water is estimated statistically as the additional price paid by firms to continue using water as a free resource. These studies arrive at "shadow price" of water for each manufacturing sub-sector that may use water either directly as a material input (process water) or for cooling/ heating purposes. These estimates however are not only contingent on the type of manufacturing sub-sector but also the value that a sector places on water internally as a utility in regions where raw water is typically not priced (Dachraoui & Harchaoui, 2004; Dupont & Renzetti, 2008; Renzetti et al., 2010).

For estimating the value of services that are primarily related to recreation, hedonic property, *revealed preference methods* like travel costs spent for recreational sites are used. Another valuation method that is popularly used to estimate both use and passive value of water resources are *contingent valuation* method. This survey-based method is used to estimate the willingness to pay or willingness to accept changes as revealed by respondents in the region. A specialized questionnaire is designed so as to record the willingness of respondents to pay for a certain ecosystem service or environmental quality under certain hypothetical scenarios.

Alternatively in a choice modeling approach, various ecosystem services are listed with an attached price and respondents choose their preferred option (Canadian Council of Ministers of the Environment, 2010).

These various economic valuation methods vary in their scope have been used to estimate both use and passive economic value of water resources for different purposes including policy decisions. Nonetheless each method suffers limitations as well as constraints of time and resources to conduct a comprehensive regional study. Thus, unlike direct market valuation methods used to price regular economic goods and services, valuation of water resources requires a conglomeration of different methods, studies, and approaches. While the concept of value of water is an overarching concept to signal the benefits provided by water resources and associated ecosystem services, pricing of water may only use ecosystem valuation to determine the environmental costs associated with extraction and pollution of water (Krantzberg & DeBoer, 2008; Renzetti et al., 2010).

Theoretically, the full costs of water resources should incorporate the environmental costs due to lost benefits of allocating resources from other users/ services but practically water abstraction charges are set based on approaches decided by the governing public authorities (OECD, 2017). While ecosystem valuation methods are more popularly used for arriving at pollution taxes and water quality trading between users, in certain cases opportunity costs for water allocation are also evaluated based on these valuation techniques (European Environment Agency, 2013; OECD, 2017). In the context of the Great Lakes basin, ecosystem valuation has been undertaken to assess the economic efficiency of various remediation programs and Great Lakes Action Plan using the costs-benefits approach (Brouwer & Pearce, 2005; Dupont & Adamowicz, 2017).

For the purposes of pricing and water allocation in the Canadian context as suggested by the Canadian Council of Ministers of the Environment in their comprehensive report on water valuation, Total Economic Valuation of water resources is not a prerequisite to arrive at water pricing. Although it is a useful tool to signal the overall comprehensive "value" of water resources, provinces across Canada have refrained from using this approach to arrive at abstraction charges or opportunity costs associated with water extraction (Canadian Council of Ministers of the Environment, 2010; Dupont & Adamowicz, 2017; Dupont & Renzetti, 2008; Renzetti et al., 2010). Nonetheless, these studies do provide a sound basis of comparing current water prices to the actual economic value of these resources so as to signal the importance of efficiently using and sustaining these valuable resources. While cost recovery of water management and environmental costs remain a popular choice in the Canadian context, global examples and practices do provide important nuances to be considered for improving existing pricing approaches. Moreover, to avoid the adverse event of degraded water resources, eventually move towards integrating full environmental and resource costs of water extraction on users (Canadian Council of Ministers of the Environment, 2010, 2015).

4.3 Volumetric Rate Structures for Cost Recovery and Demand Management

The key objectives of using economic instruments like extraction charges is not only to recover economic, resource and environmental costs but also promote conservation, use-efficiency and reduce pollution (Bruneau, Dupont, & Renzetti, 2013; European Environment Agency, 2013; OECD, 2013). Thus, the objective of pricing for overall sustainable management of water resources transcends beyond a static flat extraction charge. Dynamic consumption-based volumetric pricing structures tailored for water source conditions (temporal availability and quality) have been used to cater to water conservation and efficiency goals (de Gispert, 2004; OECD, 2013, 2017).

Widely used for municipal water tariffs, these rate structures are based on using a fixed and volumetrically linked charge in tandem. Volumetric rate is the price a user pays per unit volume water abstracted. In contrast to a flat (volume independent) or fixed charge, volume dependent charges incentivize conservation and promoting use-efficiency. There are multiple volumetric rate structures like uniform, linearly increasing, as well as seasonally variable that are employed to achieve different conservation objectives. However, the efficacy of a rate structures and extent to bring about change in demand is variable and highly contingent on individual use sector. Thus to arrive at an efficient pricing scheme, the impact of different rate structures needs to be analyzed and compared while accounting for affordability constraints (de Gispert, 2004; Griffin, 2016).

Different rate structures that can be used to arrive at different water pricing schemes are discussed below and depicted in Figure 6.

1. ***Fixed Flat Rate:*** One-time permit or license fee is charged irrespective of the volume of water consumed by end user. Even though it may be possible to recover fixed costs associated with extraction, there is absolutely no signal for conservation. Although failing to cater to water sustainability objectives, this structure is easiest to implement without any requirements for volumetric monitoring (Renzetti, 2007; Canada's Ecofiscal Commission, 2017).
2. ***Fixed and Uniform Volumetric Rate:*** In a two-part rate structure, there is a flat license fee and a price charged uniformly per unit volume consumed. While a more economically efficient charging scheme, the conservation signals are weak if the charges are not reflective of the varying scarcity conditions of the source or the peak demands of high-use sectors. Moreover, monitoring and reporting becomes a crucial aspect of these volumetric consumption based water charges framework (Mysiak & Gómez, 2015; Vander Ploeg, 2011; Brandes, Stinchcombe, & Renzetti, 2011).
3. ***Increasing Block Volumetric Rate:*** In addition to the fixed charge, this rate structure increases the price charged as volume consumed increases beyond a certain threshold. The conservation signals are high in this scheme and is most effective in curbing demand as well as incentivize use-efficiency especially for highly stressed water resources within sensitive watersheds. In order to cater to the concerns for affordability, a certain threshold "lifeline" volume is provided at minimum rates but concerns of dis-incentivizing economies of scale and economic competitiveness need to be addressed. (OECD, 2017; Vander Ploeg, 2011; Brandes, Stinchcombe, & Renzetti, 2011)
4. ***Seasonal Humpback Rates (Surcharges):*** Similar to increasing block rates, seasonal humpback rates are designed to serve as an additional surcharge that is imposed to signal temporal resource scarcity. Therefore, if there is a resource with seasonal supply variability, an add-on charge is levied on the users temporarily. If seasonal projections are available this allows the users to plan their production in accordance with the seasonal watershed conditions (Canada's Ecofiscal Commission, 2017; Renzetti, 2017; Brandes, Stinchcombe, & Renzetti, 2011).

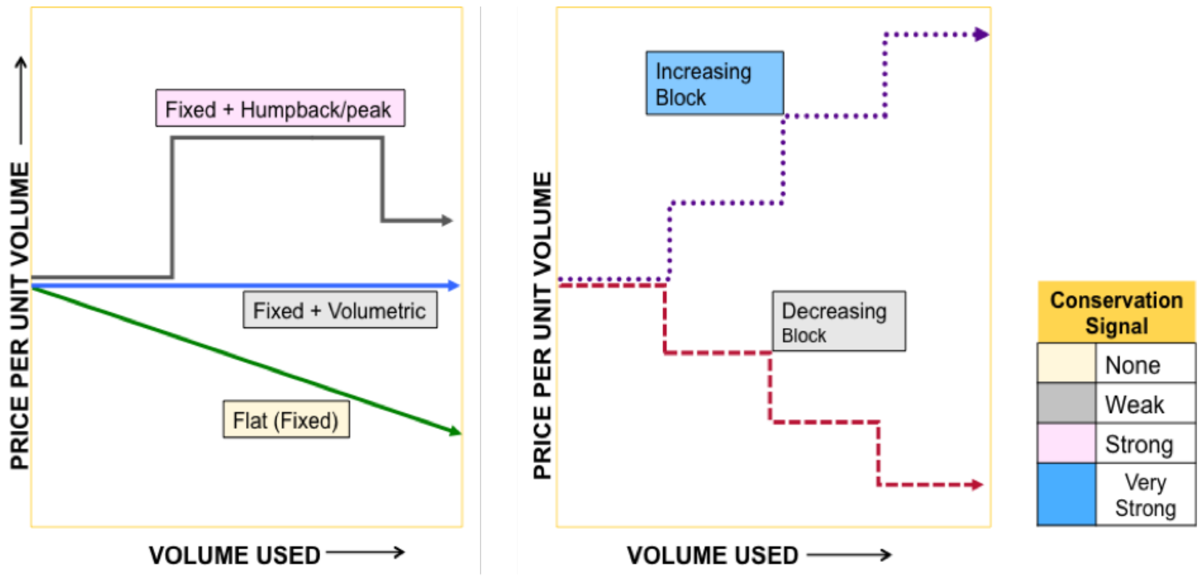

Figure 6: Various Volumetric Tariff Structures
Adapted from Sources: Griffin (2016), Beecher, Mann, Hegazy, & Stanford (1994), Canada's Ecofiscal Commission (2017)

Municipal volumetric water pricing based on different rate structures has been extremely effective in curbing excessive residential water demand and promoting domestic conservation initiatives in Ontario (Bruneau et al., 2013; Renzetti & Dupont, 2015). Similarly, bulk water pricing schemes based on dynamic rate structures for self-supplied commercial and industrial users may likely prove equally effective if instituted by the provincial government. Thus, in order to employ economic instruments like pricing, in addition to arriving at the price for water based on dynamic resource costs, it is equally important to design innovative pricing schemes to achieve the holistic goals of sustainable water management in Ontario.

Although increasing block tariffs are most effective in curbing water demand, designing an equitable and efficient increasing block tariff for self-supplied users is complex and requires metering and regular monitoring by public authorities thereby increasing the costs of water management substantially (de Gispert, 2004; Ontario Ministry of the Environment, 2007). However, in the case of sensitive water sources or watershed conditions, the provincial government can consider using increasing block charges for self-supplied water. Alternatively, seasonal surcharges as well as sub-watershed, sector, and source specific price multipliers can be used to volumetrically differentiate prices in addition to a base volumetric price designed for water extraction in the province.

4.4 Sustainability Considerations for Pricing Models

To arrive at equitable pricing schemes for various water services, it is widely recognized that objectives of social equity (affordability, material welfare, fulfillment of basic human needs), economic efficiency (cost recovery and financial sustainability for water management initiatives), and environmental sustainability (conservation of natural capital and ecological integrity) need to be balanced (Beecher & Shanaghan, 1999; Hediger, 2006). Thus, in addition to accounting for full costs to be recovered from users, equitable, efficient, and regionally attuned pricing schemes need to be designed in order to cater to the aforementioned objectives.

Viewing water resource management from the lens of sustainable development (social welfare, economic development, and ecological integrity) different water pricing models can be conceptualized based on the continuum of very weak to very strong sustainability principles that can be the basis of designing the rate structures discussed in Section 4.3. While sustainability broadly considers the preservation of critical natural capital and fulfillment of basic human needs, the concept can be further deconstructed into a range of economic and biophysical considerations (Hediger, 2006).

1. ***Very Weak Sustainability:*** In its very basic interpretation, the focus of very weak sustainability as elaborated by Solow (in line with the neoclassical economic theory) is on enabling constant per capita consumption. The outcome of sustained economic growth is the generation of material welfare and implication on natural capital and social welfare are not considered in the context of weak sustainability. From the perspective of pricing water use and extraction, prices if imposed are not based on resource/environmental costs but only on recovering economic costs incurred by public authorities while ensuring economic competitiveness or growth in the region. Thus, industrial and commercial users using bulk water as an economic resource are only charged administrative costs of licensing/permitting. The environmental objectives are not prioritized proactively in the absence of physical scarcity of water. A flat non-volumetric or declining block rate water price is charged to users that incentivizes consumption over conservation (Beecher & Shanaghan, 1999; Hediger, 2006).
2. ***Weak Sustainability:*** Building on the very weak sustainability model, weak sustainability implies a constant total aggregate capital (K) comprising of natural, man-made (material welfare), and social (affordability, normative values) capital:

   $$K_{Total} = K_{Material} + K_{Social} + K_{Natural}$$

   In the context of weak sustainability, natural capital is substitutable to an extent wherein material capital can perform the same functions as that of natural capital and there is generation of material welfare, financial growth, technical knowledge, and intellectual capacity for future generations. Thus, in addition to economic growth and productivity, social welfare or affordability is duly considered as a critical aspect of setting water prices to users (Hediger, 2006). A volumetric price based on partial recovery of only economic/administrative costs are in line with this model however provision for subsidies based on affordability can provided with reliance on more voluntary approaches like use-restrictions for conservation.
3. ***Strong Sustainability:*** The underlying premise of strong sustainability models is the non-substitutability of critical natural capital. Capitalizing or extracting natural resources irreversibly beyond the natural rate of replenishment as seen in the case of water resources should be restricted thus maintaining the ecological integrity of water resources. Thus, the environmental and resource costs of water use are considered in addition to social welfare and economic considerations for water pricing (de Gispert, 2004; Hediger, 2006). An increasing block tariff recovering full economic, resource, and environmental costs along with seasonal surcharges can be imposed in this model. However similar to social municipal water tariffs for low-income households, a basic "lifeline" volume can be provided in line with the social affordability goals for small and medium businesses (Beecher & Shanaghan, 1999; Canada's Ecofiscal Commission, 2017).
4. ***Very Strong Sustainability:*** As an extreme case of strong sustainability, very strong sustainability implies prioritizing conservation of natural capital over economic growth and material capital. The functions provided by natural ecosystems are considered unique and need to be preserved for future generations. In this case if water resources are priced, the price will be close to the full value derived from the TEV framework discussed in Section 4.2. Going above and beyond sustaining environmental quality, the premise of very strong

sustainability calls for no further change in ecological systems for future generations. Thus, under the very strong sustainability model water resources if extracted need to be returned to the original environment in its original state by complete removal of anthropogenic contaminants/pollutants. Under the strong sustainability model, economic instruments like pricing is complemented by use restrictions, highest standards of water quality, and legally enforced compliance to regulations (Hediger, 2006; OECD, 2013).

Under business as usual conditions, if anthropogenic pressures on natural resources grow and natural capital dwindles, in order to maintain inter-generational equity, the shift towards strong and very strong sustainability models can be anticipated for water pricing. (Getzner, 1999; Hediger, 2006) For water resource management under the strong sustainability regime, economic instruments like pricing and regulatory instruments will have to be integrated in the same framework. The resource and environmental costs in such a case (either marked by actual resource scarcity or pollution event) will be highest and include supplementary water sources like desalination to fulfill domestic water demand (OECD, 2013). Thus, depending on the hydrological and policy context of a region, water pricing models can fluctuate from a water abundant-reactive very weak sustainability model with higher social/environmental implications to a water scarce-proactive very strong sustainability model with higher economic implications.

4.5 Best Practices for Designing Dynamic Bulk Water Extraction Charges

In order to arrive at sound pricing principles for bulk water extraction, some global and Provincial examples are provided below summarizing their practices and approaches. As discussed earlier, the EU Water Framework Directive is a key model framework for introducing economic instruments for water management. Thus, some member states of the European Union as well as OECD countries like Australia and Israel that have been recognized in literature for their use of economic instruments for water demand management are included in this study (OECD, 2013, 2017). The synthesis provided below is based on literature survey of key policy documents published by the European Environment Agency, OECD, individual Government agencies, as well as academic research papers for the purposes of corroboration. For the provincial examples, Government regulations for water pricing, policy briefs, and academic papers were reviewed.

4.5.1 Global Examples of Bulk Water Extraction Charges

1. ***Water Abstraction Charges in England and Wales*** (OECD, 2017; Vander Ploeg, 2011)***:*** Extraction of water from different sources by users requires a license and is subject to a multi-part Water Abstraction Charge governed by the Environment Agency (England) and Natural Resources Wales. The full charge comprises of a fixed charge covering the administrative costs of licensing supplemented by an annual volumetric charge that further comprises of a standard charge (for regulating and managing water extraction and recovering costs of water resource management), compensation charge (imposed on high volume users), and an environmental improvement charge (costs to remediate the environmental damage due to water extractions) that varies regionally and is contingent on the watershed conditions.

$$\text{Water Abstraction Charge} = \text{Fixed Application Charge} + \text{Annual Volumetric Charge}$$

$$\text{Annual Volumetric Charge} = \text{Standard Charge} + \text{Compensation Charge} + \text{Environmental Improvement Charge}$$

The guiding principle behind the design of these charges is the full recovery of all costs borne by the regulator not only to administer the licensing program but also for all water resource management, monitoring, and enforcement activities. All technical assessments and planning activities to ensure source sustainability and productivity as well as hydro-ecological studies are funded by the imposed charges. The charges are calculated based on the permitted extraction volumes rather than water actually used by different sectors. Thus, the volumetric charges is based on i) the type of source (unregulated surface/groundwater or reservoirs/ pumped groundwater), ii) season of extraction (summer, winter, or all), iii) Consumptive factor (high consumptive use implies the volume of water extracted is not returned to the original source e.g. water bottling sector) iv) watershed/basin specific management charge e.g. scarcity charges

Annual Volumetric Charge = Volume licensed x Source factor x Seasonal factor
x Consumptive use (sector specific)
x Basin sensitivity/scarcity factor

2. ***Water Levy or Eco-Tax in Spain*** (European Environment Agency, 2013; OECD, 2017; Pulido-Velazquez et al., 2008)***:*** In a decentralized approach, the license or permit to extract and use water resources in Spain is administered at the river basin level by various River Basin Authorities. All water use sectors (in-stream and extractive) need to acquire this permit and pay an "Eco-tax" or water levy, which is a combined tax for the use of water resources for extraction and discharge of effluents. Based on the EU WFD principles of cost recovery (Article 9) this levy is designed to recover both resource costs (reflective of regional scarcity rents) and environmental costs (externalities due to impaired quality or over-extraction) pertaining to the supply and quality of the regional water resources.

