INTEGRATED RISK MANAGEMENT FOR MUNICIPAL WATER SYSTEMS IN CANADA THROUGH INTER-JURISDICTIONAL ECOSYSTEM MANAGEMENT USING CONSERVATION AUTHORITIES AS A MODEL

A white paper prepared for the Canadian Water Network research project:
"An Integrated Risk Management Framework for Municipal Water Systems"

Victor Mguni
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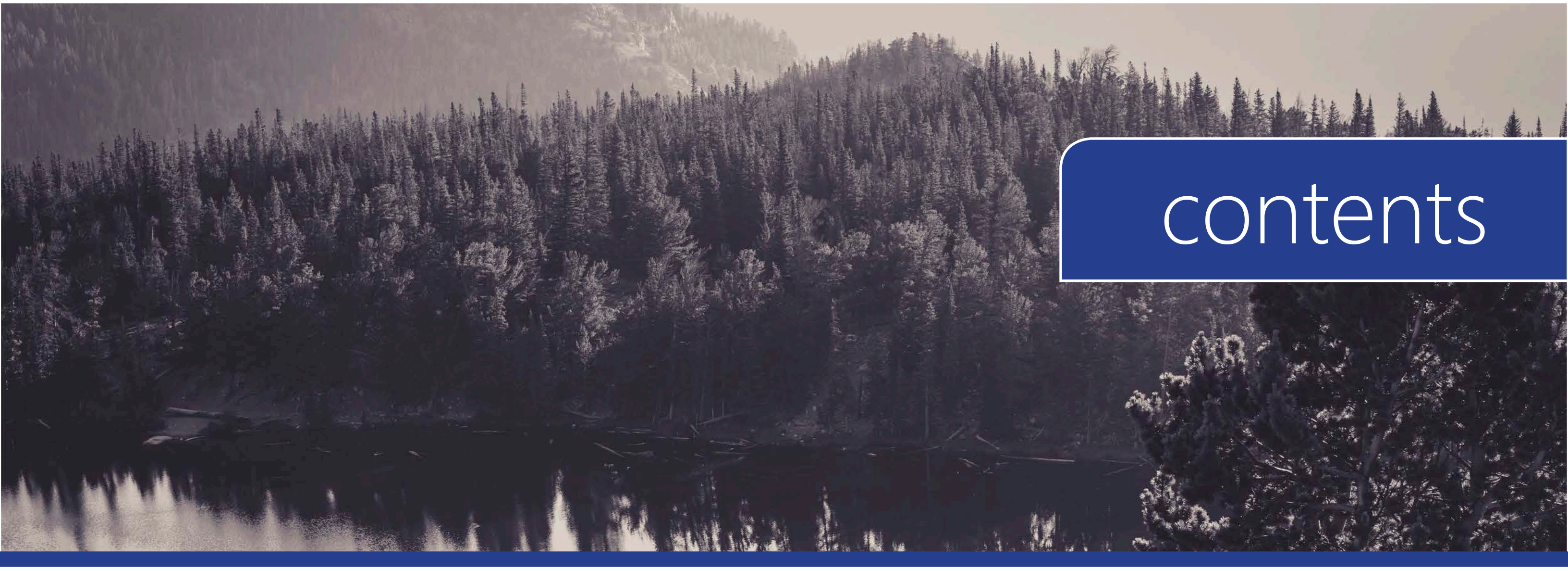
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overview

This paper examines the risks and likely opportunities related to municipal water systems from a health and regulatory perspective especially after focusing events like Walkerton Tragedy that helped push risks facing municipal water systems into the public agenda thereby requiring policy responses. It is widely acknowledged that risks to municipal water systems are rarely confined to a single municipal jurisdiction but emanate from other jurisdictions. This creates the imperative for integrated risk management through the adoption of watersheds as de facto units for water management and governance of municipal water systems. A watershed approach enables downstream and upstream municipalities and other stakeholders to collaborate and come up with creative solutions to health and regulatory risks.

These collaborative approaches imply that multiple stakeholders are involved and this necessitates the introduction of a networked form of governance. Networked governance is properly disposed to addressing the problem of jurisdictional fragmentation within the Canadian water sector. It is proposed that the steering or controlling of such networks is better achieved through Conservation Authorities that are already in existence in Ontario and are operating at a watershed level. But a multi-stakeholder approach introduces problem complexity where stakeholder interests might be entrenched. An efficacy frontier will be used to examine how these complexities are resolved through trade-offs. Applications of a reformed governance model for Canadian applications are discussed.

An Urban Water Management Transitions Framework developed in Australia will be used to show that the most optimal way to address health and regulatory risk is for municipal water systems to transition to what are called water cycle and water sensitive cities that focus on demand rather than supply side factors. This transition allows for sustainable water approaches which address cultural and historically embedded values that are then expressed in current municipal water system infrastructure. There is now a convergence on the fact that impediments to the adoption of sustainable water practices lie in the social rather than the technical domain. This framework tackles the challenges emanating from these hydro-social contracts.

pt 1. literature review

1.1 HISTORICAL EVOLUTION OF MUNICIPAL WATER SYSTEMS

The Urban Water Management Transitions Framework (developed by Brown et al. 2008) (Figure 1) presents a "typology of six city states" and identifies the ideological and technological contexts that the city states evolve through as they develop towards sustainable water conditions, which in this case is the Water Sensitive City. These city states can be taken to be representative of the evolution of municipal water systems. For the purposes of this paper, the term urban water system is synonymous with municipal water systems.

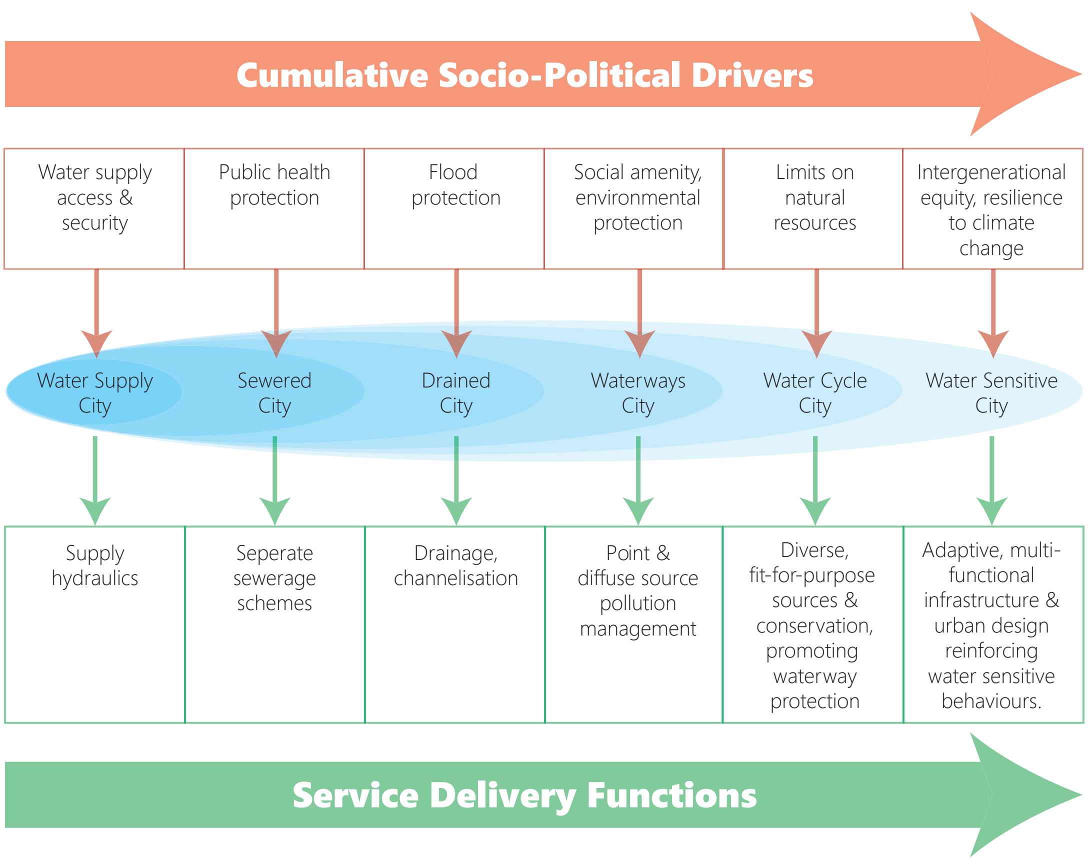


Figure 1 - Urban Water Management Transition Framework (Brown et al. 2008)

The framework is presented as a benchmarking tool to provide a vision for municipal water systems that pinpoints the requisite attributes of a sustainable and hence integrated system capable of handling risks faced by municipal water systems.

Each city state is differentiated by the services provided by the municipal water system which is a function of the dominant social and political drivers (reflecting shifts in the normative and regulative dimension) and the service functions (representing the cognitive responses). Brown et al. (2008) labels these as the hydro-social contracts manifesting themselves in "three dimensions of institutional context" namely; the cultural-cognitive, normative and, regulative. These dimensions express themselves through institutional arrangements and regulatory frameworks that are physically presented as municipal water infrastructure. They are therefore mutually reinforcing such that reforming one pillar without the other two is not effective. What is common from the first three states is the normative perception of water as a limitless resource and the environment as benign where storm and sewer water can be conveyed into receiving water bodies and the dominance of engineered technical solutions to water problems. This paradigm was challenged by the emergence of environmentalism in the 1960s and recently reinforced by extreme events of drought and flooding, causing municipal systems to start transitioning to sustainable states.

