Greenhouse Gas and Energy Co-Benefits of Water Conservation

By Carol Maas

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PREFACE

This report has been prepared to provide a summary of the water–energy nexus work completed to date by the POLIS Project on Ecological Governance. This report is a working document and will be updated and revised as POLIS continues to pursue research within the theme of the water-energy nexus, and specifically the greenhouse gas and energy co-benefits of a Soft Path for Water. The report is structured to provide a concise reporting of findings in the main body, followed by a series of appendices that provide further methodological details and a more comprehensive review of the results.

Box I: Soft Path Core Principles

Four principles distinguish the soft path from conventional planning and management:

- Treat water as a service rather than an end in itself.
- Make ecological sustainability a fundamental criterion.
- Match the quality of water delivered to that needed by the end-use
- Plan from the future back to the present.

Brandes & Brooks (2007)

This water-energy research is grounded in a Soft Path for Water approach. The Soft Path incorporates facets of water demand management while moving beyond a short-term focus on cost-benefit criteria to examine how the services currently provided by water can be delivered "in ways that recognize the need for economic, social and ecological sustainability" (Brandes and Brooks, 2007). Numerous publications on the Soft Path approach can be obtained from the POLIS website (www.poliswaterproject.org). However, readers do not require an in depth knowledge of the Soft Path to understand the impact of water efficiency measures on energy and greenhouse gas emissions. For the purpose of this report, *water conservation* is defined to include both water efficiency measures (high efficiency toilets, washing machines, etc.) and water saving measures (xeriscaping, rainwater harvesting, etc.) and is considered equivalent to the term *water demand management*.

ACKNOWLEDGEMENTS

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CWWA ACEPU Canadian Water and Wastewater Association canadienne des eaux potables et usées

CITY OF Guelph Making a Difference

INTRODUCTION TO THE WATER-ENERGY NEXUS

The flow of water – whether through forest or river ecosystems or through human built environments – creates complex interconnections among people, places and issues. This interconnectedness is often viewed as a major challenge in addressing environmental issues because of the many values, interests and actors at play. But this interconnectedness also provides opportunities. For water Soft Paths, the opportunities lie in the interconnections between water and energy, and the related climate change implications.

The story of these interconnections – often referred to as the "water–energy nexus" – has two sides. Huge amounts of water are required to generate energy - to power the turbines in hydro-electric facilities, for cooling in thermal or nuclear energy plants, and to extract oil from Alberta's tar sands. Indeed, collectively, the energy sector is the single largest user of water in Canada (Environment Canada, 2005). At the same time, large amounts of energy are required to pump, treat and distribute water for urban, industrial and agricultural use and to deal with the resulting wastes. Together, the two sides of this story are generating new research, policy proposals and public dialogue that will be critical as societies struggle to address the intersecting challenges of climate change, energy security and water scarcity.

This report deals with the second side of the story, the energy used for water provision, as it relates to urban water services. Specifically, it addresses the energy required to deliver water to, within and from our communities, to remove contaminants from water and wastewater, and to heat water in our homes.

The water-energy nexus is deeply embedded within the context of climate change, a concern that is front and centre for many Canadians and one that the Ontario Government has identified as a priority (Pembina, 2008; Office of the Premier, 2004). Burning fossil fuels to generate electricity and heat for provision of water services creates greenhouse gas (GHG) emissions, heat-trapping gases that contribute to global warming and ultimately to climate change. A discussion of the energy associated with water use, and the potential for related efficiencies, is therefore also necessarily a discussion of climate change and the potential for mitigation of greenhouse gas emissions.

Energy for Water in Ontario

The combined electrical energy to pump, treat and heat water, and to pump and treat wastewater is significant. Municipalities, largely responsible for the provision of water in Ontario, have been reported to consume "more electricity than any industrial sector outside Pulp and Paper" (Ontario Ministry of Energy and Infrastructure, 2008). In fact, according to a recent study, water and wastewater services together represent a third to a half of a municipality's total electricity consumption – double that of street lighting (PAGI, 2008). The City of Toronto, the Region of Peel and the City of Guelph have each identified water and wastewater facilities as significant energy consumers, reportedly accounting for between 25 to 60% of their respective municipal electricity bills (Harrison, 2007; Farbridge, 2008; OCMBP, 2006). Each of these municipalities has initiated progressive programs to improve the energy efficiency of this sector.

Water use *within* homes and businesses is also incredibly energy intensive. The residential sector accounts for 40% of all energy used in Ontario and heating water is typically the second largest consumer of energy in buildings (Arpke and Hutzler, 2006; Cuddihy et al., 2005). Despite an estimated 70% of water heaters fueled by natural gas in Ontario, electric hot water heating consumes 15% of the total residential electricity demand in Ontario, equivalent to that of lighting (SeeLine, 2005).

Energy consumed for heating, treating and pumping water, and for treating and pumping wastewater, generates carbon dioxide emissions – either from combustion of natural gas to heat water within our homes, or indirectly through use of electricity to drive municipal pumps. In 2007 fossil fuels contributed 30% to the Ontario electricity generation mix (Ontario Power Generation, 2008). Every kilowatt hour consumed, therefore, increases carbon dioxide emissions. Combustion of natural gas within our homes results in significant GHG emissions. Energy provided by natural gas is double that of electricity in Ontario's residential sector, and heating water consumes approximately one quarter of the natural gas used in the home (NRCan, 2006). Every kWh of electricity, and m^3 of natural gas, conserved, therefore positively contributes to the fight against climate change.

Climate Change and the Water-Energy Nexus

GHG mitigation and adaptation to global climate change are emerging as two of the most pressing concerns facing Canadian communities. Many communities are at the same time struggling to meet the rising water and energy demands of growing populations along with the associated costs of aging water and wastewater infrastructure and increasing operating expenditures.

Emerging contaminants, such as pharmaceuticals and personal care products, and high levels of nitrogen and phosphorus are increasingly leading to the adoption of advanced treatment technologies for both water and wastewater. These advanced treatment processes are a fundamental component of the environmental stewardship of our water resources, but typically come with an increase in electrical energy use.

Box 2: Climate Change and the Water-Energy Nexus

"It is anticipated that as climate changes, water resources will be altered; potentially reducing their quality, quantity, and accessibility. This in turn will require increased energy inputs to purify water of lower quality or pump water from greater depths or distances. Increased energy use will potentially lead to greater greenhouse gas emissions. Additionally, Canada's hydroelectricity sector could be affected forcing Canada to turn to other energy sources with higher emissions. All of this would ultimately reinforce climate change and create a vicious circle."

Thirwell et al. (2007)

Climate change has the potential to reduce water availability and the reliability of supply, and the resulting impacts will reverberate throughout the municipal, industrial and energy sectors. The trajectory of water and energy use in North America is contributing to a reinforcing cycle of increasing greenhouse gas emissions and detrimental impacts of climate change.

Co-benefits of Water Conservation

Water conservation has long been recognized as an important institutional and social adaptation to climate change (IPCC, 1996). But adaptation is only one of the advantages that water conservation offers with respect to climate change. Reducing water use also offers an effective way to reduce electrical energy consumption and greenhouse gas emissions (CIWEM, 2008). This concept is gaining ground in a variety of places. For example, a recent report by the California Energy Commission (CEC) highlighted water conservation as a significant, cost-effective opportunity for reducing energy use. The CEC found that implementation of all identified urban water conservation measures could "achieve 95 percent of the savings expected from the 2006-2008 energy efficiency programs, at 58 percent of the cost" (Klein, G. et al., 2005).

Box 3: Adaptation to Climate Change

"[Water conservation] is a strategic and effective adaptive strategy to the current challenge of water scarcity and will become more so as climatic variability and climate change impacts intensify. [Water Conservation] increases social resilience and contributes to preparedness policies, as opposed to the current responsiveness-policies to climate change..."

(IDRC, 2008)

INTRODUCTION TO THE STUDY

A number of Ontario's watersheds are showing signs of serious ecological stress. For example, Spencer Creek, located in southwestern Ontario, has "disappeared temporarily because of excessive water takings" (Environmental Commissioner of Ontario, 2001). However, the proximity of many communities to the Great Lakes has encouraged the "freshwater myth of abundance" that has shaped our attitudes and behaviours surrounding water for decades.

The water-energy nexus, then, provides an opportunity to highlight the energy and greenhouse gas (GHG) related environmental co-benefits of water conservation. Meeting Ontario's commitment to slow the progression of climate change will take more than changing out our light-bulbs. It will require all sectors to diligently look for opportunities to reduce waste and increase efficiency. The long-term energy and cost saving benefits that stem from efficiency will benefit municipalities, businesses, industry and agriculture and help build an efficient, resilient Ontario.

There have been an increasing number of studies published in recent years that recognize the link between water and energy use (Cheng, 2002; Cohen et al., 2004; Arpke and Hutzler, 2006). A number of additional studies have focused on optimization of pump, and treatment plant, efficiency as a first step towards reducing energy costs in the municipal water sector (Arora & LeChevallier, 1998; EPRI, 1994). Several important opportunities exist, in addition to the optimization of mechanical efficiencies, for incorporating the energy consumption associated with water use into decision making and policy (deMonsabert & Liner, 1998; Cohen et al., 2004). Encouraging water efficient communities is one such opportunity.

Energy and GHG savings associated with water conservation have been recognized by practitioners in the field for years. This report, however, marks the first comprehensive Canadian study to evaluate the energy savings potential offered by water conservation measures, and to establish a simple methodology for quantifying these co-benefits of reduced water use[1]. This report is intended to foster a greater understanding of the link between water and energy demands and to encourage policy making that builds on this new insight.

The research was conducted using data for municipalities in Ontario, in large part because POLIS sought engagement from the CWWA Water Efficiency Committee, and the majority of participants present at meetings are municipalities located within the province. Despite the Ontario focus, this report is highly relevant to the rest of Canada, and indeed much of North America. The study aimed to achieve two major research objectives: 1) to quantify the energy use associated with each component of the urban water use cycle; and, 2) to determine the potential for energy and GHG emission reductions associated with water conservation strategies.