   Even though agricultural and livestock water users are exempt from volumetric charges, in case of pesticide or excessive nutrient run-off that pose a water quality threat, charges can be imposed. Interestingly, Spain charges a special fee for water used in hydroelectric power generation differentiated based on the installed capacity of the plant. The charge is a fixed percentage of the market value of the power generated and is earmarked for funding future water resource conservation activities. The charge seems similar to the "water rental charge" levied on hydroelectric power plants in Ontario. However unlike Spain, the water rental charge levied in Ontario is neither earmarked for water resource management nor is a fixed percentage of revenue marked for conservation authorities.

3. ***Bulk Water Abstraction Charge in France*** (Dinar, Pochat, & Albiac-Murillo, 2015; OECD, 2017)***:*** Water abstraction charges in France are also administered and managed at the river basin scale by various Water Agencies. The charge itself is a volumetrically based tax and differentiated based on the type of source (groundwater or surface water), type of use sector (municipal, agricultural, or industrial), and sensitivity of the basin (quality or quantity). Generally, France has productive water resources with good ecological quality. However, similar to the case of Ontario, France also faces temporal and spatial water scarcity during summers giving rise to conflicts among competing water users. Thus, water abstraction charges in France are used primarily for allocating water resources among users by assigning fixed "water quotas" as well as imposing a scarcity rent during extended periods of droughts in conjunction with use-restrictions.

4. ***Water Abstraction Charges and Groundwater Tax in Belgium*** (OECD, 2017)***:*** In Flanders region, volumetric water abstraction charges are imposed by the regional authorities in

conjunction with the water permitting system. While the charges for surface water sources are lower and mostly charged on a declining block rate, groundwater charges are not only higher varying by aquifers but also are also charged on an increasing block rate wherein the charge increases with increased volume of extraction by different use sectors. The differentiation of prices by the type of source is an effective way of signaling sensitivity of certain sources to water quantity and quality issues.

5. ***Water Resources Charges in Portugal*** (OECD, 2017)***:*** The Water Resources Tax administered by the River Basin Authority is a combined tax imposed on all users for the use of water resources as well as discharge of effluents. Based on the "user pays" and "polluter pays" principles, the volumetric tax is contingent not only on the type of use sector but also the scarcity of water resources in different regions. The tax is designed to recover environmental costs associated with certain sectors, economic benefits (private profits) from the use of a public resource as well as the administrative costs related to various water resource management activities like planning, supervision, monitoring, evaluation, quality and quantity assurance.

   To signal the regional scarcity conditions, the volumetric charge is further multiplied by a "scarcity coefficient" that varies from 1 to 1.2 depending on the location of water extraction thus arriving at a region specific "scarcity rent". The overall Water Resource Tax thus consists of a volumetric water abstraction charge for using public resources, the amount paid for discharging effluents into the water bodies (per Kg of BOD/COD limits), scarcity rent imposed, and volumetric price paid to compensate water management and planning activities. Depending on the use-sector the tax can also include additional charges for gravel extraction or compensation for building infrastructure on natural waterways (hydropower dams, reservoirs etc.).

   This multi part additive charge structure is regularly updated with the latest addition of a charge to promote "sustainability for water services". The rationale of the tax is based on the two-fold principle of incentivizing water efficient behavior and allocation of water resources to high value uses. The revenue generated is split between the regional authorities that recycle the funds into water management activities and the national authority for their expenses as well as contribution to the National Environmental Fund that finances special projects for different river basins. Thus, the comprehensive Water Resources Tax of Portugal provides a unified framework that integrates price differentiation based on regional sub-watershed conditions, different use-sectors, and effluent pollution, in addition to recovering costs for water management activities.

6. ***Water Abstraction Charges in Germany*** (European Environment Agency, 2013; OECD, 2017)***:*** Water abstraction charges in Germany are part of the broader environmental policies administered and regulated by the state governments. Water extraction above 4,000 m^3 per annum requires a permit and is liable for a volumetric charge for both surface and groundwater sources. The rationale for the charges is to reduce water extraction as well as recover funds for future environmental management activities and other conservation projects. All water use sectors require water meters and require mandatory monitoring and reporting. The water policies for water abstraction in Germany are bolstered by a strong regulatory framework as well as the use of forecast models to assess demand and hence allocate water resources. However, there are provisions for exemption from abstraction charges for industries that can prove loss of economic competitiveness

arising from these charges after implementing water efficient processes, environmental management systems, and other conservation measures in operations.

7. ***Water Abstraction Charges in Israel*** (Becker, 2015; OECD, 2013, 2017)***:*** Water pricing has become a pertinent policy tool to effectively manage stressed water sources in Israel. With limited capacity of freshwater supply to meet the total water demands, the country has relied on alternate sources of water including desalinated water as well as recycled and treated wastewater. Water extraction for self-supplied users is charged based on the volume, sector of use, scarcity conditions, and source of water. Freshwater if extracted is charged based on an increasing block rate and each user is allotted a maximum use quota. The scarcity rents contingent on the season and region of water extraction are also charged based on an increasing block rate.

   Since desalinated water is expensive and energy intensive to produce, the charges of supplying desalinated water are substantially high. Thus, sectors that rely on high volumes of water tend to be more water-efficient to avoid the costs of purchasing desalinated water. Agriculture is the highest user of water in Israel and over the years has adopted highly water efficient irrigation practices utilizing treated wastewater instead of more expensive freshwater or desalinated water supply. Treated wastewater is the least expensive source of water and is widely used in agriculture. Given the widespread water scarcity in the region, reduction in water allocation quotas and increasing price of water, not only did the agriculture sector reduce its water demand by increasing water-efficiency but also increased their total production output thus exemplifying the efficacy of economic policy instruments like pricing for achieving eco-efficiency.

8. ***Water Abstraction Charges in Australia (Australian Capital Territory)*** (OECD, 2017; Vander Ploeg, 2011; ACT Environment, Planning and Sustainable Development Directorate, 2014)***:*** Australia is a naturally arid country with certain regions prone to severe and extensive droughts. The Murray-Darling Basin is not only one of Australia's largest river basins hosting a large population but also is one of the world's driest basins thus making water resource management a key priority of the Australian Capital Territory (ACT) Government. Agricultural irrigation is one of the main users of water and over the years a mix of economic and regulatory instruments have been an integral part of water policies across different States. In the Australia Capital Territory, water is allocated by a license to take and use water and a "Water Access Entitlement" is the right of the user to take the authorized volume from a specific area.

   The users can trade or reallocate these water rights in established water markets subject to approval by the Environment Protection Authority. The prices of these traded rights are thus set by market-based approaches and tend to increase during water scarcity. The original volume of water to be allocated for different sources is assessed by the Environment Protection Authority based on seasonal and regional scarcity as well as minimum amount required for environmental sustainability of water resources. Both license to take water and water entitlements are subject to an administrative fee and can be traded but the actual extraction of water from surface and groundwater sources is also subject to a separate volumetric water abstraction charge.

   The rationale for the water abstraction charge is primarily to reflect the value of scarce water resources in the region and recovering the costs incurred by the Government to manage, plan, assess, and monitor these resources (quantity and quality) as well as to administer the water-trading program. The water abstraction charge (single price for groundwater and surface water) is based on the opportunity costs of scarcity i.e. the loss in value by not allocating water to a valuable economic activity e.g. irrigation. The charge is also based on the environmental costs of maintaining environmental flows and impact of dams on downstream uses.

4.5.2 Provincial Examples in Canada of Bulk Water Extraction Charges

Overall water governance in Canada including management, allocation, and preservation of water resources is primarily the responsibility of individual provinces. In this highly decentralized setup with minimum Federal involvement, each province has established their own set of rules and regulations for water resource management. For the purposes of this analysis only 3 examples are considered where the province of Saskatchewan has been recognized as a water stressed region as depicted in Figure 1 owing to its natural variability of water supply (Statistics Canada, 2017). The province of British Columbia has most recently updated its Water Sustainability Act and there has been a lot of academic focus on the water regulatory frameworks that provide nuanced discussions on the same (Brandes & Curran, 2017). The province of Quebec neighboring Ontario and also perceived to be water abundant has imposed volumetric charges for water use starting January 1st, 2011. Similar to Ontario, Quebec also has the same bi-national trans-boundary commitments under Great Lakes - St. Lawrence River Basin Sustainable Water Resources Agreement for water sharing and assuring sustainable water resources with the United States (Province of Quebec, 2011; Vander Ploeg, 2011). The examples given below provide important insights on some of the unique approaches followed within Canada to price bulk water extraction.

1. ***Industrial Water Charges in Saskatchewan, Canada:*** With an exception of domestic water use, all other sectors need prior approval from the Water Security Agency of Saskatchewan for extracting groundwater and surface water. The Water Security Agency is a Crown Corporation established to undertake all water management activities to ensure sustainable use, quality, and ecological integrity of all water resources in Saskatchewan. In addition to applying for the license and approval (subject to a license fee) to acquire the right to use provincial water resources, the Water Security Agency also administers a volumetric charge exclusively on industrial water users (Water Security Agency, 2015). This industrial water charge is imposed not only to promote efficient use of water but also to recover the costs incurred by the Agency to manage water resources.

   This volumetric charge based on actual volume extracted by users and varies with location and quality of water resources (Canadian Council of Ministers of the Environment, 2015). Certain high use and specific quality water sources (total dissolved solids < 4000 mg/liter) are charged a higher rate than others and the charge varies from $46.20 to $1.86 per million liters. However, sectors like agriculture and livestock are exempted from the charge even though these sectors are major water users in the Province. In such cases command and control based regulatory initiatives as well as voluntary stewardship programs are used to manage agriculture water demand while economic instruments like charges are imposed on other industrial sectors including thermoelectric power generation (Water Security Agency, 2015; Ontario Ministry of the Environment, 2007).

2. ***Charges Payable for the Use of Water in Quebec, Canada:*** The province of Quebec passed the "Regulation Respecting the Charges Payable for the Use of Water" under chapter Q-2, r.42.1 of the Environment Quality Act on January 1st, 2011. The core objective of the

charges was to signal and promote sustainable use of water resources especially by industrial sectors that withdraw copious volumes of water (Quebec Minister of Sustainable Development, Environment, and Parks, 2010; Province of Quebec, 2018). The regulation imposes a volumetric charge on the "use" water resources by industrial manufacturing sectors in excess of 75,000 Liters/day. In the context of this regulation, the term "use" encompasses withdrawals from municipal systems, direct surface water and groundwater resources as well as any diversion or removal of groundwater.

A higher volumetric charge of $70/Million Liters is imposed on sectors that are considered to be highly water consumptive (water bottling, beverage manufacturing, non-metallic mineral product manufacturing, pesticides, fertilizer or other chemical manufacturing, inorganic chemical manufacturing, and oil and gas extraction. The remaining manufacturing sectors are charged $2.5/Million Liters. Moreover, under the Regulation Respecting the Declaration of Water Withdrawals (Chapter Q-2, r.14) all water users who withdraw water and are liable for the charges are also required to report their monthly and annual withdrawal volumes to the Ministry of Sustainable Development, Environment, and Parks (Province of Quebec, 2018).

In contrast to Ontario, not only does Quebec charge a higher price for sectors that are highly consumptive but also uses these funds to finance various water resource management initiatives under the collective "Green Fund" (Quebec Minister of Sustainable Development, Environment, and Parks, 2010). While the rationale for the charges is similar to Ontario focused on the principles of conservation, use-efficiency, and quality of water resources (in line with the commitments for the bi-national Great Lakes - St. Lawrence River Basin Sustainable Water Resources Agreement), the charge itself is significantly higher. Moreover a significant section of the regulation is dedicated to defining various fines and legal punishments for offences committed under non-compliance or falsification of information pertaining to reporting of water withdrawals (Province of Quebec, 2011; 2018).

3. ***Water Sustainability Fees, Rentals, and Charges in British Columbia, Canada:*** Under the British Columbia Water Sustainability Act, water abstraction, storage, and diversion by users requires a Water License and Use Approval. The province of British Columbia assigns the right to use water resources after technical reviews and assessments contingent on the location and sector of proposed water extraction/use. With recent changes in the Act (year 2016), groundwater is also regulated and licensed under the same mechanism with an exception for domestic groundwater users. British Columbia utilizes a mix of policy instruments to manage water use including use restrictions during scarcity (to maintain environmental flows), differentiation of sensitive watersheds (more use restrictions for these areas) as well as volumetric water rental charges (Brandes & Curran, 2017).

   In addition to a one-time application fee (based on volume of water to be used) for licensing and approval, an annual volumetric water rental is imposed on license holders, varying with water use sectors with complete exemption for domestic groundwater users. Unlike the bulk water charges applied to few industrial sectors in Ontario, British Columbia imposes a volumetric fee on all sectors while discounting uses like water conservation/storage ($0.02/million liters), agricultural irrigation, livestock, and fish hatcheries ($0.85 instead of $2.25/ million liters). Interestingly a reduced charge of $1.30/ million liters is imposed on pulp mills and water extracted for cooling purposes (Province of British Columbia, 2016). Nonetheless all sectors including municipal, commercial, institutional, agricultural, livestock, and power generation do face a water rental fee. Moreover, the annual rental fee is charged based on the volume of water approved (except power generation) in the license instead of the actual volume used thus incentivizing users to apply for volumes closer to actual water demand.

For power generation, the water rental fee is not charged volumetrically but charged based on KWh of output produced by the facilities. The charges collected from power generation facilities account for nearly 95% of the total revenue collected from water rental charges (about $350 - 450 Million per year). The province of British Columbia does recover the recurring costs of water management initiatives and the revenues collected are much higher than Ontario. However, instead of increasing the base volumetric charge directly imposed on water extraction, water charges are imposed indirectly on all users via electricity tariffs that internalize the water rental charges for power generation (Business Council of British Columbia, 2013; Renzetti, 2007). Similar to the case in Ontario, the volumetric charge of $2.25/ million liters imposed on self-supplied users has also been under academic and public scrutiny for being insufficient to change water consumption behavior. While the province predominantly recovers costs of water resource management from power generating sectors, these charges are not distributed equitably across other use sectors thereby failing to signal the actual monetary value of water being extracted (Business Council of British Columbia, 2013).

4.6 Canadian Council of Ministers of the Environment (CCME) Recommendations for Water Pricing (2015)

A guidance document was prepared by the Council of Ministers of the Environment in 2015 to inform provincial pricing frameworks specifically for self-supplied water withdrawn by industrial and agricultural users. Even though the document is not legally binding, it does provide important insights regarding the scope of water extraction charges in the context of Canada. The pricing guidelines were primarily intended for users extracting bulk water as an economic resource thus excluding water extracted for municipal water supply, domestic use, fire-fighting, environmental conservation etc. (Canadian Council of Ministers of the Environment, 2015). In the context of this report, the rationale behind suggesting water extraction charges is to change the consumption behavior of users wherein price signals are used to raise awareness, impose variable charges contingent on water quality/ watershed sensitivity, and to promote use-efficiency by prioritizing certain uses over others (e.g. drinking water supply, environmental flows etc. over industries. However, it is also mentioned that bulk water charges should also ensure economic competitiveness of water-intensive sectors while balancing other water sustainability objectives.

According to the CCME report, in line with the cost recovery principles discussed earlier, efficiently designed water charges also serve as a compensation or recovery mechanism of costs associated with water resource management initiatives undertaken by the federal and provincial government. It has been suggested that either partial recovery of costs (wherein only administrative and partial water management costs are recovered from some users) or full recovery of all environmental management, monitoring, remediation, and assessments costs can be the basis of arriving at these prices. Prices can also be set to generate revenue for future water sustainability initiatives and provide earmarked investments for special water projects rather than relying on general tax revenues for funding (Canadian Council of Ministers of the Environment, 2015; Renzetti, 2017).

In the context of Ontario, as described in the CCME report as well as the original proposal for constituting water conservation extraction charges in 2007, the MOECC designed these charges only to partially recover the costs of administering the PTTW program as well as a portion of water quantity programs attributed to the high consumptive industrial water users thereby arriving at a modest charge of $3.71/million liters. Even though the overall investment in the protection and management of water resources within the Great Lakes Basin is much higher, these charges were originally not meant to recover full costs of these programs (Canadian Council of Ministers of the Environment, 2015; Ontario Ministry of the Environment, 2007).

4.7 Conceptual Framework for Bulk Water Pricing for Ontario

Even with the basic regulatory framework for imposing water extraction charges in place, the province of Ontario has not fully utilized economic instruments for efficient water demand management based on cost recovery goals. While hydroelectric power generating stations have been paying a "water rental charge" for the (non-extractive in-stream) "use" of provincial water resources under the Electricity Act, other major extractive commercial and industrial users continue to be exempt from water abstraction charges that should be imposed equitably on all water extracting users (Renzetti & Dupont, 1999). Ideally, the complete spectrum of economic, resource, and environmental costs associated with the use of water resources should be considered in the calculation of water charges based on full cost recovery principles imposed on all water users. However, given the information gaps, data reliability issues, lack of extensive hydro-economic data at the segregated basin level as well as the practical limitations of implementing all these costs into the existing regulatory frameworks, full cost pricing based on Total Economic Valuation may be foreseen as an incremental process in the future (OECD, 2017).

Thus, for the context of Ontario, based on cost recovery principles, accounting for economic costs spent on existing programs centered at protecting, managing, and remediation of water resources may be a more practical starting point for arriving at a volumetric base water price. Moreover, the cost based approach for recovering actual costs of water management initiatives is much in line with the existing rationale for water charges followed in many provinces in Canada. Moreover, various price multipliers can be integrated in the same framework similar to the frameworks of England and Portugal to differentiate prices based on sub-watershed hydrological conditions, sensitivity of different types of sources (groundwater or surface water), seasonal surcharges (severity of drought) as well as water consumption by different use-sectors (e.g. water bottling is high consumption while thermoelectric power generation is low and releases most of the water extracted back to the original source).

The broad outline of the framework with key attributes is summarized below:

Base Provincial Water Extraction Charge ($/m³)

- Average annual volume of water extracted by sectors
- Average annual cost of water resource management
- Extreme contamination events for contingency/environmental costs

Water Risk Price Multipliers

- Moderate and high water quantity risk sub-watersheds (location) quantity risks
- Sector (water consumption) risks
- Sensitivity of groundwater sources

Seasonal and Concessional Factors

- Seasonal peak pricing for low flow/ precipitation months based on drought severity
- Concessional factor (C) to provide discounts ($0<C\leq1$) on final annual charges

To address the second research question of this study, based on the best practices discussed above, the proposed bulk water pricing framework for Ontario is constructed in the following section. As a final output of the study, a bulk water charge calculation spreadsheet (calculator) is designed that integrates various price multipliers based on spatial and temporal considerations along with sector specific water risks to calculate the final bulk water charge for different water users.