1.2 TRANSITIONING TO THE WATER-SENSITIVE CITY

According to Ferguson et al. (2013), municipal water systems deliver societal needs like water resources, sanitation, and flood protection through "traditional technocratic approaches" characterized by centralized water supply, sewage and drainage infrastructure. There is a growing recognition that municipal water systems are "socio-ecological" systems that encapsulate both complexity and uncertainty. The key to delivering societal needs under such conditions is for municipal water systems to adopt "adaptive paradigms" that capture complexity, uncertainty, and builds adaptive capacity through "flexibility, diversity, and redundancy".

Such a paradigm is provided by transitioning to "water-sensitive" cities. According to Dobbie et al. (2014), developing to a water sustainable state such as the 'water-cycle city' (or water-sensitive cities) requires "shared, diversified risk management, which acknowledges the subjective risk perceptions of all stakeholders including water practitioners".

The water systems of the water-cycle city incorporate sustainability through its ability to provide water from multiple sources like rainwater, recycled wastewater, stormwater, sewage and seawater. It is an integrated system that reduces discharge to waterways and simultaneously promotes ground water recharge (ibid). The water-sensitive city on the other hand recognizes the concept of intergenerational equity where the needs of today should not compromise those of future generations as defined in United Nations (1987). Transitioning as already alluded to in Brown et al. (2008) is possible only in the context of shifting all the three dimensions of institutional context.

1.3 DIMENSIONS OF INSTITUTIONAL CONTEXT

Ferguson et al. (2013) provides empirical evidence of the institutional context that enabled the city of Melbourne to transition towards a "hybrid of centralized and decentralized infrastructure." Fundamental changes occurred in the "cultural-cognitive, normative and regulative dimensions of Melbourne's water system". Whilst drought was a fundamental driver in Melbourne's achievement, Ferguson et al. (2013) provides lesions on how others can create "enabling social conditions for more integrated approaches to water servicing in their own institutional contexts, without having to experience a crisis" before taking action. Table 1 is a summary of levers that can be applied to shift the three dimensions of the institutional context.

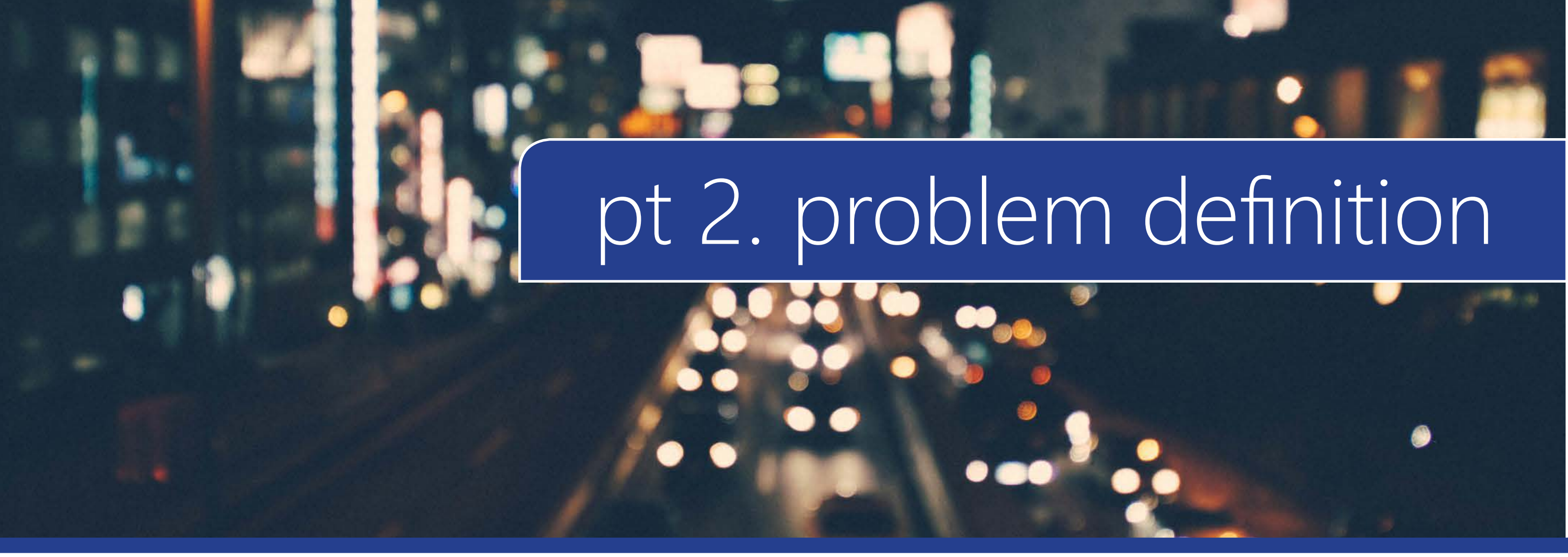
1.4 MANIPULATING CHANGE LEVERS

Table 1 - Shifting the dimensions of institutional context (Adapted from Ferguson et. al. 2013)

Dimensions	Levers to Effect Change
Cultural-cognitive	Scenario planning for future conditions/surprises; development of context-based evidence through mechanisms supporting knowledge building and sharing; local demonstrations to build practical experience
Normative	Visioning processes involving policy makers, water practitioners, and community members; active political lobbying; implementation structures and processes that support co-governance approaches
Regulative	Strategic planning processes to develop shared problem definitions and cross-boundary partnerships; mobilizing government incentives to support desired outcomes, mechanisms for transparent evaluation of costs and benefits in a business case development; establishment of conditions that provide market certainty for investments in innovative solutions

1.5 CULTIVATING LOCAL ENTHUSIASM

Floyd et al. (2014), state that cultivating "local enthusiasm" effectively drives participation in water governance than mandated approaches as it generates "autonomous motivation" which in turn drives the shifts in dominant institutional regimes. A case in point is where it can lead to the deconstruction of infinite water supply perceptions. In such a scenario, communities voluntarily invest in household infrastructure like rainwater harvesting tanks and the use of grey water for garden irrigation. Enthusiasm thus develops "social infrastructure" which in turn eases pressure on physical infrastructure.



pt 2. problem definition

2.1 AGING INFRASTRUCTURE AND THE INFRASTRUCTURE DEFICIT

Most of the water and wastewater infrastructure under the jurisdiction of municipalities is up for replacement as it was constructed in the 1950s and 1970s (Rupert 2010, Mirza 2007). Deferred maintenance is a primary cause of municipal infrastructure deterioration. Under conditions of no/deferred maintenance, the municipal infrastructure deficit will grow to about $2 trillion by 2065 (Mirza 2007). According to Vander Ploeg (2011), aging infrastructure creates two problems of leakage and elevated contamination risks.

A 2009-2010 survey of municipalities on drinking water systems, wastewater, and storm water networks revealed that 15% of drinking water infrastructure, 40% of wastewater infrastructure and 13% of stormwater management systems were rated "fair", "poor" or "very poor" Federation of Canadian Municipalities (2011). Mirza (2007) indicates that it will require capital expenditures of about a $100 billion dollars to repair, maintain, and upgrade this infrastructure (Table 2).

Table 2 - Required infrastructure costs (Adapted from Mirza 2007)

Replacement Costs	Billions of $
Drinking water infrastructure	25.9
Wastewater infrastructure	39.0
Stormwater systems	15.8
Total	80.7
Upgrading of Wastewater Plants	20
Combined Total	100.7

2.2 THE BUILT-UP LANDSCAPE

The built up landscape in urban areas is increasingly dominated by surfaces that are impervious due widespread use of asphalt, roofs, and concrete. As a result most of the rainfall no longer infiltrates into the soil but is rapidly conveyed by municipal stormwater systems to receiving water bodies as stated by Schreier (2012), Porter-Bopp et al. (2011), Norman et al. (2010) and Aquafor Beech Limited (2006). According to CVC and TRCA (2010), the hydrological cycle is significantly altered resulting in severe impacts to water quality, flooding risk and human health. Appendix A shows the net effect of these impacts. The following figure indicates the increase in surface runoff as a function of land use change.