The report begins with an overview of the energy inputs required for water provision. The methodology used to achieve the project objectives is first outlined, followed by a summary of findings. The technical findings of the study are then put into context, using illustrative examples for calculations used in water conservation programming, and examples of the GHG emissions savings that can be achieved on the municipal, provincial and citizen level. Finally, additional details of the methodology and calculations are included in the appendices of this report for readers interested in the technical details. A glossary of terms and acronyms is also included in Appendix G.

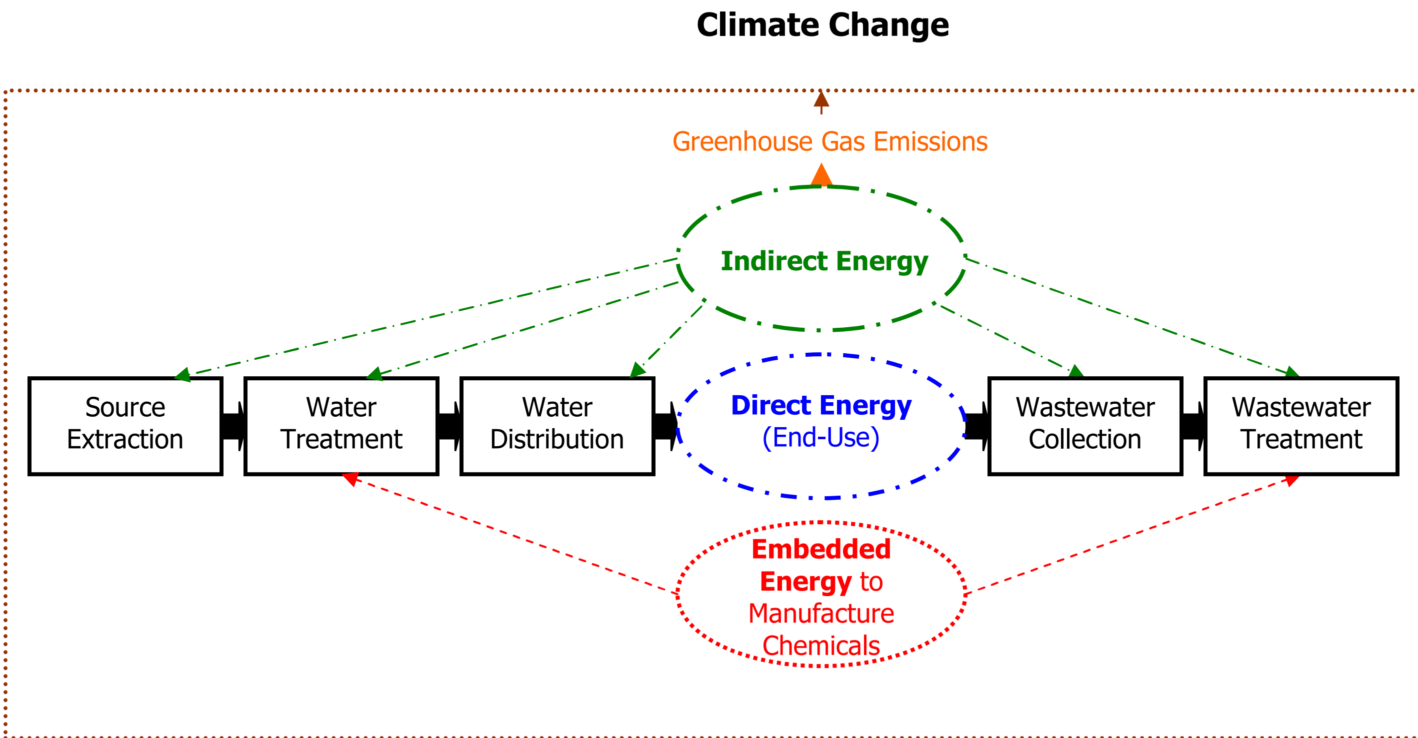
[1] The original report, published in November 2008 as a discussion paper, was retracted in December 2008 based on feedback that the assumptions and methodology were not sufficiently clear. The report structure has been revised with the intent of providing a clear methodology to determine energy and GHG emission savings for practitioners in Canada.

OVERVIEW OF ENERGY INPUTS INTO THE WATER USE CYCLE

Energy is used for a variety of water-related purposes within the boundaries of an urban community. Urban water use can be parsed into source extraction, water treatment, distribution, wastewater collection, treatment, and end-use as depicted in Figure 1. For the purpose of this report, energy inputs to the water use cycle can be further compartmentalized into:

- **indirect energy** (municipal energy to pump and treat water and wastewater);
- **direct energy** (energy used at the end-use for heating water, household purification and water softeners); and
- **embedded energy required to manufacture chemicals** used in the treatment of water and wastewater

Figure 1. Components of the Urban Water Use Cycle, including Energy Inputs within the context of Climate Change



Source: Adapted from Cohen et al. (2004)

METHODOLOGY

Indirect Energy for Municipal Water and Wastewater Provision

The energy consumed to provide municipal water services, i.e., to extract, treat and pump water to municipal customers, and to collect and treat wastewater, is referred to as "indirect energy". Quantification of the energy required for water provision has been the subject of a number of international studies (Cohen, et al. 2004; Pourkarimi, 2007; Young and Koopman, 1991; Iowa Association of Municipal Utilities, 2002; Cheng, 2002), and a component of the National Benchmarking Initiative in Canada (Earth Tech, 2007). However, differences in physical geography, distribution system pressure, proximity of water sources to the end-use, and a lack of data exploring the actual link between water conservation and energy savings, suggested that an examination of indirect energy intensity values in an Ontario context was warranted.

Three years of historical energy, chemical and water use data (2004 through 2006) were assembled from 7 municipalities in Ontario. Data were reviewed for each component of the urban water use cycle including: 11 water treatment plants[2]; 24 wastewater treatment plants and 36 wells; along with 5 water distribution systems and 5 wastewater collection systems. Annual averages of water and energy use were utilized to determine average energy intensity values, i.e., the energy in kWh required to extract, treat, and distribute 1 m^3 of water, and to collect and treat 1 m^3 of wastewater.

The Impact of Water Conservation on Indirect Energy

The focus of this study was to assess the energy savings associated with water conservation. Not all energy used for water provision will necessarily be affected by water conservation. Energy used for lighting and heating buildings, and for processes that are not impacted by flow, for example, are unlikely to elicit energy savings when water is conserved. The relationship between monthly energy use and water use within individual facilities was, therefore, examined to determine the extent to which water flows affected energy use. A complete derivation of the energy intensity values impacted by water conservation, termed the *water conservation energy intensity*, is included in Appendix B.

Direct Energy for Water Use

Direct energy savings refer to the energy saved by individual homeowners or businesses. The municipality will not directly realize the energy savings related to a reduction in a customer's direct energy demands. Direct energy savings will, however, contribute to GHG emission savings and, therefore, municipalities should encourage their citizens to reduce hot water use. The direct energy used to heat water was estimated using the specific heat capacity of water and an assumed temperature increase of 55 °C. This *net direct energy* intensity for hot water, 64 kWh/m^3, approximated the range of published energy intensity values for residential use in other jurisdictions (Cheng, 2002; deMonsabert and Liner, 1998; Cohen et al., 2004).[3]

In Ontario, an estimated 30% of water is heated using electric, and 70% using natural gas, water heaters (Ryan, 2005). The *gross equivalent direct energy intensity*, for both natural gas and electric water heating, was calculated by dividing the net energy intensity by the published efficiency of the current in-home stock of water heaters (i.e. 62% efficiency for gas-fired hot water heaters and 88% for electric models) (BC Hydro, 2009). The volume of natural gas used is determined by dividing the equivalent kWh/m^3 by a conversion factor of 10.9kWh/m^3gas (Carbon Trust, 2009). Direct energy intensities are assumed to be 100% influenced by water conservation. Full calculations are provided in Appendix C.

Embedded Energy to Manufacture Chemicals

Chemicals used in water and wastewater treatment primarily consist of disinfection chemicals such as chlorine gas and sodium hypochlorite, and coagulation and flocculation chemicals such as alum, ferric and ferrous chloride and polymers. Chemical manufacturing requires energy and, therefore, produces GHG emissions. This type of energy is referred to as *embedded energy*. Chemical use for water and wastewater treatment was determined using the raw data provided by the communities participating in the study. The energy required to manufacture chlorine, alum and ferric/ferrous chloride was determined using published values and was combined with chemical use data to establish embedded energy intensity values for each chemical. Full details are provided in Appendix D.

Carbon Footprint of Water Use

Energy consumption can generate GHG emissions as a result of either combustion of fossil fuels in electricity generating stations, or from burning oil or natural gas directly at the point of use. The greenhouse gas emissions, reported as *equivalent carbon dioxide (CO_2e)*[4], associated with generating power are used in conjunction with the energy intensity of water use to calculate a carbon footprint, the grams of CO_2e generated to extract, treat, and distribute 1 m^3 of water, and to collect and treat 1 m^3 of wastewater.

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[2] source Extraction and Water Treatment energies were reported within the same water treatment plant energy meter reading.
[3] direct energy intensity for industrial and commercial hot water use may be higher as a result of higher temperatures. The incoming temperature of the source water will also impact the amount of energy required to achieve the desired hot water temperature.
[4] CO_2e is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas (i.e. methane, perfluorocarbons and nitrous oxide)

Electrical energy use is converted to a carbon footprint ($kgCO_2e/m^3$), using a GHG emission factor (gCO_2e/kWh), a factor determined by the unique proportion of fossil-fuel fired electricity generation in each province (refer to Table E-1). Electrical energy is also lost during transmission, and transmission losses are also province specific. In Ontario, transmission losses are estimated at 6%, meaning for each 100 kWh generated, only 94 kWh reaches the end-use (a transmission factor then of 100/94 = 1.064) (BC Hydro, 2009). GHG emission factors and transmission loss factors are included in Appendix E. Chemicals were assumed to be manufactured in the province of use, using electrical energy, and the relevant provincial emission factor was applied accordingly.