5.0 Methods

5.1 Rationale for Proposed Bulk Water Pricing Framework for Ontario

As outlined in the CCME 2015 guidance document for water pricing, Ontario currently only partially recovers the costs of administering the PTTW and water quantity management programs while overall costs of various Great Lakes remediation/quality initiatives, source water protection, nutrient management, various monitoring/ evaluation programs are funded from general tax revenues (Canadian Council of Ministers of the Environment, 2015; Renzetti, 2017). Even when very specific water quantity management activities are considered, the MOECC recovers only $200,000 from the current volumetric charge out of the attributed expenditure of $17.5 million annually (Ontario Ministry of Environment and Climate Change, 2017b). Thus, in order to arrive at an equitable pricing framework that not only reflects the full costs of water resource management and protection but also the spatial and temporal risks at the sub-watershed level, the existing flat volumetric rate of $3.71/million liters imposed on few manufacturing sectors should be revised to be a more dynamic charge.

After surveying pertinent literature and synthesizing best practices for bulk water pricing at the global and provincial scale, a pricing framework based on the core principle of recovery of full water resource management and protection costs is proposed for Ontario. While the EU WFD does suggest a comprehensive pricing model inclusive of full social and environmental costs, given the institutional differences in Canada for water governance and paucity of relevant hydro-economic studies for each sub-watershed, implementing a fully-fledged framework based on the European model may not be feasible at this stage. Certain elements used in European pricing frameworks like watershed specific and sector-specific risk price multipliers are integrated in the calculation of the final charge but the base provincial water extraction charge is based on the average annual water resource management expenditures borne by the federal and provincial government. Given the ease of transition and practicality of building upon the existing regulatory foundation of water extraction charges under the PTTW program, the proposed framework provides a more comprehensive charging mechanism by integrating apt costs to be recovered as well as price multipliers specific to sub-watersheds, use sector, and source of proposed water taking.

The proposed framework holistically accounts for all water management initiatives undertaken by the province (specifically in the Great Lakes basin) that are instrumental for providing sustainable and high quality water resources that benefit all water extracting sectors. By integrating these costs in the provincial water charges under the PTTW program, high volume water users are equitably charged for their use and the revenue hence generated can be earmarked for funding these initiatives rather than using general tax revenues (Renzetti, 2017; Vander Ploeg, 2011). Since it is inherently complex to attribute certain programs/initiatives to certain sectors who benefit the most out of these programs, it is more equitable to distribute overall water resource management costs to all water extracting sectors.

For instance, while the provincial source water protection and clean water program is focused on sustainability of drinking water but the program ensures sustainable and high quality water sources shared as a common resource by all water use sectors (manufacturing, agriculture, power generation etc.). Thus, investments in programs that prevent algal blooms, maintain overall productivity of water sources, or remediate contaminated sites are holistically advantageous for all water users and not just municipal water users. These programs not only ensure continuous supply of water by maintaining productive sources (hence avoiding production disruptions) but also reduce costs of treating raw intake water for self-supplied water users (Bingham, Sinha, & Lupi, 2015; Environment and Climate Change Canada, & Ontario Ministry of the Environment and Climate Change, 2018).

From a social equity perspective, in order to provide financial relief to certain users based on provisions for affordability, a fractional concession factor is also integrated in the final charge calculator to provide discounted rates to users as deemed necessary by the MOECC. Alternatively, the province can design complementary tax credit programs where a fixed percentage of revenue generated can be recycled as credit to water-efficient users or provide subsidies for water efficient industrial technologies similar to municipal subsidies for low flow plumbing fixtures (Renzetti & Dupont, 1999; Rivers & Groves, 2013). The price multipliers integrated in the framework over and above the base provincial charge provides sufficient buffer for concessions and tax credits to be provided. It is anticipated that with the implementation of these dynamic charges not only will future businesses be informed of water sensitivity of their production location but also incentivize water conservation. As water demand and pressures on water resources decrease in the future, the base charge can be updated with newer costs and water withdrawal data while the multipliers can be recalibrated based on latest regional water risk information.

5.2 Methods and Data Considerations: Designing the Bulk Water Extraction Charge Calculator

As the first step, a provincial base volumetric charge ($/m^3) is calculated for water extraction based on the average annual costs and water withdrawn by different sectors. A database is populated with various federal and provincial costs for water resource management along with the water withdrawal data of various sectors within the time horizon of 2007-2017. In order to account for the sub-watershed level water quantity risks as well as sector specific water consumption factors, the final bulk water charges calculation spreadsheet (calculator) is designed such that both provincial base volumetric charge and various price multipliers are integrated to calculate the final water charge based on user specified inputs. To elaborate on the details for the construction of final calculator, a brief discussion on the various databases, information sources, assumptions, and estimations used is provided below:

5.2.1 Database 1: Water Resource Management Cost Accounting

Referring to various federal and provincial audit and evaluation reports, a database of expenditures including operating and capital expenses as well as grants issued to agencies is generated for initiatives undertaken from 2007 until 2017. These costs reported in ***nominal Canadian dollars*** are then averaged over their specific time periods to arrive at an average annual cost of water resource management.

1. The Federal Government has undertaken various programs under the Great Lakes Action Plan including the Lake Simcoe and South-Eastern Georgian Bay Cleanup that are funded through various cost sharing agreements with the province of Ontario. For water quantity and quality monitoring programs, like the National Hydrometric Program and Groundwater Geoscience program, the share of federal funding for Ontario is estimated based on number of monitoring sites based in Ontario. The data for Federal expenses is sourced from publicly available Audit and Evaluation Reports of the Great Lakes Action Plan and official evaluation reports of individual programs listed in Table 3 below. While majority of the federal programs, as mentioned in various policy documents, provincial strategy reports, and academic literature have been included but the database can be updated with new programs/initiatives as deemed necessary. The Invasive Species Program has been excluded from the analysis since the program is more relevant for in-stream users of water resources while the proposed framework focuses on charging water extractive sectors.

2. The provincial data on expenses for various water resource protection and management programs is sourced from the audited Ontario Public Accounts published each year by the Ministry of Finance accounting for actual revenues and expenses for all provincial ministries (Ontario Ministry of Finance, 2007-2017). Expenditures of the MOECC directly attributable to Water Program (Vote 1107 till the year 2012) are accounted from the financial year 2007-08 to 2017-18 (tabulated in Appendix 11.1) excluding costs that were attributed to drinking water infrastructure grants. To capture the entire expenditure of these programs in addition to the grants/funding provided by the MOECC for the programs, the Ministry's operating and capital expenses attributable to these programs are also included. Post 2012, individual categories for air, water, and waste programs were dissolved into a consolidated Environmental Program so the share of water expenses was estimated based on the percentage share of water program (of the total expenditure) in the year 2012. The source protection program costs were calculated to be 18.3% and clean water program costs were 37.5% of the total operating expenses under the water program. For capital expenses post 2012, the costs for the source water protection plans are clearly mentioned in the MOECC accounts for all the years.

   For the Ministry of Natural Resources and Forestry (MNRF), programs attributable to Source Water Protection and other grants issued to conservation authorities were accounted. Until the year 2010, MNRF and MOECC shared the costs of source water protection program but starting 2011, the source water protection program was solely undertaken by MOECC (Auditor General of Ontario, 2014). However, MNRF continues to provide grants to all conservation authorities for their operational expenses and supplementary water management programs like the Low Water Response Program. Thus, these grants have been accounted in the total provincial costs for water resources management.

Expenditures related to infrastructure upgrades for drinking water treatment or MOECC grants for Walkerton Training Center for drinking water were excluded since drinking water treatment is beyond the scope of water resource management. The cost data for investments for wastewater infrastructure upgrades, stewardship programs, innovation grants for nutrient management directly attributed to Great Lakes initiatives were included and alternatively extracted from the Great Lakes Strategy Progress Report, 2016 published by the MOECC. To clarify, wastewater treatment infrastructure upgrades are included in the analysis since the quality of treated wastewater eventually disposed into various surface water bodies affects the overall quality of the resource as well as downstream users/extractors of water. Thus, investments in improving wastewater treatment or industrial effluent discharge treatment are indirectly a part of overall water resource management (Ontario Ministry of Environment and Climate Change, 2016).

3. To include contingency environmental costs of contamination events that significantly degrade local water resources, some extreme events that currently being remediated in Ontario have also been accounted. The remediation and rehabilitation of Randle Reef at the Hamilton Harbor (discussed in Section 2.4.3) for removal of contaminated sediment is one such federal and provincial initiative that has been included in this cost database.

4. While federally and provincially funded water quality initiatives and remediation of sites like Randle Reef are focused on surface water bodies with keen focus on the Great Lakes, there have also been extreme contamination events due to local industrial pollution contaminating groundwater sources. From the perspective of equitably arriving at resource and environmental costs for both surface and groundwater sources, events for groundwater contamination need to be included separately. Remediating contamination of groundwater from anthropogenic pollution requires cleaning of the aquifer as well as significant investment in providing alternate water sources.

   The cleanup costs of these past extreme groundwater contamination events have been under provincial liability thus giving an insight into the total economic value of a productive aquifer yielding high quality groundwater. The groundwater contamination events mentioned in the Auditor General of Ontario's reports for Deloro (1979), Elmira (1989), Smithville (1985/89), and Walkerton (2000) have been given much emphasis solely due to the intensity and costs of remediation borne by the province. Contamination of groundwater has a wider social, economic, and environmental impact and hence remediation effort like onsite water treatment continues for a much longer duration (Auditor General of Ontario, 2004).

   For the purposes of capturing the economic value of groundwater in totality, the costs for these groundwater contamination events have been taken as a single lump sum rather than averaging over the extended time period of the remediation. The rationale behind accounting for these extreme events is to reflect some of the emergency environmental costs pertaining specifically for groundwater resources borne by the province and paid out from general tax revenues that may not be budgeted preemptively. The costs for these events have been sourced from the reports of the Auditor General of Ontario published in the year 2004, 2014 and 2015, and accounted in the framework (Auditor General of Ontario, 2004; 2014; 2015).

5. The Walkerton contamination event has also been accounted as an extreme groundwater contamination event wherein many monitoring and evaluation programs were triggered

immediately as an aftermath of this event (Loë, Kreutzwiser, & Neufeld, 2005). The provincial expenditures post the Walkerton events are sourced from Public Accounts for the years 2000 and 2001, submission reports for the Walkerton Inquiry by Conservation Ontario, and the research paper by de Loë, Kreutzwiser, & Neufeld (2005) that evaluated various provincial groundwater initiatives post Walkerton (Conservation Ontario, 2001; Loë, Kreutzwiser, & Neufeld, 2005; Ontario Ministry of Finance, 2000,2001).

6. Due consideration has been given to eliminate any possible double counting of costs under various programs and initiatives. The expenditures for the remediation and extreme contamination events have not been extracted from the public accounts since they are bundled in the MOECC's "waste program" and cannot be distinguished from solid waste management initiatives. Alternatively the Great Lakes Strategy Progress Report published by the Ontario Ministry of Environment and Climate Change as well as the Auditor General of Ontario's reports have been used to source the data for these water specific expenditures.

7. It is also important to note that expenditures of conservation authorities have not been accounted in this framework. While the federal and provincial grants given to Conservation authorities for watershed management are captured in the expenditures of Public Accounts but these grants contribute only 10-15% to the total expenditure of conservation authorities on various water, land, and biodiversity management initiatives. Majority of these expenses are funded by municipal levies that are a part of municipal property taxes levied on all residential, commercial, industrial property owners (Ministry of Natural Resources and Forestry, 2015). The expenditures for various land, water, and biodiversity management activities borne by the conservation authorities have been compensated by all sectors via municipal property taxes earmarked for conservation authorities (Ministry of Natural Resources and Forestry, 2015). Therefore, the present analysis and cost accounting for water resources management and protection is limited to the federal and provincial expenditures only.

The individual initiatives and programs under consideration for cost accounting for provincial base volumetric price calculation have been explained in detail in Section 2.4.3, a summary of which is provided in Table 3 below:

Table 3: Water Resources Management Costs under Consideration

Initiative	Description	Main Funding Agency
Great Lakes Action Plan for Areas of Concern	Assessment, design and development of remedial actions within Areas of Concern (via Great Lakes Sustainability Fund), monitoring & evaluation of sites, engagement & governance initiatives to restore environmental quality and ecological health of the Great Lakes	Federal
Great Lakes Nutrient Initiative	Science and policy research on understanding and addressing algal blooms	Federal
Great Lakes Sediment Remediation (including Randle Reef Action Plan)	Implementation of restoration and remediation in the Areas of Concern in the Great Lakes	Federal and Provincial

Groundwater Geoscience Program	Developing Groundwater Information Network for all provinces for enhanced management and understanding of ground water implemented by Natural Resources Canada	Federal
Lake Simcoe and South-Eastern Georgian Bay Clean-up Fund	Ecological health and water quality as part of supporting the Great Lakes Water Quality Agreement to control phosphorus loadings in the basin via streams/creeks	Federal and Provincial
Great Lakes Agricultural Stewardship Initiative	Canada-Ontario initiative to reduce nutrient loss and improve soil health via collaborative initiatives with farmers	Provincial
Great Lakes Protection Projects under Canada-Ontario Agreement	Remediation, restoration, and other protection initiatives	Provincial
Water Quality Initiatives in Great Lakes Basin	Municipal wastewater and storm-water infrastructure upgrades	Provincial
Ontario's New Directions research program including Ontario's Showcasing Water Innovation (SWI) program	Scientific projects on water quality and management of nutrients, solutions to enhance storm-water and wastewater management	Provincial
Provincial Source Water Protection	Operating and Capital expenses as well as grants under the Source Water Protection Plans based on data from Ontario Public Accounts	Ontario Ministry of Environment and Climate Change
Provincial Nutrient Management Plans	Operating and Capital expenses as well as grants for Great Lakes Nutrient Management program based on data from Ontario Public Accounts	Ontario Ministry of Environment and Climate Change
Provincial Great Lakes Initiatives	Operating and Capital expenses as well as grants for other Great Lakes initiatives based on data from Ontario Public Accounts	Ontario Ministry of Environment and Climate Change
Provincial Clean Water program	Operating and Capital expenses under the Clean Water program based on data from Ontario Public Accounts	Ontario Ministry of Environment and Climate Change
Investments for Water Resource Management	Operating and Capital expenses as well as grants under the Source Water Protection Plans and funding to conservation authorities based on data from Ontario Public Accounts	Ontario Ministry of Natural Resources
National Hydrometric Program (Hydrological service and Water Survey)	Water quantity monitoring stations and data repository	Federal and Provincial

Water Quality Monitoring	Water quality monitoring stations and data repository	Federal and Provincial
Experimental Great Lakes Research	State of the art facility established for ecosystem research and monitoring	Provincial
1. PCB contamination from storage facility in Smithville (Environmental Protection Act) 2. Water Treatment for Abandoned mine in Deloro 3. Groundwater Remediation in Elmira	Clean up costs, remediation, as well as alternate infrastructure costs (e.g. new pipeline, groundwater treatment) for these Extreme Groundwater Contamination Events based on data from Auditor General of Ontario Reports	Provincial
Groundwater Monitoring Network	Extreme Groundwater Event Walkerton: Establish 380 wells for groundwater monitoring (MOECC–Conservation Authorities)	Provincial
Healthy Futures for Ontario Agriculture	Extreme Groundwater Event Walkerton: Upgrade existing wells and decommission abandoned wells (Ontario Federation of Agriculture)	Provincial
Provincial Water Protection Fund (PWPF), Groundwater Management Studies + follow up funding (2001)	Extreme Groundwater Event Walkerton	Ontario Ministry of Environment and Climate Change
Groundwater Management Studies	Extreme Groundwater Event Walkerton	Provincial
Water Resource Management	Extreme Groundwater Event Walkerton	Ontario Ministry of Natural Resources

5.2.2 Database 2: Water Withdrawal Data by all Sectors in the Great Lakes Basin

In addition to the average annual expenditures, in order to calculate the average volumetric base price, reliable secondary data on the volume of bulk or self-supplied water withdrawn by all the sectors is required. For the purposes of this research, only the Great Lakes-St. Lawrence-Ottawa drainage basin is considered for bulk water pricing framework. Given the scarce population density and abundant water supply in the Northern Ontario drainage basin as compared to the populous southern parts, the scope of imposing extraction charges for demand management will be limited to the Great Lakes-St. Lawrence-Ottawa region (Bakker & Cook, 2011; Mitchell, 2017).

Moreover as observed from the cost accounting data, most of the initiatives and water management expenditures are specifically focused in the industrialized and populated Great Lakes region. Thus, the water withdrawal data collected for the whole province of Ontario cannot be directly used but has to be adjusted by excluding the volume attributed to withdrawals in Northern Ontario. Many Statistics Canada water use surveys segregate data based on drainage regions thereby collecting data for Northern Ontario drainage basin separately that can be excluded from the provincial data to obtain data for Great Lakes-St

Lawrence-Ottawa basin. Moreover, the data that is collected by Statistics Canada for the Great Lakes basin does not include Ontario's share of St. Lawrence and Ottawa drainage basin so subtracting Northern Ontario data from Ontario's data yields more reasonable estimates. However, water withdrawal data for sectors like mining, oil & gas, and agriculture is not disaggregated at the drainage basin level, so reasonable estimations (as described in Table 4) are made in these cases.

As discussed in Section 1.4, there are sector specific water use surveys conducted by Statistics Canada that quantify the volume of water withdrawn annually at the national and provincial scale. Although these surveys are conducted periodically and rely on certain assumptions and estimations to account for sectors like agriculture that do not regularly monitor their water withdrawals, Statistics Canada is a reliable publicly accessible source for the data needed. The Regional Water Use Database maintained by the Great Lakes Commission also provides water withdrawal data (Million Liters (ML)/day) by various sectors in the Great Lakes-St. Lawrence-Ottawa Basin. However the methodology and assumptions for data collection and estimation are not explicitly discussed in detail in their annual reports or supporting publications. Moreover, the data reported by Ontario to the Great Lakes Commission has been criticized in the past to be non-uniform and mismatched with the year of reporting making it less meticulous (Great Lakes Commission, 2012; Vandierendonck & Mitchell, 1997).