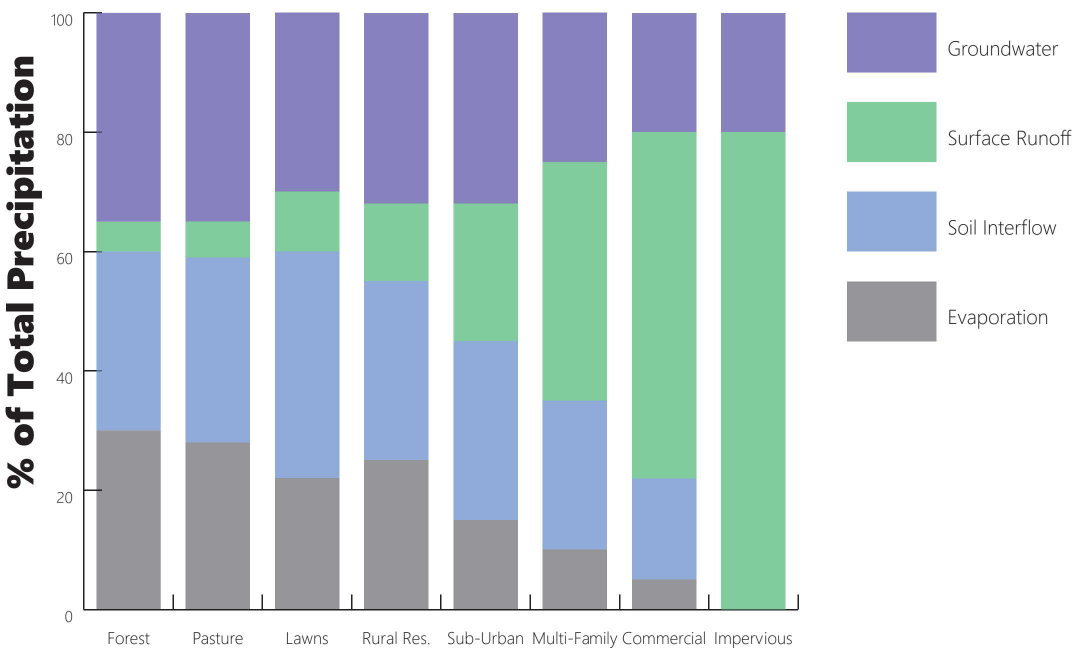


Figure 2 - Land use impacts on the distribution of precipitation within the hydrological cycle (Adopted from Schreier 2012)

Porter-Bopp et al. (2011) identifies three core problems linked to traditional stormwater management which are a "legacy of old stormwater management practices as also borne out by Brown et al. (2008). They are:

- Urban design creates a perceived "problem" of runoff when it ignores the water cycle by replacing the natural landscape
- The paradigm that rainwater poses a risk and must be conveyed from the landscape
- Fragmentation in the roles and responsibilities with respect to watersheds between government levels and the absence of integration between land use and water planning within municipalities

These core problems are at the center of the current predicament faced by municipal water systems and the resultant threats to human health and well being and they are more institutional rather than technical.

2.3 COMBINED SEWER SYSTEMS

Many Canadian municipalities depend on combined sewers "through which storm drains connect to sanitary sewer lines and discharge into water bodies when line capacity is exceeded. In Ontario, there are 107 combined sewer systems found in 89 municipalities spread across the province (Binstock 2011). Documented evidence of combined sewer overflows and bypasses was carried out by MacDonald et al. (2009) and is shown in Tables 3 and 4

Table 3 - Sewage bypasses and combined sewer overflows (2006 - 2007) (Adapted from MacDonald et al. 2009)

Sewage Releases	2006	2007
Total reported sewage releases	1,544	1,243
Total releases reported to be due to wet weather	1,256	849
Releases reported to include combined sewer overflows	376	701
Releases that included bypasses	1,061	1,089

Table 4 - Sewage bypasses by volume (2006 - 2007) (Adapted from MacDonald et al. 2009)

Watershed	Total Primary By-pass (L)	Total Secondary By-pass (L)	Total Sewage By-pass (L)	Total Sewage Flow (L)
2006 Bypass				
Lake Huron	1,313,048,000	168,765,000	1,536,366,000	166,644,113,000
Lake Erie	3,700,941,000	1,136,131,000	4,837,072,000	244,561,923,000
Lake Ontario	5,436,818,000	6,089,267,000	11,526,450,000	1,009,788,541,000
Lake Superior	346,000	57,511,000	57,857,000	23,716,153,000
St. Lawrence River	14,861,000	0	25,071,000	62,284,041,000
Ottawa River	4,817,000	72,263,000	81,235,000	180,238,612,000
Nelson River/Hudson Bay/James Bay	311,969,000	1,089,000	373,880,000	110,538,079,000
Total	**10,782,000,000**	**7,528,026,000**	**18,437,931,000**	**1,797,771,462,000**
2007 Bypass				
Lake Huron	394,813,000	134,050,000	536,698,000	135,444,622,000
Lake Erie	3,106,146,000	211,654,000	3,317,800,000	183,779,635,000
Lake Ontario	977,821,000	2,337,513,000	3,315,334,000	767,885,268,000
Lake Superior	0	231,466,000	231,466,000	22,239,380,000
St. Lawrence River	0	0	700,000	54,268,990,000
Ottawa River	3,574,000	549,252,000	552,826,000	161,119,933,000
Nelson River/Hudson Bay/James Bay	408,711,000	0	408,711,000	20,970,689,000
Total	**4,891,065,000**	**3,463,935,000**	**8,363,535,000**	**1,345,708.517,000**

2.4 CLIMATE CHANGE

Climate change is churning out extreme events that are capable of disrupting municipal water systems whose components include "drinking water supply, wastewater conveyance and treatment, and stormwater management" (Beller-Simms et al. 2014).

Traditional planning for municipal water systems is based on the concept of "stationarity". It is the "notion that seasonal weather and long-term climate conditions fluctuate within a fixed envelope of relative certainty" (Sandford 2011) such that "the statistical properties of climate variables in future periods will be similar to past periods" Means III et al. (2010). In the water resources sector, this certainty is delineated by a 100 year period of observations of climate phenomena (Beller-Simms et al. 2014). According to Schreier (2012), storm events that previously occurred once in every 100 years are more likely to occur every 7 years (ibid).

2.5 RISK OF LAWSUITS

According to the IBC (2014), severe weather damages resulting from climate change have overtaken fire damage to become the dominant cause of property insurance. In 2013 alone, floods in Toronto and Alberta reached historic proportions of $3.2 billion compared to an average of about $400 million per annum for a period of 25 years between 1983 and 2008. Table 5 is a list of some of the lawsuits resulting from wet weather events.

Table 5 - Risk of lawsuits
(Adapted from Campbell et al. 2007)

Lawsuit	Court and Case #	Reason
Port Alberni (City) v. Moyer	B.C. Supreme Court [1999] B.C.J. No. 423	Basement flooding due to sewer back-up
Carson v. Gloucester (City)	Ontario Supreme Court of Justice [2000] O.J. No. 3863	Basement flooding – drainage ditch near-by flooded due to thaw and heavy rainfall
Clemmens v. Kenora (Town)	Ontario Supreme Court of Justice [1999] 6 M.P.L.R. (3d) 59	Sewer back-up due to broken pipe
McLaren v. Stratford (City)	Ontario Supreme Court of Justice [2004] 50 C.P.C. (5th) 310	Property damage due to severe rainstorm causing flooding with both sewage and storm water
Tock v. St. John's Metropolitan Area Board	[1989] 2 S.C.R. 1181	Basement damage due to storm sewer blockage caused by heavy rainfall
Oosthoek v. Thunder Bay (City)	Ontario Court of Appeal 30 O.R. (3d) 323	Basement flooding due to back-up caused by combined sewers and from burst, leaking or corroded cast iron wa-termains after heavy rainstorm

pt 3. the solution

3.1 LID TECHNOLOGIES INTEGRATED AT THE WATERSHED SCALE

Low impact development (LID) stormwater management practices include rain water harvesting, green roofs, bioretention, permeable pavement, soakaways and swales. CVC and TRCA (2010) adapted the USEPA definition of LID:

Low impact development (LID) is a storm water management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that mimic natural or predevelopment hydrology through the processes of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows.

LID technologies "capture, retain, and treat" stormwater before it reaches municipal sewer systems and thus decreases pressure on sewers, decreasing the need for capital investments (Binstock 2011). Table 6 below shows the benefits of LID technologies as applied to different scales from property to the watershed scale.

Table 6 - Innovative approaches to reduce stormwater runoff (Adapted from Schreier 2012)

Property Scale	Neighborhood Scale	Watershed Scale
Rainwater harvesting from roofs and impervious surfaces for re-use during dry periods.	Minimize the size of roads, parking lots and impervious surfaces.	Create large, continuous riparian buffer zones along streams and lakes.
Green roofs to reduce and delay runoff.	Crate infiltration swales to direct road and impervious surface into swales.	Diversify stream channels into meandering side stream systems.
Improve soil conditions to maximize infiltration and water storage.	Crate and incorporate wetlands into neighborhoods.	Build wetlands and detention systems in the buffer zones.
Minimize impervious surface and soil compaction.	Provide temporary water storage in (e.g. ponds and detention systems).	Select appropriate topographic areas for temporary water storage.
Plant trees to reduce runoff where possible.		Enforce land use zoning in the floodplain.

3.2 THE WATERSHED SCALE AS AN INTEGRATING MECHANISM

There is an increasing recognition that water should be managed on a watershed basis (Zubrycki et al. 2011). Some of this impetus comes from the human and ecosystem health imperative and the triple bottom line perspectives.

3.3 THE HUMAN AND ECOSYSTEM HEALTH PERSPECTIVE

The Canadian Water Network prefers a definition of water security as “sustainable access, on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health” (Zubrycki et al. 2011).

This definition has an inherent implication of ecosystem health of both humans and other species as best served at the watershed level. Cities exist inside watersheds and their water is viewed from competing perspectives from both upstream and downstream actors including industrial, residential, and agricultural. One view is that of water as a “commercial asset” and the other is that of water as an “inherently shared social asset” (Norman et al. 2010). Also, there are five dimensions to water security, namely; water resources, ecosystem health, human health, infrastructure, and governance and water security is at the interface of ecological and human health (ibid), as shown in Figure 3.

According to Norman et al. (2010): water is a “flow resource” and thus cannot be managed at “fixed jurisdictional scales.” Parkes et al. (2010) also links health and well-being to watersheds and concludes that “integrated governance of watersheds” is fundamental to health and well-being.

