Incorporating Energy Impacts into Water Supply and Wastewater Management

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INTRODUCTION

Approximately 4 per cent of the nation's electricity goes towards moving and treating water and wastewater (EPRI, 2002), the majority of which is paid for by municipal operating budgets. In fact, according to a recent study, water and wastewater together represent as much as half of a municipality's total electricity consumption – double that of street lighting (PAGI, 2008). Reduced electricity consumption at treatment facilities and pumping stations could offer significantly lower costs for municipalities and agencies responsible for their operations (Tripathi 2007).

Fossil fuels continue to make up a large portion of the North American electricity mix - an estimated 25 per cent in Canada and 72 per cent in the USA (Canadian Nuclear Association, 2009; EIA, 2009). Every kilowatt hour consumed generates carbon dioxide emissions, and every kilowatt hour reduced consequently slows the progression of climate change. Municipalities will be increasingly responsible not only for the direct energy costs associated with providing water services, but also the indirect costs associated with mitigating greenhouse gas emissions. This suggests municipalities will need to carefully consider options for reducing energy use in their water and wastewater operations.

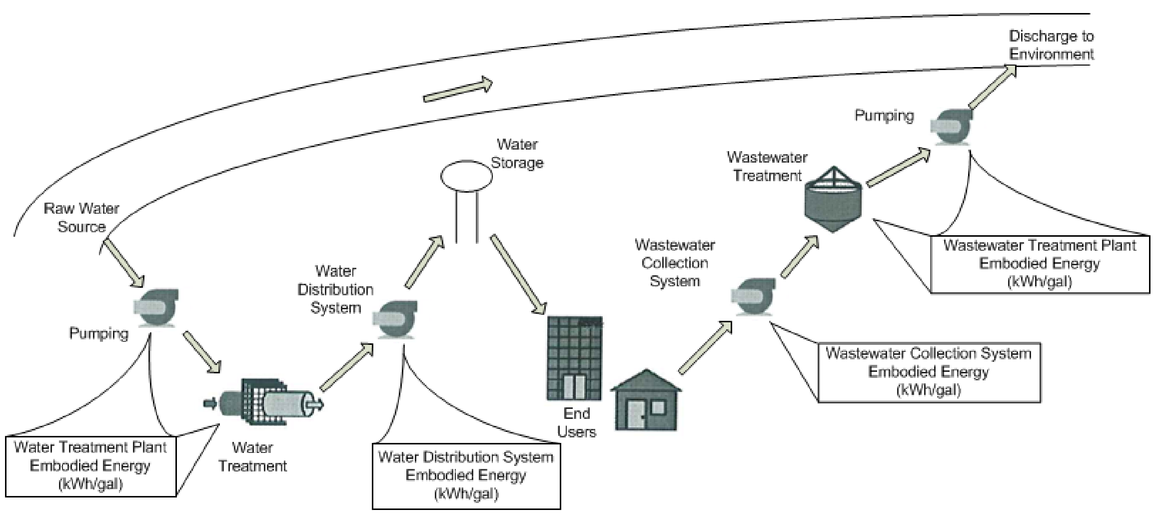
There have been an increasing number of studies published in recent years that quantify the link between water and energy use (The Brendle Group 2007, Cohen et al., 2004, Arpke and Hutzler, 2006). A number of additional studies have focused on optimization of pump, and treatment plant, efficiency as a first step towards reducing energy costs in the municipal water sector (Sandia National Laboratories, 2008; Arora & LeChevallier, 1998; EPRI, 1994). Recent work suggests there are several important opportunities, in addition to the optimization of mechanical efficiencies, for incorporating the energy impacts of water supply and wastewater management into decision making and policy (Maas, 2009; deMonsabert & Liner, 2008; Cohen et al., 2004). Three such opportunities will be explored herein: 1) incorporating the influence of site topography on municipal pumping requirements into both community planning and environmental rating systems ; 2) including the carbon footprint of water use as a criterion for water management decisions; and 3) incorporating water conservation measures as a component of municipal energy efficiency programs.

