Energy-water Nexus: Energy Use in the Municipal, Industrial, and Agricultural Water Sectors

By

Gweneth M. Thirlwell[1], Chandra A. Madramootoo[2] and Isobel W. Heathcote[3]

[1]Brace Centre for Water Resources Management, McGill University
[2]Dean, Faculty of Agricultural and Environmental Sciences
McGill University, Montreal, Canada
and
[3]Dean of Graduate Studies and Professor
University of Guelph, Guelph, Ontario, Canada

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1. Introduction

Water is essential to many activities in the home including washing, cleaning, cooking, drinking and recreation. Industrial processes rely on water for cooling, chemical solvents, cleaning, just to name a few. Forty percent of the worlds' food is produced from irrigated lands [1]. However, much of this would not be possible without energy; which is a critical input to pump, move, and treat the water required by municipalities, industries and agriculture. Ironically, however, much of this energy would not be available without water to turn turbines, wash inputs, or cool equipment. Thus in many cases use of one resource is inextricably linked to use of the other – hence, the energy-water nexus.

Decades of overuse of energy and water resources, and continued wasteful habits, have led to cumulative environmental degradation that cannot be easily reversed; polluted surface waters, depleted aquifers, loss of biological diversity, and climate change being just a few of the problems to which we have contributed. Through all of this, we have forgotten to take into account that our resources are not limitless.

In many areas, groundwater levels in aquifers that contain fossil water, and do not recharge quickly, have fallen dramatically due to excess withdrawals. Fossil fuel and coal reserves are being relentless mined and in many cases activities must now turn to reserves that previously were deemed either too low in quality or uneconomic to extract. These resources are not renewable. And yet we still over-consume.

Driven by laws of supply and demand, resources continue to be over-extracted and prices continue to rise (figure 1 below). Considering that fossil fuels and coal make up 54% of the secondary energy supply[1] the United States [2, 3], a rise in the cost of these will impact the cost of products and services which rely on energy from fossil fuels, including the cost of water. In fact, since 2002 real end-use prices have been increasing mainly due to increases in crude oil prices [3]. Canada is fortunate that the majority of its electricity is produced via hydroelectric generation, however about 20% does come from fossil fuels [4] and thus susceptible to the same price impact.

Climate change throws a wrench into the mix. It is anticipated that as climate changes, water resources will be altered; potentially reducing their quality, quantity, and accessibility [5]. 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. Thus the imperative to ratchet-down the energy-water nexus and make it more efficient is even more pressing.

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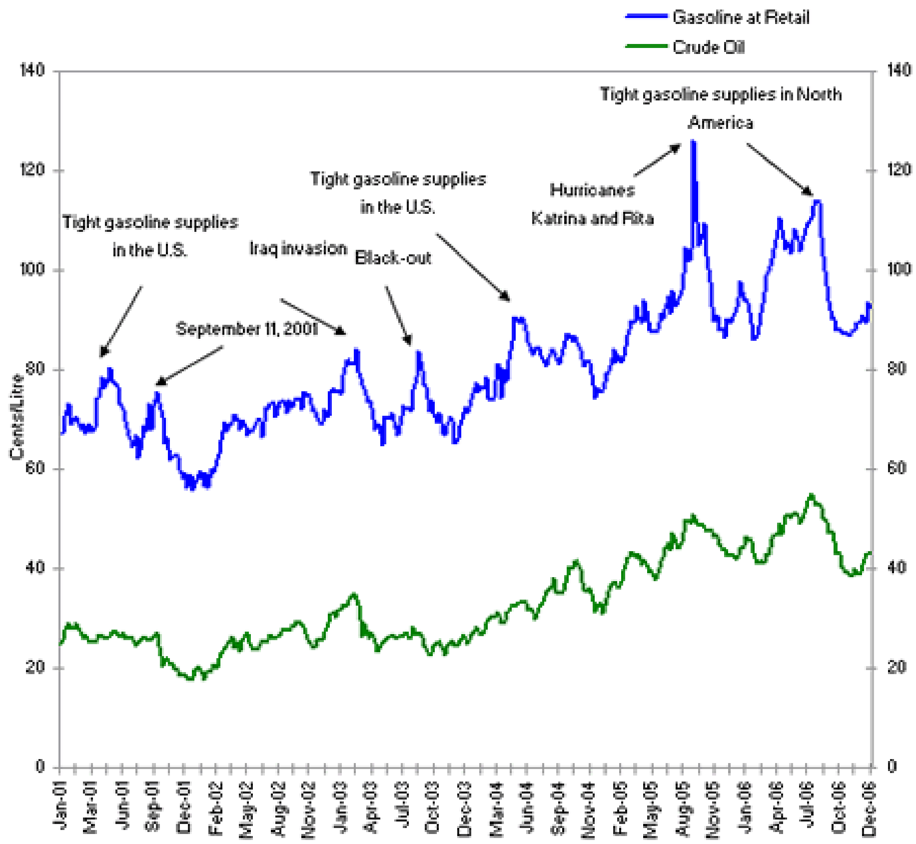
[1] Secondary energy supply is used in this paper as it is the energy used by final consumers for residential, commercial/institutional, industrial, transportation and agricultural purposes – which is most applicable to our discussion.