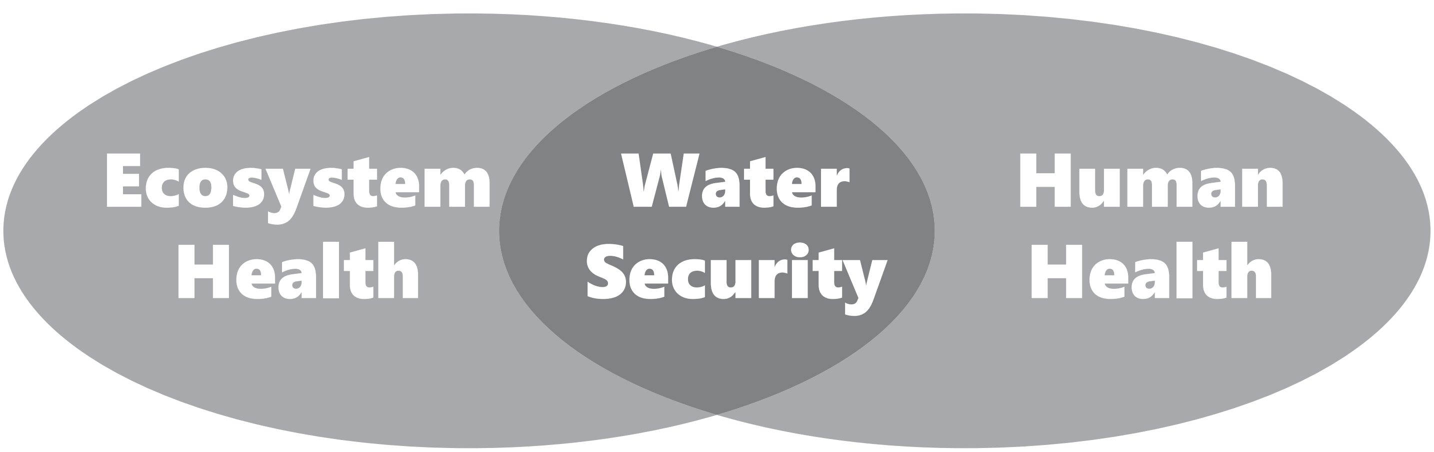


Figure 3 - Water Security - Ecological Health and Human health

3.4 THE TRIPLE BOTTOM LINE APPROACH

According to Conservation Ontario (2010), employing the watershed as a managing unit is a pre-requisite for an integrated approach to water sustainability. Integrated watershed management is defined as "managing human activities and natural resources in an area defined by watershed boundaries aiming to protect and manage all natural resources and their functions today and into the future."

Watershed management is necessary because of the link between ecology, economy, and society hence it drives the triple bottom line approach. de Loë et al. (2010) suggests that effective source water protection is accomplished when it is integrated with other strategies especially water and land use management. This task is best accomplished when source water protection is viewed as a "component of integrated watershed management" (IWM) and IWM is the most applicable frame that addresses the triple bottom line of economic, social and environmental issues that are water related (ibid).

3.5 THE CASE FOR CONSERVATION AUTHORITIES (CAs)

Once the argument is made that human health and well being is best protected at the watershed level, a supportable conclusion is that Conservation Authorities are suited to carry this task.

Mitchell et al. (2014) list six principles that underlying the Conservation Authority program: "(1) the watershed as the management unit; (2) local initiative; (3) provincial-municipal partnership; (4) a healthy environment for a healthy economy; (5) a comprehensive approach; and (6) cooperation and coordination". On the other hand, Porter-Bopp et al. (2011) makes a valid case for Conservation Authorities or similar bodies shown in Table 7.

Table 7 - Canada-wide Building Blocks for Conservation Authorities (CAs)

Location	
Alberta	8 Watershed Planning and Advisory Councils (WPACs) established under the government's Water for Life Strategy
British Columbia	Fraser Basin Council
Manitoba	18 Conservation Districts (CDs)
Ontario	36 Conservation Authorities (CAs)
Quebec	33 Watershed Organizations (WOs)
Northwest Territories	4 Land and Water Boards
Nunavut	1 Planning Commission and 1 Water Board
Yukon	3 Regional Land Use Planning Commissions, 9 Renewable Resource Councils and 1 Water Board

As already proved, there is fragmentation over freshwater decisions where there is not a single authority responsible for the whole hydrological cycle. Since land and water are part of the entire natural system, decisions on these entities should be integrated rather than the current system where land use and community development are handled by the Planning department, whereas different departments deal with sewer and stormwater which also impact drinking water systems. Such a siloed approach results in a "complex patchwork of actors and legislation" without regard to cumulative effects as also acknowledged by Chilima et al. (2013).

Collaborative planning should be done across municipal jurisdictions where a coordinating mechanism in the form of a Conservation Authority is used. While they play a coordinating role, municipalities sharing the same watershed can also share LID implementation costs (ibid).

In any case, according to Robins (2007), Canada has in place, the building blocks of what can become country-wide Conservation Authorities (as shown in Table 7), together with the momentum to integrate LID technologies within municipal jurisdictions (as shown in Table 8).

Table 8 - Momentum to integrate LID technologies (Adapted from Credit Valley Conservation 2014)

Item	Description
Water Opportunities and Water Conservation Act (2010)	Municipalities are required to develop sustainable water, stormwater, and waste water plans
Great Lakes Protection Strategy (2012)	Guides efforts to protect the Great Lakes and Ontario's role in the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem – supports green infrastructure, LID, and stormwater management
Climate Ready: Ontario's Adaptation Strategy and Action Plan	Identifies a need for increased resilience of municipal stormwater systems in light of climate change
Places to Grow	Encourages municipalities to implement and support stormwater management actions as part of development and intensification
Provincial Policy Statement (PPS) (2012)	Includes new policies for planning for stormwater management and encourages consideration of LID earlier in land use planning decisions
Ministry of Municipal Affairs: Municipal Planning and Financial Tools for Economic Development Handbook (2011)	Provides a Sustainability Checklist for land use planning which identifies groundwater recharge, reduced stormwater runoff, and water recovery and LID as an element of site plan control
Ministry of Infrastructure's Plan: Building Together for Jobs and Prosperity for all Ontarians	Acknowledges the impact of climate change on stormwater infrastructure and the need to reduce demand through by promoting conservation and use of green infrastructure

3.6 ECOSYSTEM MANAGEMENT

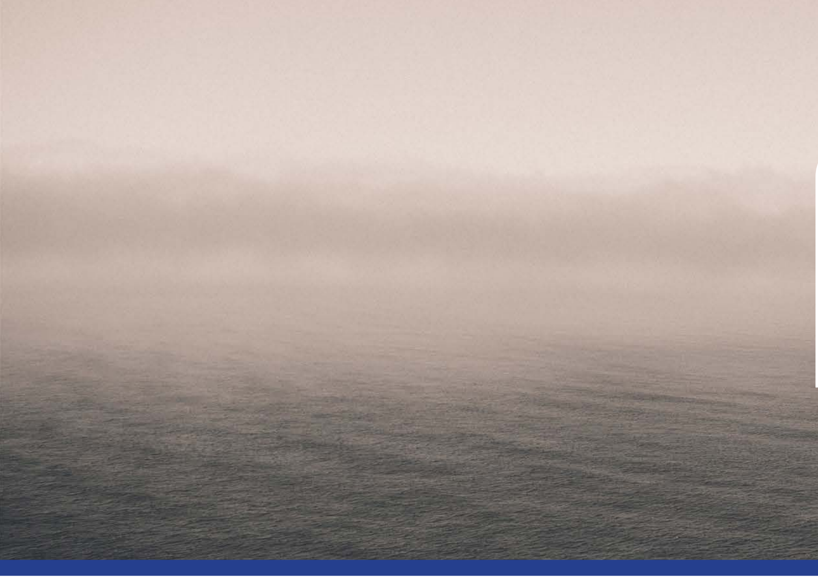
The above also helps make the case for integrating risk through inter-jurisdictional ecosystem management. Millennium Ecosystem Assessment, (2005) defines an ecosystem as "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit". There is a direct link between ecosystems and human well-being such that changes to ecosystems has consequences on all the "multiple constituents of human well-being. The ecosystem services beneficial to humanity are identified as provisioning, regulative, cultural, and supportive.

Voora and Venema (2008) looked at ecosystem services relevant to Manitoba as shown in Appendix B. The case study concluded that current landscape supplies ecosystem services valued between $0.33 billion to $1.30 billion per year compared to $0.5 to $3.02 billion per year before settlement. 80 to 96% of these services are provided by forests and wetlands.

Current institutions that are mandated to address ecosystem degradation face impediments that are related to cross sector cooperation and multiple scale coordination. This is because decisions affecting ecosystems are made mostly by agencies and in "policy arenas" not directly tasked with ecosystem protection (ibid). This also lines up with the case made by Porter-Bopp et al. (2011) above.

Munang et al. (2013) describes ecosystems as not only the "core element" to dealing with climate risk but that they enable sustainable development which in turn is rooted in the maintenance of ecosystems.

According to Mitchell et al. (2014), some of the core objectives of CAs are: to ensure Ontario's rivers, lakes and streams are protected, managed and restored; to protect, manage and restore Ontario's woodlands, wetlands, and natural habitat; and to enable the public to enjoy and learn from and respect Ontario's natural environment. This makes CAs ideal for inter-jurisdictional management of ecosystems and hence the integrated risk management of municipal water systems and the preservation of the health of Canadians when replicated across Canada.



pt 4. barriers to LID uptake

Although the technology and expertise were in existence, barriers to sustainable water supply were located in the social and political domain. Understanding such barriers must precede strategies designed to overcome them (Floyd et al. 2014).