The Energy Intensity, and Carbon Footprint, of Water Use

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 treatment, collection and end-use. Embodied energy refers to the quantity of energy required to manufacture, and supply to the point of use, a product, material or service. For the water utility sector, embodied energy or energy intensity is the total amount of energy, calculated on a whole system basis, required for the use of a given amount of water in a specific location (Wilkinson 2000).

This paper focuses on the municipal embodied energy required for the production, delivery, and disposal of water in an urban water system. Embodied energy is typically expressed in kilowatt hours per gallon of water (kWh/gallon or kWh/m^3) (TheBrendleGroup 2007).

Figure 1: Components of Embodied Energy in Water End Uses



A range of municipal embodied energy intensity values for water use are reported in the literature, generally ranging from 1-1.5 kWh/m^3 (Maas, 2009; Cohen et al., 2004; Racoviceanu et al., 2007; Arpke and Hutzler, 2006). Water and wastewater treatment energy intensities depend heavily on the prevalence of advanced treatment technologies (EPRI, 2002), whereas the energy for distribution and collection is highly influenced by distribution length, pipe material and age, topography, pumped water volumes and system pressure.

The carbon footprint, in lbs of CO_2 per m^3 of water, of the embodied energy can be determined by multiplying the energy intensity by a state specific carbon conversion factor, a value dependent on the fossil-fuel contribution to the electricity generation mix (DOE 2002).

The Significance of Embodied Energy

The carbon footprint associated with the total water system life cycle is not consistently measured, modeled, or evaluated via a standardized approach. Many energy and environmental rating systems, such as the Leadership in Energy and Environmental Design (LEED), and the Energy Star energy management tool (Portfolio Manager), focus on the energy consumed by appliances, vehicular use, lighting, heating and air conditioning but exclude the embodied energy in water. Similarly, water utility's operations are increasingly being identified as an opportunity for energy efficiency (PAGI, 2008) but typically the opportunities associated with efficient site selection and water conservation are ignored. How does the carbon footprint of the embodied energy in water and wastewater compare with some of the other well known energy and GHG saving opportunities? To answer this question, two case studies are offered. The first study compares the embodied energy of water use to appliances in American homes that are typically considered by environmental rating and energy efficiency programs. The second study explores the energy savings achievable through reduced water use, stemming from municipal water conservation programs.

Case 1: Embodied Energy for Water and Wastewater

A model was developed to estimate the embodied energy for two residential water users located in Northern Virginia. Water and wastewater treatment energy intensities were based upon a 2002 EPRI study and are noted in Table 2. The carbon conversion factor for Virginia – was extracted from a DOE study (2000). Virginia relies heavily on fossil-fuel fired power plants and therefore has a high carbon conversion factor of 1.16 lbCO2/kWh. Other states, and Canada, have somewhat lower carbon conversion factors, typically because of the higher contribution of nuclear and hydro-power to the electricity generation mix (DOE, 2002). The energy losses for the distribution and collection systems were calculated based on the Hazen Williams formula (Cameron Hydraulic Data, 1984) which calculates the friction loss for water flowing under turbulent conditions. From available GIS data, two residential scenarios were considered:

1. Scenario 1: Residence located at 50 ft (15 m) above sea level
2. Scenario 2: Residence located at 200 ft (60 m)above sea level

The following additional assumptions were held constant for both scenarios:

- Elevation of the water treatment plant was 0 ft
- Elevation of the wastewater treatment plant was 100 ft
- Distribution piping was 4 inches in diameter and has a C factor of 100
- Residential water pressure was maintained at 60 psi
- Residences were both located 5 miles from the water treatment plant and the wastewater treatment plant
- Average daily demand for each house was 350 gal/day (1,325 L/d), and
- Pump and Motor efficiencies were 90 per cent and 95 per cent respectively

Complete methodological details can be found in deMonsabert, et al. (2008). Table 2 illustrates the results for both simulations.

