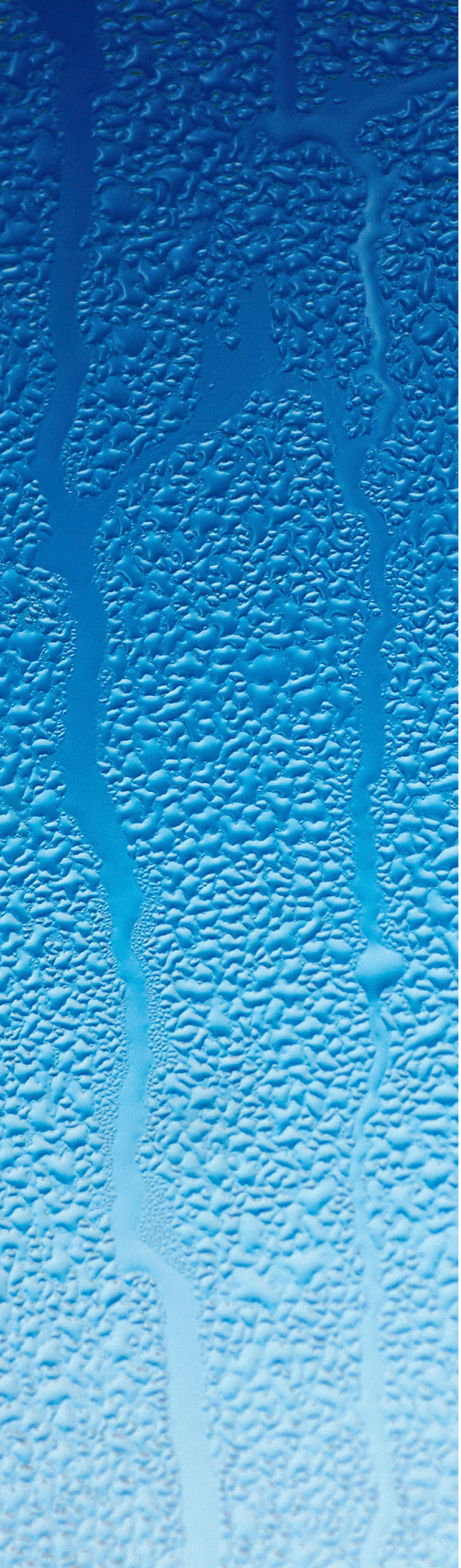

POLIS Research Report 10-01
April 2010

Ontario's Water-Energy Nexus:

Technical Appendices

POLIS Project on Ecological Governance
watersustainabilityproject

APPENDIX A - SUMMARY OF RESULTS

Table A1. Summary of Energy Use for Water Services by Sector and End-Use

	Sector	Water Use in 2006 (m^3/d)	Pumping & Treatment Energy (PJ/yr)	Hot Water Energy (PJ/yr)	Steam Energy (PJ/yr)	Totals (PJ/yr)
Municipal Supply	Municipal Pumping	*3,120,155,443*[1]	10.68	0.00	0.00	10.68
	Residential	966,600,000	0.00	85.38	0.00	85.38
	Commercial/Institutional	132,300,000	0.00	36.92	133.70	170.62
	Manufacturing	1,647,188,790	0.00	0.00	83.49	83.49
	Municipal Water Loss	374,466,653	0.91	0.00	0.00	0.91
Private Supply	Power Generation	26,687,000,000	3.60	0.01	516.00	519.61
	Agriculture - Irrigation	108,210,000	0.18	1.75	0.00	1.94
	Agriculture - Livestock	61,500,000	0.03	1.02	0.00	1.05
	Agriculture - Aquaculture	39,192,000	0.01	0.00	0.00	0.01
	Residential	171,700,000	0.25	15.17	0.00	15.42
	Manufacturing	1,622,811,210	4.28	0.00	82.26	86.54
	TOTALS	**31,810,968,653**	**19.9**	**140.2**	**815.5**	**975.6**

[1] Note the municipal water pumped is a sum of the residential, commercial/institutional, manufacturing and municipal water loss volumes and therefore is not an additional volume.

Table A2. Summary of Energy Use for Water Services by Sector and Fuel

	Sector	Pumping & Treatment Energy (PJ/yr)		Hot Water Energy (PJ/yr)			Steam Energy (PJ/yr)				Totals (PJ/yr)
		Elec	Diesel	Elec	Natural Gas / Prop	Petrol	Elec	Natural Gas / Prop	Petrol	Wood	
Municipal Supply	Municipal Pumping	10.68									10.68
	Residential	0.00		21.26	64.12						85.38
	Commercial/ Institutional	0.00		16.35	20.58			133.70			170.62
	Manufacturing	0.00						54.37	14.80	14.32	83.49
	Municipal Water Loss	0.91		0.00	0.00						0.91
Private Supply	Power Generation	3.60		0.01	0.00		516				519.61
	Agriculture - Irrigation	0.09	0.10	0.00	1.48	0.27					1.94
	Agriculture - Livestock	0.03		0.37	0.64	0.00					1.05
	Agriculture - Aquaculture	0.01		0.00	0.00	0.00					0.01
	Residential	0.25		3.78	11.39	0.00					15.42
	Manufacturing	4.28						53.57	14.58	14.11	86.54
	TOTALS	**19.8**	**0.1**	**41.7**	**98.2**	**0.3**	**516**	**241.6**	**29.4**	**28.4**	**975.6**

APPENDIX B - GENERAL METHODOLOGY

Annual Water Takings

Annual water and wastewater demands for each sector were determined using the analysis conducted by RMSI (2009: Table 36). The water taking estimates were completed using a variety of methods including water use estimates for the agricultural and manufacturing sector (Ecologistics, 1993; Statistics Canada, 2005), estimation of number of employees and number of institutions in the commercial and institutional sector (Statistics Canada, 2006), the Municipal Water Use Database to determine water loss estimates and average residential per capita use (Environment Canada, 2007), and the use of Statistics Canada Census data (2006) to disaggregate the percentage of residential households by building type.

Table A.1 summarizes the annual water takings for 2006 by sector.[2] Wastewater flows were estimated using ratios developed by RMSi (2009: Table 128). Detailed spreadsheet calculations were the basis for all tables presented in the appendix; in some cases rounding errors may result in differences in reported values and/or there may be discrepancies in the summation of individual values within a table.

Embedded Energy Estimates

Embedded energy is defined as the energy inputs upstream of the end-use and typically consists of energy use for pumping, treatment and to produce chemicals used in treatment processes. The general methodology applied in this study was to first estimate the energy intensity, the energy applied in kWh for 1 m^3 of water or wastewater, for each of these energy inputs and then to multiply the energy intensities by the annual water volume that is affected by each energy input.

End-Use Energy Estimates

End-use energy is defined as the energy input at the point of use and is primarily comprised of heating water and generating steam. Other common end-uses where energy is applied include water cooled chillers and on-site treatment systems such as water softeners and UV disinfection. Total end-use energy may be calculated by estimating the energy intensity of the end-use, for example heating water can be estimated using basic heat calculations and the volume of water heated. However, in some sectors like the manufacturing and commercial sectors, this methodology is complicated by the prevalence of other energy intensive end-uses such as steam generation. In this case, existing surveys of energy use related to hot water by sector (primarily data from NRCan, 2007) were sought out as a way to cross-check and/or over-ride the heat calculations.

[2] Note that municipal water loss estimates are higher than reported by RMSi (2009) as a result of a difference in the split between municipal and private takings in the manufacturing sector.

APPENDIX C - MUNICIPAL WATER AND WASTEWATER SUPPLY

Annual Water Takings

Table C1 summarizes the municipally supplied annual water takings by sector, with explanatory notes in the footnotes. The manufacturing sector was further disaggregated into municipally supplied water and privately supplied as detailed in the Manufacturing section. All water used in the CI sector was assumed to be municipally supplied (RMSi, 2009; Great Lakes Commission, 2009). Municipal water loss calculations differed from RMSi (2009: Table 40) because of a difference in the assumed volume of municipally supplied water used by the manufacturing sector.

The water loss calculation utilized herein was as follows:

The total volume of municipally supplied water used by the residential, commercial/institutional and manufacturing sectors was estimated to be 2,746,000,000 m^3/yr. Assuming this volume excludes municipal water loss of 12% estimated by Environment Canada (2007), these sectors together represent 88% of total municipal water withdrawals or 3,120,555,443 m^3/yr.

Table C.1. Municipal Water Demand Excluding Water Loss

Sector	Flow[3] (m^3/yr)
Residential	966,600,000
Commercial/ Institutional	132,300,000
Manufacturing	1,647,188,790
Municipal Water Use Excluding Loss	2,746,000,000

Twelve percent of total municipal water use is therefore 374,466,653 m^3/yr as noted in Table C.2. below.

Embedded Energy

Energy Intensity

The energy intensity of municipal water and wastewater pumping and treatment were derived based on a water-energy study of 7 Ontario municipalities (Maas, 2009), with the exception of the energy for primary wastewater treatment which was assumed to be 0.2 kWh/m^3 (Griffiths-Satenspiel & Wilson, 2009: Table 2.1). The municipalities studied illustrated a clear relationship between energy intensity and flow, whereby large plants (> 5,000 m^3/d) had average energy intensities of approximately 0.54 kWh/m^3 for

[3] Refer to RMSi (2009: Tables 36 and 38)

groundwater, 0.47 kWh/m^3 for surface water and 0.44 kWh/m^3 for wastewater pumping and treatment[4] (Maas, 2009).

