# Coping with Climate Change: Short-term Efficiency Technologies

**By**

**Gweneth M. Thirlwell[1], Chandra A. Madramootoo[2],**
**Isobel W. Heathcote[3] and Edward R. Osann[4]**

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

**Canada – US Water Conference**
**Washington D.C.**
**October 02, 2007**

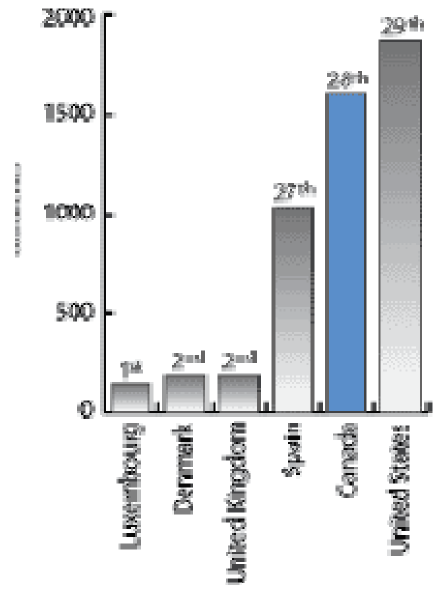
**Sponsored by**
**Policy Research Initiative of Canada and the Woodrow Wilson Institute**

# Table of Contents

## 1. Introduction

Americans and Canadians are among the highest water consumers in the world, ranking first and fourth highest consumers of water of 29 countries in the Organisation for Economic Cooperation and Development (OECD) (Figure 1). The long-held conceptions of water abundance in Canada and the US, supported by water policies and pricings that encourage wasteful, rather than wise use of this vital resource, have led to such high consumption rates. However, “the emphasis on engineering solutions, water as a free economic good, and standard bureaucratic allocation and management regimes – hallmarks of the supply era – are no longer consistent with the water challenges of the 21st century” (p.80) [1].

Figure 1: Freshwater Abstractions per capita in cubic meters (Source: OECD [2])




In addition to the anticipated pressures on water resources from population growth, urbanization, and increased pollution, climate change could possibly amplify these pressures several-fold. While natural variability in climate does occur, the Fourth Assessment Report from the Intergovernmental Panel on Climate Change asserts that there is “very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming” (p.5) [3]. It is impossible to outline the exact shifts that will occur as a result of climate change. However, the general consensus suggests that changes in temperature will alter water quantity and quality around the world [4, 5], and in many cases for worse rather than for better.

As such, it becomes imperative that Americans and Canadians prepare for potential changes in water availability. While climate change cannot be halted, its impacts can be mitigated if steps are taken to reduce reliance on natural resources. This document outlines some technologies that can be adopted to ensure more efficient water use, ultimately reducing human pressure on national water resources.

## 2. Climate Change in Canada and the United States

### *Canada: Changes and Impacts*

The IPCC Fourth Assessment Report [6] outlines the following potential climate changes for Canada:

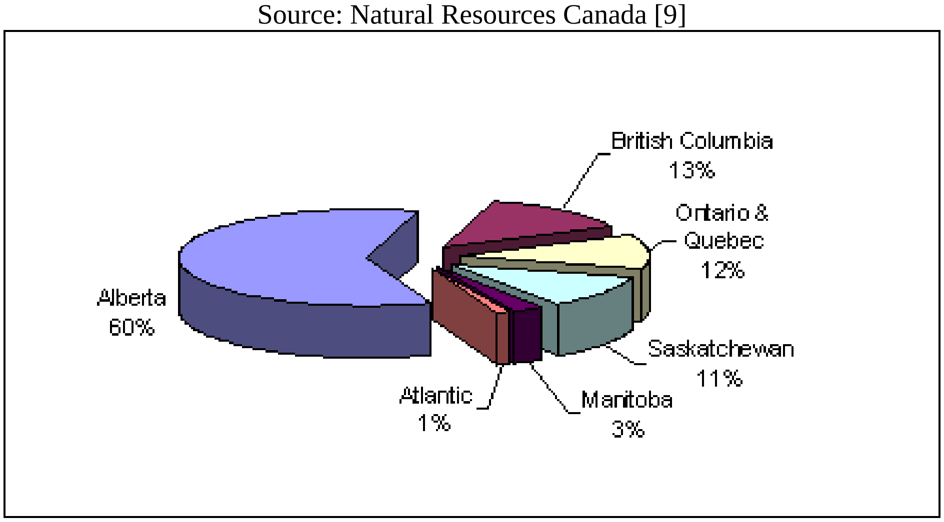
- Warming that is likely to exceed global mean warming
- Warming is likely to be largest in winter
- Annual mean precipitation is very likely to increase but may come in the form of increased extreme events such as heavy rainstorms
- Precipitation in the Prairies and Southern Ontario is likely to increase in winter and spring but decrease in summer
- Length and depth of the snow season is very likely to decrease except in the northern-most regions where snow depth may increase
- Warming is likely to contribute to earlier snowmelts
- Decrease in sea-ice extent and thickness is very likely
- Coastal regions will be exposed to sea level rise

These anticipated changes are expected to directly impact Canada's water resources in several ways, affecting populations across the country.

Increasing temperatures will cause increased evaporation. This will lead to decreased surface water levels, increasing the concentration of contaminants in freshwater [7, 8]. This will impact 70% of Canadians who draw their drinking water from surface sources; intake pipes may need to be moved as water levels fall and water treatment may need to be altered, or, at worst, new sources may need to be sought.

Decreased soil moisture is also expected from increased evaporation, leading to expanded irrigation of crops as well as reduced groundwater recharge. This will be of particular concern in the Prairie provinces, which has over 70% of Canada's irrigated farmland (Figure 2) [9] and where precipitation is expected to decrease.