As expected, even for a community with a relatively flat terrain (elevation difference of only 150 feet) the embodied energy resulting from water distribution pumping varies considerably. A change in elevation, of 150 feet in this case, increases the CO_2 emissions by 35 per cent. In both residences, the estimated carbon footprint of the embodied energy for water use was greater than 630 lbs/year (285 kg/yr). How does this value compare with other residential end-uses? Table 3 shows the approximate carbon emissions for a variety of residential appliances, assuming the residences are also located in Virginia (carbon conversion factor of 1.16 lbCO2/kWh or 0.53 kg CO_2/kWh). Even with a small difference in elevation between the water treatment plant and the end-user (50 ft, 15 m), the embodied energy for water and wastewater is greater than most common residential appliances. Of the appliances studied, only inefficient lighting (100 W bulbs) exceeds the embodied energy CO_2 emissions for the water and wastewater industries. This comparison suggests that the magnitude of embodied energy is significant when compared with other end uses.

Table 2: Total Water System Embodied Energy and Carbon Dioxide Emissions

Water System Element	Energy Intensity (kWh/gal)	House Demand (gal/day)	Energy Consumption/ Day (kWh/day)	Energy Consumption/ Day (kWh/year)	Carbon Conversion Factor lbs CO_2/kWh (kg CO_2/kWh)	CO_2 Emissions per year lbs CO_2/year (kg CO_2/year)
Water Treatment	0.001406	350	0.4921	179.62	1.16 (0.53)	208 (94)
Wastewater Treatment	0.001911	350	0.66885	244.13	1.16 (0.53)	283 (128)
Water Distribution (Pumping)	0.000764 [1]) 0.001500 [2]	350	0.2674 [1] 0.5250 [2]	97.60 [1] 191.63 [2]	1.16 (0.53)	113 (51) [1] 222 (101) [2]
Wastewater Collection	0.0001960 [1] 0.0009796 [2]	350	0.06860 [1] 0.34286 [2]	25.04 [1] 125.14 [2]	1.16 (0.53)	29 (13) [1] 145 (66) [2]
					Total	**634 (288) [1]** **859 (390) [2]**

Table 3: Residential End-Use Energy & Carbon Footprint Estimates for Virginia

Appliance	Use Assumptions	kWh/use	kWh/year	CO_2 Emissions per year lbs CO_2/year (kg CO_2/year)
Microwave Oven	96 times per year	0.945 kWh per use (based on 1.39 kWh for full power and 0.5 kWh for defrosting)	90.72	105 (48)
Washing Machine	187 washes per year	EU energy label A-rated gives an average consumption at 40°C using a 2kg load to be 0.63 kWh	117.81	137 (62)
Electric Tumble Dryer	148 uses per year	2.50 kWh per cycle	370	105 (48)
Electric Oven	135.1 uses per year	1.56 kWh per use	210.756	244 (111)
Dishwasher at 65°C	135 uses per year	1.44 kWh per use	194.4	226 (103)
Fridge-Freezer A spec	24 hours a day	408 kWh per year	408	473 (215)
Personal computer	365 days a year	270 w x 2 hrs per use	197.1	229 (104)
Standard Light Bulb; assume 15 bulbs	4 hours a day	100 W	2,190	2,540 (1,152)

Assumptions for energy use were extracted from Carbon Footprint (2009)

Case 2: Water & Energy Conservation

A study of seven municipalities in Ontario, Canada, assessed the potential for energy savings associated with water conservation (Maas, 2009). Energy is consumed in treatment plants for a variety of purposes, and not all energy used will necessarily be affected by a reduction in water volumes treated. Energy used for lighting and heating buildings, and for treatment processes that are not impacted flow are unlikely to elicit energy savings when water is conserved. The study suggested that the portion of energy used for pumping could provide a reasonable estimate of the energy savings associated with water conservation. The energy savings co-benefit of water conservation, termed the "water conservation energy intensity", was therefore estimated by multiplying the total embodied energy intensity by the proportion of energy utilized within a treatment plant for pumping. Pumping consumes an estimated 87 per cent of the total energy demand in water treatment plants, and 8.2 per cent in wastewater treatment plants (EPRI 1994; 2002). Energy consumed for distribution and collection was assumed to be utilized entirely for pumping. Full details of this methodology can be found in Maas (2009).