All water treatment systems were conservatively assumed to be larger than 5,000 m^3/d, which resulted in a conservative estimate of total energy use (large plants have lower energy intensities than smaller plants). Provincial wastewater treatment plant data was used to determine that 8% of the total wastewater volume is processed by plants having a capacity less than 5,000 m^3/d in Ontario. The energy intensity for small wastewater treatment plants was assumed to be 1.04 kWh/m^3 (Maas, 2009).

Based on the fraction of surface water and groundwater supply in the province, the following average energy intensity was determined:

Energy Intensity of Municipal Water Services:

$$e_{wat,mun,ave} = e_{wat,mun,treat,gw} \cdot \xi_{wat,mun,gw} + e_{wat,mun,treat,sw} \cdot \xi_{wat,mun,sw} + e_{wat,mun,dist}$$
$$= 0.54 kWh/m^3 \cdot 14\% + 0.47 kWh/m^3 \cdot 86\% + 0.17$$
$$= 0.65 kWh/m^3$$

where:
$e_{wat,mun,treat,ave}$ = average energy intensity of water treatment in Ontario

$e_{wat,mun,treat,gw}$ = energy intensity of treated groundwater = 0.54 kWh/m^3 (Maas, 2009)
$e_{wat,mun,treat,sw}$ = energy intensity of treated surfacewater = 0.47 kW/m^3 (Maas, 2009)
$e_{wat,mun,dist}$ = energy intensity of water distribution = 0.17 kWh/m^3 (Maas, 2009)

$\xi_{wat,mun,gw}$ = fraction of water supplied by groundwater sources = 14% is groundwater (Environment Canada, 2007)
$\xi_{wat,mun,sw}$ = fraction of water supplied by surface sources = 86% is surface water (Environment Canada, 2007)

Energy Intensity of Municipal Wastewater Services:
Based on the fraction of primary versus secondary wastewater treatment in the province, the following average energy intensity was determined:

$$e_{ww,mun,ave} = e_{ww,mun,collect} + \xi_{ww,mun,treat,prim} \cdot e_{ww,mun,treat,prim} +$$
$$\xi_{ww,mun,second} (\xi_{ww,large} \cdot e_{ww,mun,treat,second,large} + \xi_{ww,small} \cdot e_{ww,mun,treat,second,small})$$
$$= 0.06 + 0.2 kWh/m^3 \cdot 11.3\% \cdot 0.20 kWh/m^3 + 88.7\% \cdot (92\% \cdot 0.44 kWh/m^3 + 8\% \cdot 1.04 kWh/m^3)$$
$$= 0.52 kWh/m^3$$

where:
$e_{ww,mun,ave}$ = average energy intensity for wastewater treatment and collection in Ontario

[4] excluding distribution and collection

$e_{ww,mun,collect}$ = energy intensity for wastewater collection = 0.06 kWh/m^3
$e_{ww,mun,treat,prim}$ = energy intensity for primary wastewater treatment = 0.20 kWh/m^3
$e_{ww,mun,treat,second,large}$ = energy intensity for large secondary wastewater treatment plants = 0.44 kWh/m^3 (Maas, 2009)
$e_{ww,mun,treat,second,small}$ = energy intensity for small secondary wastewater treatment plants = 1.04 kWh/m^3 (Maas, 2009)
$\xi_{ww,mun,treat,prim}$ = 11.3% wastewater treatment plants assumed to be primary level treatment (Environment Canada, 2007)
$\xi_{ww,mun,second}$ = 88.7% of wastewater treatment systems are secondary or tertiary (Environment Canada, 2007)
$\xi_{ww,mun,second,large}$ = fraction of wastewater plants > 5,000 m^3/d = 92%
$\xi_{ww,mun,second,small}$ = fraction of wastewater plants < 5,000 m^3/d = 8%

Total Embedded Energy

Below is a sample calculation for the embedded energy for water services in the residential sector, applying the average energy intensity of water treatment in Ontario (0.65 kWh/m^3) to the total municipally supplied residential water volume of 966,600,000 m^3/yr:

$$E_{emb,res,elec} = 966{,}600{,}000 m^3/yr \cdot 0.65 kWh/m^3 \cdot 3.6e^{-9}$$
$$= 2.26 PJ/yr$$

where:
$E_{emb,res,elec}$ = total electrical embedded energy for pumping and treatment in the residential sector

Similar calculations were used to calculate embedded energy for water and wastewater services for each sector supplied by municipal water, and the results are reported in Table C2.

Table C2. Summary of Municipally Supply Volumetric Water and Wastewater Flows and Embedded Energy

	Water		Wastewater			
Sector	Flow[5] (m^3/yr)	Embed Energy[6] (PJ/yr)	%WW[7]	Flow (m^3/yr)	Embed Energy[8] (kWh/yr)	Total Embed Energy (PJ/yr)

[5] Refer to RMSi (2009: Tables 36 and 38)
[6] Annual water takings for each sector were multiplied by the average energy intensity for municipal water provision of 0.65 kWh/m^3
[7] Fraction of wastewater produced for each sector was determined using ratios of wastewater to water reported in RMSi (2009: Table 128)
[8] Each wastewater volume was multiplied by the average energy intensity for municipal wastewater provision of 0.47 kWh/m^3

Residential	966,600,000	2.26	88%	850,608,000	1.58	3.84
Commercial/ Institutional	132,300,000	0.31	92%	121,716,000	0.21	0.52
Manufacturing	1,647,188,790	3.85	88%	1,449,526,135	2.47	6.32
Municipal Water Loss	374,466,653	0.88	5%	89,085,000	0.03	0.91
Total Municipal	**3,120,555,443**			**839,986,651**	**4.29**	**11.59**

APPENDIX D - RESIDENTIAL

Annual Water Takings

The annual volume of water extracted from private wells in the residential sector was estimated by RMSi (2009: Table 36). All privately supplied residential water takings were assumed to be supplied by groundwater sources (Great Lakes Commission, 2009).

Privately Supplied Residential Water Takings:

$$Q_{wat,res,priv} = 171{,}700{,}000 m^3 / yr$$

where:
$Q_{wat,res,priv}$ = water takings from private wells for the residential sector

Privately Supplied Residential Wastewater Flow:

$$Q_{ww,res,priv} = Q_{wat,res,priv} \cdot \xi_{ww,res,priv}$$
$$= 171{,}700{,}000 m^3 / yr \cdot 88\%$$
$$= 151{,}096{,}000 m^3 / yr$$

where:
$Q_{ww,res,priv}$ = volume of wastewater produced by the residential sector on private wells
$Q_{wat,res,priv}$ = water takings from private wells for the residential sector =171,700,000 m^3/yr (RMSi, 2009: Table 36)
$\xi_{ww,res,priv}$ = the fraction of water takings discharged as wastewater = 88% (RMSi, 2009: ratio extracted from Table 128)

Embedded Energy

Embedded Energy for Privately Supplied Residential Water Takings

$$
\begin{aligned}
E_{emb,wat,res,priv} &= \cdot Q_{wat,res,priv} \cdot e_{wat,res,priv} \\
&= 171{,}706{,}000 m^3 / yr \cdot 0.41 kWh / m^3 \\
&= 70{,}397{,}000 kWh / yr \\
&= 0.25 PJ / yr
\end{aligned}
$$

where:
$E_{emb,wat,res,priv}$ = the total embedded energy for pumping of residential water takings from private wells
$Q_{wat,res,priv}$ = water takings from private wells for the residential sector =171,700,000 m^3/yr (RMSi, 2009: Table 36)
$e_{wat,res,priv}$ = 0.41 kWh/m^3
Typical homes use pumps ranging between ½ HP – 2 HP (EPRI, 2002) and energy intensity values reported in the literature ranges between 0.185 kWh/m^3 (EPRI, 2002) and 0.69 kWh/m^3 for residential groundwater pumping (Long Island Power Authority, 2009) depending on well depth, capacity and pump type. Sanchez (1999) suggested a typical ½ HP well pump providing 960 L/d consumed between 0.29-0.4 kWh/m^3. The average, 0.41 kWh/m^3, of all reported values was therefore assumed.

Energy for residential water treatment systems was assumed to be negligible because softeners use small amounts of energy, advanced water purification systems are generally applied only to faucet water and sufficient data on both penetration rates and energy use for these systems were not readily available.

Embedded Energy for Privately Supplied Residential Wastewater Disposal

$$E_{ww,emb,res,priv} = Q_{ww,res,priv} \cdot e_{ww,res,priv}$$
$$= 151{,}096{,}000 \cdot 0$$
$$= 0 kWh / yr$$

where:
$E_{ww,emb,res,priv}$ = the total embedded energy for pumping of residential wastewater disposal from private systems
$e_{ww,res,priv}$ = 0 kWh/m^3
Private onsite wastewater treatment and disposal systems (septic systems, leaching bed, etc.) generally gravity flow and have negligible energy inputs. The penetration rate of more energy intensive onsite advanced wastewater treatment systems were assumed negligible at this time.

100% of privately supplied water was assumed to dispose of wastewater onsite, as a conservative assumption given data on the fraction of privately supplied residences that discharge to a centralized wastewater treatment plant was unavailable.