Figure 2: Distribution of Irrigated land in Canada
Source: Natural Resources Canada [9]



That being said, all farmers across Canada may potentially experience a mis-match of water supply and demand, with precipitation expected to increase in the spring (affecting planting activities) but dwindle in the summer when plants require the most water [8]. This will be exacerbated by earlier and smaller snowmelts that will advance spring floods decreasing the water flows later in the year. Additionally, it is feared that as glaciers recede, traditional water sources from seasonal glacier melts will no longer be available [7]. Earlier spring melts and run-offs raise concerns of potential ice-jams on rivers where ice has not yet melted and concomitant flooding [10]. Risk of flooding, and the attendant property damages [11], may also come from increases in extreme events, such as heavy rainstorms or storm surges along the Atlantic coast [7].

More frequent extreme events, such as heavy rainstorms, are also expected to negatively affect quality of surface and ground waters [7, 8]. High volumes of rain will flow quickly across the ground, eroding land along the way and transporting contaminants from roads and agricultural fields to surface and ground waters. By-pass events at sewage treatment plants will increase in frequency, as treatment capacity is more often exceeded. Furthermore, this will negatively affect aquifer recharge rates since runoff will flow too quickly to be fully absorbed into the ground. Together these may translate into: increased treatment costs for drinking water supplies; increased energy costs to pump water from greater depth; and potentially the need to seek out new water sources.

In coastal regions, aquifers are expected to experience increased salt intrusion as sea levels rise [7]. These regions are also at risk from increased erosion due to a decrease in sea ice that usually protects shorelines from winter storms [12]. Northern regions will also be faced with permafrost melts, reducing land stability and increasing erosion[7, 12]. This could disrupt subsurface pipes carrying drinking and waste water.

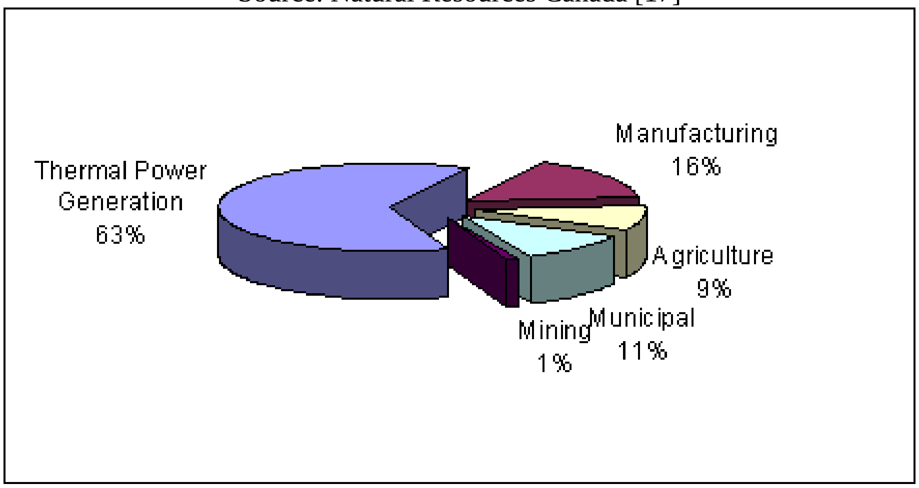
While each of these anticipated impacts will be challenging in their own right, the effects may be compounded by conflicts arising between competing users of limited water supplies. With the artificially low cost of water in Canada, all sectors viz. municipal, agricultural, and industrial have seemingly unlimited access to water and little incentive to curb use [1, 13]. As noted previously, although we cannot halt climate change, we can lessen its impacts through appropriate coping mechanisms. As climate changes, altering quality and quantity of water in Canada, water use across all sectors must become more efficient so as to avoid over-stressing vulnerable, vital water resources.

## 3. Efficiency Technologies

Historically, large infrastructure projects have been implemented to cope with flooding and to provide water during periods of shortage. However, large water diversions, particularly inter-basin transfers, are becoming less economically and environmentally attractive, particularly as alternative water sources are becoming increasingly technologically and economically feasible [14]. Moreover, a new water management trend towards sustainable management and resource use is driving new technology and innovation in water use efficiency [15].

Terms such as conservation, efficiency, and productivity are often used interchangeably to mean "doing more with less" [16]. The goal here is to outline technologies that will help sectors cope with changes in water supply, be they increases or decreases. This discussion will focus on the municipal, industrial, and agricultural sectors since these make-up the principal water uses in Canada (excluding thermal power generation): about 11%, 17%, and 9%, respectively (Figure 3) [17].

Figure 3: Principal Water Uses in Canada
Source: Natural Resources Canada [17]




***Water Scarcity – Decreased precipitation and droughts***

Despite the fact that Canada and the United States each hold about 6.5% of the world's renewable freshwater resources, this water is not evenly distributed across the countries [18]. According to Environment Canada, 1 in 4 cities have reported water shortages in recent years. As one author points out, "Pollution, profligate habits, poor management, increasing urbanization, and the looming spectre of climate change conspire to create scarcity…a water crisis in Canada will be of our own making" *p.79* [1]. Thus the imperative to reconsider water use and their water resource management plans is clear.

<u>Technologies Applicable in All Sectors</u>

*Water Reuse and Recycling*

Water reuse entails using treated municipal effluent as a source of non-potable water supply, consequently reducing the amount of waste water going into surface waters [19]. Similarly, water recycling or recirculation, used mainly in industrial systems, recovers and treats effluent which is then returned back to the industrial process [19].