4.1 BARRIER TYPES AND BARRIER INTERACTIONS

Winz et al. (2014) in the Project Twin Streams (PTS) Catchment case study carried out in Auckland, New Zealand, provides empirical evidence on how barriers interact to form "barrier interaction networks" as shown in Figure 4.

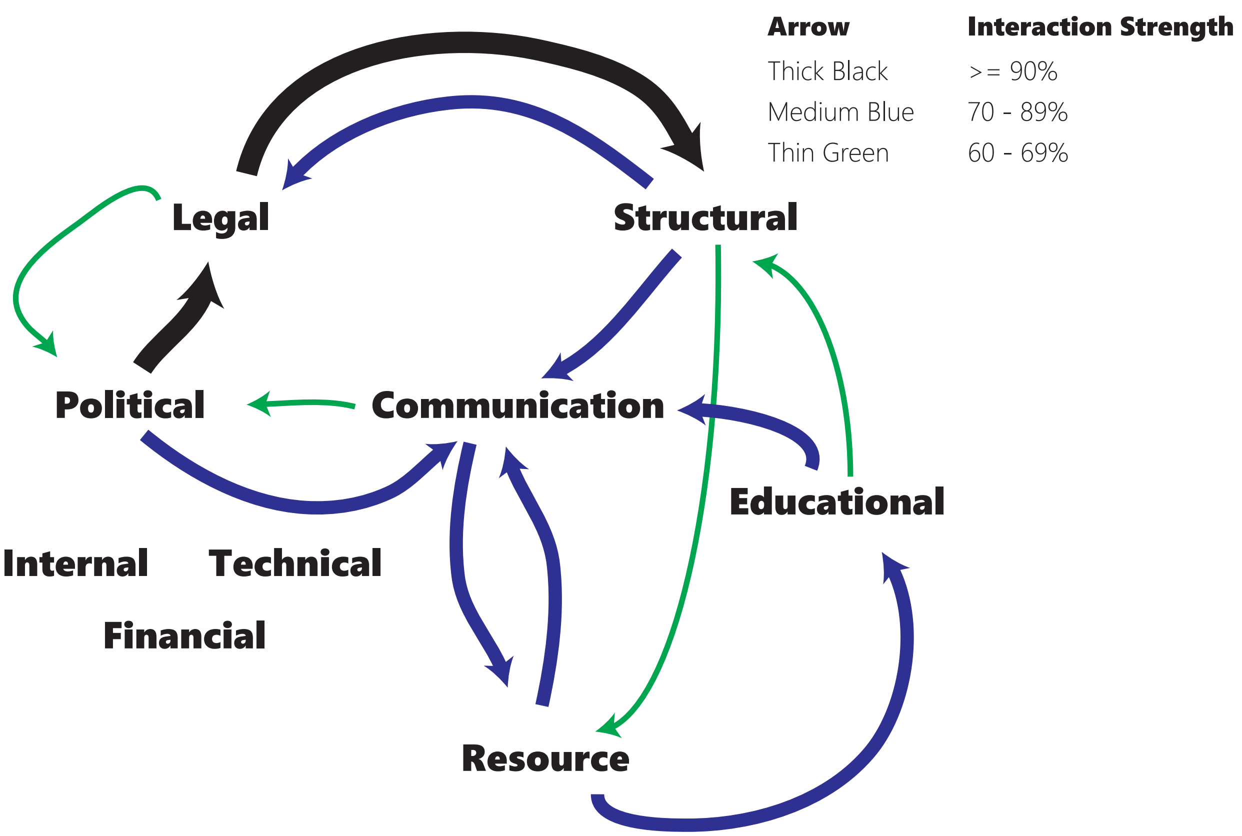


Figure 4 - Barrier Interaction Networks (Adapted from Winz et al. 2014)

The empirical data from the case study shows barriers to the uptake and implementation of LID technologies is located within the social (institutional and logistical) domain rather than the technical one.

During this interaction process, barriers reinforce each other, creating feedback loops that lead to "systemic complexity". Moreover, there is a 'causal network' where some barriers act as the driving force to other barriers (this is shown by the direction of the arrows). The former are accorded some 'barrier driving power' and the later, 'barrier dependence' power. As a result of the insight of barrier potency, implementation policies should be directed initially at tackling institutional barriers with driving power rather than dependent barriers. This generates self-reinforcing change as a leverage strategy can be built on this phenomenon to effect change with reduced effort. Appendix C shows details of how the calculations were developed.

4.2 JURISDICTIONAL FRAGMENTATION

Conservation Ontario, (2012) cites "regulatory burden" as one of the challenges to watershed management where new legislation is crafted for every emerging issue. An example is the legislative environment around drinking water protection for municipal water systems as shown in Table 9:

Table 9 - Momentum to integrate LID technologies (Adapted from Credit Valley Conservation 2014)

Water-Related Federal Legislation	Water-Related Provincial Legislation	
• Canada Water Act	• Ontario Water Resources Act	• Municipal Act
• Canadian Environmental Protection Act	• Environmental Assessment Act	• Public Utilities Act
• Environmental Contaminants Act	• Environmental Protection Act	• Drainage Act
• International River Improvement Act	• Conservation Authorities Act	• Nutrient Management Act
• International Boundary Waters Treat Act	• Lakes and Rivers Improvement Act	• Pesticides Act
• Fisheries Act	• Lake Simcoe Protection Act	• Public Lands Act
• Navigable Waters Protection Act	• Beds of Navigable Waters Act	• Safe Drinking Water Act
	• Aggregate Resources Act	• Water Opportunities Act
	• Clean Water Planning Act	

An integrated approach to the development of solutions that considers the watersheds as connected links of people, natural resources and the economy can disentangle the legislative labyrinth imposed over municipal water systems.

4.3 WATER PRACTITIONERS

According to Maas & Wolfe (2012), one of the critical impediments to be addressed which they refer to as "the rate of innovation diffusion" is the fact that LID technologies and practices are familiar to water experts (early adopters) but are relatively unknown to practitioners (late adopters). Water practitioners, classified as; builders, realtors, technology providers, planners, engineers, plumbers, and inspectors; are critical to LID technology implementation. Data and information (explicit knowledge) can be provided to this group in the form of engineering designs, instructions and formulae but what is fundamental to drive LID implementation is "tacit knowledge" (interpretive, informal, and experiential). Tacit knowledge can be transferred to water practitioners through networking, collaboration, and continuing education. The two types of networks that are relevant to water practitioners are Community of Practice (CoPs), "a group of people who share an interest, craft, or profession" and social networks (ibid). Tables 10, 11 and 12 show how water practitioners can be leveraged for the implementation of LID across municipal jurisdictions.

Table 10 - Enabling Networking for Water Practitioners (Adapted from Maas and Wolfe 2012)

Recommendation	Rationale and Process
Form a Provincial Green Building Incentive Working Group (Provincial municipal innovators).	• Knowledge exchange & dialogue coordination with builders (majority of builders work across municipal jurisdictions) • Ensures adequate representation of LID technologies both in terms of professionals in the working group and within the incentive programs i.e. water is currently overshadowed by energy reduction initiatives
Establish a Provincial Rainwater Harvesting Community of Practice (to comprise of builders, educators, technology providers, architects, water managers, water efficiency and stormwater management practitioners.	• Replicates the network of rainwater harvesting experts established at the University of Guelph • Regular meetings facilitated by either a municipality, a service provider, academia, or a community organization • Objective is to share experiences, collaboratively identify research needs, policies, and community education on rainwater harvesting
Municipal staff to engage with existing CoPs outside their core profession.	• Water spans different municipal departments (economic development, planning, wastewater, building departments) • Break down internal silos • Exposure to new ideas, perspectives, and cultural norms that enable transitioning away from limiting beliefs about LID technologies
Look beyond the backyard by bringing together practitioners from different COPs but working towards a common goal.	• Breaks down external silos • Allows for challenges on one's knowledge obtained from political or geographical contexts that are different from others through exposure to practitioners with different approaches • Best accomplished through retreats, tours, conferences and site visits • Informal networking events like sharing a meal to take precedence over conferences and workshops

Table 11 - Collaborating with water practitioners (Adapted from Maas and Wolfe 2012)