Total Embedded Energy (Privately Supplied)

$$E_{tot,emb,priv} = 0.25 + 0$$
$$= 0.25 PJ / yr$$

$E_{tot,emb,res,priv}$ = the total embedded energy for pumping of residential water takings and wastewater disposal in private supplied systems

End-Use

Hot Water Volume

Hot water volumes used and saved in the residential sector were not explicitly reported in RMSi (2009). The following calculation estimates the hot water used in both the municipally and privately supplied residential sector:

***Private Supply*:**
$$Q_{wat,res,priv,hot} = (Q_{wat,res,priv}) \cdot (\xi_{res,hot})$$
$$= (171{,}700{,}000) \cdot 30\%$$
$$= 51{,}510{,}000 m^3 / yr$$

Municipal Supply:

$$Q_{wat,res,mun,hot} = (Q_{wat,res,mun}) \cdot (\xi_{res,hot})$$
$$= (966{,}600{,}000) \cdot 30\%$$
$$= 289{,}980{,}000 m^3 / yr$$

where:
$Q_{wat,res,priv,hot}$ = volume of hot water used the residential sector on private wells
$Q_{wat,res,mun,hot}$ = volume of hot water used the residential sector on municipal supply

$Q_{wat,res,priv}$ = water takings from private wells for the residential sector =171,700,000 m^3/yr (RMSi, 2009: Tables 36 and 38)
$Q_{wat,res,mun}$ = municipally supplied water for the residential sector = 966,600,000 m^3/yr (RMSi, 2009: Tables 36 and 38)

$\xi_{res,hot}$ = the fraction of water takings that are heated = 30%

The percentage of water heated in the home can range from 25-45% depending on the type of fixtures and presence of leaks in the home. Hot water percentage estimates were based on a literature review of water end-uses and calculated using the WaterSmart Scenario Builder (Maas, 2009). Thirty percent of total water use was assumed heated in Ontario by interpolating the hot water use in a home with a water use per home of 260 Lcd, the Ontario average, within a range of inefficient (370 Lcd, 28% hot water) and efficient homes (130Lcd, 37% hot water). This method was crosschecked with a study by Veritec (2008), where an intensive monitoring program of 175 homes in Durham region and found an average of 36% of total water use was heated in newly constructed homes compared with 42% in water efficient homes. This study suggests an assumption of 30% of total water use heated is conservative from an energy perspective.

Energy Intensity of Hot Water

The energy intensity of heating water is dependent on the cold and hot water temperatures and the efficiency of the hot water heater. The energy intensity to heat hot water was estimated using standard heat calculations and typical hot water heater efficiencies:

$$e_{hot} = C_p \cdot (T_2 - T_1)$$
$$= 4.184 x (60 - 12)$$
$$= 201 J / mL$$
$$= 56 kWh / m^3$$

where:
C_p = 4.184 J/g/°C the specific heat capacity of water

T_2 = 12 °C [9] the annual temperature of the raw cold water in °C (Stats Canada, 2009: Chart 6)
T_1 = 60 °C [10] the hot water temperature exiting the water heater. Hot water temperatures typically range between 48-60 C (Canada Safety Council, 2009).

Cross-check:
Given this equation relies on a temperature differential, it similarly covers situation where the cold water temperature may be a lower value (10 °C has been utilized in the U.S.) or the hot water temperature is reduced to prevent scalding. Cohen *et al*. (2004) assumed heating from a cold water temperature of 15.5 °C to a hot water temperature of 40.5 °C for showers and baths in California. The 40.5 °C for showers and baths quoted by Cohen *et al*. (2004) is approximately equivalent to the assumption used herein that hot water was heated to 60 °C and a shower would typically utilize 65% hot water (39 °C average temperature). Energy estimates have excluded the electricity required to power appliances such as clothes and dishwashers.

The hot water energy intensity was then adjusted for the efficiency of hot water heaters fueled by both natural gas and electricity.

Natural Gas Hot Water Heaters:

$$e_{hot,ng} = \frac{e_{hot}}{n_{ng}}$$
$$= \frac{56}{0.62}$$
$$= 90 kWh / m^3$$

Electric Hot Water Heaters:

$$e_{hot,elec} = \frac{e_{hot}}{n_{elec}}$$
$$= \frac{56}{0.88}$$
$$= 63 kWh / m^3$$

where:
$e_{hot,ng}$ = the energy intensity of natural gas hot water heaters, including heater efficiency
$e_{hot,elec}$ = the energy intensity of electric hot water heaters, including heater efficiency
e_{hot} = the energy intensity of heating water

n = efficiency factor of 88% for electrical and 62% for natural gas (BC Hydro, 2009)

[9] cold water temperature significantly impacts energy use for hot water heating.
[10] Hot water temperature significantly impacts energy use for hot water heating.

End-Use Energy (Privately Supplied)

The energy for hot water heating in the residential sector supplied by private wells was estimated to be:

$$E_{end,res,priv} = Q_{wat,res,priv,hot} \cdot (\xi_{res,ng} \cdot e_{hot,ng} + \xi_{res,elec} \cdot e_{hot,elec})$$
$$= 51{,}510{,}000 m^3 / yr \cdot (68\% \cdot 90 kWh/m^3 + 32\% \cdot 63 kWh/m^3)$$
$$= 4{,}190{,}853{,}600 kWh/yr$$
$$= 15.1 PJ/yr$$

End-Use Energy (Municipally Supplied)

The energy for hot water heating in the residential sector supplied by municipal water was estimated to be:

$$E_{end,res,mun} = Q_{wat,res,mun,hot} \cdot (\xi_{res,ng} \cdot e_{hot,ng} + \xi_{res,elec} \cdot e_{hot,elec})$$
$$= 289{,}980{,}000 m^3 / yr \cdot (68\% \cdot 90 kWh/m^3 + 32\% \cdot 63 kWh/m^3)$$
$$= 23{,}715{,}000{,}000 kWh/yr$$
$$= 85.4 PJ/yr$$

Total End-Use Energy

The total energy for hot water heating in the residential sector was estimated to be:

$$E_{end,res,tot} = 15.1 + 85.4$$
$$= 100.54 PJ/yr$$

where:
$E_{end,res,tot}$ = the total end-use energy for hot water heating in the residential sector
$E_{end,res,mun}$ = the total end-use energy for hot water heating in the residential sector where water is municipally supplied
$E_{end,res,priv}$ = the total end-use energy for hot water heating in the residential sector where water is privately supplied
$Q_{wat,res,priv,hot}$ = volume of hot water used the residential sector where water is privately supplied
$Q_{wat,res,mun,,hot}$ = volume of hot water used the residential sector where water is municipally supplied
$e_{hot,ng}$ = the energy intensity of natural gas hot water heaters, including heater efficiency = 90 kWh/m^3
$e_{hot,elec}$ = the energy intensity of electric hot water heaters, including heater efficiency = 63 kWh/m^3

$\xi_{res,ng}$ = 68% of homes are assumed to have natural gas water heaters (Natural Resources Canada, 2003: Chart 47)
$\xi_{res,elec}$ =32% of homes are assumed to have electric water heaters (Natural Resources Canada, 2003: Chart 47).

Cross check:
The residential energy use for hot water heating was estimated as 105 PJ/yr in 2007 by (NRCan, 2009a), a 4% differential.

APPENDIX E - COMMERCIAL INSTITUTIONAL

Annual Water Takings

Water use for the Commercial Institutional (CI) sector was evaluated by RMSi (2009: pp 86) using the number of employees, process type and product use generated by Statistics Canada census information based on the North American Industry Code System (NAICS). Total water takings for the CI sector was estimated at 132,300,000 m^3/yr.

Golf-courses are known to withdraw large volumes of water and are typically classified as a commercial water use, but are often privately supplied. Golf-courses were not specifically mentioned in the RMSi (2009) assessment of water use in Ontario; this exclusion is recognized as a known inaccuracy, however a further disaggregation of privately supplied versus municipally supplied businesses and institutions was not possible within the scope of this report.

Embedded Energy

All Commercial Institutional (CI) water was assumed municipally supplied (RMSi, 2009: PDF Page 292), and municipal energy inputs are detailed in the Municipal Section, Appendix C.

End-Use Energy

Nearly 95 percent of all commercial and institutional establishments heat water according to a national survey of businesses and institutions (Statistics Canada, 2005). The volume of hot water saved in the CI sector was not explicitly reported by RMSi (2009). Accordingly, two different methods for estimating the annual volume of water heated and the associated energy use in the CI sector were identified in this study.

METHOD 1:

To provide an initial estimate, assumptions for the portion of water heated for each CI end-use (showers and faucets and laundries) were made and applied to water use estimates. Hot water use was estimated to be 30% of total water use for faucets, 65% for showers and 38% for laundry based on an evaluation of average temperatures assumed in Swistock & Sharpe (2009) and cross-checked with values reported by deMonsabert & Liner (1998) and Cohen *et al*. (2004). Table E.1 outlines the water demand reported by RMSi for each CI end-use (2009: PDF page 294) and the estimates of hot water volumes.