Figure 1: Crude Oil and Gasoline Prices: A Timeline
Source: Natural Resources Canada[6]



The purpose of this paper is to outline current use of energy for water consumption in Canada and the United States, some of the challenges facing this energy-water nexus, as well as outline some ways we can alter our course to avoid disaster.

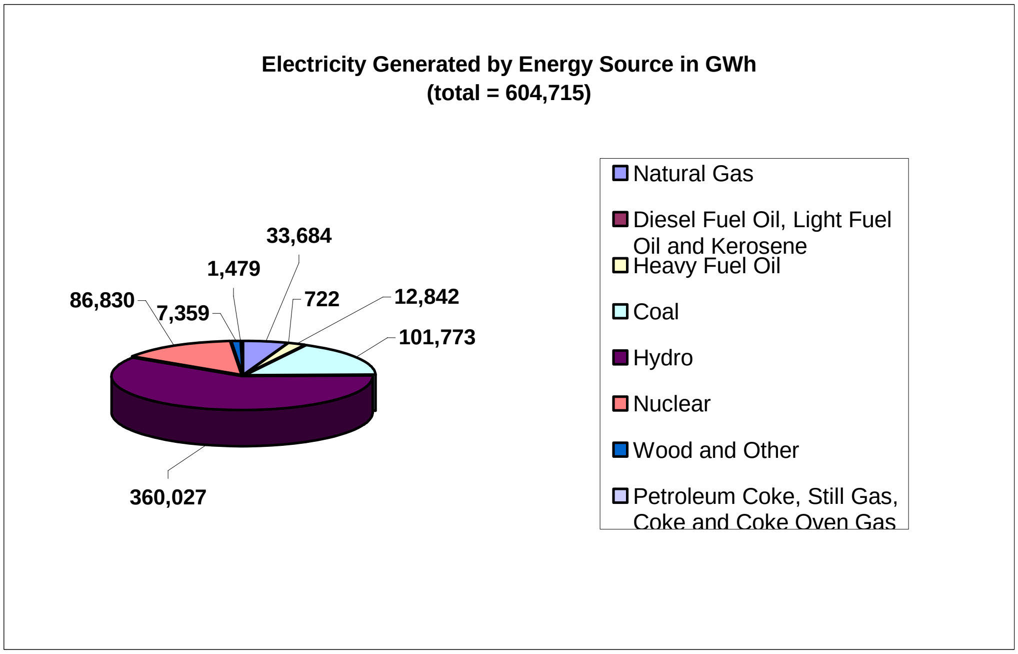
2. Background on Energy and Water Use

Water and energy use are mutually reinforcing [7]. Thus when discussing the energy used in municipal, industrial, and agricultural water sectors, one must closely examine water use itself. Often energy use is driven by water demand. If water consumption could be reduced, we would see a concomitant decrease in energy demand.

Statistics on Electricity Generation

While the focus of this paper is on the energy required to supply water, is it interesting to note that one of the largest uses of water is electricity production. Water is used in thermal, nuclear, and hydroelectric power generation. To produce one kilowatt-hour of electricity requires 140 litres of water for fossil fuels and 205 litres for nuclear power plants [8]. Every year almost two-thirds of generated power in Canada is produced via hydroelectric generation [9] (figure 2). This electricity is then used to treat, pump, move, and heat water (among other things). Thus, the nexus comes full circle; water is used to produce the electricity which is used to consume water.