Common applications for reclaimed water are in agriculture and landscape irrigation (i.e. golf courses) [19]. Other uses include: on-site residential grey water reuse, industrial reuse, rainwater and storm water collection and reuse, surface water augmentation, groundwater recharge, and potable reuse [19]. Water reuse in industrial processes is particularly attractive as it reduces energy costs, recaptures raw materials, and reduces discharges [13]. Additionally, water reclamation has many non-economic benefits that are often overlooked, including: reduction in nutrient discharge into surface waters, improved environmental quality, lower drinking water costs, and conservation of recreational land, among others [19]. Rainwater collection (or harvesting) has the added benefit of reducing erosion during heavy rainfall events and storing water for use during drier periods.

While not widely used in Canada, many regions are adopting water reuse and recycling as a way to make up for insufficient water supplies [19]. Unfortunately, some measures of grey water re-use are currently prohibited or discouraged by local building codes, such that water re-use may ultimately depend on policy changes. Furthermore, a lack of regulations and guidelines regarding water reuse/recycling in Canada has been cited as a hindrance to implementing projects [19]. This raises the important point that as water reclamation expands, quality standards must consider the various contaminants found in wastewater and the varying applications of reused water.

*Desalination*

Desalination transforms sea water into drinking water, and the reverse osmosis technology of desalination is also used to treat contaminated waste water [20]. Desalination capacity in Canada and the United States is approximately 2.85 million cubic metres per day (about 36,000 $m^3$/d and 2,814,000 $m^3$/d respectively) [21].

However, desalination is an energy-intensive process which has its own environmental drawbacks. It can be appropriate when other water sources are not physically close. Such is the case between Arizona and California. Arizona would like to withdraw more water for irrigation from the nearby Colorado River, but is currently limited by Californian withdrawals. As a result, Arizona has offered to build a desalination plant in California in exchange for a portion of California's water withdrawal quota from the river.

## Municipal Sector

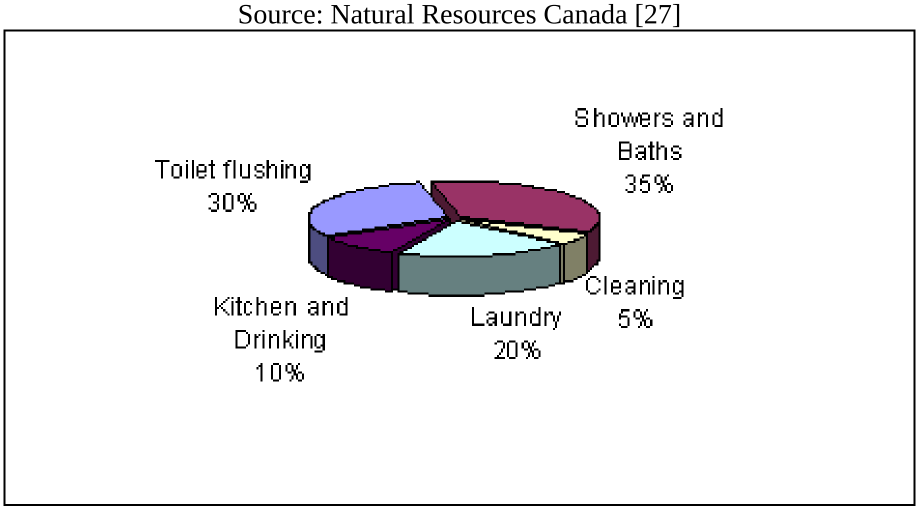
*Low-cost Technologies*

On average, each Canadian uses approximately 1,600 cubic metres of water per year [22]. This is about 2.5 times higher than in many European cities with similar standards of living; while total water use is four times higher in Canada [23]. Figure 4 shows the break-down of residential water use in Canada. Fortunately, many low-cost, easily-implemented technologies have been developed in the past two decades [16]. 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 [16]. Other low-cost technologies include water efficient shower heads and faucet aerators. Additionally, water efficient appliances also help to reduce water use. Both houses of the US Congress have recently passed legislation establishing new water efficiency requirements for residential dishwashers and clothes washers effective 2010 and 2011, respectively, and setting the stage for further improvements by 2015-2018[1].

In the United States, a staggering area – roughly 50 million acres – is devoted to turf grass and related ornamental landscaping [24]. For many applications and in many regions, quality turf requires irrigation. Improved technology can contribute significant water savings by matching water applications to plant needs and weather conditions.

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" [25]. Certainly, water-poor municipalities like Kitchener-Waterloo, Ontario, have demonstrated that reductions on the order of 25% are easily achievable [26]. Ultimately these reduce the strain on urban water infrastructure and avoid or defer costly upgrades and expansions as population grows [15].

Figure 4: Residential Water Use in Canada
Source: Natural Resources Canada [27]




*Leak Detection*

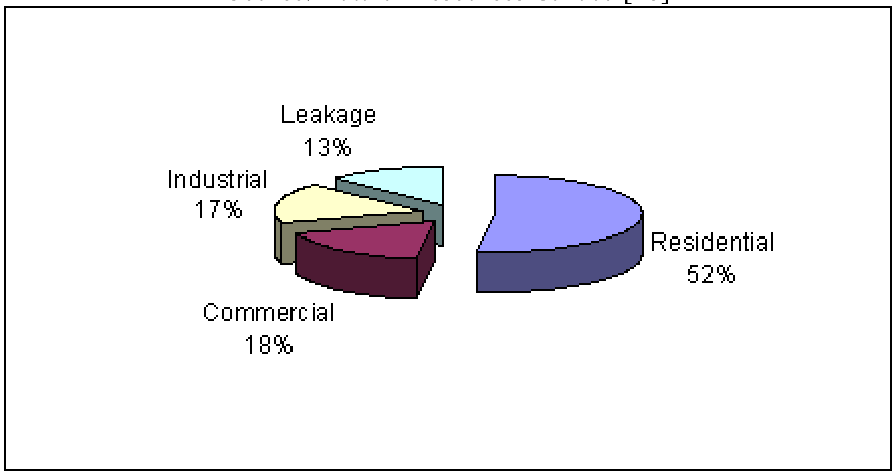
While leakage in municipal water infrastructure in Canada and the US is much lower than in many developing countries, it remains a waste. There is also a lost energy cost to provide non-consumptive water. In Canada, leakage accounts for 13% of municipal use (Figure 5) [28]. A 1996 survey of US water utilities found 16% of finished water to be unaccounted for [29]. Aggressive leak detection and repairs improves water efficiency [16]. To assist utilities in identifying cost-effective opportunities to reduce water losses, the International Water Association and the American Water Works Association are advancing new methods for