Table E1. Disaggregation of Commercial & Institutional Water Use

	Total Water Demand	Fraction of Total Hot	Hot Water[11]
Toilets	52,444,147	0%	-
Urinals	17,603,630	0%	-
Faucets	11,735,753	30%	3,520,726
Showers	733,485	65%	476,765
Laundry	25,270,833	38%	9,602,917
Irrigation	3,652,740	0%	-
Cooling	20,872,800	0%	-
Total	**132,313,388**	**10%**	**13,600,408**

Extracted from RMSi (2009: PDF page 294)

This method estimated that 10% of total CI water demand was heated. However, energy use for dishwashers, pre-rinse spray valves and car washing were excluded from this estimate because the water use for these end-usess was not available. Note that this method also excludes steam used for space heating and process use and does not assign an energy estimate to water cooled chillers which are also known to be energy intensive (55 kWh/m^3 from Cohen *et al*., 2004). In short, this estimate was assumed to be a very conservative estimate of the fraction of water that is heated in some way in the CI sector.

METHOD 2:

The total energy use for heating water in the CI sector was estimated as 36.9 PJ/yr in 2006 by NRCan (2006). Using theoretical energy calculations and assuming CI water was heated to 82 °C for sanitation purposes (Nebraska Food Code, 2003), an energy intensity for hot water heating can be estimated as:

Energy Intensity of Hot Water:

$$e_{hot} = C_p \cdot (T_2 - T_1)$$
$$= 4.184x(82-12)$$
$$= 293 J / mL$$
$$= 81 kWh / m^3$$

Natural Gas Hot Water Heaters:

$$e_{hot,ng} = \frac{e_{hot}}{n_{ng}}$$
$$= \frac{81}{0.62}$$
$$= 130 kWh / m^3$$

[11] Calculated based on 38% of laundry demand, 30% of faucet demand and 68% of shower demand is hot water (Swistock & Sharpe, 2009; Cohen *et al*., 2004)

Electric Hot Water Heaters:

$$e_{hot,elec} = \frac{e_{hot}}{n_{elec}}$$

$$= \frac{81}{0.88}$$

$$= 92 kWh / m^3$$

where:
n = efficiency factor of 88% for electrical and 62% for natural gas (BC Hydro, 2009)

Assuming an energy intensity of 92 kWh/m^3 for electricity and 130 kWh/m^3 for natural gas, and a total energy demand of 36.9 PJ/yr, the fraction of water heated was calibrated to approximately 69%.[12]

METHOD ADOPTED:

In a case study of San Diego County, Cohen *et al*. (2004: Table 7) estimated the portion of water used in each sub-sector of the CI sector including kitchen dishwashers, kitchen pre-rinse spray valves, laundries, water cooled chillers, once through cooling, and assigned energy intensity values to each end-use. This level of disaggregation is the preferred approach, however at this time the data required to refine the energy intensity and hot water use estimates by specific end-use are currently unavailable at a provincial scale in Ontario.

Hot Water Heating

Heating 10% of total water use in the CI sector was considered an overly conservative estimate (given the exclusion of steam, car washing, kitchen use and water cooled chillers). If either the energy reported by NRCan (2006) was overestimated or the water use estimated by RMSi (2009) for CI use was underestimated, the effect would be a reduction of the estimated 69% of water use that is heated, which appears to be unreasonably high.

Given the intention of the RMSi (2009) report was not to derive a total hot water use estimate for determining energy use, the NRCan (2006) values were assumed to provide the more accurate assessment of energy for hot water currently available. The energy use reported by NRCan (2006) for hot water heating in 2006 of 36.9 PJ/yr was therefore adopted. Hoewever, future resolution of the apparent discrepancy between water and energy use methodologies using more robust measuring, monitoring and reporting of both resources in the CI sector would be worthwhile.

The Total Energy Demand for Hot Water Heating:

$E_{end,CI}$ =36.9 PJ/yr (NRCan, 2006)

---

[12] Note that an infinite number of combinations of end-use energy intensity and fraction of water use heated could be employed to arrive at 36.9 PJ/yr total end-use energy.

Energy Demand from Electric Hot Water Heaters:

The total energy demand of 36.9 PJ/yr was further disaggregated into electric and natural gas energy:

$$E_{end,CI,elect} = E_{end,CI} \cdot (\xi_{ci,elec})$$
$$= 36.9 PJ / yr \cdot (53\%)$$
$$= 19.6 PJ / y$$

Energy Demand from Natural Gas Hot Water Heaters:

$$E_{end,CI,ng} = E_{hot} \cdot (\xi_{ci,ng})$$
$$= 36.9 PJ / yr \cdot (47\%)$$
$$= 17.3 PJ / y$$

where:
$E_{end,CI,elec}$ = the total end-use energy for hot water heating in the CI sector, provided by electricity
$E_{end,CI,ng}$ = the total end-use energy for hot water heating in the CI sector, provided by natural gas
$E_{end,CI}$ = the total end-use energy for hot water heating in the CI sector

$\xi_{res,ng}$ = 47% of hot water heating establishments provided by natural gas (NRCan, 2007: Chart 13).
$\xi_{res,elec}$ = 53% of hot water heating establishments provided by electricity (NRCan, 2007: Chart 13).

The Commercial and Institutional Building Energy Use Survey (CIBEUS, 2000) estimated 63% of hot water heating is provided by natural gas with the remaining supplied by electricity (CIBEUS, 2000), which conflicted with the estimates reported by (NRCan, 2007). The ratio of natural gas to electricity for hot water heating in the CI sector also conflicted with the NRCan Comprehensive Energy Use Database that suggested electricity for hot water was 0.8 PJ/yr and natural gas was 30 PJ/year in 2006 with the remaining energy provided by petroleum (NRCan, 2006).

However, the methodology employed by NRCan (2006) was based on models of calibration that do not appear to take into account the ratio of electricity and natural gas for hot water use reported for the CI sector by CIBEUS (2000) in Ontario. The ratio 47%:53% natural gas: electricity was selected for this study because the NRCan (2007) study was the most recent study of fuel sources for water heating specific to the CI sector.

Steam

Water volumes used for steam generation in the CI sector were not readily available. According to the Statistics Canada Industrial Water Use survey (2005), 120 Canadian establishments used co-generation, or generated electricity or steam in 2005 (e.g. hospital complexes, university campuses and large institutions). A significant portion of these large establishments are presumably located in Ontario given the large number of universities, institutional headquarters, and large buildings in comparison to other provinces.

An estimated 56% the CI sector generates steam to heat buildings or water to very hot temperatures including hospitals, universities, and large buildings (CIBEUS, 2002). Boilers and district steam were together found to comprise the majority (65%) of the main heating equipment according to CIBEUS (2002: Table 10.2).

NRCan (2006) estimates energy for space heating in the commercial institutional sector at 205.7 PJ/yr in 2006. Based on the CIBEUS (2002) study described above, 65% of this energy was assumed to be associated with steam. Given 79% of space heating in the CI sector is provided by natural gas (CIBEUS, 2003), in the absence of information specific to boilers, energy for steam was assumed to be provided exclusively by natural gas:

$$
\begin{aligned}
& E_{end,CI,steam} = E_{heat} \cdot (\xi_{ci,heat,steam}) \\
& = 205.7 PJ / yr \cdot (65\%) \\
& = 133.7 PJ / y
\end{aligned}
$$

where:

$E_{end,CI,steam}$ = the total end-use for generating steam in the CI sector, provided by natural gas
E_{heat} = the total energy used to provide space heating in the CI sector = 205.7 PJ/yr (NRCan, 2006)
$\xi_{ci,heat,steam}$ = the fraction of space heating provided by steam in the CI sector = 65% (CIBEUS, 2002)

APPENDIX F - MANUFACTURING

Annual Water Takings

Annual privately supplied water takings for the manufacturing sector were extracted directly from RMSi (2009). An estimated 99% of the paper manufacturing, petroleum and coal manufacturing and primary metal manufacturing annual water takings were identified by RMSI (2009: PDF page 298) as privately supplied.

The total annual volume of privately supplied water in the manufacturing sector was estimated as:

Privately Supplied Water for Manufacturing:

$$Q_{wat,man,priv} = Q_{wat,paper} + Q_{wat,petroleum} + Q_{wat,metal}$$
$$= 964{,}715{,}000 + 153{,}077{,}000 + 505{,}019{,}000$$
$$= 1{,}622{,}811{,}000 m^3 / yr$$

where:
$Q_{wat,paper}$, $Q_{wat,petroleum}$ and $Q_{wat,metal}$ represent annual private water taking volumes reported for the paper, petroleum and metals manufacturing sector respectively in RMSi (2009: PDF page 298).
$Q_{wat,man,priv}$ = the volume of privately supplied water used by the manufacturing sector

The total water demand in the manufacturing sector was identified as 3,270,000,000 m^3 by RMSi (2009: Table 49). Municipally supplied water for manufacturing can then be estimated by subtracting the volume of water that is privately supplied:

Municipally Supplied Water for Manufacturing:

$$Q_{wat,man,mun} = Q_{wat,man,tot} - Q_{wat,man,priv}$$
$$= 3{,}270{,}000{,}000 - 1{,}622{,}811{,}000$$
$$= 1{,}647{,}189{,}000 / yr$$

where:
$Q_{wat,man,mun}$ = the annual volume of municipally supplied water used by the manufacturing sector
$Q_{wat,man,priv}$ = the annual volume of privately supplied water used by the manufacturing sector = 1,622,811,000 m^3/yr
$Q_{wat,man,tot}$ = the total annual volume of water used by the manufacturing sector = 3,270,000,000 m^3/yr

Wastewater Produced

The wastewater produced from privately supplied water takings was estimated as:

Private Wastewater:

$$Q_{ww,man,priv} = Q_{wat,man,priv} \cdot \xi_{ww,man}$$
$$= 1{,}622{,}811{,}000 m^3 \cdot 88\%$$
$$= 1{,}428{,}073{,}680 m^3 / yr$$

where:
$Q_{ww,man,priv}$ = the volume of privately disposed wastewater water in the manufacturing sector
$\xi_{ww,man}$ = the fraction of water use that is disposed of as wastewater in the manufacturing sector = 88% (based on an analysis of Table 1-2 in Statistics Canada, 2005 water withdrawals vs. wastewater disposal for all industries in Ontario).