In the absence of reliable information on the data collection methodology and estimations used in the database, using this data directly by applying an annual conversion factor of 365 days/ year may be an overestimate for volumes that are not withdrawn daily. Thus, the Great Lakes Regional Water Use database is used only to fill data gaps for sectors that are not covered at all by Statistics Canada (e.g. livestock, commercial and institutional). In the absence of the access to actual water taking database maintained by the Ministry of Environment and Climate Change, Statistics Canada is considered to be a reliable secondary data source. Moreover, for the purposes of the provincial base charge calculation, an average annual volume of water withdrawn is required thus allowing some buffer for reasonable estimation errors in the analysis.

The source of data for water withdrawal volumes, time frame and frequency of surveys, as well as data assumptions and estimations used in the calculations are outlined in Table 4. Since the costs of water resource management are estimated based on simple arithmetic mean between the year 2007 and 2017, the annual average volume of water withdrawn is also considered for the same time period. However, as a limitation of the analysis, these water surveys for some of the sectors have been conducted non-periodically and at different frequencies. Thus, the average volume of water withdrawn (intake) is calculated over the time period for which the data is collected or could be reliably estimated. For the agriculture sector, the original data from the Statistics Canada survey is less accurate due to the difficulty in monitoring agricultural water use. Moreover, the volume of irrigation water is highly contingent on the yearly precipitation in the region and hence varies considerably year to year. The survey itself started in the year 2010 with constant methodology updates with changes that refined and improved data. Thus, for the purposes of this analysis only the most recent data on irrigation volume is considered to be more reliable rather than the mean. The most recent irrigation volume data is available for the year 2016 and it coincides with the driest year in Ontario hence registering the highest irrigation volume in the data series.

Table 4: Water Withdrawal Data Sources by Sector and Assumptions

Water Withdrawal Sector and Source of Data	Time Frame of Available Data and Frequency of Collection	Assumptions and Basis of Estimation
1. Self-supplied Municipal Water (for potable use by all sectors) Biennial Drinking Water Plants Survey: CANSIM Table 153-0105	▪ 2007 to 2015 (biennial) for Ontario ▪ 2011 to 2015 for Northern Ontario drainage basin	▪ Northern Ontario withdrawal volumes were on an average 1% of the total volume for Ontario so data for years 2007 to 2011 estimated based on 1% share to calculate Great Lakes-St. Lawrence-Ottawa volumes
2. Self-supplied (Rural) Domestic Water Use Biennial Drinking Water Survey (population served by municipal systems): CANSIM Table: 153-0105 ▪ Population estimates for Ontario: CANSIM Table 051-0001 ▪ Population estimates for Northern Ontario: Census of Population compiled by Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA)	▪ 2007 to 2015 (biennial) for Ontario ▪ Yearly population data available from 2007 to 2015 for Ontario ▪ OMAFRA census population for Northern Ontario as % of total Province available for 2011 and 2016. Retrieved from http://www.omafra.gov.on.ca/english/stats/county/index.html	1. The methodology used is described in Section 1.4. The population served by municipal supply systems is subtracted from total population 2. The Northern Ontario total population and population served by municipal plants is subtracted for Great lakes estimates 3. Average per capita domestic self-supplied intake of 159 L/day/person is used as described in Vandierendonck & Mitchell (1997)
3. Self-supplied Manufacturing Sector Industrial Water Survey: CANSIM Table: 153-0051	▪ 2007 to 2015 (Biennial) for Ontario and Northern Ontario drainage basin	▪ Data for intake from all sources (including municipal supply) is provided in the survey so only volumes for self-supplied intake (surface and groundwater) is considered to avoid double counting since municipal supply includes industrial sectors as well
4. Self-supplied Mining, Oil & Gas Extraction Mining Water Intake data based on Industrial Water	▪ 2007 to 2015 (biennial for mining sector Ontario) ▪ 2007 to 2013 for Oil and Gas extraction in Canada	1. Oil and gas extraction water withdrawal data was only collected at the Federal scale and not provincial. The

Survey: CANSIM Table 153-0079 ▪ Oil and Gas Extraction estimates based on the Environment Canada Report on Canadian Environmental Sustainability Indicators: Water Withdrawal and Consumption by Sector. ▪ Mining GDP value (in chained 2007 $) for Ontario: CANSIM Table 379-0030	▪ Northern Ontario's mining GDP contribution in 2011 was $1.869 Billion (adjusted to $ 2007). Source: The Conference Board of Canada. 2013. The Future of Mining in Canada's North: A Report on Economic Performance and Trends. pp.9. Retrieved from: https://www.canada2030.ca/wp-content/uploads/2013/08/Future-of-mining-in-Canadas-north_cfn.pdf	estimates for Ontario was based on the %GDP share of Ontario in the national GDP for oil and gas (0.212%) 2. The GDP share of Northern Ontario mining sector adjustment was made on the 24% share of mining GDP 3. Mine water intake was also included since this is the volume of groundwater that is removed from mines before operation
5. Self-supplied Thermoelectric Power Generation Water Intake data based on Industrial Water Survey: CANSIM Table 153-0079	▪ 2007 to 2015 (biennial)	▪ For adjusting Northern Ontario % share from the data for Ontario, 2.5% of total installed capacity of thermal power plants in Ontario is in Northern Ontario based on Ontario's Independent Electricity Systems Operator Data (2018b) and 97.5% is attributable to the Great Lakes region.
6. Self-supplied Agriculture Irrigation Agriculture Water Survey: CANSIM Table: 153-0134	▪ 2010 to 2016 (biennial)	1. Irrigation volumes are highly contingent on yearly precipitation patterns 2. The irrigation data for Ontario is predominantly relevant for the Great Lakes region (Loë, Kreutzwiser, & Ivey, 2001; Vandierendonck & Mitchell, 1997) 3. For purposes of data reliability, the latest volume registered in the survey for the year 2016 is considered in the analysis to calculate the overall volume withdrawn by the sector rather than the average

7. Self-supplied Livestock: Great Lakes Commission's Regional Water Use Database	▪ 2012 to 2016 (annual data)	▪ 365 days/year is assumed to convert Million Liters/day data to Million m^3/year
8. Self-supplied Commercial and Institutional: Great Lakes Commission's Regional Water Use Database	▪ 2012 to 2016 (annual data)	▪ 365 days/year is assumed to convert Million Liters/day data to Million m^3/year

5.2.3 Database 3: Sub-watershed, Source, and Sector Specific Risk Multipliers

In line with the bulk water pricing models used in many European jurisdictions like England, Wales, Portugal etc. that utilize a price multiplier for signaling water risks based on various sectors, sub-watersheds, as well as sources of water, a similar dynamic pricing framework can also be designed for Ontario. As discussed in Section 2.4.3, various conservation authorities across Ontario have undertaken detailed technical assessments quantifying various water risks for regional groundwater and surface water sources under the Source Water Protection Program. Based on the approved "Source Water Protection Technical Assessment Report" for each of the 35 conservation authorities in the Great Lakes basin (accessible at https://www.ontario.ca/page/source-protection), a database is constructed, identifying all the "high" and "moderate" risk quaternary watersheds for both surface water and groundwater sources (see sample assessment map provided for Grand River in Appendix 10.5).

For each of the 5 main watersheds in the region (Lake Erie, Lake Ontario, Lake Huron, Lake Superior, and St Lawrence-Ottawa River) and 35 sub-watersheds (refer to Appendix 10.1 and 10.3 for sub-watershed classification), specific regions are identified to be at a risk of over-extraction (refer to Appendix 11.4 to 11.7 for identified regions). Thus, if the location of a high volume water extraction permit is in the location of a moderate or high risk quaternary sub-watershed (as identified by the technical assessment report), a price multiplier will be applied to the base provincial charge thus sending a price signal of regional water risk in the area. Similarly to account for variability in water consumption among various industrial sub-sectors, categories can be assigned to sectors based on "high", "moderate" and "low" water consumption as outlined and considered by the Ministry of Environment and Climate Change in the original proposal of water conservation charges (Ontario Ministry of the Environment, 2007). Various water use sectors and assigned water consumption categories is tabulated in Appendix 10.4. Using these categories, a price multiplier is assigned to each consumption category to differentiate risks of different sub-sectors.

To account for the sensitivity of groundwater sources in the basin, wherein water extracted from groundwater wells is seldom recharged into the original source but discharged into surface water bodies (becoming 100% consumptive for all water use sectors based on this rationale), a price multiplier can be assigned based on the proposed source of water extraction (Grand River Conservation Authority, 2015; Morris, Mohapatra, & Mitchell, 2008). Similar to the "humpback" or seasonal volumetric rate structure discussed in Section 4.3 a seasonal peak price surcharge is also included in the framework. Based on the chosen scale of drought severity (high, moderate, low) for a particular year, an additional seasonal price multiplier kicks in for low flow/ precipitation months along with the other risk multipliers. However, this surcharge is imposed only for number of months experiencing low precipitation conditions and for the remaining year, the location, source, and sector specific risk price multipliers apply.

Seasonal Price multiplier (for low flow months) $M = M_{Watershed} \times M_{Sector} \times M_{Source} \times M_{Seasonal}$

Regular Price multiplier (for regular flow months) $M = M_{Watershed} \times M_{Sector} \times M_{Source}$

Number of low flow months entered = N_{Low}

All Year Charges = {Seasonal Price Multiplier x (N_{Low} /12) + Regular Price Multiplier x [(12- N_{Low})/12]} x Base Provincial Volumetric Charge x Annual Volume of Water Extracted

Thus, with the use of these price multipliers integrated in the framework, the province has the flexibility to account for various regional, seasonal, as well as sector specific nuances/signals to arrive at a dynamic bulk water charge in addition to the provincial base volumetric charge for the permit applicant. A fractional concessional factor is also integrated in the same framework to provide financial relief either based on income brackets and to provide discounted charges to sectors like municipal water supply etc. that have already been engaged in voluntary stewardship programs for water use efficiency. For the purposes of this study, arbitrary values (>1) are selected for each of the category of multipliers that proportionally increase with intensity of risk (medium to high). For practically implementing this calculator, the Ministry of Environment in consultation with various stakeholders (including municipalities, conservation authorities, and industry representatives) can deliberate and arrive at fair values to be assigned to each of the risk categories.

While costs accounted in Table 3 include the full spectrum of water resource management expenditures, the provincial base volumetric charge can also be varied based on the choice of costs to be recovered and water using sectors to be charged. Thus, the calculator is designed in a way to allow the Ministry to consider multiple pricing scenarios and options for designing the base charge as well. If it is decided to only recover the existing PTTW and water quantity program costs from industrial users, the calculator provides necessary options to calculate the provincial base price based on that choice. While the framework has data on all use sectors and all program expenditures, there is flexibility to select specific sectors liable for charges as well as programs to be considered for cost recovery and consequently the base charge is calculated based on the selections in the spreadsheet. This allows the MOECC flexibility to introduce charges based on different cost components incrementally over time thereby giving different sectors time to proactively invest in water-efficient technologies and conservation practices, or otherwise adapt to the new bulk water pricing framework. To demonstrate the calculation of bulk water charges using the designed calculator, a sample calculation for a hypothetical water permit applicant is presented in Section 6.2.

6.0 Results

6.1 Results for Base (Average) Provincial Water Extraction Charge Calculation

1. When different federal and provincial expenditures are tabulated (Appendix 11.1 and 11.2) for different water resource management initiatives as well as certain extreme contamination events for proxy environmental costs, 3 main categories of costs emerge:

Cost Category Assigned	Description
1	Ontario source water protection, water quantity monitoring, water quality monitoring (all operating expenses and grants included), Ontario clean water program, monitoring initiatives post Walkerton
2	Great Lakes quality initiatives, nutrient management, monitoring of Areas of Concern (stewardship and supporting initiatives included)
3	Extreme events due to industrial contamination directly impacting groundwater resources, Randle Reef remediation project

When different scenarios for recovering these costs are considered, the average annual cost of water resource management is calculated in Table 5 (Nominal CAD):

Table 5: Target Cost Recovery Scenarios for Different Costs Categories

Program Category for Cost Recovery	Programs Covered	Cost to be Recovered, Nominal Million $
Business as Usual MOECC Water Quantity and PTTW	MOECC defined costs for managing PTTW program and water quantity management attributable to industrial/commercial users only	17.5*
All Water Management Programs (Quality, Quantity, Contingency) (Category 1 +2+ 3)	Full Cost Recovery and all programs included	535.193
Water Quantity & Quality Management, Source Water Protection and Clean Water (Category 1)	Source Water Protection, water quantity monitoring, water quality monitoring (all operating expenses and grants included) and Clean Water Program	233.532
Water Quantity & Quality Management, Source Water Protection, Clean Water, Great Lakes Initiatives (Category 1 + 2)	Nutrient Management and Great Lakes Initiatives included with Source Water Protection and Clean Water Program	361.860
Water Quantity & Quality Management, Source Water Protection, Clean Water, Extreme Contamination Contingency (Category 1 + 3)	Source Water Protection, Clean Water Initiatives, and Extreme Contamination Events	406.865
Water Quantity & Quality Management, Source Water Protection Program Only	Partial recovery of category 1 costs excluding Clean Water Program	126.467

*As published by MOECC (2017) in Environmental Registry 013-2020 retrieved from: https://www.ebr.gov.on.ca/ERS-WEBExternal/displaynoticecontent.do?noticeId=MTM0MTU1&statusId=MjA0MDkz

In order to visualize the trend of extraction of self-supplied water between the years 2007 and 2017, the annual volume of water withdrawn by different sectors in the Great Lakes-St. Lawrence-Ottawa drainage basin/ watershed is depicted in Figure 7 and Figure 8:

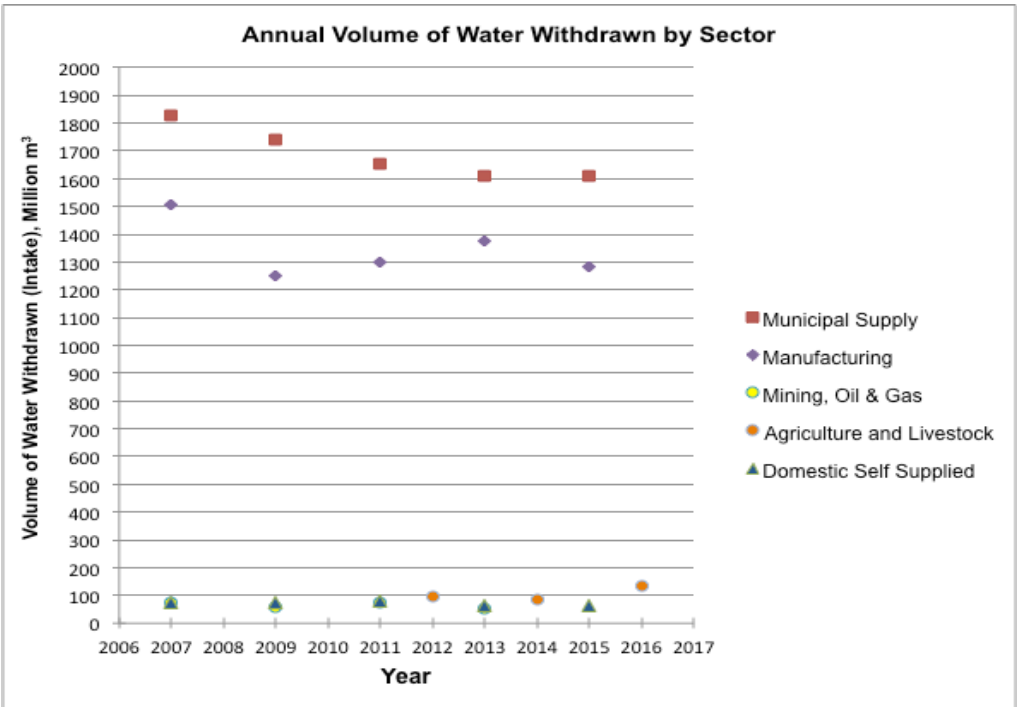

Figure 7: Volume of Water Withdrawn by Sector in Million m3/year for Great Lakes-St. Lawrence-Ottawa Watershed

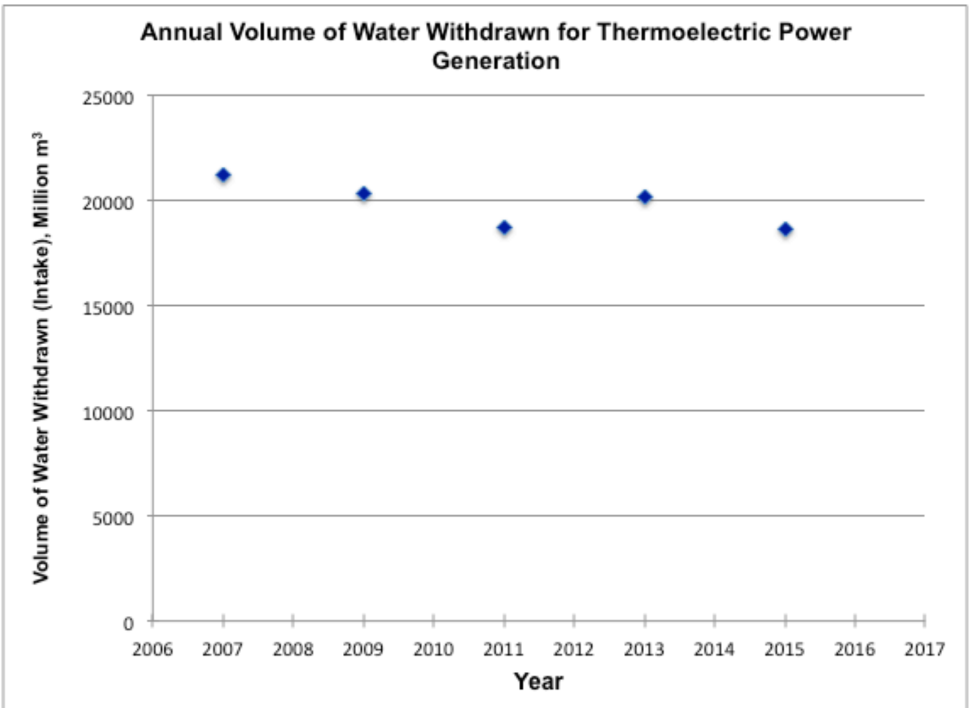

Figure 8: Volume of Water Withdrawn by Thermoelectric Power Generation in Million m3/year for Great Lakes-St. Lawrence-Ottawa Watershed

2. The average annual volume of self-supplied (bulk) water withdrawn (intake) the Great Lakes-St. Lawrence-Ottawa drainage basin/ watershed by all sectors in ***Million m³/year*** based on the annual data available (Appendix 11.3) and assumptions defined in Table 4 above is depicted in Figure 9.