A summary of mean water conservation energy intensity values derived from the Ontario study, for both surface and groundwater systems, are included in Table 4. Municipalities can use Table 4 to estimate the energy savings of water conservation measures. GHG savings can then be approximated by multiplying the energy intensity by the appropriate carbon conversion factor. If possible, the embodied energy intensity for pumping should be assessed using water and energy data for the municipality in question. However, the mean values reported herein are anticipated to provide a reasonable first estimate. Communities served by large reservoirs, gravity flow potable water distribution systems or primary level wastewater treatment systems, such as in British Columbia, Canada, may need to consult alternative published values for lower energy intensity values.

Table 4. Summary of Water Conservation Energy Intensities, Ontario Canada

Water Use Component	Mean Energy Intensity kWh/1000gal (kWh/m^3)			
	Surface Supply (WTPs)		Groundwater Supply (Wells)	
	Small Capacity < 1.3 MGD (< 5,000 m^3/d)	Large Capacity > 1.3 MGD (> 5,000 m^3/d)	Small Capacity < 0.3 MGD (< 1,000 m^3/d)	Large Capacity > 0.3 MGD (> 5,000 m^3/d)
Water Treatment and Source Extraction[1]	3.0 (0.80)	1.5 (0.41)	2.8 (0.74)	1.78 (0.47)
Water Distribution	0.64 (0.17)	0.64 (0.17)	0.64 (0.17)	0.64 (0.17)
Water Sub-Total	3.7 (**0.97**)	2.2 (**0.58**)	3.4 (**0.91**)	**2.4 (0.64)**
Wastewater Treatment	0.32 (0.085)	0.14 (0.036)	0.32 (0.085)	0.14 (0.036)
Wastewater Collection	0.23 (0.06)	0.23 (0.06)	0.23 (0.06)	0.23 (0.06)
Wastewater Sub-total	0.53 (**0.14**)	0.38 (**0.10**)	**0.53 (0.14)**	**0.38 (0.10)**
Total Indirect Energy Intensity	4.2 (**1.11**)	2.6 (**0.68**)	**4.0 (1.05)**	**2.8 (0.74)**

A case study on the City of Guelph, a medium sized city with a population of 115,000, supplied by groundwater, was conducted to put the embodied energy intensity values into context. Guelph is a progressive community with both well established water conservation planning and a community energy plan. The City's Water Conservation and Efficiency Strategy is targeting a total water use reduction of 20 per cent from the projected business as usual

[1] Includes source extraction, treatment and in some cases a portion of high lift pumping

scenario in 2025, an equivalent water savings of 10,600 m^3/d. This target offers significant water and energy savings benefits for Guelph.

The municipal electricity savings stemming from water conservation, estimated at more than 2400 MWh/yr, could provide half of the pumping energy used for source extraction from the City's wells in 2006 (Maas, 2009). 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 energy efficiency and greenhouse gas mitigation measures currently being pursued in Guelph, such as powering the Woods Pumping station with green energy, which could offset the GHG emissions from generating an estimated 2.8 million kWh/yr (City of Guelph, 2008).

Incorporating Energy Impacts into Water Management

The case studies above suggest that several key opportunities exist to integrate the energy impacts of water provision into decision-making policies and processes.