Figure 2: Electricity Generated by Energy Source
Source: Natural Resources Canada [4]



Statistics on Water Use

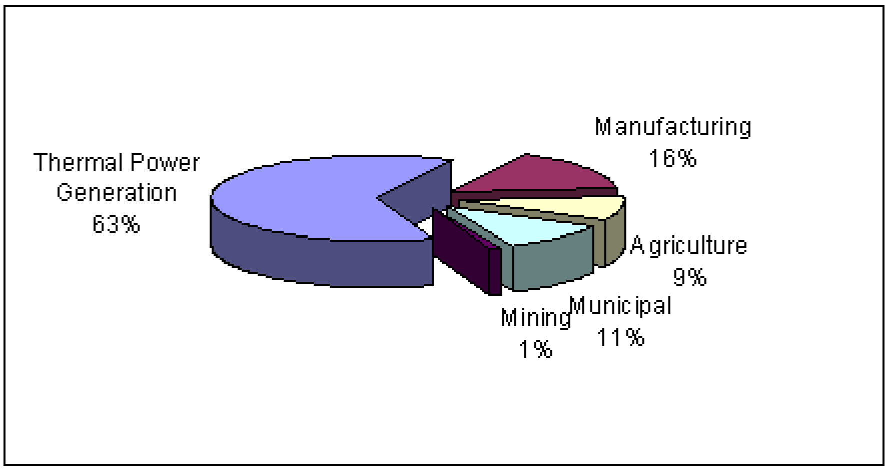
We consume more water than most other countries: Americans ranking first and Canadians ranking fourth highest consumers of water out of 29 countries in the Organisation for Economic Cooperation and Development (OECD) [10]. Canada's annual per capita use sits around 1430 m^3 while the United States' is approximately 1730 m^3. Canada's per capita water consumption is 65 % higher than the OECD average and overall use has increased by 25.7 % since 1980 [10]. While some municipalities have been successful in curtailing water use, overall residential water use increased by 21% during the 1990s [11]. In part, this is because of demographics: our growing population places steadily increasing demands on water supplies, even if per-capita consumption is stable or decreases.

Overall water use has declined in the United States [12], although per capita use remains the highest in the world. While abstraction rates in the United States and Canada are only a small portion of our renewable freshwater resources about 20 % and 2.5 % respectively, it is important to note that water distribution is not even across the country and some areas may be mining groundwater, while others have an overabundance [3]. Even though Canada is commonly seen as a water abundant country, 60 % of its renewable freshwater resources flow north, away from the major population centres [13]; limiting the amount of water that is easily accessible.

Based on the example set by European countries, it is possible to have a high standard of living and consume less water. The average Dane uses eight times less water than a Canadian [10]. And yet we chronically over-use water. There are several reasons for this; having some of the lowest water costs in the industrialized world has certainly not encouraged us to curtail our water use [11]. Indeed, many municipalities do not require water metering, or even charge less per cubic meter as consumption increases (declining block pricing), so consumers are not even aware of the costs of their consumption. In part, this may be because Canada has a long held the belief that it is a water abundant nation, and therefore does not need to worry about consumption rates[13]. This is reflected in Canadian policy and consequently supply-side driven management of water resources[11, 13]. However, we are finally beginning to realize that we can no longer afford such careless attitudes towards our resource use.

Water use can be broken down into three main sectors: municipal, industrial[2], and agricultural. In Canada, the usage is 11%, 80%, and 9%, respectively (figures 3) [14]. Generally, irrigation, industry, and household water use are pushing up demand worldwide [3].

Figure 3: Principal Water Uses in Canada
Source: Natural Resources Canada [14]



Unfortunately fiscal policies are leading to a cut back in data collection, limiting available information. In the United States "data on commercial water use, wastewater treatment, reservoir evaporation, and hydroelectric power are no longer being collected nor is information on consumptive use, reclaimed wastewater, return flows, or deliveries from public suppliers" (*p.292)* [15]. Consequently long-term trends will not be clearly delineated and decisions on water use will made with only limited information [15].