Embedded Energy

Total Embedded Energy

Electricity is the primary energy source used for pumping and treatment of privately supplied water for the manufacturing sector (Phil Dick, 2009: PC). Accordingly, the total embedded energy for privately supplied manufacturing is determined by multiplying the ratio of water supplied by groundwater (2%) and surface water (98%) by the respective energy intensity values noted below for water supply.

The fraction of water treated (19%) was multiplied by the energy intensity for filtration noted below. Similarly, the wastewater treatment energy was estimated by multiplying the volume of privately generated wastewater by the percentage treated using primary (19%) and secondary (46%) treatment, and by the respective wastewater treatment energy intensities. All wastewater was assumed to gravity flow to a treatment plant as a conservative assumption (no energy input).

$$E_{emb,man,priv,elec} = Q_{wat,man,priv} \cdot (\xi_{man,gw} \cdot e_{gw} + \xi_{man,sw} \cdot e_{sw} + \xi_{wat,man,treat} \cdot e_{wat,man,treat}) +$$
$$Q_{ww,man,priv}(\xi_{ww,man,treat} \cdot e_{ww,man,treat})$$
$$= 1{,}622{,}811{,}000 m^3 / yr \cdot (2\% \cdot 0.18 kWh / m^3 + 98\% \cdot 0.0793 kWh / m^3 + 18.9\% \cdot 0.0053 kWh / m^3) +$$
$$1{,}428{,}073{,}680 m^3 / yr (19.2\% \cdot 0.18 kWh / m^3 + 45.6\% \cdot 0.661 kWh / m^3)$$
$$= 613{,}381{,}000 kWh / yr$$
$$= 2.21 PJ / yr$$

where:
$E_{emb,man,priv,elec}$ = the total electrical embedded energy in the privately supplied manufacturing sector

$\xi_{wat,man,sw}$ = fraction of privately supplied manufacturing water sourced from surface water = 98% (Great Lakes Commission, 2009)
$\xi_{wat,man,gw}$ = fraction of privately supplied manufacturing water sourced from surface water = 2% of water sourced from groundwater (Great Lakes Commission, 2009)
$\xi_{ww,man,treat}$ = fraction of wastewater is treated by primary/secondary treatment = 19.2% for primary and 45.6%[13] for secondary/tertiary and the remainder is not treated (assumed Canadian average for all industries based on Statistics Canada, 2005, Table 7-2).

$\xi_{wat,man,treat}$ = 18.9% of water intake is treated using filtration in Canada (Statistics Canada, 2005: Table 4);
$e_{wat,,sw}$ = energy intensity for water takings from surface water = 0.0793 kWh/m^3 (EPRI, 2002)
$e_{wat,gw}$ = energy intensity for water takings from groundwater = 0.18[14] kWh/m^3 (EPRI, 2002)
$e_{wat,man,treat}$ = energy intensity for water treatment in the manufacturing sector = 0.0053 kWh/m^3 (EPRI, 2002: Figure 2-1)
$e_{ww,man,treat}$ = energy intensity for privately owned wastewater treatment = 0.661 kWh/m^3 for secondary/tertiary treatment (EPRI, 2002: pg 3-13); 0.18 kWh/m3 for primary treatment (lower end of the range of wastewater collection and treatment energy intensities reported by Griffiths-Satenspiel & Wilson, 2009: Table 2.1)

End-Use

Recycling Wastewater

Energy is used for recycling wastewater in the manufacturing sector. This energy was considered to be input at the point of use and was calculated as follows for privately and municipally supplied manufacturing facilities respectively:

Recycling Energy for Privately Supplied Manufacturers

$$E_{rec,man,priv} = Q_{wat,man,priv}(\xi_{rec,man,treat} \cdot e_{rec,man,treat})$$
$$= 1{,}622{,}811{,}000 m^3/yr \cdot 40\% \cdot 0.44 kWh/m^3$$
$$= 285{,}615{,}000 kWh/yr$$
$$= 1.03 PJ/yr$$

Recycling Energy for Municipally Supplied Manufacturers

[13] The majority of the volume treated is in industries that are assumed self-supplied: pulp and paper, petroleum and metals.
[14] This energy intensity is lower than for domestic self supplied groundwater because of larger pumps with improved pump efficiency

$$E_{rec,man,mun} = Q_{wat,man,mun}(\xi_{rec,man} \cdot e_{rec,man,treat})$$
$$= 1{,}647{,}189{,}000 m^3 / yr \cdot 40\% \cdot 0.44 kWh / m^3$$
$$= 289{,}905{,}000 kWh / yr$$
$$= 1.04 PJ / yr$$

where:
$E_{rec,man,priv}$ = the end-use energy for recycling wastewater in the manufacturing sector, in privately supplied facilities
$E_{rec,man,mun}$ = the total end-use energy for recycling wastewater in the manufacturing sector, in municipally supplied facilities
$Q_{wat,man,priv}$ = the annual volume of privately supplied water for manufacturing = 1,622,811,000 m^3/yr
$Q_{wat,man,mun}$ = the annual volume of municipally supplied water for manufacturing = 1,644,189,000 m^3/yr

$\xi_{rec,man}$ = the fraction of water that is recycled in the manufacturing sector = 40% estimated using the volume of water recirculated in Ontario divided by the intake volume reported by Statistics Canada (2005:Table 1-2)
$e_{rec,man,treat}$ = energy intensity of recycling water = 0.44 kWh/m^3 assumed approximately equivalent to the energy intensity of secondary wastewater treatment (Maas, 2009)

Steam

Because of the difficulty in securing high quality data on energy requirements for steam generation in the manufacturing sector, largely given to the diversity of factors involved (boiler efficiency, operating pressure, fraction of condensate return, etc.) an estimation based on a literature review was instead applied.

A literature review revealed that steam comprises between 20-45% of industrial energy use in the Netherlands and the U.S. (ETSAP, 2009; Blok and Worrell, 1992; Ellis *et al.*, 2009; US DOE, 2009). The proportion of natural gas used for steam and hot water end-uses by industry was estimated by Marbek (2009) as 34% in the Central Region of Ontario. The total energy demand in the Ontario manufacturing sector fueled by natural gas, propane and petroleum was therefore derived from NRCan (2007) and multiplied by the estimates of the fraction of energy used to fire industrial boilers by fuel type as outlined in Table F1 below.

Table F1. Estimates of Energy for Steam in the Manufacturing Sector by Fuel Type[15]

Fuel Source	Total Energy Demand (PJ/yr)	% Steam	Reference	U.S. Estimates by Einstein, *et al*. (2001)	Energy for Steam (PJ/yr)
Electricity	142.65	0%		1%	0
Natural Gas	313.55	34%	Marbek (2009)	39%	106.6
Propane	8.92	15%	Einstein *et al.* (2001: Table 2)	15%	1.3
Wood	69.34	41%		41%	28.4
Coal	12.02	73%		73%	8.78
Petroleum Products[16]	158.46	13%	Calibrated using Griffin & Johnson (2006: Table 3)	60%	20.6
Steam	11.85	0%		0%	0
Total	**844.60**	**20%**		**37%**	**165.75**

Propane and wood energy were assumed to be utilized for steam to the same extent as in the U.S. as reported by Einstein *et al.* (2001). Griffin and Johson (2001) estimated 65% of industrial boilers are fueled by natural gas, 18% oil and the remaining wood and other fuels. These ratios were utilized to cross-check the estimates for natural gas and to calibrate the percentage of petroleum products used for steam in Ontario. Both steam and electricity energy were excluded from the energy to generate steam in Ontario.

A total of 166 PJ/yr was estimated to fuel boilers in Ontario's manufacturing sector.

The calculation above resulted in an energy demand for steam that consumes an estimated 20% of total manufacturing energy demand from all fuel sources (including electricity, coke, coal and steam in addition to natural gas, propane and petroleum), which is within the range of literature estimates for the U.S. and Netherlands. Hot water for end-uses such as washwater and domestic use was assumed to be generated using heat from boilers and therefore was excluded from the analysis to avoid duplication (and thus overestimation) of heat energy.

End-Use Energy (Privately Supplied)

The total energy for privately supplied manufacturing was estimated by adjusting the total energy for steam (166 PJ/yr) proportional to the fraction of privately supplied water (1,622,811,000 m^3) in comparison to the total volume of water used by manufacturing (3,270,000,000 m^3):

[15] note that all values and totals may be slightly different due to rounding
[16] oil, petroleum coke and still gas

$$E_{end,man,priv} = \frac{1{,}622{,}811{,}000}{3{,}270{,}000{,}000}166$$
$$= 82 PJ / yr$$

$E_{end,man,priv}$ = the total end-use energy for privately supplied manufacturing

End-Use Energy (Municipally Supplied)

Municipally supplied manufacturing facilities were calculated using the same approach as for the private facilities:

$$E_{end,man,mun} = \frac{1{,}647{,}189{,}000}{3{,}270{,}000{,}000}166$$
$$= 83 PJ / yr$$

$E_{end,man,priv}$ = the total end-use energy for municipally supplied manufacturing

APPENDIX G - AGRICULTURAL IRRIGATION

Annual Water Takings

The following table disaggregates agricultural water use by crop type and identifies the total volume of water used for irrigation. Agricultural water use was assumed to be 100% privately supplied (RMSi, 2009; Great Lakes Commission, 2009).