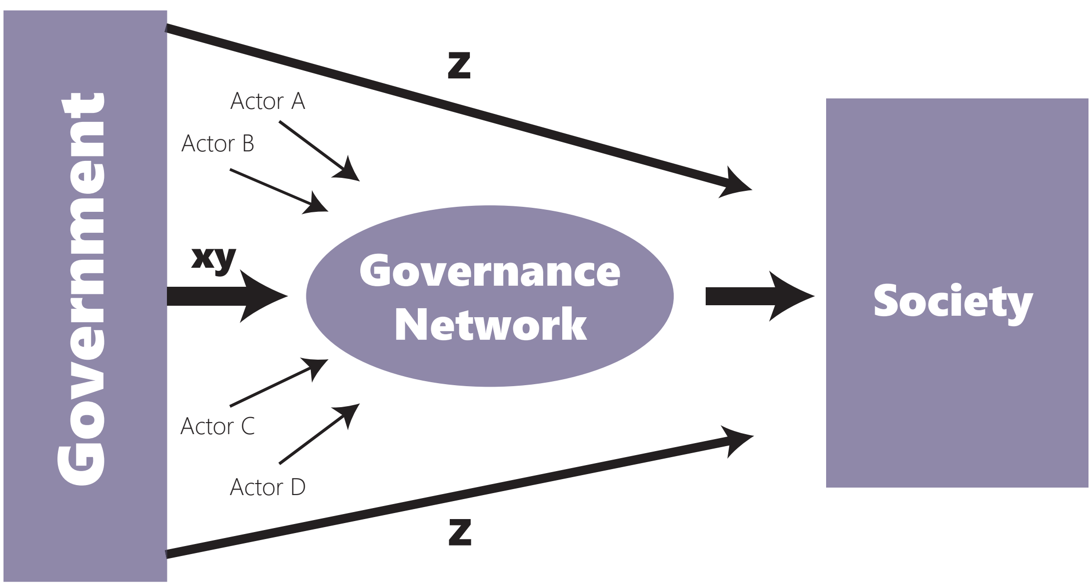
Partnership	Rationale
Municipal partnerships	• For joint social marketing campaigns to increase awareness of LID technologies. • Partnerships on piloting LID technologies, monitoring & production of guidelines. • Region of Waterloo, City of Cambridge, City of Guelph, City of Kitchener, and City of Waterloo have collaborated on educational campaigns to promote municipal tap water.
Create Municipal-Social Enterprise Partnerships	• Local enterprises and community organizations are a natural partner in delivering innovative municipal programs in a cost effective way. • Member organizations of Green Communities Canada are experienced in education programs. • Social enterprises like REEP Green Solutions have strong community connections and skills that need not be reinvented within government.
Water and Energy Utility Partnerships	• Utilities like Ontario Power Authority have mandates to improve energy efficiency. • Municipal water and wastewater treatment are high energy consumers and collaboration between water and energy utilities can be beneficial.
Partnerships with Academia	• Collaboration between the private sector, municipalities, and academia provides opportunities for risk sharing related to innovative projects infusion of new ideas and perspectives. • City of Guelph is collaborating with University of Guelph in installing and monitoring rainwater harvesting systems with a view for large-scale adoption.

Table 12 - Continuing education for water practitioners (Adapted from Maas and Wolfe 2012)

Association	Rationale
Building relationships with professional associations: local real estate associations, apartment, property, and condo management associations, landscape associations, and local plumbing association chapters.	• These are trade and professional associations with influence on end-use water decisions • They hold annual meetings for educational seminars that are prerequisites for members to attain professional certificates • Dialogue, relationship-building, and sharing water expertise with network hubs is fundamental to effective knowledge transfer and diffusion of innovation
Technical training of practitioners partnerships	• Rainwater Harvesting Training provided by Credit Valley Conservation, Toronto and Region Conservation Authority, and the Canada Green Building Council on a collaborative basis • LID Techniques Training offered by Green Roofs Industry association, Ontario Green Infrastructure Coalition, Green Communities Canada, and Credit Valley Conservation

pt 5. governance at the watershed scale

The literature review has shown that urban water management issues are best described as wicked problems landing themselves to high levels of complexity, uncertainty and multi-actor involvement Patterson et al. (2013), Cook et al. (2013). On the other hand, Salamon (2002) sees a "new approach to public problem solving" that places emphasis on the centrality of collaborative approaches to allow for multi-actor involvement of which the government is one of the actors. The most appropriate form for this governance is Networked Governance (shown in Figure 5).



x = tools applied by government to influence on networks as an entity
y = tools applied by whole networks to influence on society
z = tools applied by government to influence on society

Figure 5 - Tools of government applied at different levels (Adopted from Vabo and Roiseland 2012)

The question is how central authorities fulfill their mandates in such structures. Vabo and Røiseland (2012) addressed challenges faced by public leaders arising from new governance set-ups (networks) where government is just one of many stakeholders, thus rendering hierarchical approaches problematic.

An empirical assessment of whether "classic and generic analytical framework to tools of government" such as the NATO-scheme (ibid) is relevant in hierarchical contexts would be applicable in network relations. The conclusion is that, the NATO-scheme remains relevant to networked governance. NATO stands for the tools available to governments to influence networks to achieve public goals. These are nodality (where governments have influence by virtue of being at the center of the network). Authority refers to the legislative and regulative powers of governments while Treasure are the financial incentives or disincentives that they can apply to steer networks. Organization is the administrative capacity the government has to deliver services on its own.

According to Huppé et al. (2012), networked governance is a "decentralized integrative form of problem solving". Networked governance can leverage "distributed capacities" brought by different actors who can deploy their unique skills and resources to generate creative, collaborative, and complex solutions. Collaborative efforts are not guaranteed to succeed especially where social capital is deficient amongst stakeholders more so because the efficacy of network governance is a function of problem complexity and social capital. This creates an "efficacy paradox" (Figure 6), which determines how far centralized authorities get involved in controlling (actively steering) the networks.

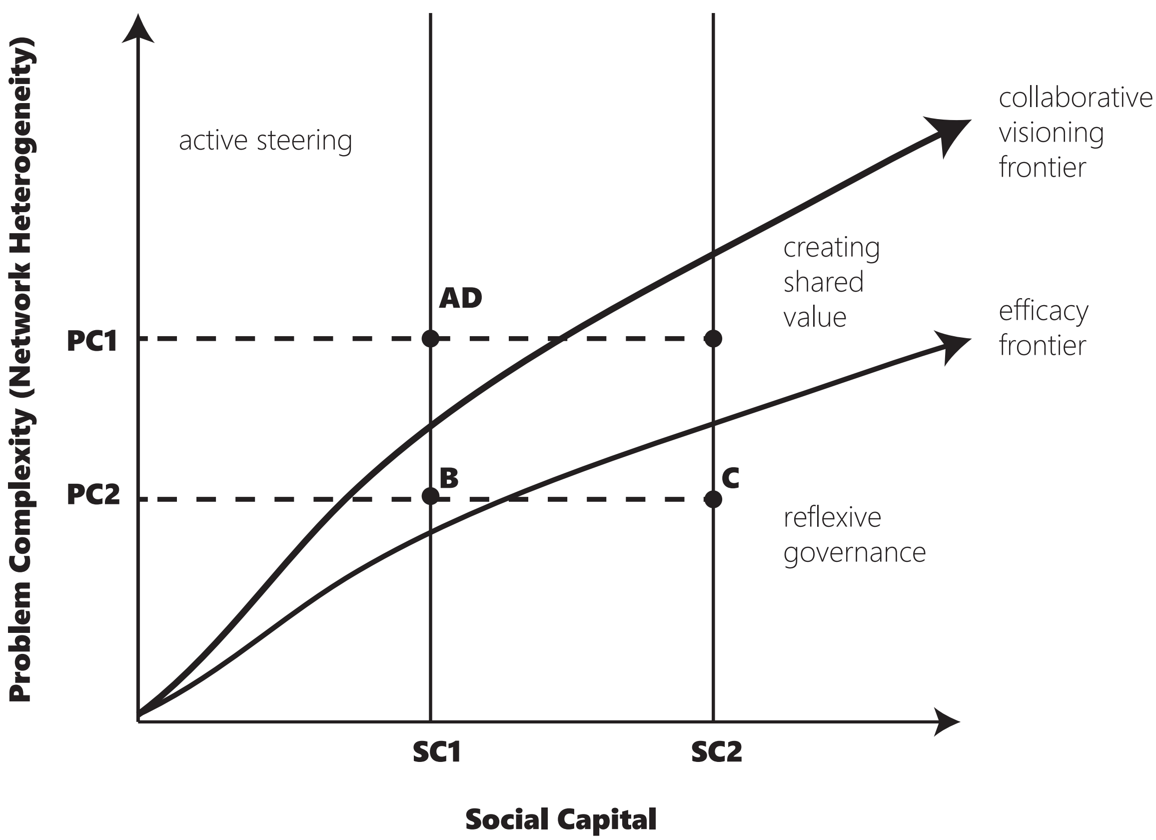


Figure 6 - The Frontiers of Networked Governance (Adapted from Huppe et al. 2012)

Where there is a balance between problem complexity and social capital, the networks can steer themselves with little top-down involvement. Table 13 summarizes the trade-offs between active and self-steering:

Table 13 - Summary of trade-off between active and self-steering (Adapted from Huppe et al. 2012

Problem	Applicable Tools
A: Insufficient social capital, inefficacy of collaborative processes	• Network management (policy & knowledge networks) • Active steering • Centralized problem solving
B: Social capital lies outside efficacy frontier but within collaborative visioning frontier	• Possibility of creating shared value • Use collaborative visioning processes • Adaptive governance and transition management – hybrid models between active steering and self-steering approaches • Modulated by centralized governance authorities
C: Same level of complexity as in B but higher levels of social capital	• Networked governance processes • Governance network has some capacity for self-steering • Decentralized power • Modulators partly distributed outside of centralized governance authorities • High investment of resources required to maintain this capacity
D: Complexity level as B Higher Social capital, not sufficient for networked governance, capacity for self-steering as in C	• Employ collaborative visioning processes as in B • Modulators partly distributed outside of centralized governance authorities • High investment of resources required to maintain this capacity

Engle et al. (2011) raises a fundamental water governance issue also addressed by networked forms of governance, that is, the limitations of hierarchical institutional arrangements and decision-making in an environment of uncertainty.

Two "institutional and management paradigms" seek to address these limitations, namely, Integrated Water Resources Management (IWRM) addresses the former, while Adaptive Management (AM) addresses the later.