Statistics on Energy Use

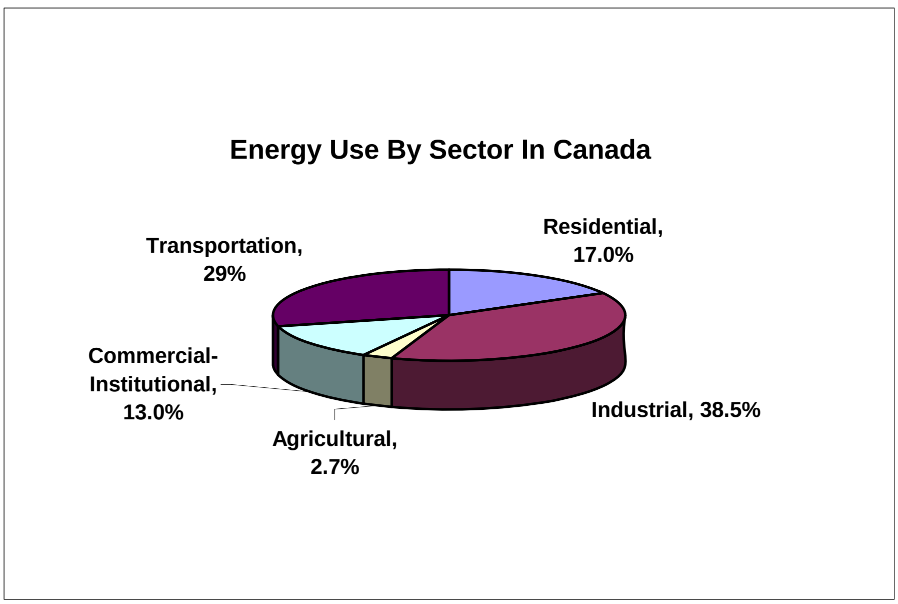
On the energy use side, Canada and the United States are among the top four highest consumers of energy in the 29 OECD countries [16]. While Canada has become 21% more energy efficient since 1980, population and economic growth have led to an increase in overall energy consumption of 20% – two percent more than the OECD average [16].

[2] In this case industrial includes power generation, manufacturing, and mining activities

In Canada, energy use can be broken down as follows: 20% residential; 38.5% industrial; 2.7% agricultural; 13% commercial-institutional[3]; and 29% transportation (figure 4 below) [17]. Among these, 22% of residential energy goes towards water heating, while this accounts for 7% of commercial-institutional energy use [17]. Energy needed to run household, water-consuming appliances (e.g. dishwasher and clothes washer) is only a small proportion of total household energy requirements [4]. Unfortunately due to the extensive diversity in industrial activities, it is difficult to identify energy use that goes directly into supplying water, however it can be noted that some industries, such as pulp and paper, are far more water intensive than others. Consequently, such industries are sited along major water sources so as to ensure adequate supply at as low cost as possible. In the agricultural sector, water-use related energy consumption is concentrated in irrigation activities which must pump and spray water across large areas.

Up until recently, we experienced overall declining energy costs. This can be seen by comparing the cost of energy over the years in 1990 constant dollars per kilowatt-hour: $2.50 in 1902; $1.12 in 1912; $0.15 in 1950; and $0.06 in 1990 [18]. Considering that the drop in prices were accompanied by rising incomes and energy efficiency, energy costs have been very inexpensive [18]. As such, North Americans[4] have been able to consume without being hindered by costs, ultimately developing wasteful habits. In recent years, however, these trends have been changing. Increasing oil prices and dwindling reserves have led consumers to be more mindful of their energy use and have brought energy issues and future access to resources back to the fore.

Figure 4: Energy Use by Sector in Canada
Source: Cuddihy *et.al.* [17]



California provides a clear example of the energy-water nexus. The state has long pumped municipal water from far distances. As the state's population and consequently water demand

[3] This includes municipal uses such as commercial, institutional and public administration categories, but excludes transportation-related energy.
[4] For the purpose of this report, we exclude Mexico in our discussion of North America.

expands, energy costs associated with providing water are on the rise [19]. Water is heavy and moving it is energy intensive. Added to this is the fact that drinking water must be treated; another energy intensive process. As a result, supplying water is the single most significant use of electricity in California, making up seven percent of the state's total usage [19]. Clearly, if water use could be curbed, this would lead to a concomitant decrease in energy use.

3. Challenges Facing Water and Energy Use

Outcomes of Wasteful Habits

North America has fortunately been endowed with many natural resources and North Americans have made use, often over-use, of easily accessible water and energy resources without any major barriers. However, we are now experiencing the impacts of wasteful consumption.