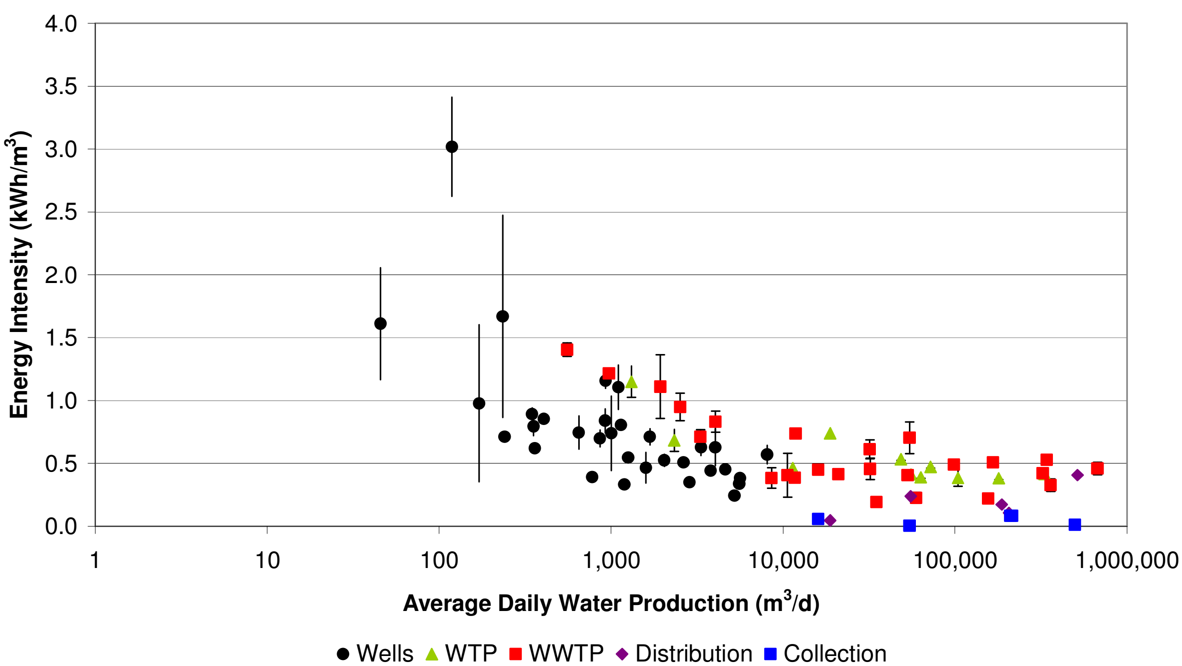
Customer water heating via natural gas generates GHG emissions at the point of use as opposed to producing emissions upstream in a gas-fired generating station. Natural gas usage for customer hot water heating is converted to GHG emissions using a standard equivalency of 1,903 gCO_2e/m^3 natural gas and an additional 191 gCO_2e/m^3 natural gas in transmission and production losses (refer to Appendix E for full calculations and references).

RESULTS & DISCUSSION

Indirect Energy for Municipal Water and Wastewater Provision

The three-year average energy intensity values for each facility studied are illustrated in Figure 2. Annual average energy intensity values correlated well with water production. Energy intensity values for surface water treatment, well water production, and wastewater treatment increased as flow rates decreased below production rates of 5,000 m^3/d (1,000 m^3/d for wells) but seemed to plateau for plants with production rates of greater than 5,000 m^3/d. This result suggests that larger systems are generally more energy efficient, possibly due to the use of larger pipe diameters (less head loss) and the higher mechanical efficiency of larger pumps. Water distribution energy was more variable, likely resulting from differences in distribution length and topography, differences in operating pressure, and the inability to dissociate the energy used to pump finished water (high lift pumping) from the energy used to extract and treat water.

Figure 2. Energy Intensity Factors vs. Average Annual Water Production



At higher flow rates, wells, water treatment and wastewater treatment plants all consumed approximately equivalent amounts of energy per m^3 of water produced (~0.5 kWh/m^3), whereas water distribution and collection energy intensities were found to be significantly lower. This finding, also evidenced by Arpke and Hutzler (2006), suggests that equal opportunity exists for energy savings in both water and wastewater components of water related services. A summary of the mean *raw indirect energy intensity* values for both large and small systems are reported in Table A-1 in Appendix A.

Published values correlated well with the indirect energy intensities determined in this study considering the wide range of physical geography, treatment technologies employed, etc. (Appendix A, Figure A-1). The general agreement of published energy intensity values with the findings of this study suggest that the average values reported herein provide a reasonable first estimate of the energy intensity of water use for communities with similar geographical context and treatment technologies across Canada.[5] Canadian communities with pressurized distribution systems, water treatment plants or groundwater pumping, and secondary wastewater treatment facilities will likely be well represented by the mean energy intensity values presented herein. Communities served by large reservoirs, gravity flow water distribution systems or primary wastewater treatment systems, such as in British Columbia, may need to consult alternative published values for lower energy intensity values.

The Impact of Water Conservation on Energy

A summary of water conservation indirect energy intensity values for large and small surface and groundwater systems are included in Table 1. Table 1 can be used to estimate the municipal energy savings associated with the implementation of water conservation measures. While it is recommended that municipalities calculate the *actual* energy intensities associated with their particular system, the values reported in Table 1 can provide a reasonable first estimate for communities with a similar geographical and treatment context to those studied herein.

Table 1. Water Conservation Indirect Energy Intensities

Water Use Component	Mean Energy Intensity (kWh/m^3)			
	Surface Supply (WTPs)		Groundwater Supply (Wells)	
	Small Capacity (< 5,000 m^3/d)	Large Capacity (> 5,000 m^3/d)	Small Capacity[6] (< 1,000 m^3/d)	Large Capacity (> 5,000 m^3/d)
Source Extraction & Water Treatment[7]	0.80	0.41	0.74	0.47
Water Distribution	0.17	0.17	0.17	0.17
Water Sub-Total	**0.97**	**0.58**	**0.91**	**0.64**
Wastewater Treatment	0.085	0.036	0.085	0.036
Wastewater Collection	0.06	0.06	0.06	0.06
Wastewater Sub-total	**0.14**	**0.10**	**0.14**	**0.10**
Total Indirect Energy Intensity	**1.11**	**0.68**	**1.05**	**0.74**

This report includes the energy savings associated with both reducing hot water by the end-use and reducing the overall water and wastewater demands within the entire system. Table 2 summarizes the indirect and direct water conservation energy intensities described in the preceding sections.

The analysis of chemical use data could only confirm that water conservation measures would reduce chlorine use in potable water treatment plants. As illustrated in Table 2, the energy used to manufacture the chemicals used in water treatment was found to be relatively insignificant when compared to the indirect and direct energy intensity of water use.

[5] exceptions would include locales where geography significantly influences the length or required head of distribution and collection systems. For example, daMonsabert et al. (2008) found considerably higher wastewater collection energies (0.25 kWh/m^3), and Cohen et al. (2004) found a large range of distribution energy intensities (0.13 to 0.76 kWh/m^3) emphasizing the dependency of collection and distribution energy on topography, length of collection/distribution mains and system pressure.
[6] small groundwater based systems may need to exclude distribution pumping energy if the well pumphouse provides all distribution
[7] in some municipalities, a portion of high lift pumping may have been included

As such, energy related to chemical manufacturing has not been included in the example energy calculations included in this report for simplicity.

Table 2 provides insight into the relative energy intensity of each component in the water use cycle, and highlights the importance of considering both municipal pumping and treatment and sector-specific hot water end-uses to extract the full environmental benefits of water conservation measures.

Table 2 - Summary of Water Conservation Energy Intensities	
Energy Inputs into Water Use	**Energy Intensity (equiv. kWh/m^3water)**
Indirect Energy (Municipal Pumping)	0.68-1.1
Direct Energy (Hot Water – Electric)[8]	73
Direct Energy (Hot Water – Natural Gas)[9]	103
Embedded Chemical Energy	0.01

EXAMPLE CASE STUDIES

Several example case studies have been provided, including a) simple calculations to illustrate how the GHG savings offered by individual water conservation measures can be estimated; and b) municipal, provincial and citizen case studies to provide a sense of the opportunities offered by a reduction in water use. A summary of the findings presented in Table 3 demonstrates the quantifiable potential of water conservation to provide carbon dioxide emission reductions. The details of each case study are discussed below, and calculations are provided in Appendix F.

Table 3. Summary of Case Study Examples				
Case Study	**Water Saved (m^3/d)**	**Municipal Energy Saved (MWh/yr)**	**Hot Water Saved (m^3/d)**	**Ontario Greenhouse Gas Emission Savings[10] (tCO_2e/yr)**
Irrigation Reduction Program	100	21.1	0	6
Toilet Retrofits	100	24.6	0	7
Showerhead Retrofits	100	24.6	50	396
City of Guelph	10,600	2,470	530	4,835
Province of Ontario	1.56 million	330,000	155,844	1.3 million

A Water Conservation Program Example

The following table can be used to estimate the GHG savings based on the water savings achieved for large, surface water supplied communities. The table provides a conservative estimate for small communities or communities serviced by groundwater, where the energy intensity of pumping is typically higher. Note that, on a volumetric basis, the GHG emissions associated with water provision is much less than the GHG emissions associated with water heating. While the GHG produced by heating water via natural gas is identical for each province, the electrical hot water savings varies

[8] assumes a temperature increase of 55 °C
[9]alternatively a value of 10.3 m^3gas/m^3 water can be used (refer to Appendix C for calculations)
[10]GHG Emissions are estimated for Ontario; a GHG Emission factor of 0.270 $kgCO_2e$/kWh was used

significantly from province to province depending on how the electricity is produced. For example, reducing water demands in Quebec where almost all of the electricity is generated in hydro stations results in far less GHG savings than reducing water demands in Alberta where electricity is generated primarily by burning fossil fuels.

The GHG savings related to each program or measure can be calculated separately and then added together to get the total GHG savings. Sample calculations (based on Table 4) for determining the greenhouse gas emission savings from measures such as irrigation programs and toilet and showerhead retrofits, that each use different amounts of cold and hot water, and produce different amounts of wastewater, are included in Appendix F. The results of the sample calculations have been summarized in Table 3 above.