According to Schoeman et al. (2014), IWRM provides a governance platform which allows for multiple-actor decision-making processes at watershed scales while AM enables decision-making in the face of uncertainty where policy is shaped through continuous feed-back loops that create "systemic experimentation and learning". AM thus has an inherently self-organizing ability (Engle et al. 2011).

Schoeman et al. (2014) adds a third governance arrangement, Ecosystem-based Approach (EBA), which provides adaptation to climate change with little risk. They term these three, "new water paradigm" approaches (ibid).

Integrating these systems seems looks advantageous as the strengths of each of these can be leveraged, producing systems that are more flexible, legitimate and accountable. The Brazilian water systems have exposed the gap between theory and practice which manifested itself in the form of "incomplete transitions" (Engle et al. 2011).

There is a paradox in that systems that did not fully transition but retained remnants of hierarchical and technical mechanisms like "technical bodies and sectoral dominance" are capable of rapid decision making when the need arises. Those that have fully transitioned into "deliberative, participatory and pluralistic forms" seem to struggle. The conclusion is that there needs to be trade-offs between democratic decision-making and technical knowledge (ibid). An interesting case that seems to apply this valuable lesson is that of the Lakeview Neighbourhood Bioretention Road Right-of-Way (ROW) retrofit located in Mississauga (Credit Valley Conservation 2014). An organic decision making process was applied through the combination of both technical and public knowledge where municipal technical requirements were adhered to but wherever there were unresolved issues, public feedback was used for final resolution.

A detailed bottom-up study was carried out by the Water Policy and Governance Group at the University of Waterloo with findings that are pertinent to the Canadian environment (de Loe and Murray 2012). From a historical perspective, Canada followed a top-down approach where governments were central actors in decision making. Emerging trends show growing reliance on economic instruments, partnerships, multi-stakeholder councils, and shared and collaborative governance.

Despite this trend, governments have retained their role as central actors because these roles are constitutionally determined (Sandford 2011). Such a scenario has created a situation where delegated responsibility does not include corresponding decision-making authority and it is imperative to accept that authority for decision making should be located within the Provincial and Federal governments as a fait accompli. Doing otherwise compromises the concept of legitimacy and accountability.

There is need to ensure legislative fragmentation does not lead to governance paralysis, hence "strong coordinating institutions that clarify roles and responsibilities for key players; inclusive, transparent, and accountable governance structures; and sufficient funding" are an imperative Cook (2011). The first step in this direction is a macro-level approach by the Federal government to coordinate interprovincial integration of water management by reviving the 1987 Federal Water Policy (Robins 2007, Cook 2011). The Federal government can replicate the successes under the Canada-wide Strategy for the Management of Municipal Wastewater Effluents, an initiative through the Canadian Council of Ministers of the Environment (CCME) (Cook 2011).

At a provincial level, significant infrastructures in the form of policy frameworks already exists and this according to Robins (2007) are the building blocks that can be evolved into a coordinating and integrating framework across provinces (Table 14).

Table 14 - Existing infrastructure for an inter-provincial framework (Adapted from Robins 2007)

Province	Policy Framework
Quebec	• Water Policy (2002)
Alberta	• Water for Life Strategy (2003)
Ontario	• Clean Water Act (2006)
British Columbia	• Living Water Smart (2008)
Northwest Territories	• Water Stewardship Strategy (2009)
Nova Scotia	• Water Strategy (2010)

Institutions like the CCME, Council of the Federation, and Federation of Canadian Municipalities are instrumental in coming up with these overarching policy frameworks.

Both de Loë and Murray (2012) and Sandford (2011) suggest a workaround exists in addressing implementation problems arising from collaborative approaches. A policy framework that aids collaborative processes should be put in place so that a "safety net" is provided in case collaborative processes fail. (This is great for dealing with political risk). Memorandums of Understanding (MOUs) which provide clarity to "the purpose of collaboration and how outcomes would be implemented by governments and other actors" are an alternative to policy frameworks. Governance should be coordinated across Canadian provinces and this can be done through the Council of the Federation and the Canadian Council of Ministers of the Environment according to Sandford (2011).

Governance around watersheds raises the problem of legitimacy which in this respect has two perspectives, one with regards to "legislated legitimacy" and the other, "social legitimacy." Elected representatives bring legislated legitimacy to the decision-making process. But there is also an imperative to bring social legitimacy to the decision-making process in watershed governance which is fraught with complexity and fragmentation. Incorporating multiple stakeholders is a means to building this legitimacy (de Loë and Murray 2012) but it is also imperative to take cognizance of lesions from the water management systems in Brazil (Engle et al. 2011).

pt 6. risk management: climate & political risk

6.1 ESTABLISHING AN ACCEPTABLE LEVEL OF RISK

Managing climate risk entails the integration of top-down (leadership directed) and bottom-up (grassroots) approaches (NASA 2013). Leadership focuses on policy coordination while the grassroots focus on "site specific, locally-led initiatives". Best available science is continuously evolving, creating an imperative to allow for the evolution of site-specific adaptation (ibid). Both NASA (2013) and Beller-Simms et al. (2014) suggest a paradigm that encourages the adoption of "flexible adaptation pathways" such that "a continuous, dynamic consideration of risk tolerances and corresponding policies" is provided. Such flexible adaptation pathways are established within the bounds of "Acceptable Risk" (as shown in Figure 7).

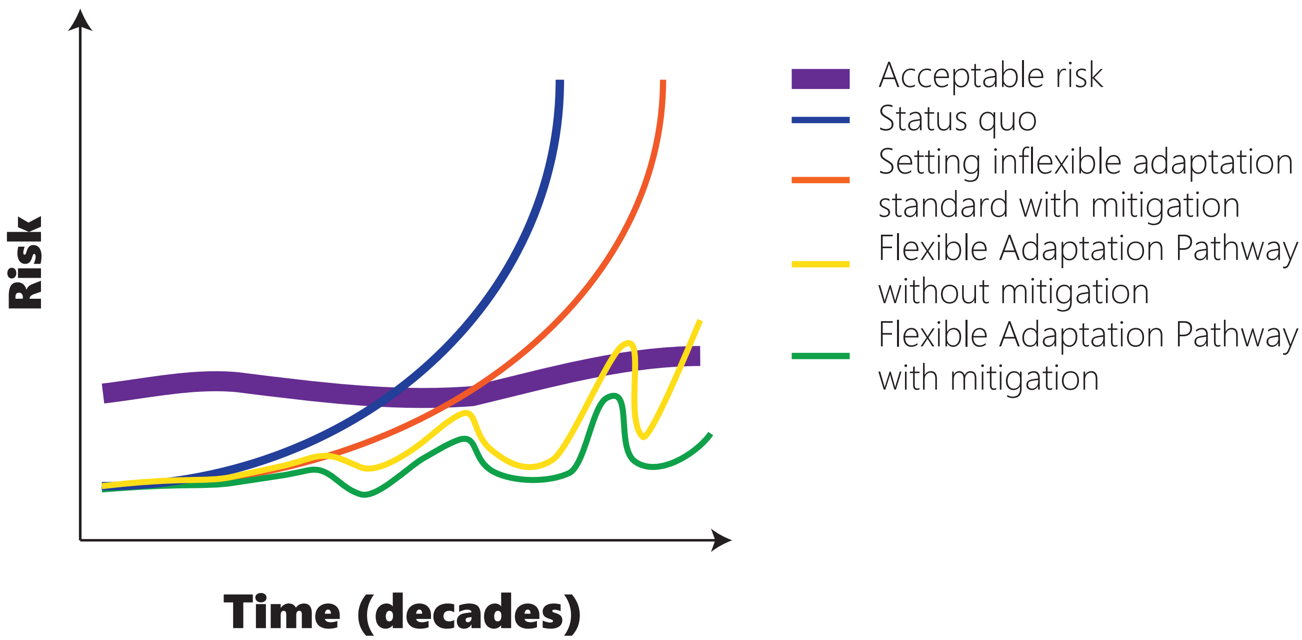


Figure 7 - Flexible adaptation pathways (Adapted from Beller-Simms et al. 2014)

The levels of acceptable risk are defined this level becomes the "target threshold" (ibid). Communities are not locked into long-term strategies as a result of imperfect information but they can adapt as accurate information becomes available. This implies that site specific information should be provided to local communities bringing into play the role of local universities and research institutions (ibid) and effectively combining science and policy.

Ferguson et al. (2013) encourages the recognition that societal values are not permanent as they evolve through "contextual drivers like resource limitations, environmental impacts, and socio-economic conditions." Since these factors cannot be controlled, it follows that the underlying integrating structure and relationship is not fixed, but must incorporate flexibility to enable adaptation when new conditions arise. Municipal water systems cannot be protected from all forms of risk. This implies that these systems should be enabled with in-built resilience capabilities to confront future extremes and surprises.

Some strategies for embedding resilience into municipal water systems include "diverse portfolio of water sources" and "smart integrated and connected water grids that allow self-sufficiency and fit-for-purpose water to meet demands" (ibid). This goes a long way in aiding communities establish acceptable risk.

6.2 SCENARIO PLANNING

Developing acceptable risk levels is indispensable from scenario planning. Rankin-Gouthro and Krantzberg (2011) employ a planning technique of scenario building as a means of describing different future scenarios and related outcomes. By examining the fundamental "what can happen if..." question, the approach acts as a driver enabling disparate stakeholders in "setting the foundation for desired policy and management outcomes".