One in four communities in Canada experienced water shortages in 2002 [11]. There are major concerns about an impending crisis in the regions served by the Ogallala aquifer which comprise eight states [20]. The water shortages could worsen if the anticipated impacts of climate change on water availability occur. Concerns about energy supplies are emphasized almost daily by ever increasing prices of fossil fuels. Unfortunately, due to the interconnectedness of water and energy use, inefficiencies in the management of either resource exacerbates shortages, wastes, and unsustainable use in the other [7]. Unless we re-evaluate and change our water and energy use habits, it will become more and more difficult to access suitable water supplies at affordable prices.

Economic and Environmental Challenges

The challenges that currently face water and energy use are economic and environmental. Since fossil fuels make up about 54% of the secondary energy supply in the United States [3], increases in the cost of these will impact the cost of products and services which rely on energy from fossil fuel, including the cost of water. Canada's energy production, which is primarily hydro-electric will be impacted particularly as precipitation, and consequently river flows, decrease due to climate change, ultimately increasing energy costs. While each sector uses water in different ways, each one will be affected by energy uncertainties.

Unfortunately, most environmental challenges do not impact the average citizen directly, and are consequently overlooked. Yet they may be the biggest threat we face for the future. Water withdrawals alter an ecosystem's ability to function. As water is "over-withdrawn", valuable habitats are lost. These may take the form of: loss of wetlands and riparian buffer zones that are important in filtering water and mitigating floods; loss of habitat for birds; loss of spawning grounds for fish weakening fisheries, among other effects. In turn these have carry-on effects into other ecosystems – all of which will be further affected by climate change.

Again here, California provides an illustration of the challenges facing water and energy use. Current decreases in rainfall in California are taxing the state's ability to maintain a delivery system that provides water and energy for municipal, industrial, and agricultural sectors at prices acceptable to the public. At the same time, California needs to ensure there is enough water left in the environment to maintain healthy ecosystems, as well as minimise emissions to reduce impacts on air quality and global climate change [19].

4. Tackling the Challenges

There is need to adopt less wasteful practices that will decrease our impact on natural resources, particularly water and fossil fuels and coal. To bring about change, prices for water and energy need to reflect the true costs, internalizing current external costs [7]. Additionally, pricing needs to consider upstream and downstream effects in both water and energy resource chains [19].

More generally, decision makers need to review current policies that may encourage wasteful energy and water use [7]. This must consider the fact that actions to improve resource use in one area may have a negative impact in other areas e.g. building a power plant to increase energy supply may increase demand for limited water resources [7, 19, 21]. While ensuring adequate supply has been the goal of utilities for many decades, this approach must now become demand-side oriented, managing consumption and promoting conservation of water and energy [22]. However, real success and change in resource management will only occur with the participation of all stakeholders; individuals, farmers, companies, and policy makers [7, 19, 21].

That being said, it is important to remember that encouraging change in individuals may require overcoming individual decision making barriers such as: risk aversion or sensitivity to change; personal discount rates; personal preferences; lack of awareness or inclination to seek out information; energy costs are only a small portion of total expenditures nowadays; the need for positive feedback for altered behaviour [15]. Change takes time.

While some changes require government to act, some changes do not. Efficiency technologies that reduce water (and consequently energy) use, are accessible to individuals, companies, and more broadly, industrial and agricultural sectors.

5. Reducing Water and Energy Use

If the demand for water can be reduced, then energy used to pump and treat water will decrease. Additionally, if we can limit the amount of waste water that flows to treatment plants, this will further reduce the energy requirements.

For sanitary sewers and associated treatment plant, such reductions will normally be achieved by demand-side reductions, especially residential and industrial water conservation. For storm and to some extent combined sewers, energy use reductions can be achieved by technologies that detain flows and encourage infiltration to groundwaters, and which provide some degree of treatment. Many technologies are available for this purpose, including infiltration ponds, trenches, constructed wetlands; and similar structures; rain gardens (lot level infiltration structures); rain barrels; green roofs; narrower roads bordered by permeable surfaces such as grass or ornamental planting; and so on. Further reductions could be achieved by implementing water reuse and recycling strategies.

Some caveats apply, however. Management practices that encourage infiltration can facilitate the movement of surface pollutants into groundwater. Sediment accumulating in stormwater management structures can contain high levels of metals and organic pollutants such as pesticides, and must therefore be managed carefully. There is also evidence that the close juxtaposition of stormwater management structures, especially in headwater and recharge areas, can have significant negative consequences for downstream base flows.