---

[1] See section 230 of H.R. 6 as approved by the Senate and section 9001 of H.R. 3221 as approved by the House of Representatives at <www.thomas.loc.gov>. Final reconciliation and enactment of these bills is expected before the end of this year.

accounting for water losses and planning intervention strategies [30]. Traditional acoustic leak detection equipment is now being supplemented with more sophisticated leak noise correlators, and pressure reducing valves are being enlisted to reduce losses from the myriad small leaks that will always escape individual detection [29, 31].

Figure 5: Municipal Water Use by Sector
Source: Natural Resources Canada [28]




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 water efficiently. 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 [32]. Buying, using, treating, and discharging water can use up to 40% of total production overhead [32]. Furthermore, water shortages and other environmental constraints affect the ability of a plant to expand and operate profitably [32]. Consequently, reducing water consumption and optimizing resource conservation, without affecting plant performance, is a realistic and cost effective strategy [32].

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 [18]. Between 1981 and 1996 industrial water intake declined from 11,042 million cubic metres (MCM) to 7,508 MCM [18]. However, appropriate pricing is still necessary to encourage efficient water use, since low water costs contribute to water overuse in any sector.

Agricultural Sector

Water management is an integral part of agricultural activities [18]. Water scarcity reduces crop yield and limits expansion of agricultural activities [33]. As temperatures increase, leading to increased evapotranspiration and longer growing seasons, so too will agricultural water requirements [34]. Thus, the agricultural sector is expected to be more strongly affected by climate change than the municipal or industrial ones.

Fortunately, impacts of climate change can be mitigated through appropriate crop and water management decisions [34]. Several water efficient technologies for agriculture in warm, dry areas already exist and, as climate changes, may be easily "imported" into previously cool, moist areas [35].

Nevertheless, it is important to bear in mind that farmers are often driven by production levels, costs, and government policies (i.e. subsidies), so appropriate policies and prices are necessary to encourage farmers to implement more water saving technologies [7, 35]. That being said, it is possible that the impact of climate change on agriculture in Canada may come from outside and will be dependent on how climate change affects the crop growing regions of other major food producing countries such as the US, Brazil, Argentina, China and India [35].

*Irrigation*

Seventy percent of global available water is used in agriculture and 40% of the world's food is produced in irrigated regions [33]. Unfortunately, in some regions, irrigation water is drawn from aquifers, depleting underground water sources and reducing their quality [33]. In other areas, water is drawn from surface flows, competing with municipal, industrial, and in-stream ecological requirements [36]. By fine-tuning irrigation, farmers can improve crop water-use efficiency and reduce water use [33]. 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 systems that discharge water just above the soil surface; introducing drip irrigation and subirrigation; improving irrigation scheduling, and; reducing water losses from evaporation, among others [16, 37].

As freshwater resources for irrigation become depleted, non-conventional water sources will be developed and implemented. These may include reuse of agricultural drainage water, use of industrial or municipal wastewater, or even using brackish water [38]. Experiments with green peppers (*Capsicum annuum*) show that brackish water can be used for irrigation without increasing the amount of water needed and that the incumbent saline accumulation is diluted through rain events or irrigation with good quality water [38].

*Water Table Management*

Water Table Management (WTM) is a technique that controls the level of the water table in a field to maximise crop production, in both wet and dry periods [39]. Initial experiments show that the water-use efficiency (WUE) of WTM is higher than that of sprinkler irrigation and similar to that of furrow irrigation combined with deficit sprinkler irrigation [39]. Water table management could become a valuable technique for crop production as climate change brings about warmer, drier conditions [39].

***Excess Water – Heavy precipitation events and floods***

Impacts from heavy precipitation events and floods are usually dealt with by the various levels of government (i.e. municipal, provincial, or federal), rather than individual sectors (perhaps with the exception of the hydro-electricity sector). In Canada, due to budget cuts and shifting priorities, responsibility for water management has been passed from one-level of government to the next, such that resource management regularly falls on the shoulders of municipalities [40, 41]. While in many cases this is the best level at which to address water issues, all too often municipalities are lacking to necessary resources to adequately carry-out the responsibilities related to water resource management [41]. Additionally, with high run-off volumes there are increased risks of combined sewer overflow and wastewater treatment plant bypass, discharging untreated wastewater into lakes and streams, further compromising water quality and possibly tainting both surface and ground water drinking water supplies [10].

These factors, in addition to warmer temperatures, contribute to the risk of increased incidences of waterborne diseases and degraded water quality in Canada. The most infamous and recent example of degraded water quality in Canada was in Walkerton, Ontario, in 2000, where an *E. coli* outbreak caused seven deaths and thousands of illnesses. Expert witnesses testified that the outbreak was partly due to unusually heavy rainfall event, which followed a period of drought [42]. Considering that 30% of Canadians rely on groundwater and 70% on surface water for their consumptive uses, it becomes clear that adequate management plans and use of all available technologies to reduce risks to water quality are vitally important.