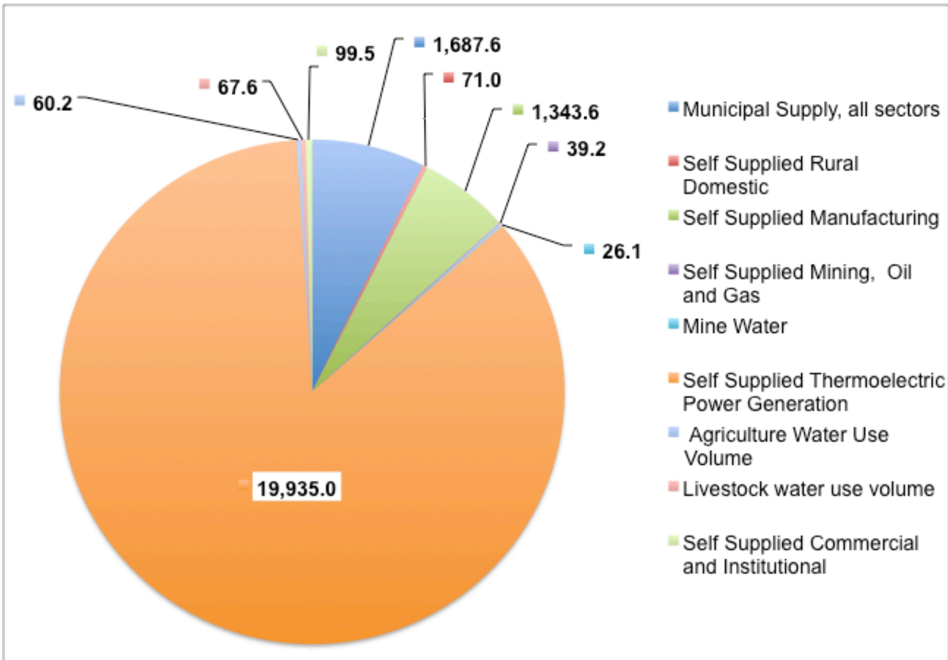

Figure 9: Average Volume of Water Withdrawn in Million m³ /year by Sector in Great Lakes-St. Lawrence-Ottawa Watershed

3. Base provincial charge (in $/Million Liters) calculated in Table 6 for different cost recovery scenarios outlined in Table 5 imposed on 3 different categories of water use sectors:
   i) All permit liable sectors
   ii) All industrial and commercial sectors (excluding agriculture, livestock, municipal supply, domestic self-supplied users)
   iii) Industrial and commercial sectors excluding thermal power generation, agriculture, livestock, municipal supply, domestic self-supplied users

Table 6: Base Provincial Charge in $/Million Liters for Different Cost Recovery Scenarios

Program Category for Cost Recovery	Cost to be Recovered, Nominal Million $	Base Provincial Charge, $/ Million Liters i) All Permit Liable Sectors	Base Provincial Charge, $/ Million Liters ii) Industrial & Commercial Sectors	Base Provincial Charge, $/ Million Liters iii) Industrial & Commercial Sectors (excluding thermal power generation from category ii)
Business as Usual MOECC Water Quantity and PTTW	17.5*	0.75	0.82	11.6

All Water Management Programs (Quality, Quantity, Contingency) (Category 1 +2+ 3)	535.193	23.08	24.96	354.82
Water Quantity & Quality Management, Source Water Protection and Clean Water (Category 1)	233.532	10.07	10.89	154.83
Water Quantity & Quality Management, Source Water Protection, Clean Water, Great Lakes Initiatives (Category 1 + 2)	361.860	15.60	16.88	239.91
Water Quantity & Quality Management, Source Water Protection, Clean Water, Extreme Contamination Contingency (Category 1 + 3)	406.865	17.54	18.97	269.74
Water Quantity & Quality Management, Source Water Protection Program Only	126.467	5.45	5.90	83.84
Water Quantity & Quality Management, Source Water Protection, Great Lakes Initiatives	254.795	10.99	11.88	168.92

*As published by MOECC (2017) in Environmental Registry 013-2020 retrieved from: https://www.ebr.gov.on.ca/ERS-WEB-External/displaynoticecontent.do?noticeId=MTM0MTU1&statusId=MjA0MDkz

6.2 Sample Calculation of Full Bulk Water Charges for a Hypothetical Permit Applicant

A. User Defined Inputs for Calculation of Base Provincial Charge

1. Water use sectors liable to pay water extraction charges (chosen from drop-down list): All permit liable sectors*
   * in this example, sectors that do not require a permit are exempt
2. Programs to be considered for cost recovery (chosen from drop-down list): All water resource management costs (including extreme contamination events for contingency)

B. User defined Inputs for Full Bulk Water Extraction Charge

1. Main Watershed of the proposed location for extraction (chosen from drop-down list): Lake Erie
2. Sub-watershed of the proposed location (chosen from drop-down list filtered automatically based on input provided in step 1.): Grand River
3. The water use sector (chosen from drop-down list): Water bottling
4. Volume of water to be extracted (entered manually in Million Liters/day): 3.6 (Million L/day)
5. Days in a year for water extraction (entered manually in days/year): 365 (days/year)
6. Number of months of low precipitation (entered manually): 4 (months)
7. Source of water extraction (chosen from drop-down list): Groundwater

The predefined risk price multipliers are factored in the final charge calculation based on the inputs provided (use sector, location of proposed water extraction, source of water, seasonal severity) for the specific permit applicant:

Price multiplier (for low flow months) $M = M_{Watershed} \times M_{Sector} \times M_{Source} \times M_{Seasonal}$

Price multiplier (for regular flow months) $M = M_{Watershed} \times M_{Sector} \times M_{Source}$

Watershed Quantity Risk Category	Price Multiplier
High	2
Moderate	1.5
Low	1

Sector Water Consumptive Use Category	Price Multiplier
High	1.5
Moderate	1.25
Low	1

Water Source Multiplier	Price Multiplier
Groundwater	1.5
Groundwater and Surface water	1.25
Surface water	1

Seasonal Surcharge Drought Severity Category	Price Multiplier
High	1.5
Moderate	1.25
Low	1

Outputs of Bulk Water Charge Calculator for user defined inputs in Steps A and B

Bulk Water Charges Calculator for Ontario

Click on individual grey cells to view the selection lists.
Blue Cells need manual entry of values

USER INPUTS FOR PROVINCIAL BASE CHARGE CALCULATION				
Choose Target Water Use Sectors liable for water charges	All Permit Liable Sectors	Average Volume Extracted by Sectors Chosen	23191.05	Million m^3/year
Choose Cost Category for Recovery	All Water Management Programs (Quality, Quantity, Contingency)	Total Cost to be Reocvered	535.19	Million $
Base Price for Ontario	0.0231	$/ m^3		
USER INPUTS FOR FULL BULK WATER EXTRACTION CHARGE CALCULATION				
Select Main Watershed	Lake_Erie			
Select SubWatershed	Grand River			
Select Water Use Sector	Water Bottling			
Enter Volume of Water to be Extracted (Self Supplied)	3.6	Million Litres/ day	1 meter^3 = 1,000 Liters	
Enter Days in a Year for Water Extraction	365	Days/year		
Enter Number of Low Precipitation Months	4	months		
Select Source of Water	Groundwater			
Total Volume of Water Extracted in a Year	1314000	meter^3/year		

C. User chooses (yes/no) if the location of water extraction is in the risk identified quaternary watersheds:

Sub Watershed Multipliers

	Watershed Senstivity Category	Risk-Selected Quaternary Watersheds	Category	Location Listed in Risk-Selected Quaternary Watershed?	Price Multiplier
1	High Risk for Surface Water Quantity	0	HIGH	NO	1
2	Moderate Risk for Surface Water Quantity	Eramosa Above Guelph, Whitemans Creek, McKenzie Creek	MODERATE	NO	1
3	High Risk for Groundwater Quantity	Central Grand	HIGH	NO	1
4	Moderate Risk for Groundwater Quantity	Canagagigue Creek, Upper Speed, Mill Creek, Big Creek, Irvine River	MODERATE	YES	1.5

D. ***User chooses the seasonal severity category for the seasonal surcharge multiplier: (the consumptive use and groundwater use multiplier is calculated automatically based on user inputs in Step B)***

Consumptive Use Multipliers		
Sector	**Consumptive Use Category**	**Multiplier**
Water Bottling	**High**	**1.5**
Seasonal Surcharge Multiplier		
Seasonal Low Flow Severity	**High**	
Seasonal Multiplier	1.5	

Groundwater Use Multiplier Calculated:	**1.5**
Groundwater as Main Source	1.5
Both GW and SW as Main Source	1.25
Surface Water as Main Source	1

E. ***Final Bulk Water Charges inclusive of All Price Multipliers:***

Here a "Special" sector price concession factor can be entered for a discounted charge, value chosen between 0 (full discount or no charge) and 1 (no discount or full charge).

FINAL WATER CHARGES IN	Grand River	SUBWATERSHED			
All Year Final Water Charges					
Total Volume Extracted			Total Volume Extracted		
1314000	meter^3/year		1314000	meter^3/year	
Provincial Base Unit Charge			Provincial Base Unit Charge		
0.0231	$/ m^3		0.0231	$/ m^3	
Price Risk Multiplier (Subwatershed x Sector x Groundwater Use)			Seasonal Surcharge (Based on add-on seasonal multiplier)		
3.375			5.0625		
"Special" Sector Price Concession Factor	NO		"Special" Sector Price Concession Factor	NO	
Enter Price Concession Factor	1	Enter value between 0 and 1	Enter Price Concession Factor	1	Enter value between 0 and 1
Price Multiplier (not adjusted for Seasonal Surcharge)			Price Multiplier (for Low Flow Months)		
3.375			5.0625		
			Number of Low Precipitation Months	4	
			Total Bulk Water Charge		
			Charges for Low Precipitation Months	51172 $/ year	
			Charges for Normal Precipitation Months	68229 $/ year	
			TOTAL	119400 $/ year	
			Average Price per m^3 for Permit Holder		
			0.0909	$/m^3	
			90.87	$/ Million Liters	

Bulk Water Charge in case if only Provincial Base Charge (no multipliers) imposed on applicant:
Total Volume Extracted: 1314000 m^3/year
Provincial Base Unit Charge: 0.0231 $/$m^3$
Total Provincial Bulk Water Extraction Charge: $30324/year

7.0 Discussion of Results and Contribution of the Study

7.1 Discussion of Results

There has been paucity in literature especially in the context of Canada that addresses the process of arriving at water extraction charges that cater to various objectives for sustainable water management. While the key characteristics of water charges like social equity, economic efficiency, and environmental sustainability have been discussed theoretically, a unified framework for the evaluation of these charges based on established pricing principles and spatial and temporal water conditions has not yet been put forth (Renzetti, 2007). Thus, the twofold aim of this study was to first explore best practices followed in some key global countries and provinces within Canada to design water extraction charges for self-supplied users. Then based on the best practices as well as contextual considerations for the province of Ontario, design a dynamic bulk water pricing framework by integrating economic and regional hydrological data available to arrive at regionally attuned volumetric water extraction prices.

When academic and policy literature is reviewed for pricing bulk water extraction, a plethora of theoretical principles and methodological approaches emerge that aim at reducing the value and price gap for water resources. "Value" of water resources has been articulated using multiple approaches by means of first establishing various social, economic, and environmental costs attributable to different uses or services of water resources as well as designing various volumetric rate structures. While the concept of value is inherently complex and subjective, a cost based approach does provide an objective framework of arriving at various schemes for pricing water extraction (Canadian Council of Ministers of the Environment, 2010; Dupont & Adamowicz, 2017; Dupont & Renzetti, 2008).

The complexity of pricing water as a resource stems from the multiple objectives that are to be achieved simultaneously. Water charges are meant to cater to objectives like cost recovery of water resource management programs, social equity, affordability, economic competitiveness, as well as signal conservation and use-efficiency. Thus, charges need to be dynamic in signaling not only the value of water resources and the regional risks so as to change consumption behavior of high volume water users but also to recover costs associated with water resource management (Cantin et al., 2005; European Environment Agency, 2013; Renzetti, 2007). Even in the case of the European Union Water Framework Directive, where the member states have a uniform set of objectives and guidelines for full cost pricing of water resources, each member has a unique pricing framework for arriving at extraction prices. Ranging from hydro-economic modeling, ecosystem services valuation, as well as combined water extraction and quality frameworks, the operationalization of resource allocation and evaluation of prices is highly variable (DG ECO2, 2004; OECD, 2017). Thus, reinforcing the challenge of pricing a resource like water that is a social-economic-ecological resource where conventional market rules for private goods do not apply.

While the aforementioned objectives for sustainable water management can be integrated using different rate structures, multipliers or concessional factors, the methodological approach for the calculation of the charge is highly contextual and contingent on the institutional and legislative frameworks of the region. In the context of Canada, the calculation of water extraction charges is seldom based on full social, economic, and environmental costs using the Total Economic Valuation Framework (Dupont & Adamowicz, 2017; Dupont & Renzetti, 2008). While there are studies undertaking valuation of ecosystem services for the Great Lakes basin but granular analysis that quantify social, economic, and environmental value of water resources at the sub-watershed scale is absent (Dupont &

Adamowicz, 2017). Addressing this gap, given the contextual considerations, ease of administration and implementation within the existing legislative framework set up for extraction charges, this study used the principle of full economic cost recovery of overall water resource management to calculate a base provincial volumetric charge. While the province exclusively associates water extraction charges to water quantity management, the nuances of value added due to water quality management to water users is generally overlooked.

Water resource management in a multidimensional construct, which encompass initiatives that address both quantity and quality of water resources in the region (Cantin et al., 2005; Renzetti, 2007). Thus, for extractive water sectors a sustainable source implies adequate quantity and quality of water resources in line with the rationale used by the province for its Source Protection Plans for drinking water. Hence, in contrast to the original objective used by the Province of partially recovering select water quantity and permitting costs, this study accounted all Federal and Provincial costs attributable to all initiatives centered on water resources (quantity and quality) from 2007-2017.

When economic expenditures are parsed at the provincial scale, as emphasized in the Environmental Commissioner of Ontario's report (2015) and Auditor General of Ontario's report (2014, 2015), this study has also found that over the years the federal and provincial government have spent significant financial resources to assure the quality and productivity of water resources especially in the Great Lakes region. The province has also borne significant costs as a result certain extreme contamination events, which are indicative of the environmental costs of remediation that assure quality of these resources. However, these costs are disconnected from the current extraction charges and water use sectors that are the beneficiaries are oblivious to the value added to the resource by both water quantity and quality federal and provincial programs (Renzetti, 2007).

While the province attributes an annual cost of $17.5 Million to the water quantity management programs, this study accounted for all federal and provincial costs (operating, capital, and grants disbursed) for water resource management initiatives undertaken in the last ten years to arrive at an average annual cost (excluding the contingency costs of extreme contamination events) of $361.86 Million. When contingency costs of extreme groundwater contamination events are taken lump sum as a proxy for environmental costs these average resource management costs increase to $535.193 Million/year. Thus, it can be concluded that the initiatives undertaken by the province for overall water resource management rise over and above water quantity management and are significantly higher than what the province aims to recover.

These costs are currently sourced predominantly from general tax revenues, hence the actual value of these water resource management programs do not get transferred equitably on a volumetric basis to the various end-users or beneficiaries of these value-added and well-managed resources (Auditor General of Ontario, 2014; Renzetti, 2007). A holistic accounting of these expenditures brings to fore not only the widening value-price gap of the current water charges but also the inability of current water policies to signal to users the sheer amount of investment being made on water sustainability initiatives.

When the hydrological data for water intake in the Great Lakes basin is reviewed, the three sectors that extract majority of the volume of water are thermoelectric power generation, municipal water supply, and manufacturing. Municipal water supply includes both residential as well as industrial and commercial sectors connected to municipal systems supplying treated water. In the past ten years, the municipal water supply sector has consistently shown improvement and has reduced its water intake as attributed in literature to various municipal initiatives including revising water supply tariffs, awareness programs, and rebates on innovative water efficient plumbing fixtures for the residential sector (Bruneau et al., 2013; Environmental Commissioner of Ontario, 2017). Thermoelectric power generation and manufacturing sectors have shown improvement but the trend is rather non-linear with sudden peaks in demand for the year 2013. Interestingly the water intake for the agriculture sector has been the highest in the year 2016 coinciding with the reduced precipitation patterns for the region. The volume extracted by the sector is considerably lower than the industrial and municipal counterparts but being highly water consumptive makes agriculture a key sector to be scrutinized for sustainable water use. Given the increasing uncertainty in natural productivity of water resources due to stressors like climate change, population growth, and economic development, further improvement in use-efficiency as well as conservation is warranted to dissipate the growing water stress in the Great Lakes Basin (Environment Canada & Ontario Ministry of the Environment and Climate Change, 2014; Statistics Canada, 2017).

The average annual volume withdrawn for all permit liable sectors based on 2007 to 2015 data is calculated to be approximately 23.2 Billion m^3 /year. Out of this total, about 86% is attributable to thermal power generation sector. Using the average volume of water intake by permit liable self-supplied sectors, the base provincial charge to recover all water resource management and extreme contamination events is approximately $23/Million Liters. If a major water extracting sector like thermal power generation is excluded like in current provincial pricing scheme, the charges increase manifold for the remaining sectors. Thermal power generation is considered to be a low consumptive user of water since majority of the water extracted is returned to the watershed (Ontario Ministry of Environment and Climate Change, 2007). However, from a sustainability and equity perspective, the sector extracts the maximum volume of water and benefits equally from the water quantity and quality programs so should be liable for extraction charges. Nonetheless, again reiterating the point made previously if the hydroelectric power generation facilities in the province are liable for a "water rental charge" for the in-stream use of provincial water resources, the same rationale should apply for thermal power generation or extractive use sectors as well (Business Council of British Columbia, 2013; Dupont & Renzetti, 1999).