Table 4. CO_2e savings Water Use Reduction, by Province and Water Use Cycle Component

Province	Emission Factor	Transmission Factor	Water	Wastewater	Hot Water (gas)	Hot Water (Electric)
	gCO2e/kWh		gCO_2e/m^3 ($kgCO_2e/1000m^3$)			
Alberta	930	1.04	552	91	21514	70425
British Columbia	20	1.03	11.8	1.9	21514	1499
Canada	205	1.06	124	21	21514	15869
Manitoba	10	1.14	6.5	1.1	21514	826
New Brunswick	366	1.06	222	37	21514	28305
Newfoundland and Labrador	15	1.10	9.4	1.6	21514	1198
Northwest Territories	80	1.08	49	8.1	21514	6254
Nova Scotia	549	1.04	326	54	21514	41574
Nunavut	80	Not Available	46	7.6	21514	5816
Ontario	270	1.06	166	28	21514	20881
Prince Edward Island	192	1.06	116	19	21514	14849
Quebec	6	1.04	3.6	0.6	21514	454
Saskatchewan	810	1.06	491	81	21514	62643
Yukon	80	Not Available	46	7.6	21514	5816

Table concept provided courtesy of B. Gauley, Veritec Consulting

A Municipal Example

The City of Guelph is a medium sized city on 100% groundwater, with a current population of approximately 115,000 and a build-out population of approximately 169,000 in 2031. Guelph is a progressive community with both well established water conservation planning and a community energy plan (Garforth International, 2007). The City's Water Conservation and Efficiency Strategy is targeting a total water use reduction of 20% from the projected business as usual scenario in 2025. This target offers significant water and energy savings benefits for Guelph. Guelph will save an estimated 20% of the full capacity of Guelph Lake every year, the equivalent of 10,600 m^3/d of water (RMSi, 2009).

The municipal electricity savings, estimated at 2,470 MWh/yr, could power half of the City's existing wells. At today's electricity prices ($0.06/kWh), in 2025 the City could save more than $2700/week in water and wastewater electricity expenditures alone. The electrical energy savings achieved through water conservation were found to be on par with other GHG mitigation measures currently being pursued in Guelph, such as powering the Woods Pumping station with green energy, which could offset the emissions from an estimated 2.8 million kWh/yr (City of Guelph, 2008).

RMSi (2009) estimated a GHG savings of 2,412 tonnes of CO_2e/yr for the City of Guelph's rebate programs, 70% of which will be achieved through showerhead and pre-rinse spray valves retrofits. This estimate excluded hot water savings from efficient washing machine retrofits, hot and cold water savings for fixture retrofits that are completed *outside* of Guelph's rebate programs, and industrial process hot water savings. If we assume that 5% of the total water conserved (5% x 10,600 m^3/d = 530 m^3/d) would have been heated by 55 °C, an estimated total of 4,835 tonnesCO_2e/yr (cold and hot water savings) could be conserved. The GHG savings is the green energy equivalent of approximately four 1.5 MW windmills.[11] Guelph is a municipality that, as of 2006, has a lower per capita water use (230 LCD) than many other communities in the province (RMSi, 2009). The potential for savings could be even greater in municipalities where water conservation remains a significant untapped water and energy resource. Full calculations for this case study are provided in Appendix F.

A Provincial Example

Ontario municipalities consume more electricity than any other sector outside of pulp and paper - in excess of 1.5 million tonnes of carbon dioxide per year (Ontario Ministry of Energy and Infrastructure, 2008). A rough calculation of the potential for energy savings through water conservation provides perspective on the relevance of water efficiency to energy reduction programs. These calculations are a simple "back of the envelope" estimation to demonstrate what could be, and all assumptions and calculations are provided in Appendix F.

The population of the province is expected to increase to 16.2 million in 2029 (Ministry of Finance, 2007) and a business as usual gross per capita water demand (total water production divided by total residential population) of 481 LCD was used to determine the total future water use (Environment Canada, 2007). Increasing province-wide water efficiency by 20% in 20 years (municipally supplied water[12]) could save 1.56 billion litres of water every day (16.2 million x 481 LCD x 20% = 1.56 billion L/d). To achieve this increase in efficiency in the residential customer sector, average per capita water demands would need to decrease from 260 LCD to 208 LCD – an achievable goal given new, water efficient homes can achieve 120-150 LCD indoor water use *today* (Veritec, 2008b).

The back of the envelope calculations suggest that, should Ontario as a whole become 20% more water efficient by 2029, the greenhouse gas emission savings from reduced hot and cold water use[13] would be equivalent to providing electricity for 87% of homes in the City of Toronto using wind energy, an estimated 1,200 windmills.

A study by the Power Applications Group (PAGI, 2008) identified the current opportunities to reduce municipal electricity use at 792 million kWh, or 12% of the total use, using a variety of measures including energy demand management during peak periods. The municipal energy savings associated with a 20% increase in water efficiency today (cold water only) could achieve a whopping 34% of the reported energy reduction potential for municipalities. This finding is significant; it suggests that the co-benefits of municipal water conservation offer an untapped opportunity to realize energy savings.

An Example for Citizens

A culture of energy conservation is slowly taking hold in Canada, for example many of today's citizens would be hesitant to leave a light on for hours on end. However, wasting water is not typically given the same consideration. For example, showering for just an extra 2 minutes consumes the equivalent energy of leaving a 60 W light-bulb running for 12 hours. Conversely, a 20% reduction in either shower time or the flow rate of showerhead fixtures, for example from 9.5 Lpm to 7.6 Lpm[14], could achieve the energy efficiency equivalent of changing 5 incandescent light-bulbs to compact fluorescent.

CONCLUSIONS

In Canada, energy for water is *significant* at the residential, municipal and provincial scale, and an increasing number of international studies support this finding. This study, the first of its kind in Canada, demonstrates that the energy used for water provision can be influenced by water conservation, and the energy savings can be estimated using the methodology presented. The potential for both energy and greenhouse gas emission savings via water conservation is

[11] based on equivalent GHG emissions from the Ontario electricity generation mix offset by use of 1.5 MW windmills
[12] excludes all self-supplied users
[13] assuming 10% of the water saved would have been heated to 55°C
[14] performance of showerheads at 7.6 Lpm has been reported to be both satisfactory and safe in preliminary studies (Veritec, 2008b)

therefore quantifiable. Significantly, the energy savings linked to water conservation were found to be on par with typical energy efficiency and green energy strategies in practice today, highlighting the largely untapped opportunity of water conservation to help meet energy efficiency and climate change targets in Ontario. The conclusions of this study, and the recommendations for linking energy and water policies, are indeed relevant to most jurisdictions in North America.

There is a strong potential for climate change to negatively impact both water and energy availability. Reduced water availability and an increasing need for advanced water treatment technologies are likely to increase the cost of, and demand for, energy. Rising temperatures may also increase the demand for water, creating a vicious circle of increasing energy and water demands, and decreasing availability of both vital resources.

To slow the progression of climate change, significant mitigation efforts will be required in all sectors. Unfortunately, there will be fewer and fewer opportunities for achieving direct energy savings from rapid payback technologies typical of initiatives such as compact fluorescent light bulb change-out programs (PAGI, 2008). Ensuring every community, and most importantly every new home, is equipped with water efficient fixtures simultaneously addresses the intersecting challenges of climate change, energy security and water scarcity. The technologies and programs required to affect measurable water savings are already available "off-the-shelf" (see for example Brandes et al., 2006), and will be complemented by Canadian companies offering emerging clean technology and services related to water conservation and efficiency.

Communities around the world are beginning to respond to the challenges and opportunities of the water-energy nexus. The Ontario government has recognized the emerging threat of an energy crisis and has committed to promoting a culture of energy conservation (Office of the Premier, 2004). This study emphasizes the inextricable linkages between water and energy, and concludes that building a "culture of conservation" must necessarily include both energy and water conservation efforts to stem the progression, and the impacts, of climate change.

APPENDIX A: INDIRECT ENERGY FOR MUNICIPAL WATER & WASTEWATER PROVISION

This appendix includes methodological details for assessing the indirect energy used for water provision in seven Ontario municipalities. This information is an adjunct to the information provided in the main body of the report.

Study Basis

The seven communities participating in the study included: Region of Peel, Township of Minden Hills, Halton Region, City of Toronto, City of Guelph, Durham Region and the Town of Collingwood. Over 70 water and wastewater treatment and pumping facilities were examined.

Methodology for Assessing Indirect Energy Intensity

Energy intensity values (kWh/m^3) were determined for well pump houses, surface water treatment plants, and wastewater treatment plants by dividing the annual sum of monthly electricity consumption by the annual sum of monthly water or wastewater production (m^3). Water distribution energy intensity values were determined by first identifying the electricity accounts in each community that represented pumping stations, water towers and reservoirs. The electricity accounts associated with potable water distribution were then summed for each year and divided by the total annual water treatment plant or well production volumes. Similarly, wastewater collection energy intensities were calculated by summation of electricity consumption from all accounts pertaining to sewage pumping stations, divided by the total annual wastewater volumes treated. Because water distribution and wastewater collection pumping stations in many cases did not have individually metered flows, the energy intensity values were municipal-wide averages and the total number of data points was therefore limited to five.

The median, mean and 95% confidence intervals for energy intensity were assessed for each component of the municipal water use cycle and the mean energy intensity was differentiated for small and large treatment facilities. An extensive literature review was completed to determine the range of energy intensity and carbon footprint factors observed for water use internationally and to investigate studies that quantified energy use reductions realized through water conservation.