Thus, by targeting water use, energy use can also be reduced. As such, some of the applicable technologies have already been discussed in the related document: Coping with Climate Change: Short-term Efficiency Technologies. Please see in particular: constructed wetlands; green-roofs; and water reuse and recycling.

The Municipal Sector

The largest uses of municipal water are residential (52%) and leakages (13%). Thus, tackling these uses would target 65% of water use, and the incumbent energy use. Many low-cost, easily-implemented technologies have been developed in the past two decades [23]. Old model toilets used 6 gallons per flush, while new models use only 1.6 gallons, and composting toilets do not require flushing at all [12]. Other low-cost technologies include low-flow shower heads and faucet aerators. Additionally, water efficient appliances also help to reduce water use and ultimately energy use.

One study in California by the Pacific Institute shows that "total commercial, industrial, residential, and institutional water use could be cut by at least 30% using available "off-the-shelf" technologies" [12], ultimately leading to reduced energy use for supplying and treating water. In some cases, this reduces the strain on urban water infrastructure and avoids costly upgrades and expansions as population grows [24]. The city of Cochrane, Alberta, reduced water consumption by 15% by giving away toilet dams[5] flow showerheads, and faucet aerators. This reduction enabled the city to defer the construction of a multimillion-dollar pipeline [24].

Energy used for water supply and waste water treatment is fairly low compared to the rest of a city's activities [17]. In Toronto, Canada (a city of about 4.6 million people [25]), this accounts for about 2.4% of the city's electrical consumption [17]. While this seems quite low, opportunities still exist for energy reduction by addressing: pump inefficiencies; losses due to leakage; pressure losses; the use of separate waste water streams [17]. As noted above, many municipalities lack adequate metering or full-cost pricing for water and sewerage services. Indeed, some municipalities have declining-block water pricing, in which customers pay less per unit as they use more water. Natural Resources Canada reports that when priced by volume, the average daily consumption per person is about 150 litres less than if there is a flat rate and water use is unmetered [17]. Considering that Switzerland has some of the highest municipal water prices in the OECD and is among the top ten lowest per capita consumers of water [17], it is realistic to believe that the increase in water metering would encourage less wasteful water use. Implementing ways to reduce the amount of water entering the sewer system and needing treatment will lower energy costs and lessen the strain on aging urban water infrastructure.

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[5] A toilet dam is a partition within the toilet tank, so that only part of the tank fills; reducing the amount of water used per flush.

In addition to reducing the demand for treated water, differentiated waste-water streams separating grey water from sewerage may further cut energy in supplying municipal water [17]. It is also interesting to note that the potential energy in raw waste water exceeds the energy requirements of the treatment facility by a factor of 9.3 [26]. Further development of energy recovery technology could transform municipal waste-water treatment plants into net producers of renewable energy [26].

The Industrial Sector

Of the three sectors discussed in this paper, industry is probably the least subsidized sector, and as such, has the greatest incentive to use resources efficiently. This will become even more important as fuel prices, and consequently energy costs, continue to rise and attempts are made to lower energy costs by reducing water use. In newsprint and kraft pulp mills, reductions in energy demand can be made by recovering heat from one process and redirecting it to another, such as heating water [26].

Buying, using, treating, and discharging water can use up to 40% of total production overhead [26]. Furthermore, water shortages and other environmental constraints affect the ability of a plant to expand and operate profitably [27]. The main drivers for improved water management have been identified as: cost reduction; wastewater reductions and standards compliance; environmental policy/regulations; changes in water quality and availability [27]. Consequently, reducing water consumption and optimizing resource conservation, without affecting plant performance, can be considered a realistic and cost effective strategy [28].

As a result, the industrial sector is the one sector that is making tangible progress towards more efficient use of water and water recycling, ultimately reducing its water intake [29, 30], and in turn reducing energy use. Between 1981 and 1996 industrial water intake declined from 11,042 million cubic metres (MCM) to 7,508 MCM [1]. It is important to note, however, that water use and opportunities for water efficiency (and thus energy efficiency) vary hugely from sector to sector. For example, pulp and paper operations and food processing facilities use significant quantities of water, while organic chemical manufacturing and paint and solvent operations may use considerably less.

To encourage new and continued efficiency improvements appropriate water pricing will be key.