<u>Urban Water Infrastructure</u>

One of the most dramatic consequences of urbanization is the conversion of pervious land surfaces (fields, forests, and so on) to impervious surfaces (roads, parking lots, and roofs). In urbanized areas, rain and melting snow are diverted over hard, warm surfaces into storm and combined sewer systems, and then conveyed into receiving waters, often with minimal or no treatment. This process changes natural hydrologic systems in urban and urbanizing areas, by changing the timing and volume of flows. It also creates new point sources of pollution at sewer outfall points, and increases the loadings of nonpoint source pollutants associated with automobile traffic and land use practices. These include road salt, particulates, and the various metals and organic pollutants associated with road washoff [10, 43].

Climate change will create several additional pressures on this system. First, the frequency of extreme storm events is expected to increase under climate change. This will place additional strain on municipal infrastructure, particularly facilities that are close to capacity. These events have the potential to exceed the capacity of, or even cause structural damage to, municipal infrastructure. There is therefore a need for real-time observation tools that allow the prediction of weather events.

A warmer climate will also result in greater evaporation from surface waters and thus reduced base flows, and therefore less assimilative capacity for discharges, as noted previously [7, 8]. There may therefore be a need for enhanced treatment capacity and/or augmented treatment of storm, combined, and sanitary sewage prior to release, particularly to control contaminants such as ammonia, chlorine (from disinfection), and biochemical oxygen demand. While increasing the capacity of water infrastructure is a costly endeavour, it can be made more manageable if done over time as routine upgrades are performed on the system [11]. Ideally, these measures would be implemented in conjunction with efforts to reduce runoff volumes, ultimately reducing the need for expansive infrastructure expansions.

The challenge of climate change is therefore to protect costly urban infrastructure against damage from extreme high flows, while maintaining baseflows and associated aquatic life. This is no simple challenge. Traditional "best" management practices such as wet ponds are effective at controlling high flows but, especially if clustered in a sensitive watershed area, may have a significant cumulative impact on base flows [44]. At the same time, so-called "low-impact development" practices aimed at protecting natural hydrologic functions in urban areas cannot accommodate extreme high flows. Such measures include green roofs, rain barrels, rain gardens, smaller road widths coupled with roadside plantings, and similar actions. Choosing an optimal combination of lot-level and regional infrastructure is therefore a complex task, with significant capital and operating cost implications for municipalities. While these structures are not expensive on an individual basis, the large number needed to serve a municipal area means that the cumulative costs can be very large, especially if structures are not adequately maintained.

Somewhat surprisingly, there is a dearth of empirical data on the performance of lot-level stormwater management structures in different climates, soil types, and other site conditions [44], despite the fact that performance – and impact – can vary hugely from site to site. Recent studies have demonstrated that in an ideal site, a new, well-maintained stormwater detention pond can remove up to 55% or more of total phosphorus in stormwater, but an older structure, poorly maintained, may remove less than 5% [45-47]. Similarly, a single stormwater detention pond in the lower reaches of a stream may be effective in reducing the impact of the highest flows on downstream systems, without impinging on base flow levels. But sited in a headwater region, in close proximity to similar structures, the same pond may contribute to fundamental alteration of downstream base flows. The selection of urban stormwater treatment measures must therefore be tailored to individual site conditions, including soils and slope, and may require planning tools (e.g., dynamic continuous modeling of surface and groundwater flows) not available to all but the largest municipalities. Most regions will benefit from a combination of traditional flow-retention facilities like wet ponds (to capture the most extreme flows in major storm events) and a combination of smaller, lot-level practices geared to capture and treatment of moderate stormwater flows.

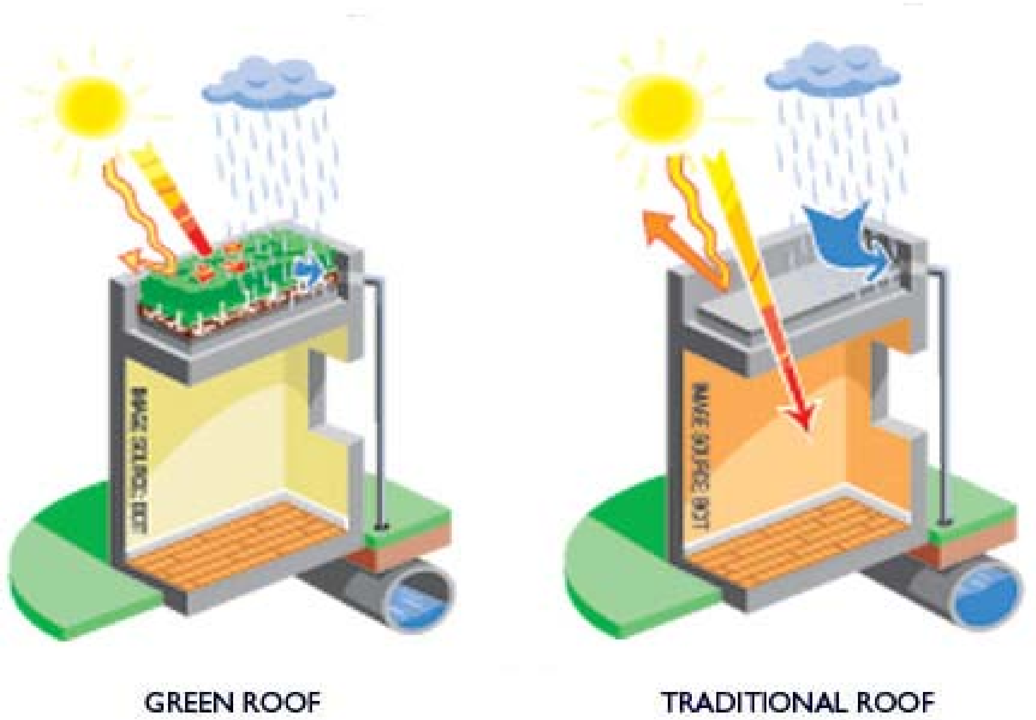
Managing municipal water infrastructure under climate change therefore requires a suite of new tools beyond those currently in routine use. Among these are new data-capture technologies, and integrated surface/groundwater models to assess the cumulative regional impact of individual management practices. Such models require extensive input information, including data on the frequency, timing, volume, and areal distribution of precipitation, runoff, and streamflows, and the performance of management alternatives such as wet ponds and green roofs. More research is needed to determine optimal conditions for the siting and maintenance of lot level structures, to ensure that watershed management decisions under climate change do not exacerbate low-flow and pollutant loading conditions.