Limitations of the Methodology & Analysis

A number of studies have examined the environmental impact of the municipal water use cycle using different assessment frameworks including energy, operational use, and life cycle assessment (Friedrich, 2002; Cohen et al., 2004; Racoviceanu et al., 2007; Stokes and Horvath, 2006; Cheng, 2002; Arpke and Hutzler, 2006). This study focused on the operational phase of municipal water and wastewater provision, including energy and chemical process inputs. The construction and decommissioning phases were excluded for two reasons: the operational phase was identified by others as the most energy intensive phase (Friedrich, 2002); and the benefits of delayed plant expansion and decommissioning stemming from water conservation were anticipated to be more site specific than the operational phase. Savings related to construction, including energy, greenhouse gas emissions and costs, are known to be significant for many municipalities and should not be excluded when preparing a complete business and ecological case for water conservation (Brandes et al., 2006).

Energy use at water treatment plants (WTPs) included energy for source water pumping, treatment processes, as well as a portion of distribution in the form of high-lift pumping. The inability to distinguish energy used for high-lift pumping from energy used for source extraction and treatment within water treatment plants may have resulted in artificially depressed distribution energy intensities as a result of limited electricity metering or reporting. This is also anticipated to be at least partially responsible for the variability in reported water distribution energy intensity values across communities. This variability was particularly evident in the energy intensity values for wells, given they were approximately 0.25 kWh/m^3 higher than the mean of published energy intensity values. This discrepancy is believed to be attributed to the well pump houses in some cases providing both source extraction and distribution functions, with only a single electricity meter.

Energy intensities were calculated using the water and wastewater volumes treated at each plant, as opposed to selecting a normalized water production value as proposed by Cohen et al. (2004). In this study, a number of municipalities had geographically different water and wastewater service areas making a normalized approach misrepresentative. The employed methodology enabled specificity of energy intensities to water and wastewater flows, which may prove useful in municipalities with different levels of water loss, inflow and infiltration.

Biogas produced at wastewater treatment plants (WWTPs) can offset the energy utilized for wastewater treatment processes. However, facilities utilized biogas to different extents, and it was generally difficult to distinguish the percentage of biogas that was used to offset process energy vs. that utilized to offset heating of buildings. Water conservation would not impact the energy used to heat buildings and therefore biogas usage was excluded from the energy intensity of water provision at this time. Natural gas consumption was also excluded from the energy analysis because in most cases it was utilized for heating buildings and the data was not consistently available for each plant. As a point of clarification, increases in wastewater concentrations resulting from water conservation were not assumed to impact process efficiency.

Studies suggest that increasing treatment needs for water will result in an upward trend in energy use (Thirwell et al., 2007). Within the data set examined, 7 wastewater treatment plants, 8 wells, and 1 water treatment plants used ultraviolet disinfection; 1 water treatment plant used ozone and 1 water treatment plant employed ultrafiltration membranes. The majority of the facilities employing advanced technologies were also small facilities, and so it was difficult to dissociate the impacts of inefficiencies of scale, leading to an increased energy intensity, from tertiary treatment processes. A detailed evaluation of the increased energy required for emerging trends in water and wastewater treatment such as ultrafiltration and membrane bioreactors, UV disinfection and ozone use for disinfection, odour control and wastewater reuse were beyond the scope of this study, however this is an important area for future research.

Summary of Raw Indirect Energy Intensity Values

Median values were used to assess the full dataset of raw, indirect energy intensity values to minimize skewing of the arithmetic average by outliers. Mean indirect energy intensities for small and large capacity facilities are also assembled in Table A-1. The energy intensities for water distribution and wastewater collection were more appropriately represented with a range, given the large variation and small sample size.

Table A-1. Summary of Raw Indirect Energy Intensity Values

Water Use Component	Energy Intensity					
	Full Data Set		Small Capacity		Large Capacity	
	Median (kWh/m^3)	Data (#)	Mean (kWh/m^3)	Data (#)	Mean (kWh/m^3)	Data (#)
Wells[15]	0.63 ± 0.14	31	0.85 ± 0.22	19	0.54 ± 0.11	13
WTPs[16]	0.46 ± 0.16	11	0.92 ± 0.52	2	0.47 ± 0.09	9
Distribution	0.17 ± 0.14	5	(0.05-0.41)			
WWTPs[16]	0.46 ± 0.14	24	1.04 ± 0.23	6	0.44 ± 0.07	18
Collection	0.06 ± 0.04	5	(0-0.08)			

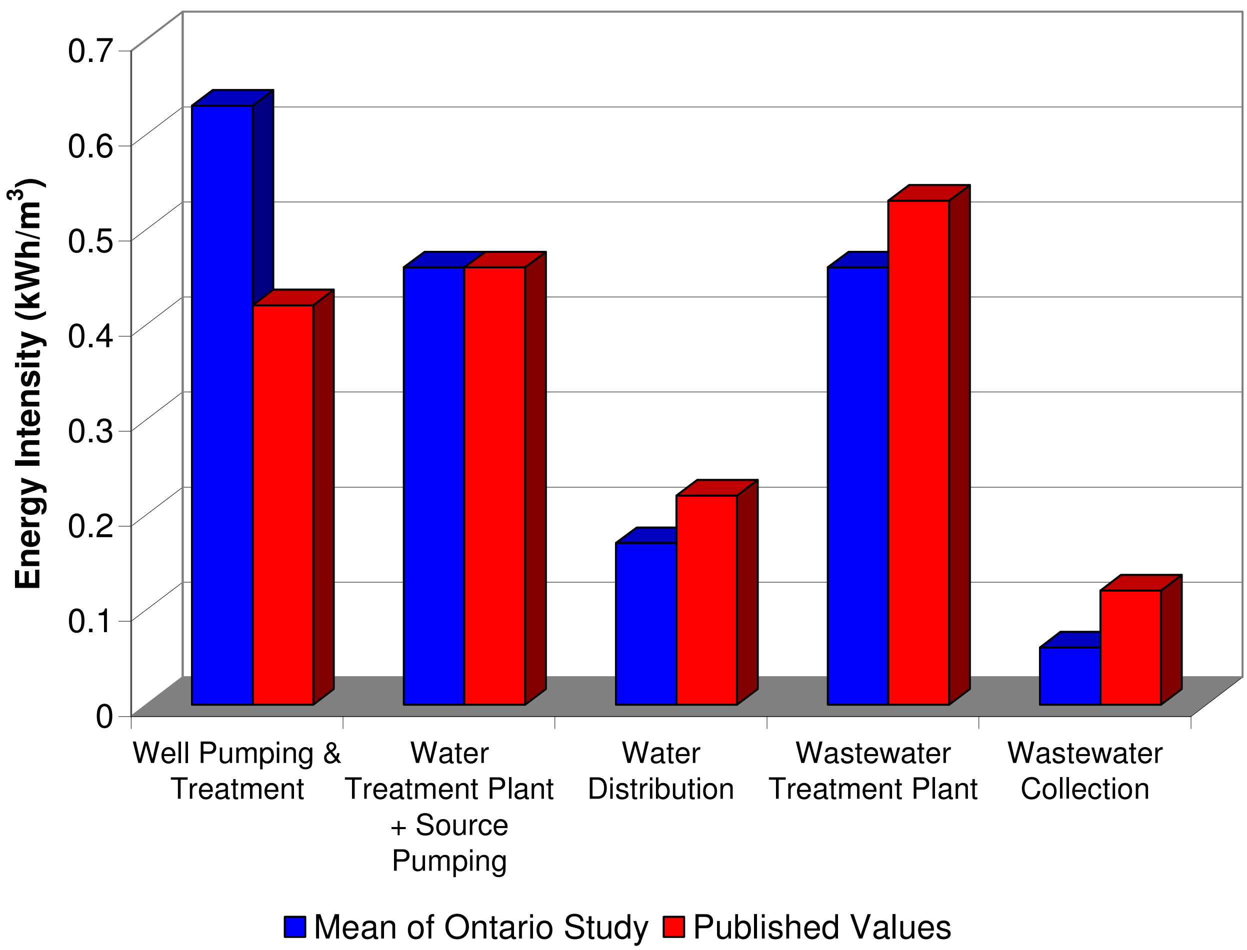
Note the values in this table cannot be added together because Wells and WTPs are two alternative sources of supply

[15] Small Capacity Wells < 1,000 m^3/d; Large Capacity Wells > 1,000 m^3/d
[16] Small Capacity Facilities < 5,000 m^3/d; Large Capacity Values > 5,000 m^3/d

Literature Review of Energy Intensities

Several major reviews of energy intensity factors were uncovered, most notably in California, British Columbia, Iowa, Florida and Taipei in addition to the reporting made available by the Canadian National Benchmarking Initiative (Cohen, et al. 2004; Pourkarimi, 2007; Young and Koopman, 1991; Iowa Association of Municipal Utilities, 2002; Cheng, 2002; Earth Tech, 2007). The average of all identified published indirect energy intensity values are presented in Figure A-1. The energy intensities identified in this study fell within the range of published studies for each component of the municipal water-use cycle.

Figure A-1. Mean Indirect Energy Intensity for each component of the water use cycle



APPENDIX B: IMPACT OF WATER CONSERVATION ON INDIRECT ENERGY

Methodology for Assessing the Impact of Water Conservation on Indirect Energy

Recognizing that it cannot be assumed that all energy used for water provision will be affected by water conservation, an analysis of the actual relationship between energy use and water use was completed. Monthly energy consumption was plotted against monthly water production for each component of the municipal water use cycle for individual facilities. A study of individual facilities was necessary to determine how a reduction in water flow will affect pump efficiencies and treatment processes. The data was analyzed graphically by visually evaluating the correlation of the data. A direct linear correlation suggested that a reduction in water use would produce a direct reduction in energy use. A literature review corroborated these findings.

The Relationship between Water and Energy Use

Monthly water production vs. monthly energy conumption (Figure B-1) illustrated that the energy required to produce potable water was highly correlated with flow, within a single facility, and therefore signaled a strong potential for energy savings through water conservation. Well water production was also clearly correlated to energy consumption (data not shown) although the data set exhibited considerably more scatter, likely owing to the reduced scale (much smaller flows) and a higher prevalence of inefficient pumping regimes. Wastewater energy, however, was not highly correlated to flow (Figure B-2) within individual facilities suggesting a more complex interrelationship between water conservation and energy savings.