The Agricultural Sector

Of the global water available, 70% is used in agriculture [31]. Generally, agricultural use of water is perceived as very inefficient and is often under scrutiny as it competes with other sectors [3]. Irrigated land makes up 2% of Canada's total cultivated land and 13% of the USA's [32]. Over 70% of irrigation in Canada occurs in the Prairie provinces [33] where precipitation is expected to fall with impending climate change [31]. As water resources dwindle and energy costs rise, farmers will feel the pressure to adopt more efficient water use practices [34]. In some cases, the implementation of new practices to limit water use may not be driven by concern over water supplies so much as the desire to reduce the energy costs associated with irrigation [35].

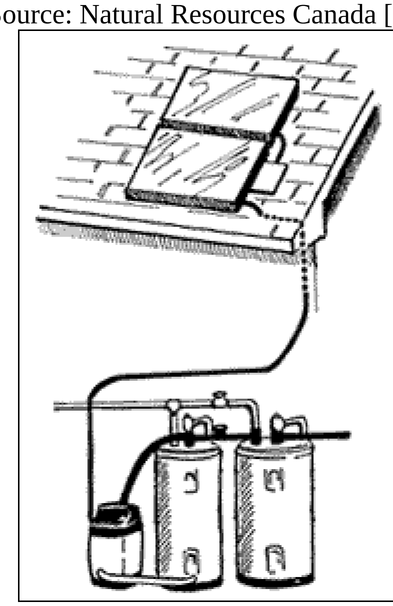
By fine-tuning irrigation, farmers can improve crop water-use efficiency and reduce water use [36]. This may include: adding drop tubes to central pivot irrigation mechanism; improving timing of irrigation; changing to low pressure sprinkler systems; implementing low-energy precision application (LEPA) systems that discharge water just above the soil surface and reduce water losses from evaporation; drip irrigation, among others. Reductions in irrigation translate directly into energy savings since most irrigation systems require energy to pump the water.

A 2005 OECD workshop on water and agriculture sustainability concluded that, "agricultural production support and subsidies for variable inputs, especially for water and energy, continue to misalign farmer incentives and aggravate overuse and pollution of water across many OECD countries" [35]. It is important to bear in mind factors such as these that influence farmers' decision-making. Consequently, appropriate policies and prices are necessary to encourage farmers to implement more water and energy saving technologies [36] – as is the case with the other sectors discussed above.

Other Energy Sources

In addition to adopting efficiency technologies that reduce water consumption, and ultimately energy use, it is important to consider other energy sources. Drawing on alternative sources of energy to move, treat, and pump water would reduce greenhouse gas emissions and help mitigate the extent and severity of climate change. In some instances this may consist of reverting to technologies such as wind and solar energy to pump water, particularly for livestock watering on farms [35]. In other instances this may entail installing a solar collector to collect solar radiation to heat household water tanks (figure 6 below)[35].

Figure 6: Solar Collector on Roof to Heat Water
Source: Natural Resources Canada [37]



An interesting innovation to reduce energy costs for cooling in Toronto's downtown office buildings has highlighted another aspect of interconnectedness of water and energy use. Deep lake water cooling is a system that draws water from 5 km out into Lake Ontario from a depth of 83 metres where waters are only four degrees Celsius [37]. The cold energy from the lake is used to cool water in a closed chilled water supply loop. This chilled water acts an all alternative to conventional air-conditions in 140 buildings in Toronto's downtown core [37]. This saves reduces energy consumption by 90% and has additional benefits of reducing emissions of ozone-depleting substances and greenhouse gases.

While alternative energy sources may not be applicable in all sectors, there are clearly possibilities for their implementation in some areas.

6. Conclusions

Our use of water, and consequently energy, makes our lives more comfortable in the short-term, but is causing a great deal of harm in the long-term. Not only are we degrading the quality of our water resources and drawing-down aquifers, we are also destroying valuable habits. Furthermore, due to our reliance on electricity to treat, move, pump, and heat the water we use, we are mining non-renewable fossil fuels and contributing to climate change via greenhouse gas emissions. The energy-water nexus perpetuates wasteful use of natural resources. We are creating the challenges that are limiting our access to water and energy resources. Change is needed.

While much of this change can take the form of water conservation in the home or more efficient practices in the agricultural and industrial sector, new policies from governments are needed to incite the adoption of these options. Technologies and management practices to reduce water and energy use exist in all sectors. Unless we start implementing these technologies through a more sustainable demand-side approach to resource management and use, we will continue to degrade vital resources and create even larger problems in the long-run.

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