Based on the econometric analysis for Canada, Rivers and Groves (2013) estimated that in order to reduce water demand by 25% nationally, an annual volumetric charge of $13/Million Liters would have to be imposed on all water extractive sectors. However, this national analysis and similar analysis conducted for Ontario by Dupont and Renzetti (1999) do not account for actual resource costs to arrive at a holistic multi-objective water extraction charge for water demand reduction (Dupont & Renzetti, 1999; Rivers & Groves, 2013). Thus, alluding to the results of this study, the calculated water extraction charge of $23/Million Liters on permit liable sectors will not only most likely reduce overall water demand but also recover the costs of water resource management such that these programs are financially self-sustained in the future.

It is duly acknowledged that the province may need flexibility in deciding what specific water management programs to consider for cost recovery as well as what sector to impose charges on. It may be decided by the province to exclude certain sectors like municipal water supply, agriculture or sectors exempted from permits to be charged for these programs (Canadian Council of Ministers of the Environment, 2015; Ontario Ministry of Environment and Climate Change, 2007). All permit liable sectors that extract water should be equitably charged based on recovery of full water resource management costs but sectors involved in efficiency programs can be given a discount using the concessional factor provided in the calculator designed in this study.

Various academic papers have concluded that by underpricing water both the value of the resource is overlooked and there is failure of signaling the looming risks of water resources to users thereby resulting in over extraction, wastage, and ultimately conflicts among users (Bruneau et al., 2013; Cantin et al., 2005; Renzetti, 2017; Vandierendonck & Mitchell, 1997). Thus, by including various price multipliers for source, location, and sector specific water risks, a dynamic water extraction charge can be designed to signal these regional water conditions. A recurring theme in the various global and provincial examples for water pricing frameworks was the differentiation of charges based on factors like watershed conditions, type of source, seasonal conditions, quality of source, as well as consumptive use of water by certain sectors (OECD, 2017).

Similar themes are seen in Canadian provinces where instead of a multiplier, in the case of Saskatchewan extraction by industrial sectors in certain high use or sensitive watersheds as well as higher quality water sources are charged a higher volumetric price. Even in the case of Quebec which is considered to be water abundant like Ontario, water extraction by high consumptive industrial sectors are charged $70/Million Liters and $2.5/Million Liters for remaining industrial sectors. This relative differentiation becomes an important tool to cater to the sustainability objectives of water charges where risks can be signaled via proportional increase in prices (Cantin et al., 2005; Eurpoean Environment Agency, 2013; Morris et al., 2008; OECD, 2017; Renzetti, 2007).

As evident from the extensive hydrological technical assessment reports submitted by Conservation Authorities to the province as a part of the Source Protection Plans, there are many quaternary watersheds that are potentially at risk for surface water and groundwater quantity issues. Findings of these technical assessments funded by the provincial government can be incorporated for future water allocation decisions (Conservation Ontario, 2016). Thus, for the purposes of arriving at a dynamic bulk water pricing framework, these scientifically identified high and moderate risk quaternary watersheds are included in the designed framework and assigned a multiplier in the charge calculator. Moreover, in order to address the issues highlighted in the literature and recent developments regarding water bottlers in the province on sensitivity of groundwater sources in the province along with high and medium consumptive use sectors price multipliers are assigned to each of the category (Ontario Ministry of Environment and Climate Change, 2017a; Morris et al., 2008).

As demonstrated in the sample calculation for a hypothetical water bottling permit presented in Section 6.2, based on the specific inputs on location, sector, and source of water, different multipliers help in generating price differentiation specific to the water risk involved. Thus, a multiplier of 3.375 is applicable for the watershed, location, and sector risks that further increases to 5.0625 for the low precipitation months as a added seasonal surcharge. Thus, once again the proportionally increasing peak prices can signal not only change in consumption behavior but also can guide decisions for production during drier or higher priced months. The higher revenue generated in such cases provide enough contingency for ongoing resource management initiatives as well as funds for future sustainability initiatives in line with the Quebec “Green Fund”. A similar fund can be generated dedicated to water management in Ontario where revenues can be directed to support more technical assessments, municipal infrastructure upgrades, supporting smaller conservation authorities, and other provincial water related initiatives that tend to be underfunded.

The values assigned to the multipliers in the study are currently set arbitrarily with relative higher weights assigned to the “high” risk categories. These multipliers can be calibrated and set by policy makers after engaging various stakeholders representing different use sectors. As outlined in the original proposal for water conservation charges drafted by the Ontario Ministry of Environment in 2007, key feature of the volumetric charge was the ease of administration and implementation (Ontario Ministry of Environment and Climate Change, 2007). However, given the hydrological reality ten years later, a static volumetric charge will not suffice if the dual goals of revenue generation and promotion of sustainable use is to be attained in a populous and booming economy (Bruneau et al., 2013; Environmental Commissioner of Ontario, 2014). Thus, based on existing principles of cost recovery and volumetric pricing, rather than using complex increasing block rate structures, a series of multipliers are integrated in this dynamic bulk water pricing framework to achieve the same objective.

7.2 Contribution of the Study

Assuring sustainability and quality of water resources in a climatically uncertain future is an increasingly pertinent policy objective in the populous and industrialized province of Ontario (Environmental Commissioner of Ontario, 2014; Ontario Ministry of Environment and Climate Change, 2007; Ontario Ministry of Environment and Climate Change, 2017a). The objective and hence research questions of this study have been motivated by the recently imposed temporary moratorium by the Ontario Ministry of Environment and Climate Change on new water bottling permits to extract groundwater along with the hike of extraction fees for the sector (Ontario Ministry of Environment and Climate Change, 2017a,d). The concerns and conflicts about unsustainable use of water resources as well as temporal and spatial water stress have been prevalent in the province since long but the recent moratorium itself presents an opportunity for policy reform. Since the province is considering overall reforms in the Permit to Take Water program to cater to overall sustainability of water resources, this provides an apt avenue to suggest pertinent measures for all water use sectors.

Water extraction charges have been championed as important water demand management instruments across policy and academic literature in the past few decades that complement existing regulatory instruments and voluntary stewardship initiatives (Cantin et al., 2005; Finney, 2013; OECD, 2017). The regulatory and legislative framework for implementing these charges currently exists in the province of Ontario, where a volumetric charge of $3.71/Million Liters is imposed on a few high water consumptive sectors. Over the years this charge has been deemed insufficient in catering to the demand management objectives of use-efficiency and conservation as well as for recovering costs of water resource management (Environmental Commissioner of Ontario, 2014; Renzetti, 2007). With the current fee hike to $503.71/Million Liters for water bottling sectors, the dialogue on overarching reforms in abstraction charges for all sectors has been refueled (Ontario Ministry of Environment and Climate Change, 2017a; Water Canada, 2016). Given the impetus on imposing charges on other sectors and increasing focus on more transparent means of arriving at charges, the need for a dynamic bulk water pricing framework was evident.

A pertinent policy and academic gap that this study addresses and hence contributes to is the design of a dynamic bulk water pricing framework attuned to the regional context of Ontario. Over the years, academic literature has criticized the limitation of current static volumetric extraction charges in reflecting spatial and temporal water conditions to users to effectively bring about a change in consumption behavior (Renzetti, 2007). Moreover, by underpricing water extraction by partially recovering only costs of quantity management programs and relying majorly on general tax revenues for funding the extensive water management initiatives not only are the users oblivious of the value added by the initiatives but also high volume users are subsidized (Ontario Ministry of Environment and Climate Change, 2017a; Renzetti, 2007; Vander Ploeg, 2011).

This study tends to correct these distortions by accounting for all costs of water resource initiatives and volume extracted by all water use sectors in the calculation of the base volumetric water extraction charge that necessitates the revision of the current static charge of $3.71/Million Liters imposed on a few sectors. Thus, instead of using general tax revenues, an earmarked stream of revenues from these charges is generated purely based on volumetric basis in line with the beneficiary pays principles using a transparent and equitable pricing framework. This implies that water resource management can be financially sustained independently and provide relief to existing general taxes in tandem.

This study investigated various practices for pricing policies and strategies in some of the key countries across the globe along with provincial practices followed in Canada. Given the regional and regulatory context for Ontario, the bulk water-pricing framework is objectively designed based on the principle of cost recovery principles that draws on both economic and hydrological information publicly available. While the base provincial charge caters to the cost recovery objective of pricing, the price multipliers based on quaternary watershed quantity risks, use of groundwater sources, water consumption based sectors and seasonal severity of flow provide price signal to cater to the environmental sustainability objectives. Here the users are signaled various water risks that are temporally and spatially defined at the sub-watershed level.

To cater to the social equity or affordability concerns for certain permit applicants or to provide relief to firms involved in water stewardship programs a similar concessional factor is integrated. It is duly recognized that there are many decisions that the province has to make especially in regards to the transition from partial to full cost recovery as well as sectors that will be chosen for the charges. Thus, the bulk water charges calculator designed as an output of this study, not only provides flexibility to update data and price multipliers but also the choice of selecting programs for cost recovery as well as sectors for charge imposition to arrive at a provincial base volumetric water charge. Ideally all permit liable sectors and all water resource management costs including the contingency of extreme contamination events should be the basis for calculating the charge. However, in order to make the calculator flexible for use and implementation, these options have been integrated.

The study also provides insights into not only the various spatial water risks identified by technical assessment source protection studies for various quaternary watersheds but also the extensive investments made by the provincial and federal government to assure the sustainability and quality of water resources in Ontario. Thus, in addition to addressing the value-price gap there is also a signal to the use sectors about the costs of managing and sustaining water resources that were previously not transferred to them. While comprehensive bulk water pricing and extraction charges have been theoretically suggested by various studies in the Canadian context, a comprehensive pricing framework and a charge calculator based on actual volumetric and cost accounting principles has not been designed for the province (Bruneau et al., 2013, Cantin et al., 2005; Morris et al., 2008; Renzetti, 2007).

Addressing this gap, a key output of this study is a framework that operationalizes the theoretical principles of water pricing, which is used to design a bulk water charges calculator catering to the objectives of equity, cost recovery, and environmental sustainability. Thus, this study provides a practical, easy to use, and flexible tool that can be implemented by the province to calculate region and sector specific charges in response to the ongoing water policy review.

7.3 Data Limitations

1. Due to the lack of current data for all water use sectors specifically for the Great Lakes-St. Lawrence-Ottawa basin, reasonable estimations/approximations were made using assumptions outlined in Table 4. Not all Statistics Canada water use surveys for different sectors are collected at the same frequency or same years (e.g. manufacturing and agricultural surveys) so the average annual volume is calculated over the time period of individual surveys within the time frame of 2007 to 2017. Since for the purposes of this analysis an average volume was needed, some error of estimation was acceptable. While majority of the water use sectors like manufacturing, thermal power generation, agriculture, municipal supply, mining are surveyed by Statistics Canada, sectors like construction, sand and gravel, clay, ceramic and refractory minerals mining and quarrying were not included in the industrial water use surveys.
2. Water used for certain sectors like agriculture and livestock are highly variable and cannot be estimated with complete accuracy due to lack of monitoring. Moreover there are certain sectors like construction that apply for temporary permits for water withdrawal that are not accounted for in these surveys. Thus, for more accurate charge estimates water withdrawal surveys need to include all water sectors.
3. The Ontario Ministry of Mines and Northern Development also makes annual investments on groundwater science and aquifer mapping (Ontario Ministry of Environment and Climate Change, 2016). However, the exact amount of investment is not explicitly stated in the public accounts or provincial/academic reports so the costs of such programs cannot be accounted in the framework.
4. The current analysis on water withdrawn by different sectors relies on secondary data sourced various from Statistics Canada water use surveys for different sectors. The primary data for the industrial sector is collected by Statistics Canada using cross-sectional sample surveys administered via questionnaires. While the methodology is sound, various estimations have also been made to correct errors, overcome issues like partial responses to finally generalize the data to the entire population based on sampling weights. Hence the secondary data used is also not completely free of errors of estimations or assumptions.
5. The data used in the framework needs to be updated regularly as more detailed technical assessments are conducted in the region for water risks. The federal and provincial expenditures will also need to be updated to account for any new or discontinued water resource management programs and initiatives in the future.

8.0 Conclusion

Water is a unique resource that is crucial for human survival, ecological vitality, a key material input for production in economic sectors and is at the core of human lifestyle as well as culture. With growing stressors like climate change, population growth, and industrial activities both quantity and quality of water resources are potentially threatened. Given the looming threat of uncertain supply, deteriorating water quality, and burgeoning demand, sustainable water management has become a key policy objective. Even in the context of Canada and Ontario, over the years sustainable and efficient use of water resources has been echoed in many water policies and regulatory frameworks (Cantin et al., 2005; Ontario Ministry of Environment and Climate Change, 2007; Vandierendonck & Mitchell, 1997). However, the policy instruments used to operationalize these objectives have been rather ineffective for many high volume water extractive sectors where water continues to be undervalued (Bruneau et al., 2013). Thus, many concerns and conflicts between various water users erupt in the province of Ontario warranting a much needed reform in current water policies (Morris et al., 2008). While the current policy framework does include economic instruments like water extraction charges for demand management, the charges themselves have been rather low to incentivize conservation and change the consumption behavior of users failing to reflect the true value of water as a well-managed resource (Bruneau et al., 2013; Environmental Commissioner of Ontario, 2014; Renzetti, 2007).

Stemming from the economic theory of pricing, policy instruments like water charges can indeed be cost effective means of achieving both environmental and financial objectives in tandem (Cantin et al., 2005; Finney, 2013; OECD, 2017). However, the design of the pricing framework to arrive at appropriate water charges that cater to these objectives holistically is of critical importance and is also an avenue where the province of Ontario falters (Cantin et al., 2005; Renzetti, 2007). Most of the water demand management strategies in Ontario are reactively driven and the ongoing controversy on groundwater extraction by water bottling sectors has once again resurrected the need for holistic measures for signaling temporal and spatial water conditions proactively to all use sectors (Ontario Ministry of Environment and Climate Change, 2017a; Water Canada, 2016). Thus, given this academic and policy gap for designing regionally attuned bulk water extraction charges, the study provides a dynamic bulk water pricing framework based on global best practices adapted to the context of Ontario.

Water is both a common and economic resource thus pricing of water resources has been articulated in many different ways. The arguments for accessibility to water as a human right, affordability concerns as well as economic implications of water pricing on competitiveness of certain water-reliant sectors are important considerations that can be addressed using a comprehensive water policy using a complementary mix of regulatory, economic, and voluntary instruments rather than maintaining status quo (European Environment Agency, 2013; OECD, 2017; Renzetti, 2007). Previous econometric studies have also established efficacy of volumetric water extraction charges to reduce demand without significant economic implications. Moreover, using the proposed unified pricing framework, the surplus revenue generated can be earmarked to provide financial relief or routed to tax credit programs to support water-efficient practices/measures undertaken by permit holders (Dupont & Renzetti, 1999; Rivers & Groves, 2013).

As elaborated earlier, recovering water management expenditure from sectors proportional to their actual volumetric water intake while including provisions for affordability is a transparent way of imposing charges rather than indirectly funding water initiatives from general tax revenues. Thus, from overarching sustainability considerations, the pricing framework designed in this study tends to signal the objectives of equity, economic efficiency, and environmental sustainability in tandem by means of different surcharges and concession factors while recovering full costs of water resource management from beneficiaries directly. Extraction charges based on cost recovery of average annual water resource management costs is an immediate starting point. However, expanding the charge to account for full social, economic, and environmental costs using the Total Economic Valuation framework at the sub-watershed scale can be seen as a pertinent future research direction in designing more comprehensive economic instruments. Including water quality objectives by including charges or taxes for discharge effluents based on target pollutant limits should also be considered for a comprehensive water resources "use" charge over and above extraction.

Water has been a core resource for the economy as well as cultural identity of Ontario. Given the forecasted demand for water reliant industries and trade, water will continue to be a key resource to pursue future economic opportunities (Rubin, 2017). Thus, the province can utilize the complete potential of economic instruments that can complement existing regulatory instruments and voluntary initiatives to proactively foster sustainable management of water resources so as to transition Ontario into a water secure and sustainable economy.

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10.0 Appendices

10.1 Key Terms and Definitions

Bulk/ self-supplied Water: Water directly extracted by users from a water source like lakes, rivers, streams, creeks, and wells.

Bulk Water Price: The price of bulk/ self-supplied water as resource (raw bulk water at the source and is not treated).

Water Intake/ Abstraction/ Withdrawal: Total volume of water extracted or withdrawn from the source directly and entering the production facility.

Water Demand: "Relationship between the *desired* quantity of water and the sector of factors (prices, income, output, technology, climate etc.) that have been demonstrated to influence that desire." - Renzetti, S. (2002). *The economics of water demands*. Boston: Kluwer Academic Publishers. pp. 145

Water Consumption: Volume of water that is permanently removed and not returned to the original water source. Thus, the difference between water intake and water discharged is water consumed. This includes the water lost to evaporation or embedded in the product itself or is the product itself.

Water Recirculation: Water in a facility that is recycled in the process (same purpose).

Water Intensity: Amount of intake water per unit economic output.

Waste Assimilation: Waste discharged from different industrial and municipal facilities, farms into water bodies that serve to dilute and remove the waste.

Process Water: Water that is used directly in the production of a product or is the product itself (bottled water, beverages).

Heating/ Cooling Water: Water is not used directly to make the product but is used to heat (steam run heat exchangers) or cool (cooling water heat exchangers) other reactants or products in the process. In thermal electricity generation, water is converted into steam in order to generate electricity.

Total Water-use Costs: Overall costs incurred by user associated with water used from abstraction to discharge in a facility. This includes abstraction fee (access), costs paid for municipal water, pumping costs, treatment costs, operations & maintenance of supporting water instruction for intake, recirculation, and discharged water.

Price elasticity of Demand: Change in quantity demanded by the consumer when the price of a good changes by a unit. Generally expressed as a negative quantity since increase in price for a good reduces demand for a relatively elastic response. - Griffin, R. C. (2016). *Water Resource Economics: The Analysis of Scarcity, Policies, and Projects*. MIT Press.