Figure B-1. Monthly Water Treatment Plant Production vs. Energy Use

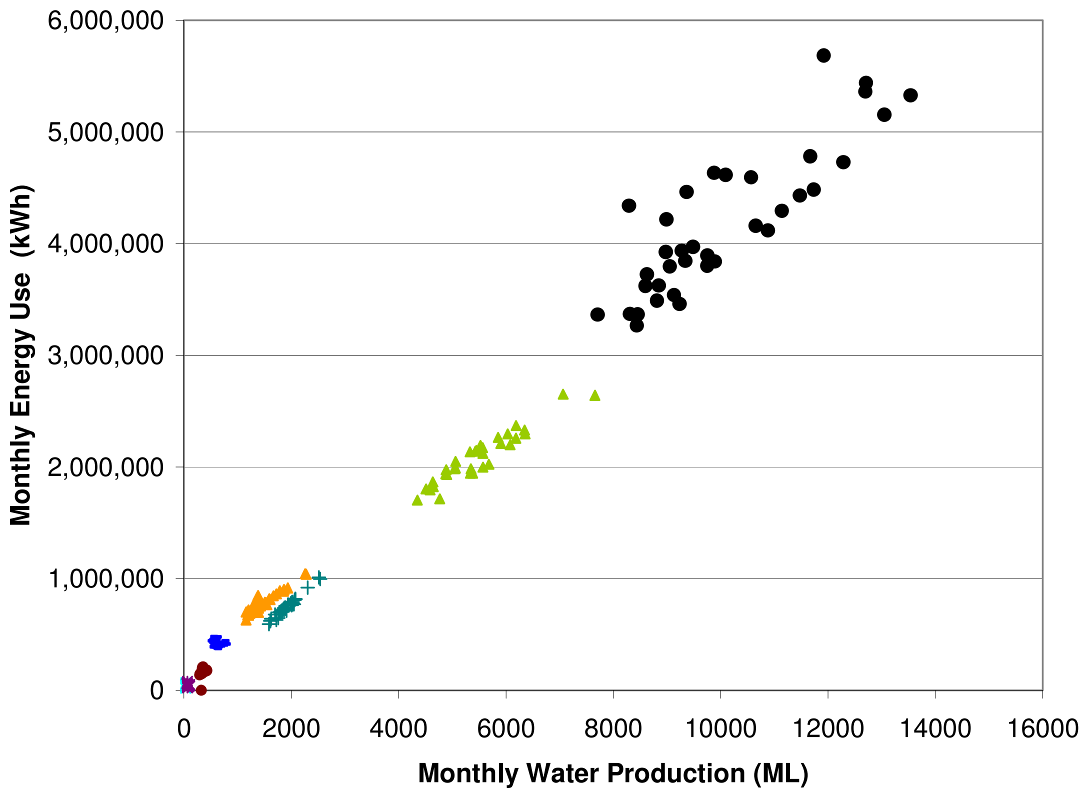
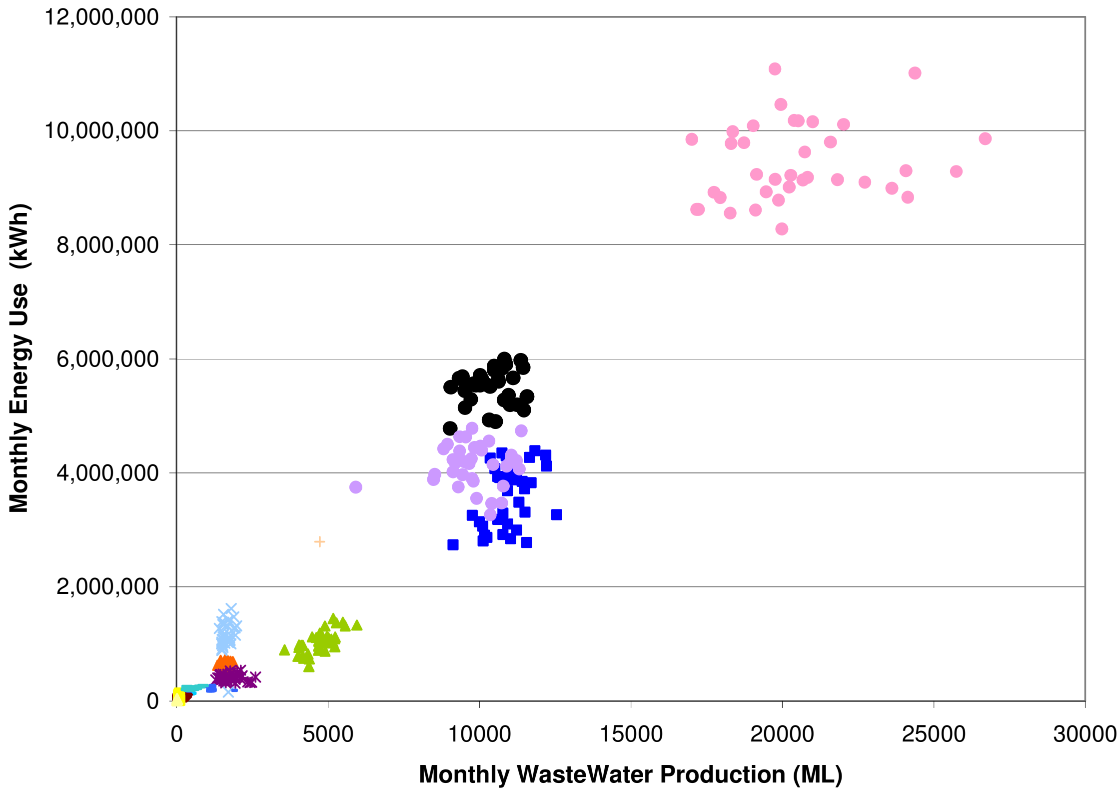


Figure B-2. Monthly Wastewater Treatment Production vs. Energy Use



Methodology for Calculating Water Conservation Indirect Energy Intensities

The results of the data analysis of monthly water and energy use suggested that all energy used in a wastewater treatment plant could not necessarily be conserved through water conservation. This finding can be explained by the differences in energy consumed in water and wastewater treatment plants. The Electric Power Research Institute (EPRI, 1994; 2002) reported the typical breakdown of energy use within water and wastewater treatment plants. Pumping consumed 87% of total energy use for production of water but only 8.2% for wastewater. In a wastewater treatment plant, 50-80% of the total energy use is for aeration to treat the contaminant load which is highly dependent on population as opposed to flow (Jonasson, 2007). The proportion of total energy use influenced by water conservation was therefore assumed to be equivalent to the percentage of the energy typically consumed for pumping. While this assumption is an oversimplification of the impact of flow reductions in water and wastewater treatment plants, it is a simple way to exclude the energy used for treatment processes and buildings unaffected by changes in flow. The energy used for pumping, is expected to represent the minimum energy use affected by water conservation, and is considered a conservative estimate.

The energy savings co-benefit of water conservation, termed the "water conservation energy intensity", was estimated by multiplying the raw energy intensity for water treatment by 87%; the raw wastewater treatment energy intensity by 8.2%; and the collection and distribution energy intensities by 100%.

Water Conservation Indirect Energy Intensity = Raw Energy Intensity[17] (kWh/m^3) x % Influenced by Conservation

These calculations are illustrated in Table B-1, and the resulting total water conservation energy intensities are reported for both small and large capacity surface and groundwater supply systems.

Table B-1. Calculation of Water Conservation Energy Intensities

Water Use Component	Mean Energy Intensity (kWh/m3)			
	Surface Supply (WTPs)		Groundwater Supply (Wells)	
	Small Capacity (< 5,000 m^3/d)	Large Capacity (> 5,000 m^3/d)	Small Capacity (< 1,000 m^3/d)	Large Capacity (> 5,000 m^3/d)
Source Extraction and Water Treatment	0.92 x 87% = 0.80	0.47 x 87% = 0.41	0.85 x 87% = 0.74	0.54 x 87% = 0.47
Water Distribution	0.17 x 100% = 0.17	0.17 x 100% = 0.17	0.17 x 100% = 0.17	0.17 x 100% = 0.17
Wastewater Treatment	1.04 x 8.2% = 0.085	0.44 x 8.2% = 0.036	1.04 x 8.2% = 0.085	0.44 x 8.2% = 0.036
Wastewater Collection	0.06 x 100% = 0.06	0.06 x 100% = 0.06	0.06 x 100% = 0.06	0.06 x 100% = 0.06
Total Indirect Energy Intensity	**1.11**	**0.68**	**1.06**	**0.74**

Limitations of the Methodology

Energy intensities have not been adjusted for pump inefficiencies. The results of this study illustrated a direct relationship between energy and water use for large flow systems, and did not appear to be significantly affected by pump inefficiencies. In many cases, source water is pumped, at a constant rate, directly to a water storage tank or tower, in which case the pump time would be reduced by water conservation, saving energy directly. However, communities should consider optimizing pump efficiency on a case by case basis given the potential for impeded electricity savings. Energy consumed for distribution system pumping is also highly dependent on the required water pressure within the system (deMonsabert et al., 2008). A lower distribution system pressure could offer additional energy savings that have not been accounted for herein.

It is anticipated that additional energy savings will be realized in the wastewater treatment process resulting from reduced flows including a portion of chemical usage and aeration (dependent on design parameters) and sludge processing. In particular, advanced technologies including tertiary treatment processes such as nitrification, filtration, ultraviolet disinfection and ozonation may benefit from reduced flows. A detailed quantification of energy savings for wastewater treatment was beyond the scope of this study, however future research is warranted to fully extract these benefits. Energy savings for pumping are therefore expected to be the minimum savings associated with wastewater treatment plants.

Greenhouse gas emissions from water and wastewater treatment processes (for example the CO_2 emitted from secondary wastewater treatment) were not anticipated to be impacted by water conservation and were excluded from all calculations. Energy use for rainwater, grey-water and wastewater reuse treatment and pumping has been excluded at this time. The reduction in chemical costs, costs of plant expansions, infrastructure, etc. that will offer additional benefit to municipalities have not been included in the estimated savings.

[17] Raw Energy Intensity values are reported in Table A-1 for the Ontario study.