Table G.1. Annual Water Takings for Agricultural Crops and Greenhouses

Agriculture Type	Total Irrigation (m^3/yr)	Other[17] (m^3/yr)
Field Crops	15,800,000	847,000
Fruit Crops	16,012,000	616,000
Vegetable Crops	22,400,000	222,000
Greenhouses, Sod, Nursery	51,500,000	357,000
Total	**105,712,000**	**2,042,000**
%'s	98%	2%

Summarized from Tables 58 and 59 RMSi (2009) based on Ecologistics (1993)

Irrigated water was further broken down by the irrigation method: overhead irrigation (commonly traveling gun); and drip irrigation (an estimate of the division of system types used in Ontario). Other water uses were assumed to be provided by a standalone pump. Greenhouse irrigation techniques vary, for example floriculture tends to use a combination of hand watering and overhead sprinklers whereas the majority of greenhouse vegetable operations use drip irrigation.

Table G.2. Irrigation Method

Crop Type	Overhead Irrigation[18]	Drip Irrigation[19]	Pumping Alone
Field Crops	9,480,000	6,320,000	847,000
Fruit Crops	9,607,200	6,404,800	616,000
Vegetable Crops	13,440,000	8,960,000	222,000
Total	**32,527,200**	**21,684,800**	**1,685,000**
%'s	58%	39%	3%

Embedded Energy

Energy Intensity for Irrigation Methods

Energy intensities for different irrigation types were based on studies by Cooley *et al.* (2008) and modified for the Ontario context (Shortt, 2010: PC):

[17] Other includes spraying, washing, harvesting/transport, on farm processing and other
[18] Calculated assuming 60% of irrigation water is applied using overhead irrigation (Shortt, 2010: PC)
[19] Calculated assuming 40% of irrigation water is applied using drip irrigation (Shortt, 2010: PC)

$e_{wat,ir,priv,over}$ = energy intensity of a typical travelling gun system in Ontario = 0.614 kWh/m^3 (Shortt, 2010)
$e_{wat,ir,priv,drip}$ = energy intensity of a typical drip irrigation system in Ontario = 0.287 kWh/m^3 (Shortt, 2010: PC)

Energy Intensity for Water Uses Other than Irrigation

Other water uses such as spraying and washing, were assumed to be extracted from 44% groundwater sources and 56% surface water sources (Great Lakes Commission, 2009). Accordingly the average energy intensity was calculated as follows:

$$e_{wat,other} = \xi_{wat,priv,gw} \cdot e_{wat,gw} + \xi_{wat,priv,sw} \cdot e_{wat,sw}$$
$$= 44\% \cdot 0.18 kWh/m^3 + 56\% \cdot 0.0793 kwh/m^3$$
$$= 0.12 kWh/m^3$$

where:
$e_{wat,other}$ = the average energy intensity for irrigation water applied using a method other than traveling guns or drip irrigation
$e_{wat,gw}$ = groundwater pumping energy intensity = 0.18 kWh/m^3 (EPRI, 2002)
$e_{wat,sw}$ = surface water pumping energy intensity = 0.0793 kWh/m^3 (EPRI, 2002)

$\xi_{wat,priv,gw}$ = fraction of irrigation supplied by groundwater = 44% (Great Lakes Commission, 2009)
$\xi_{wat,priv,sw}$ = fraction of irrigation supplied by surface water = 56% (Great Lakes Commission, 2009)

Total Embedded Energy

Diesel was assumed to be the primary fuel source for agricultural irrigation/pumping (Phil Dick, 2009: PC; Shortt, 2010: PC). Greenhouses are typically irrigated using traveling spray systems (Khosla, 2010: PC) and were assumed to have a similar energy intensity to drip irrigation. Energy for water treatment was assumed negligible and all water was assumed to be consumptive, meaning energy inputs for wastewater treatment and disposal were also assumed negligible.

The embedded energy for irrigation (excluding greenhouses) using diesel fuel was estimated as:

$$E_{emb,ir,priv,crop} = Q_{wat,ir,priv,over,crop} \cdot e_{ir,over} + Q_{wat,ir,priv,drip,crop} \cdot e_{ir,drip} + Q_{wat,ir,priv,pump,crop} \cdot e_{ir,pump}$$
$$= 32{,}527{,}200 m^3 / yr \cdot 0.614 kWh / m^3 + 21{,}684{,}800 m^3 .yr \cdot 0.287 kWh / m^3 + 1{,}685{,}000 m^3 / yr \cdot 0.12 kWh / m^3$$
$$= 26{,}404{,}854 kWh / yr$$
$$= 0.10 PJ / yr$$

The embedded energy for greenhouse, sod and nursery irrigation using electricity was estimated as:

$$E_{emb,ir,priv,green} = Q_{wat,ir,priv,drip,green} \cdot e_{ir,drip} + Q_{wat,ir,priv,pump,green} \cdot e_{ir,pump}$$
$$= 51{,}500{,}000 m^3 .yr \cdot 0.287 kWh / m^3 + 357{,}000 m^3 / yr \cdot 0.12 kWh / m^3$$
$$= 14{,}824{,}911 kWh / yr$$
$$= 0.05 PJ / yr$$

Total Embedded Energy for Agricultural Irrigation

$$E_{emb,ir,priv} = E_{emb,ir,priv,crop} + E_{emb,ir,priv,greenhouse}$$
$$= 0.10 + 0.05$$
$$= 0.15 PJ / yr$$

where:
$E_{emb,ir,priv}$ = the total embedded energy used for irrigation
$E_{emb,ir,priv,crop}$ = the embedded energy used for irrigation of crops
$E_{emb,ir,priv,green}$ = the embedded energy used for irrigation of greenhouses, sod and nursery

$Q_{wat,ir,priv,over}$ = the water for irrigation delivered by traveling guns = 32,527,200 m^3/yr
$Q_{wat,ir,priv,drip}$ = the water for irrigation delivered by drip irrigation = 73,184,800 m^3/yr
$Q_{wat,ir,priv,other}$ = the water for irrigation delivered by other methods = 2,042,000 m^3/yr

$e_{wat,ir,priv,over}$ = energy intensity of a typical travelling gun system in Ontario = 0.614 kWh/m^3 (Shortt, 2010)
$e_{wat,ir,priv,drip}$ = energy intensity of a typical drip irrigation system in Ontario = 0.287 kWh/m^3 (Shortt, 2010: PC)
$e_{wat,ir,priv,other}$ = energy intensity for pumping water in Ontario = 0.12 kWh/m^3

Cross-check:
Cooley, *et al*. (2008) reported booster pump energy intensity for spray irrigation as 0.23 kWh/m^3 and 0.17 kWh/m^3 for drip irrigation. Irrigation in Ontario is generally privately supplied meaning the energy to pump from the source must be added to the pressure required for the irrigation system which explains the difference in energy intensities (Shortt, 2010).

End-Use

Greenhouse irrigation water is typically heated during winter months to 20 °C (Khosla, 2009: PC). To account for seasonal variation in heating (water is not heated during summer months), an average incoming raw water temperature of 12 °C was assumed which accounts for both low winter temperatures and higher summer temperatures. Energy intensities based on this temperature differential are anticipated to be conservative given that greenhouses are anticipated to use boilers in some cases for both hot water heating and space heating which would involve much higher temperatures. Sufficient information was not available to conduct a detailed analysis and so energy for steam generation in greenhouses was excluded at this time.

Energy Intensity for Heating Water in Greenhouses:

$$
\begin{aligned}
e_{hot} &= C_p \cdot (T_2 - T_1) \\
&= 4.184x(20-12) \\
&= 33J/mL \\
&= 9kWh/m^3
\end{aligned}
$$

e_{hot} = the energy intensity to heat water from 12 to 20 °C
C_p = heat capacity of water = 4.184 J/g°C

Total End-Use Energy

The water volume for greenhouses, sod and nurseries was reported in RMSi (2009: 59). Further disaggregation of water use for greenhouse irrigation of fruits, vegetables and flowers, excluding sod and nurseries was not available. The entire volume of water used for irrigation of greenhouses was therefore assumed to be heated from 12 to 20 °C and the total energy demand for heating water was calculated as follows:

Natural Gas:

Boiler efficiencies in greenhouses are known to be higher than residential boilers, however high quality data could not be identified. Boiler efficiency for natural gas and oil fired boilers was assumed to be 80%:

$$
\begin{aligned}
E_{end,ir,ng} &= Q_{wat,green,priv,hot} \cdot \left(\xi_{ir,hot,ng} \cdot \frac{e_{hot}}{n_{ir,hot,ng}}\right) \\
&= 51{,}500{,}000\, m^3/yr \cdot \left(7\% \cdot \frac{9}{80\%} kWh/m^3\right) \\
&= 411{,}356{,}250\, kWh/yr \\
&= 1.48\, PJ/yr
\end{aligned}
$$

Petroleum Products:

$$E_{end,ir,petrol} = Q_{wat,green,priv,hot} \cdot (\xi_{ir,hot,petrol} \cdot e_{ir,hot,petrol})$$
$$= 51{,}500{,}000 m^3 / yr \cdot (13\% \cdot \frac{9}{80\%} kWh / m^3)$$
$$= 75{,}318{,}750 kWh / yr$$
$$= 0.27 PJ / yr$$

where:
$E_{end,ir,ng}$ = the total end-use energy for irrigation fueled by natural gas
$E_{end,ir,petrol}$ = the total end-use energy for irrigation fueled by petroleum products including oil
$Q_{wat,green,priv,hot}$ = the volume of water heated in greenhouses = 51,500,000 m^3/yr
$\xi_{ir,hot,ng}$ = fraction of greenhouses assumed to heat water using natural gas = 71% (Agviro and AMEC, 2009).
$\xi_{ir,hot,petrol}$ = fraction of greenhouses use coal and oil to heat water = 13% (Agviro and AMEC, 2009).