Energy for Water in Environmental Rating Systems

The embodied energy in delivered water is currently not considered by environmental and energy rating systems such as LEED. Based on the energy consumption of water pumping alone, LEED should consider giving credit to buildings sited in locations that reduce the embodied energy required to deliver potable water and collect wastewater. For example, buildings that require a lower potable water system pressure, or have access to gravity driven wastewater collection systems, have a lower environmental impact than buildings situated higher in elevation with respect to the water treatment plant and lower in elevation with respect to the wastewater treatment facility. A credit could be given for buildings sited at a similar elevation to water and wastewater treatment plants, just as a credit is currently given for developing on a Brownfield site.

Carbon Footprint as Criteria for Decision Making

A holistic approach to water management decisions must address the potentially conflicting goals of economics (financial), environmental, and social sustainability that define the Triple Bottom Line (TBL). Performance measures for each of the three goals (economic, environmental, and social sustainability) are the core building blocks of effective long-term water management decision making.

Generally, economic performance measures are well understood and defined. These may include capital costs, operating costs, return on investment, etc. Over the past decade, environmental performance measures, such as measures of water quality, have received increased attention, research and use in decision making. This paper demonstrates that the carbon footprint and embodied energy of providing water services need to be included as both an environmental, *and* an economic, criterion for decision making. For example, new developments requesting a connection to municipal water and wastewater services, should be encouraged to include high efficiency water conserving fixtures (i.e. WaterSense approved fixtures), and to evaluate site selection based on minimizing the elevation differential between the new construction and the existing water and wastewater pumping stations. Yet another opportunity for energy savings in new construction includes the adoption of gravity flow, non-potable, alternative water supply systems, such as using rainwater for toilet flushing and outdoor water use. This alternative would reduce both pumping and treatment energy in comparison to conventional water supply.

Water conservation programs are already well known to make good economic sense, typically costing a fraction of a water treatment plant expansion. Water conservation offers clear environmental and economic benefits over expanding supply, both in reduced energy and carbon footprint from lower rates of pumping.

Water Conservation as an Energy Reduction Measure

A recent report by the California Energy Commission (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). The study estimated the cost per annual kWh saved at $0.22 for proposed energy efficiency programming, whereas water conservation programs, consisting of toilet retrofits, metering, landscape audits, etc. could achieve equivalent energy savings for only $0.13 / annual kWh saved.

California accordingly diverted a portion of energy efficiency funding for water conservation programming. Wisconsin's Strategy for Reducing Global Warming suggests the same (2008), and recent research in Ontario, Canada confirms that water conservation is a significant opportunity for energy savings. Municipalities will soon need to move beyond rapid payback energy efficiency measures, such as efficient lighting, and water conservation is anticipated to be among the most cost effective energy saving strategies.

Government at all levels, municipal, state, and federal, should consider including water conservation strategies as part of their energy reduction programs. The Energy Policy Act in the U.S. and the newly proposed Green Energy Act in Ontario, have both recognized this opportunity by including standards for water efficient appliances. Despite recent policy advancements, water conservation today remains a largely untapped opportunity for energy savings in North American municipalities.

Conclusions

The case studies presented suggest that the embodied energy for municipal water and wastewater treatment and pumping is significant in comparison to both appliances within the home, and energy and greenhouse gas mitigation strategies employed today. The energy expended in the distribution and collection of water and wastewater depends heavily on both the topography of the service area and the volume of water delivered. The estimated energy savings must be determined on case by case basis depending on the siting of the treatment plant and the demand side distance, water consumption and its elevation. Unfortunately, statewide and national estimates of the energy (and GHG) savings are difficult to achieve due to the wide variance in topography and operating characteristics. Future research could help yield regional factors that could be used in conjunction with the treatment plant permit requirements to provide estimates for each specific case. Regardless of the issues related to obtaining a national energy and GHG reduction estimate, it is clear that a significant opportunity exists for energy and GHG savings by incorporating the embodied energy of water and wastewater into environmental rating programs, municipal decision-making, and energy reduction programs.

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