APPENDIX C: DIRECT ENERGY FOR WATER USE

Methodology for Calculating Direct Energy Intensities

The heat capacity of water was used to calculate the net direct energy intensity to heat water by 55 °C.

$$\textbf{Net Direct Energy Intensity} = C_p \times (T_2 - T_1)$$
$$= 4.184 \times (55) = 230 \text{ J/mL}$$
$$= 64 \text{ kWh/m}^3$$

where C_p is the specific heat capacity of water, 4.184 J/g/°C, T_2 is the temperature of the heated water in °C and T_1 is the temperature, in °C, of the cold water supplied by the municipality. The net energy intensity is then converted to a gross equivalent energy intensity using the efficiency factors for residential hot water heaters noted in Table C-1.

Table C-1. Calculation of Gross Energy and Natural Gas Intensities of Hot Water

	Electric	**Natural Gas**	
Net Direct Energy Intensity	64	64	equiv.kWh/m^3
Efficiency Factor[18]	88%	62%	
Gross Equivalent Energy Intensity	**73**	**103**	**equiv.kWh/m^3**
Natural Gas Volume		**10.3**[19]	**m^3gas/m^3water**

Note that equiv.kWh/m^3 for natural gas hot water heaters is not an actual electricity use; it represents an equivalent energy

To estimate the total equivalent energy savings resulting from hot water savings, first the percentage of homes or businesses using electric vs. natural gas heaters must be identified. The respective electric or natural gas equivalent energy intensities (or volume of natural gas used) can then be multiplied by the volume of hot water saved.

[18] BCHydro (2009)
[19] converted by multiplying equivalent kWh/m^3 x 10.04 m^3gas/kWh

APPENDIX D: EMBEDDED ENERGY IN CHEMICALS

Methodology for Calculating the Embedded Energy in Chemicals

Chemical use (mg/L) for water and wastewater treatment was first determined using raw data provided by the participating communities. The energy required to manufacture chlorine, alum and ferrous chloride was determined using published values and was combined with chemical use to establish an embedded energy intensity for each chemical. Among the many chemicals used in water and wastewater treatment, chlorine in particular was noted to require large amounts of energy to produce. Chlorine data was available for most municipalities and the energy consumption to manufacture chlorine was also well documented (Owen, 1982; Tripathi, 2007). Limited data on flocculant and coagulant usage in water and wastewater treatment was available from the study participants, however a few published values were identified (Racoviceanu et al., 2007; Tripathi, 2007).

Raw Embedded Energy Intensity of Chemicals

Mean values for chemical use reported by the Ontario municipalities studied are reported in Table D-1.

Table D-1. Chemical Use for Water and Wastewater Treatment

Chemical	Water	Wastewater	Arpke and Hutzler (2006)
Chlorine	3.3 $mgCl_2$/L	2.2 $mgCl_2$/L	1.2-4 $mgCl_2$/L
Coagulant Use	Not Available	16 mgAl/L 8.9 mgFe/L	12.7 – 50 mgAlum/L

The equivalent energy to manufacture chemicals for both water and wastewater treatment is presented in Table D-2.

Table D-2. Energy Intensity of Chemical Manufacturing

Chemical	Energy Intensity[20]	Units
Chlorine Gas	5.59	kWh/kgCl2
Sodium Hypochlorite	0.314	
Ferrous & Ferric Chloride	3.20	
Alum	4.04	

The average embedded energy intensity of all individual facilities for each chemical type is reported in Table D-3. The values were estimated by multiplying the monthly chemical use by the kWh/kg of chemical produced for individual facilities.

[20] all values adapted from Owen (1982)

Table D-3. Raw Embedded Energy Intensity to Manufacture Chemicals				
	Chemical	**Mean Energy Intensity (kWh/m^3)**	**# of Facilities**	**Published Values Energy Intensity (kWh/m^3)**
WATER	Polymers for Water Treatment	Exclude[21]		0.04 (Tripathi, 2007)
	Chlorine for Water Treatment	0.013[22]	33	0.09 (Tripathi, 2007) - 0.003 (Arpke & Hutzler, 2008)
	Chemicals for WTP	**0.01 kWh/m^3**		
WASTE-WATER	Chlorine for Wastewater Treatment	0.010	13	0.003
	Alum for Wastewater	0.06	3	0.04
	Ferrous & Ferric for Wastewater	0.03	4	
	Chemicals for WWTP[23]	**0.056 kWh/m^3**		

Impact of Water Conservation on Embedded Energy

A strong correlation between chlorine embedded energy and flow was identified for potable water treatment but not for wastewater (data not shown). Flocculation chemicals for both water and wastewater could not be correlated to flow because of a lack of data. The embedded energy for producing flocculation chemicals was therefore not included as a savings offered by reduced water use. A conservative assumption was made to account only for the chlorine saved in water treatment (0.01 kWh/m^3) as the embedded energy directly reduced by water conservation. Wastewater treatment chemicals were assumed to experience no reduction in use.

[21] No data was presented on polymers in water treatment – either communities did not use polymers or the information was not available. The use of polymers was anticipated to be significantly lower in drinking water than in wastewater treatment applications and has therefore been excluded from this study.

[22] NaOCl and Cl2 was used in different facilities; the value presented represents an average of the entire data set.

[23] embedded energy for WWTP chemicals was calculated as = 0.010 (chlorine) + (0.06 + 0.03)/2 (average of alum & ferrous and ferric chloride, chemicals used for coagulation) = 0.056 kWh/m^3

APPENDIX E: CARBON FOOTPRINT OF WATER USE

Methodology for Calculating the Carbon Footprint of Water Use

The Energy Information Administration (2002) publishes statewide averages for electricity emission factors which range from 0.1 to 1.0 kgCO_2/kWh for the USA and Table E-1 illustrates the GHG emissions factors, and transmission losses, for each province in Canada. The large nuclear and hydroelectric contribution to the electricity generation mix reduce the overall greenhouse gas emission factor for Ontario. However, it should be emphasized that these forms of power generation can lead to significant environmental impacts that are not accounted for by a carbon footprint metric. The overall ecological impacts of energy use for water extend beyond the greenhouse gas emissions quantified in this study.

Table E-1. GHG Emission Factor and Transmission Losses by Province for Electricity Generation (2006)

Province	Emission Factor (gCO_2e/kWh)	Transmission Losses[2] (%)	Transmission Factor
Alberta	930	4%	1.04
British Columbia	20	3%	1.03
Canada	205	6%	1.06
Manitoba	10	12%	1.14
New Brunswick	366	6%	1.06
Newfoundland and Labrador	16	9%	1.10
Northwest Territories	80	7%	1.08
Nova Scotia	549	4%	1.04
Nunavut	80		
Ontario[24]	270	6%	1.06
Prince Edward Island	192	6%	1.06
Quebec	6	4%	1.04
Saskatchewan	810	6%	1.06
Yukon	80		

Environment Canada (2008)

Natural gas emission factors are similarly calculated based on the conversion of natural gas to greenhouse gases formed during combustion. Greenhouse gases (CO2, N2O and CH4) are then converted to equivalent CO_2e values using the conversion factors noted in Table E-2. Finally, emissions associated with natural gas production and processing have been estimated and added to the combustion emission factor to obtain an overall GHG emission factor of 2,094 gCO2e/m^3 natural gas.

Table E-2. Calculation of Natural Gas Emission Factors

	CO2	**N2O**	**CH4**	**Total**	
Combustion Emission Factors[25]	1891	0.04	0.04		g/m^3 natural gas
CO2e Conversion Factors[26]	1.00	298	25		gCO2e/gchemical
Equivalent CO_2e	1891	11.92	1	**1903**	gCO2e/m^3natural gas
Production & Processing Losses[27]				**191**	gCO2e/m^3 natural gas
Total GHG Emission Factor				**2094**	gCO2e/m^3 natural gas

24 a 2007 emission factor for Ontario was utilized (Ontario Power Generation (2007))
25 Environment Canada (2008)
26 IPCC (2007)
27 Canadian Association of Petroleum Producers (2004). Excludes transmission losses.

Limitations of the Methodology

When reviewing the case studies for Ontario, it should be cautioned that the GHG emission factor (270 gCO_2e/m^3) may be considerably lower in Ontario than other locations in the world. For example, a study of Alberta (930 gCO_2e/m^3) or Saskatchewan (810 gCO_2e/m^3), where emission factors are significantly higher, would result in a much greater GHG emissions savings from water conservation.

Literature Review of the Carbon Footprint of Water Use

A literature review of carbon footprint factors revealed a handful of studies with a large variation of reported values, likely owing to highly variable electricity emission factors combined with the differences in methodology and context of the systems studied (Tripathi, 2007; Racoviceanu et al., 2007; Sahely et al., 2006; Stokes and Horvath, 2006).

Carbon footprint estimates and comparative published values are noted in Table E-3. Carbon footprint factors for chemical use identified in this study were much lower than those reported in Tripathi (2007). This study examined fewer chemicals and excluded transportation of the chemicals from factory to plant which resulted in slightly lower values. Another possible explanation for lower carbon footprints could be differences in the reporting basis for dilute chemicals. Hot water end-use values also differed by approximately two-fold which can be attributed to differences in assumed cold and hot water temperatures in addition to differences in GHG emission factors.

Table E-3. Carbon Footprint Factors

Component	Carbon Footprint	
	Published Values ($kg\ CO_2e/m^3$)	References
Water Treatment & Distribution	0.12 – 0.61	Racoviceanu et al., 2007; Stokes and Horvath 2006
Wastewater (indirect energy emissions only)	0.08 – 0.13	Monteith et al., 2005; Sahely et al., 2006
Hot Water End-Use	6.2	UK Environment Agency, 2008
Chemical Use at WTPs	0.01 – 0.29	Racoviceanu et al., 2007; Tripathi, 2007
Chemical Use at WWTPs	0.029[28]	Tripathi, 2007

[28] Facility investigated had UV disinfection, which may have resulted in low consumption of chlorine

APPENDIX F: SAMPLE CALCULATIONS

A Water Conservation Program Example

Example 1 – Ontario Municipality saves 100 m^3/d (36.5 thousand m^3 of water per year) via an irrigation reduction program. Note that reducing irrigation demands affects only water provision – there is no effect on wastewater treatment and the water is not heated.