10.2 Sub-watershed Classifications for Great Lakes-St. Lawrence-Ottawa Region in Ontario

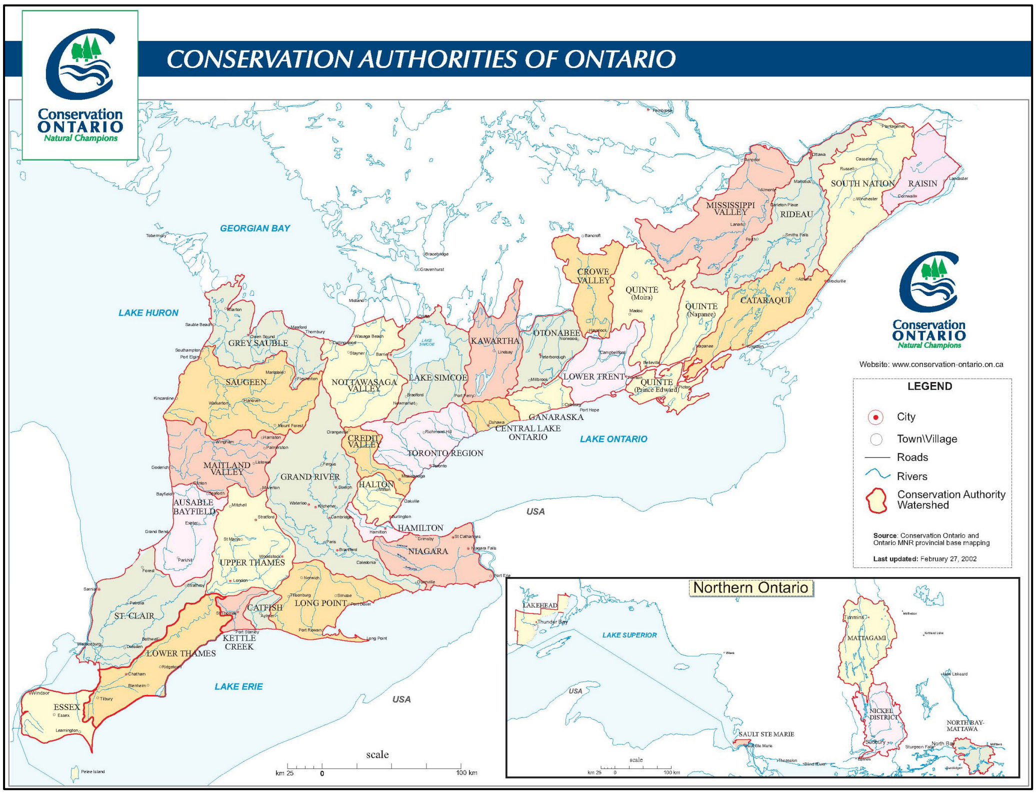
Great Lakes Main Watershed	Source Protection Regions (18)	Sub Watersheds by Conservation Authority (35)	Municipal Regions Covered
Lake Erie	1. Essex	Essex	Essex
	2. Thames-Sydenham	St. Clair	Lambton (Wyoming)
		Lower Thames	Chatham-Kent
		Upper Thames	Perth (Stratford), Middlesex (London), Oxford
	3. Lake Erie	Kettle Creek	Elgin (St. Thomas)
		Catfish Creek	Elgin (St. Thomas), Oxford,
		Long point	Haldimand-Norfolk
		Grand River	Waterloo, Guelph, Brant, Haldimand-Norfolk
Lake Ontario	4. Niagara	Niagara	Niagara
	5. Hamilton-Halton	Hamilton	Hamilton
		Halton	Halton
	6. CTC	Credit Valley	Dufferin (Orangeville)
		Toronto Region	Toronto, Peel, York
		Central Lake Ontario	Durham
	7. Trent	Ganaraska	Northumberland (Cobourg)
		Kawartha - Haliburton	Kawartha, Haliburton (Minden)
		Otonabee - Peterborough	Peterborough
		Lower Trent	Durham
		Crowe Valley	North Kawartha
	8. Quinte	Quinte	Prince Edward, Lennox & Addington (Napanee), Hastings (Belleville)
	9. Cataraqui	Cataraqui	Leeds & Grenville(Brockville), Frontenac(Kingston)
St. Lawrence-Ottawa	10. Raisin-South Nation	Raisin	Stormont, Dundas & Glengarry (Cornwall)
		South Nation	Prescott & Russell (L'Orignal)
	11. Rideau-Mississippi	Rideau	Ottawa
		Mississippi Valley	Lanark (Perth)
	12. North Bay - Mattawa	North Bay - Mattawa	Nipissing, Timiskaming, Parry Sound
Lake Huron	Thames-Sydenham	St. Clair	Lambton (Wyoming)
	13. Ausable Bayfield-Maitland Valley	Ausable Bayfield	Huron (Goderich)
		Maitland Valley	Huron (Goderich)
	14. Saugeen-Grey Sauble-	Saugeen	Bruce (Walkerton)
		Grey Sauble	Grey (Owen Sound)

Great Lakes Main Watershed	Source Protection Regions (18)	Sub Watersheds by Conservation Authority (35)	Municipal Regions Covered
Lake Huron	Northern Bruce		
	15. South Georgian Bay Lake Simcoe – Severn Sound Environmental Association	Nottawasaga Valley	Simcoe (Midhurst), Muskoka
		Lake Simcoe	Simcoe (Midhurst)
	16. Sudbury	Sudbury	Sudbury
	North Bay - Mattawa	North Bay - Mattawa	Nipissing, Timiskaming, Parry Sound
	17. Sault Ste Marie	Sault Ste Marie Region	Sault Ste Marie
Lake Superior	Sault Ste Marie	Sault Ste Marie Region	Sault Ste Marie
	18. Lakehead	Lakehead	Thunder Bay

*Color shaded sub-watersheds have partial overlap with more than 1 main watershed

Source: Conservation Ontario (2018)

10.3 Map of Various Conservation Authorities in Ontario



Source: Conservation Ontario (2018)

10.4 Water Consumption Categories by Sector

Water Consumption Percentage*	Industrial Sector	Category
High Consumption (30-100%)	Water Bottling	High
	Fruit and Vegetable Canning or Pickling	High
	Beverage Manufacturing	High
	Ready-mix Concrete Manufacturing	High
	Non-metallic Mineral Product Manufacturing	High
	Pesticide, Fertilizer and other Agricultural Chemical Manufacturing	High
	Inorganic Chemical Manufacturing	High
	Golf Course Irrigation	High
Medium Consumption (1-30%)	Dewatering - Pits, Quarries, Aggregate Washing	Medium
	Construction	Medium
	Mining and Oil and Gas	Medium
	Food Processing	Medium
	Primary Metal Manufacturing	Medium
	Textile and Textile Product mills	Medium
	Clothing Manufacturing	Medium
	Leather and Allied Product Manufacturing	Medium
	Wood Products Manufacturing	Medium
	Paper and Pulp Manufacturing	Medium
	Petroleum and Coal Manufacturing	Medium
	Plastics and Rubber Manufacturing	Medium
	Fabricated Metal Product Manufacturing	Medium
	Machinery Manufacturing	Medium
	Computer and Electronic Product Manufacturing	Medium
	Transportation Equipment Manufacturing	Medium
	Furniture and related Product Manufacturing	Medium
	Self Supply Commercial and Institutional	Medium
	Miscellaneous Manufacturing	Medium
Low Consumption (<1%)	Thermal Power Generation	Low

Water Consumption Percentage*	Industrial Sector	Category
Very Low Consumption (<0.1%)	In-stream water users e.g Hydroelectric Power Generation	Very Low
Special Sectors	Municipal Water Supply	Medium
	Domestic Self Supply	Medium
	Agriculture Irrigation	High
	Livestock	High

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

* % consumption is based on the volume of water withdrawn that is permanently removed and hence not returned the original water source due to consumption in various production processes or evaporative losses.

10.5 Sample Water Quantity Risk Assessment Maps by Grand River Conservation Authority

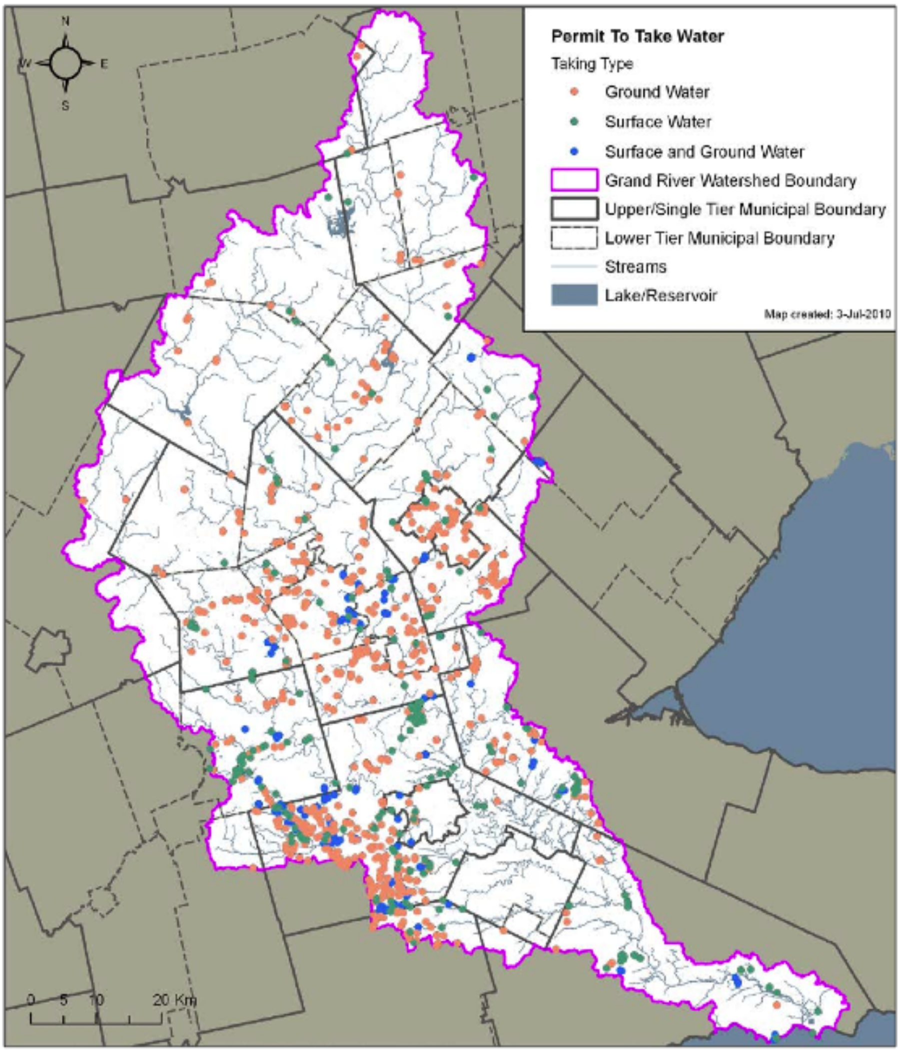


Figure 10: Permits to Take Water, All Sectors

Source: Grand River Conservation Authority (2015) Approved Assessment Report for Source Protection

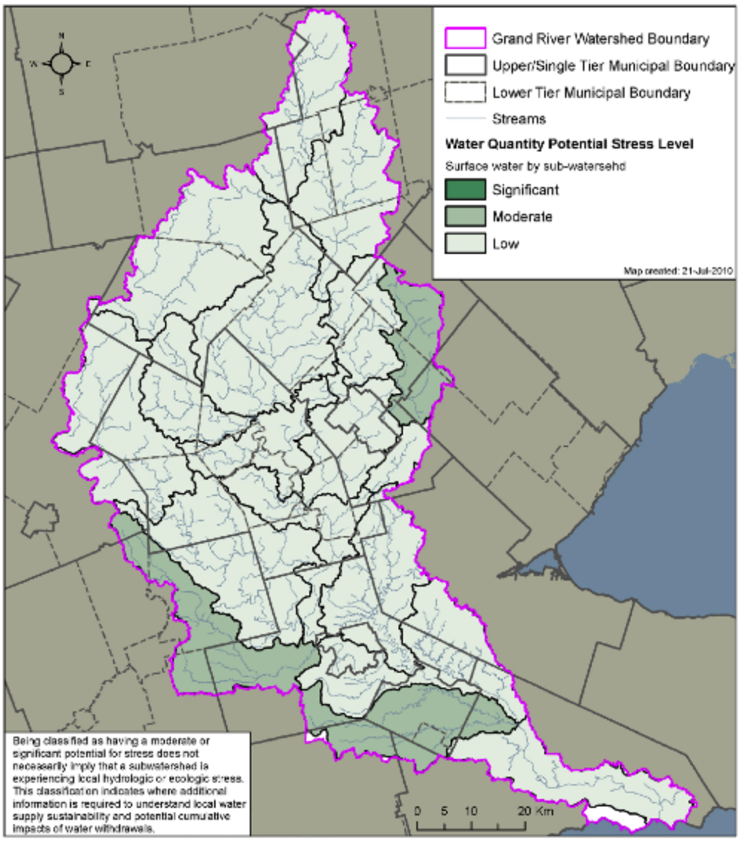


Figure 11: Surface Water Quantity Risk Assessment for Grand River Watershed

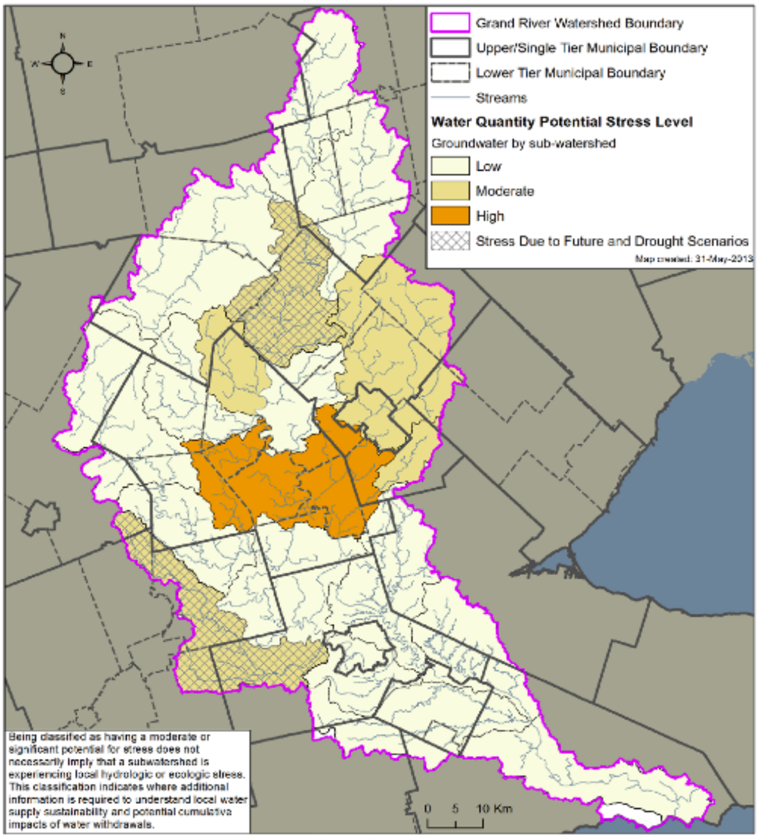


Figure 12: Groundwater Quantity Risk Assessment for Grand River Watershed

Source: Grand River Conservation Authority (2015) Approved Assessment Report for Source Protection

11.0 Data Appendices

11.1 Provincial Operating and Capital Expenditures on Various Water Management Initiatives (2007-08 to 2017-18)

Year	Type of Expense in Nominal Million CAD	MOECC, in Nominal Million CAD	MOECC Source protection, in Nominal Million CAD	MOECC Nutrient Management, in Nominal Million CAD	MOECC Great Lakes Initiatives, in Nominal Million CAD	MOECC, Clean Water, in Nominal Million CAD	MNR Source Protection Grants to CA, in Nominal Million CAD	MNR, Grants to CA for other program initiatives and adminstration in Nominal Million CAD	Total in Nominal Million CAD
2000	Total	17.162					9.384		26.546
2001	Total	14.387					7.791		22.178
2007	Operating		36.2	5.71		99.78	14	7.73	163.42
	Capital		23.25		1.713		3.26		28.223
2008	Operating		44.69	5.99		98.90	13.93	7.73	171.24
	Capital				1.86		2.01		3.87
2009	Operating		47.22	6.72		98.22	12.837	7.73	172.73
	Capital				1.52		2.01		3.53
2010	Operating		46.33	8.28		98.36	11.52	7.73	172.22
	Capital						2.01		2.01
2011	Operating		61.72	8.25		100.34		7.73	178.04
	Capital		3.61						3.61
2012	Operating		40.34	8.15	2.66	104.83		7.45	163.43
	Capital		1.81						1.81
2013	Operating		44.03	8.89	2.90	114.37		8.08	178.27
	Capital		2.01						2.01

Year	Type of Expense in Nominal Million CAD	MOECC, in Nominal Million CAD	MOECC Source protection, in Nominal Million CAD	MOECC Nutrient Management, in Nominal Million CAD	MOECC Great Lakes Initiatives, in Nominal Million CAD	MOECC, Clean Water, in Nominal Million CAD	MNR Source Protection Grants to CA, in Nominal Million CAD	MNR, Grants to CA for other program initiatives and adminstration in Nominal Million CAD	Total in Nominal Million CAD
2014	Operating		43.28	8.74	2.86	109.59		7.45	171.92
	Capital								
2015	Operating		44.17	8.92	2.91	111.75		7.45	175.21
	Capital								
2016	Operating		47.00	9.49	3.10	119.10		7.45	186.14
	Capital								
2017	Operating		48.30	9.75	3.19	122.48		7.45	191.17
	Capital								
								Total Expenditure from 2007 to 2017	**1968.833**

Expenditures for Ministry of Environment and Climate Change (MOECC) and Ministry of Natural Resources and Forestry (MNR) included from Public Accounts of Ontario.