Acquisition of dynamic precipitation data may be a more straightforward prospect. For example, a real time technology called Optimal Global Perspective (OGP) monitors precipitation amounts from satellite information and meteorological stations and uses this information to control the flow of water through a sewerage system and maximize water storage in the tunnel [43]. This leads to a decrease in the amount of wastewater discharged into surface waters. A preliminary study shows that the cost of implementing the OGP scheme in Quebec City, Canada, would be about $4 million; which is less than four percent of the total cost of Quebec City's long-term Combined Sewer Overflow plan [43] – a worthwhile investment in the long run.

Runoff Reduction Technologies

As mentioned above, increases in the number of heavy rainfall events are expected to stress current urban water infrastructure [7]. Many options are available to mitigate these effects. Some (e.g., rain barrels) provide only flow reduction; others (e.g., infiltration trenches, rain gardens) may also provide some degree of treatment.  As one example, green roofs have been shown to reduce urban runoff by absorbing rain that would otherwise flow directly into the sewer system [36]. Green roofs are engineered roofing systems that use vegetation that make environmental, economic, and social contributions to urban areas [48]. Roofing systems reduce runoff by 65 percent [49] during frequent moderate rain events. Unfortunately, though, the systems are less effective during extreme weather events. While they are more costly than traditional roofing, green roofs provide additional benefits, such as temperature moderation, ultimately making them cost-competitive over the long-term (Figure 6) [48].

Figure 6: Green Roof versus Traditional Roof
Source: Centre for the Advancement of Green Roof Technology [48]



Maintenance of Dykes/Levees

Networks of dykes and levees are especially important to coastal cities and towns sensitive to sea level and storm surges.  As seen with the New Orleans disaster in 2005, monitoring and improvement of dykes and levees are essential in order to protect coastal communities from flooding. Some maritime cities have used flood modelling to predict “worst case scenarios” and adapt emergency evacuation and response plans accordingly [12].

Constructed Wetlands

Nature has its own clean water filtration system made up of wetlands, bogs, forests, slow moving streams.  Each of these ecosystems absorbs water, substantially slowing its flow and removing impurities as the water passes through.  Not only do these ecosystems improve water quality, they also help mitigate floods by acting as a natural sponge and reducing water flow across the surface.

Mimicking these natural filtration systems, wetlands are being constructed as a low cost water-treatment option for a variety of waste water streams (i.e. municipal wastewater, industrial discharges, livestock wastewater, and storm water) [50]. Unfortunately, their effectiveness decreases as temperatures drop.

Land-use Practices and Urban Planning

There is no one cure-all technology that can be implemented to reduce the impacts of climate change. It is, however, possible to influence the location, timing, and quality of flows through management actions on the land surface. Land-use practices and urban planning are critical in this regard. Coping with increases in precipitation and floods due to climate change will require the implementation of various preventative strategies, particularly integrated watershed planning and management. An example of this multi-pronged approach can be seen through a plan adopted by the Canadian city of Vancouver. Because many areas of Vancouver lie in the Fraser River Delta and/or are below sea level, the city has developed the Greater Vancouver Integrated Storm Water Management Plan. The goal is to achieve no net loss in environmental quality and protect communities from localised flooding [12]. The plan is innovative in that it is watershed specific, uses flexible and adaptive strategies, and integrates watershed health [12].  Furthermore, it draws on land-use planning, engineering, community values, and climate change variability to inform its activities [12]. This includes changing zoning regulations to prohibit construction in flood-prone areas or valuable wetlands. Finally, the plan also addresses potential drainage, erosion, and flooding concerns as well as to protect riparian and aquatic habitat, and remediate existing excess storm water runoff [12]. Many other Canadian cities, notably Toronto, Calgary, Winnipeg, and Ottawa have also engaged in comprehensive watershed planning [51-54]

## 4. Other Strategies to Reduce the Impact of Climate Change

As mentioned above, reducing the impacts of climate change will require the implementation of many different strategies.  In addition to relying on technological solutions, there are several other steps that must be undertaken in concert with technological innovations.  These may include: demand-side management of resource use; emphasis on conservation; awareness raising campaigns; policies and regulations to encourage efficient use of water; vulnerability assessments in communities to identify effective courses of action; and consultation with all stakeholders, among others [7, 12, 55, 56].

## 5. Conclusions

Canada and the United States are experiencing increasing shortages and decreasing water quality. Freshwater availability is likely to decrease as climate change progresses, altering precipitation patterns. That being said, both countries have the natural resources to meet their domestic water needs if changes in uses, technology, regulations, pricing, and so on, are implemented to better control the use of the world's most valuable and vital resource, water [57].