CO_2e Savings Calculation
= 100 m^3 x 166 gCO_2e/m^3 x 1kg/1000 g x 365 days/yr = 6059 kg of CO_2e/yr

Example 2 – Ontario Municipality saves 100 m^3/d (36.5 thousand m^3 of water per year) via a toilet replacement program. Note that toilet replacement programs reduce both water and wastewater flows, but the water is not heated.

CO_2e Savings Calculation
= 100 m^3 x (166 + 28) gCO_2e/m^3 x 1kg/1000 g x 365 days/yr = 7081 kg of CO_2e/d

Example 3 – Ontario Municipality saves 100 m^3/d (36.5 thousand m^3 of water per year) via a showerhead replacement program. Note that reducing water demands related to bathing affects both water and wastewater, plus a portion of the water is heated. In this example it is assumed that 50% of the water saved is hot water. It is also assumed that 70% of water heaters in the municipality are gas-fired.

CO_2e Savings Calculation
= 100 m3 x (166 + 28) gCO_2e/m^3 + (100/2 x 0.7 x 21,514) gCO_2e/m^3 + (100/2 x 0.3 x 20,881) gCO_2e/m^3 x 1kg/1000 g x 365 days/yr
= 396,250 kg of CO_2e/yr

City of Guelph Case Study

The municipal energy saved can be estimated using the indirect water conservation energy intensity for a large groundwater system (Table 1), a factor of 0.64[29] kWh/m^3. Wastewater energy has been excluded because outdoor conservation measures will not elicit a savings for wastewater pumping and a detailed breakdown was not available.

Municipal Energy Saved
= 10,600 m^3/d x 0.64 kWh/m^3 x 365 days/yr x 1MWh/1000 kWh = 2,476 MWh/yr

Five percent of the water saved was assumed to be water that would have been heated by 55°C, and 70% of hot water heaters used natural gas. This percentage was assumed reasonable based on an estimated 30 to 37% of water heated within the home (Veritec, 2008a; Vickers, 2001). Given this assumption, the associated end-use GHG emission savings in Ontario could be estimated as follows:

Municipal CO_2e
= 2,476 MWh/yr x 0.270[30] $kgCO_2e$/kWh x 1.06 x 1000 kWh/MWh x 1 tonne/1000 kg
= 710 tonnes CO_2e/yr

[29] note when determining municipal energy saved, transmission losses are excluded.
[30] note Table 4 is not used in this example because Table 4 is appropriate only for large, surface treatment systems

Electric Hot Water CO_2e
= 10,600 m^3/d saved x 5% hot water x 30% x 20,881 gCO_2e/m^3 x 365 days/yr x 1 tonne/1000 kg
= 1211 tonnes CO_2e/yr.

Natural Gas Hot Water CO_2e
= 10,600 m^3/d saved x 5% hot water x 70% x 21,514 gCO_2e/m^3water x 365 x 1 tonne/1e6g
= 2913 tonnes CO_2e/yr.

Total CO_2e Emissions Saved
= 4835 tonnes CO_2e/yr

Equivalent Green Energy

One 1.5 MW Windmill offsets the equivalent CO_2e emissions produced by the Ontario Electricity Grid:
=1.5 MW x 24 h/d x 365 d/yr x 30%CapacityFactor x 0.270 kgCO2e/kWh x 1000kWh/MWh x 1tonne/1000kg
=1,064 tonnesCO2e/yr

A savings of 4835 tonnes CO_2e/yr in Guelph would therefore save the construction and continuous operation of:

= 4835 tonnesCO2e/yr / 1064 tonnesCO2e/windmill/yr
=4.5 windmills

Province of Ontario Case Study

Back of the envelope approximations of energy and GHG savings for the Province of Ontario that assume a 20% increase in efficiency, in municipally supplied water[31], by 2029 are provided below.

Water Saved
= 16,200,000 cap x 481 LCD x 20% = 1,558,440 m^3/d

If we assume 10% of the water saved is hot[32], and 70% of hot water heating is provided by natural gas, no wastewater energy is saved[33], and the savings are achieved in large surface water treatment plants[34], the results achieved would be:

Hot Water Saved
= 1,558,440 m^3/d x 10% = 155,844 m^3/d

Indirect GHG Saved
= 1,558,440 m3/d x 166 gCO2e/m3 x 365 days/yr x 1tonne/1e6 g
= 94,424 tonnesCO2e/yr

Electric Hot Water Energy Saved
= 155,844 m^3/d saved x 30% x 20,881 gCO2e/m3 x 365 days/yr x 1 tonne/1e6g
= 356,300 tonnesCO2e/yr

[31] excludes all self-supplied users
[32] Ontario as a whole is anticipated to have a significant opportunity to reduce hot water given an estimated 30% of water use in commercial/institutional settings for pre-rinse valves, restrooms and laundry alone (Cohen et al. 2004), up to 50% of wash-water used in food processing is hot water, and other industrial processes heat water more than 55°C
[33] wastewater pumping energy has been excluded because of the unknown volume of outdoor water savings
[34] 85.8% of flow is from surface water in Ontario (Environment Canada, 2007)

Natural Gas Hot Water GHG

= 155,844 m^3/d saved x 70% x 21,514 gCO2e/m3water x 365 x 1 tonne/1e6g

= 856,650 tonnesCO2e/yr

Total GHG Emissions Saved

= 1,307,372 tonnes/yr

The residential sector in the City of Toronto was noted by Cuddihy et al. (2005) to consume 5.27 million MWh/yr of electricity. Converting this value to a GHG emission in Ontario:

Equivalent Homes Powered

= 1,307,372 tonnesCO2e/yr / (5.27 million MWh/yr x 1.06 x 0.270 kgCO2e/kWh x 1000kWh/MWh x 1 tonne/1000kg)

= 87% of the GHG emissions for residential electricity use in City of Toronto

Equivalent Municipal Energy

The equivalent indirect, municipal, electricity saved from reduced pumping is estimated as:

= 1,558,440 m^3/d x 0.58 kWh/m3 x 365 days/yr x 1 MWh/1000 kWh

= 329,922 MWh/yr

The Power Application Group (PAGI, 2008) estimated that Ontario municipalities have the potential to increase efficiency by 12% or 792 million kWh. The municipal savings associated with a 20% increase in water use efficiency TODAY (population in 2009 is approximately 13.094 million) is approximately equivalent to:

= (13,094,000 cap x 481 LCD x 20% x 0.58 x 365 days/yr x m^3 /1000 L x1 MWh/1000 kWh) / 792,000

= 34% of Municipal Energy Efficiency Potential

Equivalent Green Energy

One 1.5 MW Windmill offsets the equivalent CO_2e from the current Ontario Electricity generation mix of:

=1.5 MW x 24 h/d x 365 d/yr x 30%CapacityFactor x 0.270 kgCO2e/kWh x 1000kWh/MWh x 1tonne/1000kg

=1,064 tonnesCO2e/windmill/yr

A savings of 1,282,255 tonnesCO_2e/yr in Ontario would save the construction and continuous operation of:

= 1,282,255 tonnesCO_2e/yr / 1,064 tonnesCO2e/windmill/yr

=1,200 windmills

An Example for Citizens

Showering for an extra 2 minutes uses:

=9.5 L/m x 2 min x (0.68[35]kWh/m3+ 50%hotwater x 73[36]kWh/m^3) x 1m^3/1000L

=0.71 kWh

An inefficient 60 W compact fluorescent light-bulb would therefore run for:

= 0.71 kWh / 0.060 kW

= 12 hours

20% reduction in shower flow rate:

[35] indirect energy for a large surface water system, both water and wastewater production

[36] assumes electric hot water heating

$=(9.5-7.6)$LPM x 7 minutes x (0.68[37]kWh/m3+ 50%hotwater x 73[38]kWh/m^3) x 1m^3/1000L
=0.494 kWh saved / shower

Assuming 2.6 persons/home, each showering 0.75 times / day (Mayer & DeOreo, 1999):
= 0.494 kWh saved / shower x 2.6 persons / home x 0.75 showers/person/d x 365 d/yr
= 352 kWh/yr

Equivalent to changing 60W bulbs to 13 W, operating 4 hours per day:
= 352 kWh/yr / ((0.06 - 0.013) kWh x 4 hours/day x 365 days/yr)
= 5.1 bulb changes

[37] indirect energy for a large surface water system, both water and wastewater production
[38] assumes electric hot water heating

APPENDIX G: GLOSSARY OF TERMS & ACRONYMS

Carbon Footprint - the grams of CO2e generated to extract, treat, and distribute 1 m^3 of water, and to collect and treat 1 m^3 of wastewater.

Direct energy – the energy that is directly consumed at the end-use such as hot water, household purification and water softeners

Embedded energy – the energy required to manufacture chemicals used in the treatment of water and wastewater

Energy Intensity – the energy in kWh applied to 1 m^3 of water

Equivalent Carbon Dioxide (CO2e) - the concentration of CO2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. Examples of such greenhouse gases are methane, perfluorocarbons and nitrous oxide.

GHG – Greenhouse Gases - are gases in an atmosphere that absorb and emit radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. Common greenhouse gases in the Earth's atmosphere include water vapor, carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbons.

GHG Emission Factor – for the purpose of this report, the GHG Emission Factor is the average mass of greenhouse gas emissions in g per unit of electrical energy generated in kWh

Indirect Energy - the municipal energy used to pump and treat water and wastewater

kWh – Kilowatt hours

MWh – Megawatt hours

Raw Indirect Energy Intensity – the total electrical energy in kWh applied to 1 m^3 of water, including energy used for lighting buildings, all treatment processes, etc.

Transmission Losses – the percentage of electricity lost during transmission from a generating station to a sub-station

Water Conservation Energy Intensity – the energy in kWh that can be reduced by a 1 m^3 reduction in water use

WTPs – Water Treatment Plants

WWTPs – Wastewater Treatment Plants

APPENDIX H: REFERENCES

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