11.2 Average Annual Costs of all Water Resource Management Initiatives

Resource Management Initiative	Funding Source	Cost Category	Starting Year*	Ending Year*	Expenditure, $	Average Expenditure/Program Cost per year
Great Lakes Action Plan for Areas of Concern	Federal	2	2007	2016-17	80000000	8000000
Great Lakes Nutrient Initiative (Lake Erie)	Federal	2	2011	2016-17	31800000	5300000
Great Lakes Sediment Remediation	Federal	2	2008	2015-16	11600000	1450000
Groundwater Geoscience Program	Federal	1	2007	2011-12	2583333.333	516666.6667
Randle Reef Remediation Project	Federal	3	2016	2021-22	46300000	7716666.667
Lake Simcoe and South-Eastern Georgian Bay Clean-up Fund	Federal	2	2007	2016-17	59000000	5900000

Resource Management Initiative	Funding Source	Cost Category	Starting Year*	Ending Year*	Expenditure, $	Average Expenditure/Program Cost per year
Lake Simcoe and South-Eastern Georgian Bay Clean-up Fund	Ontario	2	2007	2011-12	28500000	5700000
Randle Reef Remediation Project	Ontario	3	2016	2021-22	46300000	7716666.667
Great Lakes Agricultural Stewardship Initiative	Ontario	2	2015	2018-2019	16000000	4000000
Great Lakes Protection Projects under Canada-Ontario Agreement	Ontario	2	2007	2016-17	150000000	15000000
Water Quality Initiatives in Great Lakes Basin	Ontario	2	2007	2016-17	660000000	66000000
Ontario's Showcasing Water Innovation (SWI) program	Ontario	2	2011	2016-17	17000000	2833333.333
Ontario's New Directions research program	Ontario	2	2016		2000000	2000000

Resource Management Initiative	Funding Source	Cost Category	Starting Year*	Ending Year*	Expenditure, $	Average Expenditure/Program Cost per year
Provincial Management of PCB contamination from storage facility in Smithville (Environmental Protection Act)	Ontario	3	**Extreme Event**		77900000	77900000
Water Treatment for Abandoned mine in Deloro	Ontario	3	**Extreme Event**		30000000	30000000
Groundwater Remediation in Elmira	Ontario	3	**Extreme Event**		50000000	50000000
Provincial Groundwater Monitoring Network	Ontario	1	**Extreme Event Walkerton (2000 - 2003)**		6000000	6000000
Healthy Futures for Ontario Agriculture	Ontario	1	**Extreme Event Walkerton (2000 - 2003)**		7000000	7000000
Provincial Water Protection Fund (PWPF), Groundwater Management Studies + Ontario MOECC follow up funding (2001)	Ontario	1	**Extreme Event Walkerton (2000 - 2003)**		19300000	19300000
Groundwater Management Studies	Municipalities	1	**Extreme Event Walkerton (2000 - 2003)**		1900000	1900000
Ministry of Natural Resources, Water Resource Management	Ontario	1	**Extreme Event Walkerton (2000 - 2002)**		17175000	17175000

Resource Management Initiative	Funding Source	Cost Category	Starting Year*	Ending Year*	Expenditure, $	Average Expenditure/Program Cost per year
Provincial Source Water Protection, MOECC	Ontario	1	2007	2017-18	533962305	48542027.7
Provincial Nutrient Management Plans, MOECC	Ontario	2	2007	2017-18	88881834	8080166.695
Provincial Great Lakes Initiatives, MOECC	Ontario	2	2007	2017-18	22710496	2064590.522
Provincial Clean Water program, MOECC	Ontario	1	2007	2017-18	1177712500	107064772.7
MNR Investments for water resource management	Ontario	1	2007	2017-18	145566000	13233272.73
National Hydrometric Program (Hydrological service and Water Survey)	Federal and Provincial	1	2008	2012-13	35000000	7000000
Water Quality Monitoring	Federal and Provincial	1	2009		5800000	5800000
Experimental Great Lakes Research	Ontario	2	2014	2017-18	8000000	2000000

Total Average Annual Cost of Water Resource Management	**535.19**	**Million $/ year**

11.3 Volume of Self-supplied Water Withdrawal (in Million m³ /year) by Sector

Coefficient for Ontario - Great Lakes Mining/ Oil and Gas Adjustment	**0.76**	Based on 24 % GDP share of Northern Ontario mining to Provincial Mining GDP in 2011
Coefficient for Ontario -Great Lakes Thermoelectric Adjustment	**0.975**	Based on % share of thermal power generation capacity (Ontario-Northern Ontario)

Geography	**Sector of use (1,000,000 m³)**	**2007**	**2009**	**2011**	**2013**	**2015**	**2016**	**Average per year X 1,000,000 m³**
Great Lakes (St Lawrence-Ottawa Included)	(1) Total potable water volume, all sectors of use	1825.5	1740.6	1652.8	1610.3	1608.8		1687.6
Great Lakes (St Lawrence-Ottawa Included)	(2) Total Self-supplied Rural Domestic	75.8	73.4	79.3	63.8	62.7		71.0
Great Lakes (St Lawrence-Ottawa Included)	Self-supplied Manufacturing	1506.9	1253.0	1296.6	1378.2	1283.3		1343.6
Great Lakes (St Lawrence-Ottawa)	Self-supplied Mining, Oil and Gas	40.7	32.7	54.0	29.5	39.1		39.2
Great Lakes (St Lawrence-Ottawa Included)	Mine water (GW removed to dewater mines)	33.1	27.5	20.4	23.3	29.8		26.1

Geography	Sector of use (1,000,000 m³)	2007	2009	2011	2013	2015	2016	Average per year X 1,000,000 m³
Great Lakes (St Lawrence-Ottawa Included)	Self-supplied Thermoelectric	21250.1	20380.6	18763.7	20219.0	18645.9		19935.0
Great Lakes (St Lawrence-Ottawa Included)	(3) Total Self-supplied Water, Manufacturing, Mining, Oil and Gas, Thermo-electric	22940.3	21798.9	20231.4	21754.1	19998.1		21343.8

Geography	Water Use Volumes x 1,000,000 m³	2010	2012	2014	2016	Average per year x 1,000,000 m³
Great Lakes (St Lawrence-Ottawa Included)	Total Agricultural irrigation volume	20.17	38.02	12.67	60.16	60.16
Great Lakes (St Lawrence-Ottawa Included)	Total Livestock water use volume		57.74	73.55	71.56	67.62
Great Lakes (St Lawrence-Ottawa Included)	(4) Total Agriculture and Livestock Water Intake Volume	74.34	95.77	86.22	131.72	127.78
Subtotal (1)(3)(4)	Subtotal of Average Volumes per year					**23159.2**
Great Lakes (St Lawrence-Ottawa Included)	Self-supplied Commercial and Institutional per year					99.5
Great Lakes (St Lawrence-Ottawa included)	**Average Water Intake, all water extractive sectors**					**23329.7**

Categories of Water Use Sectors Liable for Bulk Water Charges	Average Volume of Water Extracted in Million m³/ year
Industrial and Commercial (excluding Thermal Power Generation)	1508.3
Industrial and Commercial (including Thermal Power Generation)	21443.3
Industrial, Commercial, Thermal Power, and Agricultural	21503.5
All Permit Liable Sectors*	23191.0
All Water Use Sectors	23329.7

* Permit Exempt Sectors: Users taking water for livestock, poultry, domestic purposes, firefighting, other emergency services, wetland conservation, diversions for construction

11.4 High Surface Water Quantity Risks based on Source Protection Technical Assessments Reports of Conservation Authorities

Main Watershed	Sub-Watershed	Quaternary Watershed Under HIGH SW Quantity Risk	Water SW Quantity Vulnerability Category
Lake Erie	Essex	Little River, Pike Creek, Puce River, Ruscom River, Big Creek, Cedar Creek, Wigle Creek, Mill Creek, Hilman Creek, Muddy Creek, Sturgeon Creek, Areas around Point Pelee	High
	St. Clair	Plympton Shore Tributaries, St. Clair River Tributaries, Lake St. Clair Tributaries, Black Creek	High

Lake Erie	Lower Thames	Rondeau Bay, Lake St. Clair	High
	Upper Thames	Avon River,Cedar Creek, Reynolds Creek	High
	Kettle Creek		Low
	Catfish Creek	Silver Creek	High
	Long point	North Creek, Young / Hay Creeks	High
Lake Ontario	Niagara	Beaverdams and Shriners Creeks, Big Forks Creek, Fifteen, Sixteen, Eighteen Mile Creeks, Grimsby, Lincoln, Niagara-on-the-Lake, Twenty Mile Creek,	High
	Hamilton	Borer's Creek, Flamborough Creek, Spring Creek, West Spencer Creek, Hannon Creek	High
	Halton	Grindstone Creek, Upper Rambo Creek, Flamboro Creek, Willoughby Creek, Lowville Creek, Mount Nemo Creek, Middle East Branch, East Branch, Lower Middle Tributary, East Branch Lisgar	High
	Toronto Region	Etobicoke Region 4, Mimico Region 3, Humber Region 4, Rouge Region 2, Rouge Region 7, Duffins Region 6	High
	Central Lake Ontario	Lynde Creek, Goodman Creek, Oshawa Creek, Darlington Creek, Soper Creek	High
	Quinte	Consecon, Hillier, West Lake, East Lake	High

Lake Ontario	Cataraqui	Lyn Creek, Buells Creek, Bay of Quinte, Lake Ontario Tributaries, Sydenham Lake tributaries	High
St. Lawrence - Ottawa River	South Nation	Louis Lafleur Tributaries and Bouvier Tributaries, Central Cobb's Lake Creek and Bussiere Tributaries, Ottawa River Tributaries, Piperville Tributaries, Henderson Creek	High
Lake Huron	St. Clair (Overlapping Watershed with Lake Erie)	Plympton Shore Tributaries, St. Clair River Tributaries, Lake St. Clair Tributaries, Black Creek	High
	Saugeen Valley	Underwood/Tiverton, North Penetangore River/Kincardine, Pine River/Lurgan Beach,	High
	Grey Sauble	Craigleith, Bighead River/Georgian Bay Shore	High
	Nottawasaga Valley	Boyne River, Innisfil Creek, Middle Nottawasaga, Pine River, Upper Nottawasaga, Blue Mountain Watersheds	High
	Lake Simcoe	West Holland River, East Holland River, Black River, Georgina Creeks, Maskinonge River	High
	Severn Sound	Tiny Coastal Area North West, Tiny Coastal Area South, Tiny Coastal North East	High
	Sudbury	Ramsey Lake	High

11.5 Moderate Surface Water Quantity Risks based on Source Protection Technical Assessments Reports of Conservation Authorities

Main Watershed	Sub-Watershed	Quaternary Watershed Under Moderate SW Quantity Risk	Water SW Quantity Vulnerability Category
Lake Erie	St. Clair	Cow and Perch Creeks, East Sydenham Headwaters, Upper Sydenham, Lower East Sydenham, Lower North Sydenham, Bear Creek Headwaters	Moderate
	Upper Thames	Trout Creek/North Thames River	Moderate
	Catfish Creek	Catfish Above Aylmer, Lower Catfish	Moderate
	Long point	South Otter, Big Above Cement Road, Big Above Delhi, Venison Creek, Dedrick Creek, Nanticoke Upper, Stoney Creek, Lynn River	Moderate
	Grand River	Eramosa Above Guelph, Whitemans Creek, McKenzie Creek	Moderate
Lake Ontario	Niagara	Central Welland River, Fort Erie Creeks, Lake Erie North Shore, Lower Welland River, South Niagara Falls, Upper Welland River	Moderate
	Hamilton	Ancaster Creek, Logie's Creek, Middle Spencer Creek, Sulphur Creek, Sydenham Creek, Tiffany Creek, Stoney Creek Watercourses	Moderate
	Halton	Mountsberg Creek, Indian Creek, Middle Branch, Lower Middle Branch, West Branch	Moderate

	Credit Valley	Fletcher's Creek	Moderate
	Toronto Region	Etobicoke Region 1, Mimico Region 1, Humber Region (1,2,3,5,10), Don Region 5, Highland Region 5, Rouge Region (3,6)	Moderate
	Ganaraska	Wilmot Creek, Gages Creek	Moderate
	Kawartha - Haliburton	Burnt river, Ouse river, Lake Ontario tributaries, Bay of Quinte tributaries, Lindsay	Moderate
	Otonabee - Peterborough	Burnt river, Ouse river, Lake Ontario tributaries, Bay of Quinte tributaries, Lindsay	Moderate
	Lower Trent	Burnt river, Ouse river, Lake Ontario tributaries, Bay of Quinte tributaries, Lindsay	Moderate
	Crowe Valley	Burnt river, Ouse river, Lake Ontario tributaries, Bay of Quinte tributaries, Lindsay	Moderate
	Quinte	Parks, Ameliasburgh,	Moderate
	Cataraqui	Wilton Creek, Millhaven Creek, Collins Creek, Little Cataraqui Creek, St. Lawrence Tributaries	Moderate
St. Lawrence - Ottawa	Raisin	Westley's Creek, Garry River, Raisin River (South Branch)	Moderate

River	South Nation	North Castor River, Middle Castor River and Craig Street, Grantley Creek	Moderate
	Rideau-Mississippi Valley	Carp River near Kinburn, Ottawa MVC, Fall River at Bennett Lake	Moderate
	North Bay - Mattawa	Trout/Turtle Lake	Moderate
Lake Huron	St. Clair (Overlapping Watershed with Lake Erie)	Cow and Perch Creeks, East Sydenham Headwaters, Upper Sydenham, Lower East Sydenham, Lower North Sydenham, Bear Creek Headwaters	Moderate
	Saugeen Valley	Mill Creek	Moderate
	Grey Sauble	Beaver River/Kimberley, Bighead River	Moderate
	Nottawasaga Valley	Lower Nottawasaga, Willow Creek	Moderate
	Lake Simcoe	Pefferlaw Brook, Beaver River, Innisfil Creeks, Hewitts Creek, Oro Creeks North, Ramara Creeks, Upper Talbot River	Moderate
	Severn Sound	Copeland Creek, North River, Lafontaine Creek	Moderate
	North Bay - Mattawa (Overlapping watershed with Ottawa River)	Trout/Turtle Lake	Moderate

11.6 High Groundwater Quantity Risks based on Source Protection Technical Assessments Reports of Conservation Authorities

Main Watershed	Sub-Watershed	Quaternary Watershed Under HIGH GW Quantity Risk	Water GW Quantity Vulnerability Category
Lake Erie	Essex	Cedar Creek, Wigle Creek, Mill Creek	High
	Long point	Big Above Kelvin Gauge, Nanticoke Upper	High
	Grand River	Central Grand	High
Lake Ontario	Niagara	Lake Erie North Shore	High
	Hamilton	Lower Davis Creek	High
	Toronto Region	Lake Ontario Region 1	High
	Cataraqui	Lake Ontario	High
St. Lawrence - Ottawa River	Raisin	Gray's Creek, Raisin River (South Branch)	High
	South Nation	Henderson Creek	High

Main Watershed	Sub-Watershed	Quaternary Watershed Under HIGH GW Quantity Risk	Water GW Quantity Vulnerability Category
	Saugeen Valley	North Saugeen River/Chesley West	High
	Lake Simcoe	East Holland River, Barrie Creeks, Maskinonge River	High
	Severn Sound	Midland Area, Penetanguishene and Tay Point	High
	Sudbury	Valley East	High

11.7 Moderate Groundwater Quantity Risks based on Source Protection Technical Assessments Reports of Conservation Authorities

Main Watershed	Sub-Watershed	Quaternary Watershed Under Moderate GW Quantity Risk	Water GW Quantity Vulnerability Category
Lake Erie	Essex	(Hilman Creek, Muddy Creek), (Sturgeon Creek, Areas around point Pelee), Big Creek, Canard River, Turkey Creek (and nearby drainage areas	Moderate
	Long point	Big Above Delhi, North Creek, Big Above Minnow Creek, Lynn River	Moderate

Main Watershed	Sub-Watershed	Quaternary Watershed Under Moderate GW Quantity Risk	Water GW Quantity Vulnerability Category
	Grand River	Canagagigue Creek, Upper Speed, Mill Creek, Big Creek, Irvine River	Moderate
Lake Ontario	Niagara	Fort Erie Creeks, Fifteen, Sixteen, Eighteen Mile Creeks	Moderate
	Hamilton	Logie's Creek, Middle Spencer Creek	Moderate
	Halton	Upper West Branch, Willoughby Creek	Moderate
	Credit Valley	Black Creek, Silver Creek, Orangeville	Moderate
	Toronto Region	Don Region 6, Rouge Region 2, Duffins Region 6, Lake Ontario Region (2,3)	Moderate
	Central Lake Ontario	Lynde Creek, Darlington Creek	Moderate
	Kawartha - Haliburton	Crowe Lake, Kawartha Lake East 5, Lake Ontario	Moderate to High
	Otonabee - Peterborough	Crowe Lake, Kawartha Lake East 5, Lake Ontario	Moderate to High

Main Watershed	Sub-Watershed	Quaternary Watershed Under Moderate GW Quantity Risk	Water GW Quantity Vulnerability Category
	Lower Trent	Crowe Lake, Kawartha Lake East 5, Lake Ontario	Moderate to High
	Crowe Valley	Crowe Lake, Kawartha Lake East 5, Lake Ontario	Moderate to High
	Quinte	Picton	Moderate
	Cataraqui	Collins, Above Delta Gananoque River, Bay of Quinte, Lansdowne	Moderate
St. Lawrence - Ottawa River	South Nation	North Castor River	Moderate
	Rideau-Mississippi Valley	Rideau River at Ottawa	Moderate
Lake Huron	Ausable Bayfield-Maitland Valley	Goderich and Bayfield Gullies	Moderate
	Saugeen Valley	Lake Rosalind , Saugeen River/Walkerton	Moderate
	Grey Sauble	Sydenham River/Owen Sound E.	Moderate
	Nottawasaga Valley	Innisfil Creek, Middle Nottawasaga, Pine River, Willow Creek	Moderate
	Lake Simcoe	West Holland River, Uxbridge Brook, Hewitts Creek, Lovers Creek	Moderate

Main Watershed	Sub-Watershed	Quaternary Watershed Under Moderate GW Quantity Risk	Water GW Quantity Vulnerability Category
	Severn Sound	Coldwater River, Wye River, Port Severn and Matchedash Bay North, Tiny Coastal Area North West	Moderate
	Sault Ste Marie Region	Central Basin, East Basin of St Mary's River	Moderate
Lake Superior	Sault Ste Marie Region (Overlapping watershed with Lake Huron)	Central Basin, East Basin of St Mary's River	Moderate