$n_{ir,hot,ng}$ = boiler efficiency = 80%
$n_{ir,hot,petrol}$ = boiler efficiency = 80%

Total End-Use Energy for Irrigation:

$$E_{end,ir,tot} = 1.48 + 0.27$$
$$= 1.75 PJ / yr$$

where:
$E_{end,ir,tot}$ = the total end-use energy for irrigation

APPENDIX H - AGRICULTURE - LIVESTOCK

Annual Water Takings

All livestock water takings were assumed to be sourced privately (Great Lakes Commission, 2009). Water withdrawals for livestock were extracted from RMSi (2009: Table 60) based on a prior study by Ecologistics (1993). Total takings for this sector were estimated at 61,500,000 m^3/yr.

Embedded Energy

Electricity was assumed to fuel all livestock water withdrawals (Clarke, 2010: PC). Water treatment energy was assumed negligible and no wastewater generated (both conservative assumptions from an energy perspective). The embedded energy to pump water for livestock operations was therefore based on the ratio of water supplied by groundwater versus surface water and typical energy intensity values for pumping.

$$E_{emb,live} = Q_{wat,live,priv} \cdot (\xi_{live,gw} \cdot e_{wat,gw} + \xi_{live,sw} \cdot e_{wat,sw})$$
$$= 338{,}483{,}613 m^3 / yr \cdot (069\% \cdot 0.18 kWh/m^3 + 31\% \cdot 0.0793 kWh/m^3)$$
$$= 9{,}150{,}155 kWh/yr$$
$$= 0.03 PJ/yr$$

where:
$E_{emb,live}$ = the embedded energy to pump and treat water for livestock
$Q_{wat,live,priv}$ = the annual volume of water used for livestock in Ontario = 338,483,61 m^3/yr (RMSI, 2009: Table 60)

$e_{wat,gw}$ =0.18 kWh/m^3 (EPRI, 2002)
$e_{wat,sw}$ = 0.0793 kWh/m^3 (EPRI, 2002)
$\xi_{live,gw}$ = 69% groundwater (Great Lakes Commission, 2009)
$\xi_{live,sw}$ = 31% surface water (Great Lakes Commission, 2009)

End-Use

Annual volumes of water used for washing were provided in RMSi (2009: Table 60). Sanitary and equipment washing was assumed 50% hot (Cuthbertson, 2006).

$$Q_{wat,live,hot} = Q_{wat,live,san} \cdot \xi_{san,hot} + Q_{wat,live,wash} \cdot \xi_{wash,hot}$$
$$= 5{,}910{,}000 \cdot 50\% + 22{,}000 \cdot 50\%$$
$$= 2{,}966{,}000 m^3 / yr$$

where:
$Q_{wat,live,hot}$ = the volume of hot water used in the livestock sector

$Q_{wat,live,san}$ = the volume of sanitary water used in the livestock sector = 5,910,000 m^3/yr (RMSi, 2009: Table 60)
$Q_{wat,live,wash}$ = the volume of washwater used in the livestock sector = 22,000 m^3/yr (RMSi, 2009: Table 60)
$\xi_{san,hot}$ = the fraction of sanitary water heated = 50% (Cuthbertson, 2006)
$\xi_{wash,hot}$ = the fraction of washwater heated = 50% (Cuthbertson, 2006)

Energy Intensity

$$e_{hot} = C_p \cdot (T_2 - T_1)$$
$$= 4.184 x (77 - 10)$$
$$= 280 J / mL$$
$$= 78 kWh / m^3$$

where:
e_{hot} = the energy intensity to heat water in the livestock sector

T_2-T_1 = 77-10 C water was assumed to be heated from 10 °C to 77 °C (Cuthbertson, 2006; Clarke, 2010)

Total End-Use Energy

95% of energy to heat water for milking is from electricity (Clarke, 2010: PC). Milking and Dairy were estimated to use 1,018,350 m^3/yr of hot water (approx. 1/5 of total estimated for livestock) (RMSi, 2009: Table 60). Therefore electricity use should comprise a minimum of 20% for total livestock water heating, which corroborates the *On Farm Energy Audit* that found 39% of energy for heating water was provided by electricity in (Agviro, 2006).

The energy intensity for heating water was combined with hot water volumes and efficiency factors for water heaters to derive the total end-use energy estimates for natural gas and electricity.

Natural Gas:

The total end-use energy for heating water by natural gas in the livestock sector was estimated as:

$$E_{end,live,ng} = Q_{wat,live,priv,hot} \cdot (\xi_{live,hot,ng} \cdot \frac{e}{n_{live,hot,ng}})$$

$$= 2{,}966{,}000 m^3 / yr \cdot (61\% \cdot \frac{78}{80\%} kWh / m^3)$$

$$= 178{,}644{,}000 kWh / yr$$

$$= 0.64 PJ / yr$$

Electric:

The total end-use energy for heating water by electricity in the livestock sector was estimated as:

$$E_{end,live,elec} = Q_{wat,live,priv,hot} \cdot (\xi_{live,hot,elec} \cdot \frac{e}{n_{live,hot,elec}})$$

$$= 2{,}966{,}000 m^3 / yr \cdot (39\% \cdot \frac{78}{88\%} kWh / m^3)$$

$$= 103{,}843{,}705 kWh / yr$$

$$= 0.37 PJ / yr$$

Total End-Use Energy for the Livestock Sector:

$$E_{end,live,tot} = 0.64 + 0.37$$
$$= 1.0 PJ / yr$$

where:
$E_{end,live,tot}$ = the total end-use energy for the livestock sector
$E_{end,live,ng}$ = the total end-use energy for the livestock sector, fueled by natural gas
$E_{end,live,elec}$ = the total end-use energy for the livestock sector, powered by electricity

$Q_{wat,live,hot}$ = the volume of hot water used in the livestock sector = 2,966,000 m^3/yr

$\xi_{live,hot,ng}$ = 61% of farms use natural gas or propane (Agviro, 2006).
$\xi_{live,hot,elec}$ = 39% of farms use electricity, with natural gas second and propane third (Agviro, 2006: 29)

$n_{live,hot,ng}$ = assumed efficiency of natural gas hot water heaters = 80%
$n_{live,hot,elec}$ = efficiency of electric gas hot water heaters = 88% (BC Hydro, 2009)

APPENDIX I - AGRICULTURAL AQUACULTURE

Annual Water Takings

Water withdrawals for land-based aquaculture in Ontario were estimated by RMSi (2009) as 96,200,000 m^3/yr based on an Ecologistics (1993) study. Discussions with Steve Naylor (2010:PC), an aquaculture specialist, suggested that the volume of water withdrawn for land-based aquaculture may have decreased since 1993 and also that the vast majority of aquaculture relies on gravity flow surface water sources or artesian wells to minimize the energy costs of pumping.

Estimates of actual water takings for land-based aquaculture were extracted from the Water Taking Reporting System (Ministry of the Environment, 2009). The estimated aquaculture takings were 13,925,000 m^3/yr for groundwater takings in 2008 and 39,192,000 m^3/yr for total takings. These volumes represent only the volume of takings from permit holders who reported water takings in 2008, and also exclude water takings from operations who may not have a permit and/or who operate caged cultures. Caged aquaculture was not included in this analysis because it was assumed that there were no energy inputs for water.

Embedded Energy

A first estimate of energy use for aquaculture was therefore obtained by examining the water pumped from groundwater sources, assuming all surface water takings required negligible energy inputs. All pumping energy was assumed to be provided by electricity.