## 6. References


1. Brandes, O.M., *At a Watershed: Ecological Governance and Sustainable Water Management in Canada.* Journal of Environmental Law and Practice, 2005. **16**(1): p. 79-97.
2. Organisation for Economic Co-operation and Development. *Canada vs. The OECD: An Environmental Comparison / Water Consumption*. 2000 [cited 2007 July 27]; Available from: www.environmentalindicators.com/htdocs/indicators/6wate.htm.
3. IPCC, *Summary for Policymakers*, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA. p. 1-996.
4. Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis, Summary for Policy Makers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC, Editor. 2007.
5. Zhang, X., et al., *Detection of human influence on twentieth-century precipitation trends.* Nature, 2007. **448**: p. 461-465.
6. Intergovernmental Panel of Climate Change and Working Group I: The Physical Science Basis of Climate Change, *Regional Climate Projections*, in *The Intergovernmental Panel on Climate Change Fourth Assessment Report*, IPCC, Editor. 2007, IPCC: Geneva.
7. Lemmen, D.S. and F.J. Warren, eds. *Climate Change Impacts and Adaptations: A Canadian Perspective*. 2004, Natural Resources Canada: Ottawa.
8. Kling, G.W., et al., *Confronting Climate Change in The Great Lakes Region: Impacts on our Communities and Ecosystems*. 2003, Union of Concerned Scientists and Ecological Society of America: Cambridge, Massachusetts and Washington, D.C.
9. Natural Resources Canada. *Pie Chart of the Distribution of Irrigated Land in Canada (late 1990s)*. The Atlas of Canada 2004 March 15 [cited 2007 July 27]; Available from: http://atlas.nrcan.gc.ca/site/english/maps/freshwater/consumption/irrigation.gif/image_view
10. Mehdi, B., *Five Year Compendium: Status of Climate Change Impacts and Adaptation from the Perspective of C-CIARN Water Resources*. 2007, Canadian Climate Impacts and Adaptation Research Network (C-CIARN). p. 1-19.
11. Infrastructure Canada, *Adapting Infrastructure to Climate Change in Canada's Cities and Communities: A Literature Review*. 2006, Research & Analysis Division of Infrastructure Canada: Ottawa. p. 1-21.
12. Mehdi, B., ed. *Adapating to Climate Change: An Introduction for Canadian Municipalities*. 2006, Canadian Climate Impacts and Adaptation Research (C-CIARN).
13. Dupont, D.P. and S. Renzetti, *The role of water in manufacturing.* Environmental & Resource Economics, 2001. **18**(4): p. 411-432.
14. Lasserre, F., *Drawers of Water: Water Diversions in Canada and Beyond*, in *Eau Canada: The Future of Canada's Water*, K. Bakker, Editor. 2007, UBC Press: Vancouver. p. 143-162.

15. Brandes, O., D. Brooks, and M. M'Gonigle, *Moving Water Conservation to Centre Stage*, in *Eau Canada: The Future of Canada's Water*, K. Bakker, Editor. 2007, UBC Press: Vancouver. p. 281-300.
16. Gleick, P.H., *WATER USE.* Annual Review of Environment and Resources, 2003. **28**(1): p. 275-314.
17. Natural Resources Canada. *Pie Chart of the Principal Water Uses in Canada, 2000*. The Atlas of Canada 2004 March 15, 2004 [cited 2007 July 27]; Available from: http://atlas.nrcan.gc.ca/site/english/maps/freshwater/consumption/wateruse_principal.gif/image_view
18. Shrubsole, D. and D. Draper, *On Guard for Thee? Water (Ab)uses and Management in Canada*, in *Eau Canada: The Future of Canada's Water*, K. Bakker, Editor. 2007, UBC Press: Vancouver. p. 37-54.
19. Exall, K., J. Marsalek, and K. Schaefer, *A review of water reuse and recycling, with reference to Canadian practice and potential: 1. Incentives and implementation.* Water Quality Research Journal of Canada, 2004. **39**(1): p. 1-12.
20. Dore, M.H.I., *Forecasting the economic costs of desalination technology*. Desalination, 2005. **172**(3): p. 207-214.
21. Pacific Institute. *The World's Water: Desalination Capacity by Country*. 1999 April 21, 1999 [cited 2007 August 30]; Available from: http://www.worldwater.org/data19981999/table16.html.
22. OECD. *Canada vs. The OECD: An Environmental Comparison*. 2000 [cited 2007 July 27]; Available from: www.environmentalindicators.com/htdocs/indicators/6wate.htm.
23. OECD, *The Price of Water: Trends in OECD Countries*. 1999, OECD: Paris.
24. National Turfgrass Evaluation Program and National Turfgrass Research Initiative. *Enhancing America's Beauty Protecting America's Natural Resources Ensuring the Health and Safety of all Americans*. April 2003 [cited 2007 September 24]; Available from: www.ntep.org/pdf/turfinitiative.pdf.
25. Gleick, P., et al., *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. 2003, Pacific Institute: Oakland.
26. Lameka, R., *Regional Case Studies: Best Practices for Water Conservation in the Great Lakes-St. Lawrence Region*. 2004, Great Lakes Commission: Ann Arbor, Michigan. p. 1-36.
27. Natural Resources Canada. *Pie Chart of Residential Water Use in Canada, 1999*. The Atlas of Canada 2004 March 15, 2004 [cited 2007 July 27]; Available from: http://atlas.nrcan.gc.ca/site/english/maps/freshwater/consumption/wateruse_home.gif/image_view
28. Natural Resources Canada. *Pie Chart of Municipal Water Use by Sector, 1994*. The Atlas of Canada 2004 March 15 [cited 2007 July 27]; Available from: http://atlas.nrcan.gc.ca/site/english/maps/freshwater/consumption/municipal_use_1994.gif/image_view
29. Thornton, J., *Water Loss Control Manual* 2002, New York: McGraw-Hill. p.49; p.103-107.
30. AWWA Water loss Control Committee, *Committee Report: Applying Worldwide BMPs in Water loss Control* Journal of American Water Works Association, 2003. **95**(8): p. 65-79.

31. Walski, T., et al., *Modeling Leakage Reduction through Pressure Regulation.* Journal of the American Water Works Association, 2006. **98**(4): p. 147-155.
32. Williams, P.J. and P.A. Anderson, *Operational cost savings in dairy plant water usage.* International journal of dairy technology, 2006. **59**(2): p. 147-154.
33. Chaves, M.M. and M.M. Oliveira, *Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture.* Journal of Experimental Botany, Water-Saving in Agriculture Special Issue, 2004. **55**(407): p. 2365-84.
34. Tung, C. and D.A. Haith, *Climate change, irrigation, and crop response.* Journal of the American Water Resources Association, 1998. **34**(5): p. 1071-1085.
35. Easterling, W.E., *Adapting North American agriculture to climate change in review.* Agricultural and Forest Meteorology, 1996. **80**(1): p. 1-53.
36. Neilsen, D., et al., *Potential impacts of climate change on water availability for crops in the Okanagan Basin, British Columbia.* Canadian Journal of Soil Science, 2006. **86**(5): p. 921-936.
37. Johnston, T.R.R., D.E. Kromm, and J.M. Byrne, *On-farm Water Conservation Practices in Southern Alberta* Journal of the American Water Resources Association, 2001. **37**(3): p. 737-750.
38. Patel, R.M., et al., *Brackish Water Subirrigation for Vegetables.* Irrigation and Drainage 2003. **52**: p. 121-132.
39. Stampfli, N. and C.A. Madramootoo, *Water table management: A technology for achieving more crop per drop \h [electronic resource]*. Irrigation and drainage systems, 2006. **20**(1): p. 41-55.
40. Milne, R., et al., *Multi-Party Monitoring in Ontario: Challenges and Emerging Solutions.* Environments, 2006. **34**(1): p. 11.
41. Boyd, D.R., *Within limits: Canada's record on environmental protection is a patchwork of weak laws and even weaker enforcement.* Alternatives Journal, 2004. **30**(1): p. 37.
42. Last, J.M. and Q.P. Chiotti, *Climate change and health.* Canadian Journal of Policy Research, 2001. **2**(4): p. 62-69.
43. Field, R., et al., *Get real!* Water Environment and Technology, 2000. **12**(4): p. 64-68.
44. International Joint Commission. *Priorities 2003-2005: Priorities and Progress under the Great Lakes Water Quality Agreement*. 2006 [cited 2007 September 8]; Available from: http://www.canamglass.org/glwqa/files/prioritiesfullreport.pdf
45. American Society of Civil Engineers (ASCE). *International Stormwater BMP Database*. 2005 [cited 2007 September 8]; Available from: www.bmpdatabase.org
46. Schueler, T.R. and S.C. Caraco, *Prospects for low impact land development at watershed level*, in *Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation: Proceedings of Engineering Foundation Conference*, B.R. Urbonas, Editor. 2001, ASCE: Reston, Virginia. p. 196-209.
47. Taylor, S., et al., *Stormwater treatment with a wet pond: a case study.*, in *Designing Successful Stream and Wetland Restoration Projects ASCE Wetland Engineering and River Restoration Conference* D.F. Hayes, Editor. 2001, ASCE: Reston, Virginia. p. 1-10.
48. Centre for the Advancement of Green Roof Technology. *FAQ -- Centre for the Advancement of Green Roof Technology -- BC Institute of Technology*. 2006 [cited 2007 August 17]; Available from: http://commons.bcit.ca/greenroof/faq.html.
49. Banting, D., et al., *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto*. 2005, Ryerson University: Toronto. p. 88.

50. Kennedy, G. and T. Mayer, *Natural and constructed wetlands in Canada: An overview*. Water Quality Research Journal of Canada, 2002. **37**(2): p. 295-325.

51. Palliser Environmental Services Ltd., *Nose Creek Watershed Water Management Plan*. 2007. p. 1-52.

52. Toronto and Region Conservation Authority. *A Watershed Plan for Duffins Creek and Carruthers Creek*. in *4th Canadian River Heritage Conference*. 2003. Guelph: Canadian Heritage Rivers System.

53. Rideau Valley Conservation Authority, *Annual Rideau Valley Watershed Checkup*. 2006, Rideau Valley Conservation Authority: Manitock. p. 1-16.

54. La Salle Redboine Conservation District. *LaSalle River Watershed: State of the Watershed Report*. 2005 [cited 2007 September 13]; Available from: http://www.lasalleredboine.com/images/LaSalle%20River%20S%20of%20W/State_of_the_Watershed.htm.

55. Mehdi, B.B., C.A. Madramootoo, and A. Cobbina, *Water Resources at Risk Due to Climate Change: Identifying Knowledge Gaps and Research Gaps*. 2004, C-CIARN Water Resources, Brace Centre for Water Resources Management, McGill University: Ste. Anne-de-Bellevue. p. 1-8.

56. Muldoon, P. and T. McClenaghan, *A Tangled Web: Reworking Canada's Water Laws*, in *Eau Canada: The Future of Canada's Water*, K. Bakker, Editor. 2007, UBC Press: Vancouver. p. 245-261.

57. Pentland, R. and A. Hurley, *Thirsty Neighbours: A Century of Canada-US Transboundary Water Governance*, in *Eau Canada: The Future of Canada's Water*, K. Bakker, Editor. 2007, UBC Press: Vancouver. p. 163-182.