The total electrical embedded energy for aquaculture withdrawals was estimated at:

$$
\begin{aligned}
E_{emb,aqua} &= Q_{wat,aqua,priv} \cdot (\xi_{aqua,gw} \cdot e_{wat,gw} + \xi_{aqua,sw} \cdot e_{wat,grav}) \\
&= 338{,}483{,}613 m^3 / yr \cdot (36\% \cdot 0.18 kWh / m^3 + 64\% \cdot 0 kWh / m^3) \\
&= 2{,}539{,}642 kWh / yr \\
&= 0.01 PJ / yr
\end{aligned}
$$

where:
$E_{emb,aqua}$ = the embedded energy for pumping water for aquaculture
$e_{wat,gw}$ = energy intensity of pumping groundwater = 0.18 kWh/m^3 (EPRI, 2002)
$e_{wat,grav}$ = energy intensity of gravity flow surface water = 0 kWh/m^3
$\xi_{aqua,gw}$ = percentage of land-based aquaculture withdrawals from groundwater = 36% (Ministry of the Environment, 2009)
$\xi_{aqua,sw}$ = percentage of land-based aquaculture withdrawals from surface water = 64% (Ministry of the Environment, 2009)

APPENDIX J - POWER GENERATION

Annual Water Takings

Private water takings for power generation are sourced from 100% surface water supplies (Great Lakes Commission, 2009; RMSi, 2009) and the annual volume was estimated by RMSi (2009: Table 38) as:

$$Q_{water,power,priv} = 26{,}687{,}000{,}000 m^3 / yr$$

where:
$Q_{wat,power,priv}$ = the total water withdrawals by the thermal and nuclear power generation sector in Ontario = 26,687,000,000 m^3/yr (RMSi, 2009: Table 38)

Embedded Energy

The fuel source for pumping cooling water is electricity. Ontario Power Generation (2009:PC) conducted a survey of electric and volumetric capacity ratings for 62 pumps in several thermal and nuclear power generation facilities in the province and provided the following weighted average energy intensity of once through cooling pumps:

$e_{power,emb}$ = 0.0375 kWh/m^3

where:
$e_{power,emb}$ = the energy intensity of cooling pumps for thermal and nuclear power plants in Ontario = 0.0375 kWh/m^3

Cross-check:
The reported range in energy intensity of the single speed (on/off) once through cooling pumps in Ontario power plants was 0.021 to 0.063 kWh/m^3. Pumping for once through cooling was estimated by (EPRI, 2002) as 0.0794 kWh/m^3. The approximately 50% higher energy intensity value reported by EPRI represented a generic assumption for large surface water pumps and was not based on actual measurements at power plants.

The cooling pumps at power plants are typically very efficient large capacity axial flow pumps that would be expected to have a lower energy intensity than a typical surface water pump used in another sector. These pumps operate over a narrow volumetric flow range and the electric motor drivers for the pumps are rated to provide at least 10% excess input energy capability. The actual rated kW of the motor was used to calculate the energy intensity (kWh/m^3) of the main circulating cooling water pumps and is anticipated to provide a reasonable estimate of the actual operating energy intensity in the Ontario power sector.

The embedded energy intensity was assumed to apply to all water takings including steam generation, cooling, domestic, etc. as a conservative estimate (i.e. the energy intensity would be higher if smaller pumps were used for services other than cooling).

The total embedded energy was calculated as:

$$E_{power,emb,elec} = Q_{power,priv} \cdot e_{power,embed}$$
$$= 26{,}687{,}000{,}000 m^3 \cdot 0.0375 kWh / m^3$$
$$= 1{,}000{,}762{,}500 kWh$$
$$= 3.6 PJ / yr$$

where:
$E_{power,emb,elec}$ = the total embedded electrical energy for pumping all water withdrawals in the thermal and nuclear power generation sector in Ontario
$Q_{wat,power,priv}$ = the total water withdrawals by the thermal and nuclear power generation sector in Ontario = 26,687,000,000 m^3/yr (RMSi, 2009: Table 38)
$e_{power,emb}$ = the energy intensity of cooling pumps for thermal and nuclear power plants in Ontario = 0.0375 kWh/m^3

End-Use

Hot Water

Hot water is used for showers and faucets at Ontario's power plants. This energy was estimated by first determining the volume of hot water used:

$$Q_{wat,power,priv,hot} = Q_{power,shower} \cdot \xi_{shower,hot} + Q_{power,faucet} \cdot \xi_{faucet,hot}$$
$$= 21{,}782 m^3 / yr \cdot 68\% + 91{,}714 m^3 / yr \cdot 30\%$$
$$= 42{,}326 m^3 / yr$$

where:
$Q_{wat,power,priv,hot}$ = the total volume of hot water used at Ontario's power plants
$Q_{power,shower}$ = the volume of water used for showers in Ontario's power plants = 21,782 m^3/yr (RMSi, 2009)
$Q_{power,shower}$ = the volume of water used for faucets in Ontario's power plants = 91,714 m^3/yr (RMSi, 2009)

Energy Intensity of Hot Water Use:

$$e_{hot} = C_p \cdot (T_2 - T_1)$$
$$= 4.184 x (60 - 12)$$
$$= 201 J / mL$$
$$= 56 kWh / m^3$$

where:
e_{hot} = the energy intensity to heat water for domestic use in the power sector

T_2-T_1 = 60-12 °C water was assumed to be heated from 12 °C to 60 °C

The energy to heat water for showers and faucets is provided by electricity, and is estimated as:

End-Use Energy for Hot Water

$$E_{power,hot} = \frac{e_{hot} \cdot Q_{wat,power,priv,hot}}{n_{elec}}$$

$$= \frac{56kWh/m^3 \cdot 42{,}326m^3/yr}{88\%}$$

$$= 2{,}693{,}472kWh/yr$$

$$= 0.01PJ/yr$$

where:
e_{hot} = the energy intensity to heat water for domestic use in the power sector = 56 kWh/m^3
$Q_{wat,power,priv,hot}$ = the total volume of hot water used at Ontario's power plants = 42,326 m^3/yr
n_{elec} = efficiency of electric gas hot water heaters = 88% (BC Hydro, 2009)

Steam Generation

Energy use and savings associated with steam generation in power plants could not be calculated directly, because of a lack of sufficient information to calculate the energy intensity (Rosen, 2001). However, the waste heat lost to cooling water and steam in thermal and nuclear power generation in Ontario was instead estimated by accounting for the waste heat embedded in the discharged cooling water.

In 2008, OPG generated about 107.8 terawatt hours (TWh), with an electricity generation mix of 45% nuclear, 34% hydroelectric and 22% fossil-fuelled electricity (OPG, 2010). The estimated electricity generated by nuclear and fossil-fuelled power plants was therefore 67% of 107.8 TWh or 72 TWh/yr (277.9 PJ/yr).

Method 1:
Assuming a thermal efficiency of 35% (Roth, 2005), and an electricity output of 278 PJ/yr, the total energy inputs for nuclear and fossil fuel power plants were estimated at 794 PJ/yr.

The energy lost to the atmosphere and to cooling water was estimated as the difference between total energy inputs (794 PJ/yr) and total electricity produced (277.9 PJ/yr), **516 PJ/yr.**

Method 2:
Assuming that cooling water withdrawn from the lake is raised by 11 °C, the heat contained in the waste water discharged from thermal and nuclear power plants could be estimated as:

$$e_{wasteheat} = C_p \cdot (T_2 - T_1)$$
$$= 4.184x(11)$$
$$= 46J / mL$$
$$= 12.8kWh / m^3$$

where:
$e_{wasteheat}$ = represents the waste heat held by the cooling water

$$E_{power,waste} = Q_{wat,power,priv} \cdot \zeta_{wat,power,cool} \cdot e_{power,losses}$$
$$= 26{,}645{,}000{,}000m^3 / yr \cdot 90\% \cdot 12.8kWh / m3$$
$$= 3.06x10^{11} kWh / yr$$
$$= 1105PJ / yr$$

where:
$E_{power,waste}$ = the total waste heat absorbed by the cooling water
$Q_{wat,power,priv}$ = the total water withdrawals by the thermal and nuclear power generation sector in Ontario = 26,687,000,000 m^3/yr (RMSi, 2009: Table 38)
$\zeta_{wat,power,cool}$ = the fraction of total withdrawals used for once through cooling = 90% (RMSi, 2009)

Method Adopted:

The waste heat rejected into cooling water was expected to be less than the estimated waste heat lost resulting from an efficiency calculation. In fact the waste heat discharged into cooling water was estimated to be larger than the energy inputs for power generation which is not thermodynamically possible. Possible reasons for the discrepancy could include an inaccurate thermal efficiency assumption, an overestimated temperature rise in cooling water on an average annual basis, heat contributions to the cooling water other than from fuel inputs or another unknown error. For these reasons, the waste heat associated with water in nuclear and thermal power plants was estimated as 516 PJ/yr as this value was anticipated to be a more reasonable approximation.

APPENDIX K - UNIT CONVERSIONS

1 joule is equal to 1.0E-15 petajoule

1 kilowatt hour = 1 kWh = 3.6 MJ = 3,600,000 J = 3.6×10^{-9} PJ

1 kilojoule = 1 kJ = 1×10^{3} J

1 Gigajoule = 1 GJ = 1×10^{9} J

1 Terajoule = 1 TJ = 1×10^{12} J

1 Petajoule = 1 PJ = 1×10^{15} J

1 Million Btu/hr = 293.07 kW

1 kW = 1.34 HP

1 cubic meter = 1 m^3 = 264 gallons

APPENDIX L - SYMBOLS

Symbols	**Description**	**Units**
E	energy demand, the annual energy consumption	kWh/yr or PJ/yr
e	energy intensity, the energy applied to a specific volume of water or wastewater	kWh/m^3
Q	Annual flow	m^3/yr
ξ	Factors or percentages	unitless
Subscripts		
emb	Embedded Energy, the energy used for pumping and treating water and wastewater (both privately and municipally supplied)	
end	End-Use energy, energy applied directly at the end-use such as hot water, onsite treatment energy such as recycling wastewater, etc.	
wat	Potable water	
ww	Wastewater	
rec	Recycling	
hot	Heated water	
priv	Privately supplied services	
mun	Municipally supplied services	
treat	Treatment	

APPENDIX M - REFERENCES

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