Ferguson et al. (2013) refers to "explorative scenario techniques" that focus on the long-term so that municipal water systems are not "locked into current generations of technology". Also as per Rankin-Gouthro and Krantzberg (2011) scenarios facilitate the creation of a common language that can be used by different expert groups. An example is where science and policy domains approach issues from different perspectives with scientists from a resource perspective whilst policy makers start with "social consequences of resource decisions". "Actor-focused scenarios are based on group participation with an emphasis on the actors involved, their relationship to the environment and their interpretation of events (ibid).

According to Means III et al. (2010) for municipality water systems to address the risks posed by climate change, a transition from conventional planning assuming climate stationarity to "uncertainty-based planning" is required. Scenario-based planning is ideal for such a transition to occur. Such transitions imply transitioning from classic decision analysis approaches where occurrences are assigned probabilities to a situation where all scenarios are treated as likely to occur. Adaptation strategies for each scenario are developed and it is prudent to adopt those strategies that have "near term actions that are common to all or most scenarios."

This is the essence of "No Regrets or Low Regrets strategies" which are "robust across multiple outcomes." Such strategies have the advantage of reducing risk from climate change at the same time they address other co-beneficial objectives of municipal water systems (IPC 2012). Because climate change impacts are already being felt by municipal water systems, a sense of urgency is created which originates from the fact that municipal infrastructure is long lasting and hence the necessity to include climate change in early design and operations decisions. Investing early in No and Low Regrets becomes imperative. Projects fitting in this are:

- Water efficiency.
- Treating water to be "fit for purpose" where non-portable supplies, reuse, recycled water projects and programs to stretch portable supplies (ibid).

6.3 THE PRECAUTIONARY PRINCIPLE

In the case of Canada Ltee (Spraytech, Societe d'arrosage) v. Hudson (Town), 2001 SCC 40 the Supreme Court of Canada endorsed the precautionary principle, "the idea that policy makers should act to protect human health and the environment even in the face of uncertainty" Pralle (2006). Political risk can be handled through this principle since it provides some legal basis for potentially risky undertakings like LID projects which may fail on implementation.

6.4 PILOTING

Morrison et al. (2012) raises the importance of a "strategic but incremental process of piloting" so that evaluations and comparisons of watershed-based public health initiatives can be tested for viability. Farrelly and Davis (2009) use the term demonstration projects and assert that they act as "bounded experiments, trialling the application of structural innovations, such as technology, infrastructure, or science…" These piloting projects are critical in providing new insights into how technologies contribute to the enhancement of existing practices. Through piloting, communities build on others' experiences and they fill existing knowledge gaps including pitfalls. Because of low political risks, lessons learnt under safe conditions can significantly help in the uptake of LID technologies.

According to Binstock (2011), barriers to the uptake of LID technologies and can be addressed through creation of substantial performance database of the various LID technologies. The study conducted a jurisdictional review which indicated that implementation barriers will be overcome through alleviation of risk faced by municipalities. This is possible through funding pilot projects across provinces to generate performance data that is regionally specific.

6.5 OPPORTUNITIES

Canada is the world's "largest repository of fresh water" and this resource can be leveraged for economic opportunities including "development of fresh water technology (Rankin-Gouthro and Krantzberg 2011). Henderson and Parker (2012), also states that Canada's water treatment technology sector has international acclaim.

According to the Federation of Canadian Municipalities (2011), the global green economy is estimated to be in excess of US$4 trillion whist the Canadian sustainability market is projected to grow from $2 billion in 2010 to $4 billion by 2014.

Henderson and Parker (2012) assert that current infrastructure can be upgraded to meet current demand, but future demand will require water infrastructure to shift away from "large-scale centralised engineering projects to small-scale technologies and practices..." that can be deployed in households. Wastewater treatment and reuse, rain harvesting, and LID technologies such as urban wetlands that slow stormwater runoff and filter pollutants. These solutions create green jobs in areas like plumbing, manufacturing, and urban design and planning.

Crane (2013) discusses a "Growth path to 2050" where an additional two billion people, are a "game-changing new wave of consumers" and its implications on demand for clean water and sanitation. Demand for municipal water will rise by 80 billion cubic metres by 2025 from 190 billion cubic metres, a 40% increase from current levels (ibid). A significant growth will be in the world's "Emerging 440 Cities" which will need access to advice on infrastructure planning and implementation. The global market is large and expanding currently stands at US500 billion per annum and is poised to reach US$1 trillion per annum. Canada should indeed develop its water technology potential in terms of LID and take advantage of this huge emerging market.

Some of the economic benefits are pointed out in Martin-Downs (2010) where a study by Ryerson University shows that retrofitting green roofs throughout Toronto has benefits amounting to about $313 million in stormwater, combined sewer overflow, air quality, building energy and urban heat island and cost savings of about $37 million every year. Further to that, wetlands, forests and watercourses of the Credit River in excess of $371 million in water filtration and regulation of water supply. It is also estimated that taxpayers save $100 million in differed water pumping costs from Lake Ontario.

pt 7. conclusion

Municipal water systems have evolved through history driven by socio-political paradigms that led to unsustainable path dependences that disregarded the hydrologic cycle. Urban development created high levels of impervious surfaces that dramatically altered the hydrologic cycle by increasing the proportion of surface runoff flowing into stormwater systems into receiving water bodies and conveying pollutants into drinking water systems. The result has been threats to human health and well being of Canadians creating the imperative for effective responses to these threats.

Climate change is compounding these negative impacts thereby compelling municipal water systems to transition to sustainable practices like integrating risk management through LID technologies applied at watershed scales, across municipal jurisdictions, and across sectors that although they are outside the purview of municipal water systems; they play a significant role in impacting these systems.

Although the solutions are technically feasible, barriers to implementation are located in the institutional domain which can be enabled through collaborative and multi-actor approaches. The governance implication is that the implementation of LID practices across municipal jurisdictions is best accomplished using the model of Conservation Authorities as the coordinating mechanism for networked governance and the watershed as the defacto management unit. This entails establishing an overarching framework at the Federal level for a Canada-wide water management vision and the creation of a coordinating framework across provinces to reflect the Canada-wide vision.

pt 8. recommendations

This research provides background information on integrating risk faced by municipality water systems. Municipalities provide direct services to their communities and it is necessary that actionable information be provided.

It is therefore recommended that the next phase of this research be based on practical data gathered from a watershed wide case study especially from working primarily with a conservation authority and a sample of municipalities on the downstream and upstream of a watershed. The primary purpose is to provide practical answers to the following gaps:

- Lessons from international jurisdictions on overarching frameworks.
- Clarity on how the CA model will interface with the 3 levels of government, namely: Federal, Provincial/Territory, and Municipal.
- Identify an organizational chart clearly showing the hierarchical structure including the lowest levels.
- How is the Board of Directors constituted and what are the term limits if any and how are lower levels governed?
- What protects the model from political changes both at the Federal and Provincial levels?
- Aspects of approaches in other provinces and territories that can be integrated into the current CA model for a Canada-wide authority.
- How will Provincial variations be accommodated?
- Criteria for stakeholder classification and selection.
- Public engagement processes.
- Prioritization and selection of LID projects across municipal jurisdictions.

references

Beller-Simms, Nancy, Erica Brown, Lauren Fillmore, Katy Lackey, Karen Metchis, Kenaa Ozekin, and Claudio Ternieden. 2014. "Water/wastewater Utilities and Extreme Climate and Weather Events: Case Studies on Community Response, Lesions Learned, Adaptation, and Planning Needs for the Future. Project No. CC7C11 by the Water Environment Research Foundation: Alexandria, VA."

Binstock, Matt. 2011. "Greening Stormwater Management in Ontario: An Analysis of Challenges and Opportunities." Canadian Institute for environmental law and policy. www.cielap.org.

Brown, Rebekah, Nina Keath, and Tony Wong. 2008. "Transitioning to Water Sensitive Cities: Historical, Current and Future Transition States." In 11th International Conference on Urban Drainage. Vol. 10. http://web.sbe.hw.ac.uk/staffprofiles/bdgsa/11th_International_Conference_on_Urban_Drainage_CD/ICUD08/pdfs/618.pdf.

Campbell, Jackie, Dianne Saxe, and Frank Zechner. 2007. "Municipal Liability for Sewer and Water Pipe Failures... Despite Statutory Authority and Immunity." OSWCA.

Chilima, Jania S., Jill A.E. Gunn, Bram F. Noble, and Robert J. Patrick. 2013. "Institutional Considerations in Watershed Cumulative Effects Assessment and Management." Impact Assessment and Project Appraisal 31 (1): 74–84. doi:10.1080/14615517.2012.760227.

Conservation Ontario. 2010. Integrated Watershed Management: Navigating Ontario's Future. Water Management Framework. http://books.scholarsportal.info/viewdoc.html?id=577597.

Conservation Ontario. 2012. "Watershed Management Futures for Ontario: Conservation Ontario Whitepaper." http://books.scholarsportal.info/viewdoc.html?id=577634.

Cook, Christina L. 2011. "Putting the Pieces Together: Tracing Jurisdictional Fragmentation in Ontario Water Governance."

Crane, David. 2013. "Canada as the Water Solutions Country: Defining the Opportunities." Blue Economy Initiative. http://www.blue-economy.ca.

Credit Valley Conservation (CVC). 2014. "Grey to Green Road Retrofits: Optimizing Your Infrastructure Assets through Low Impact Development." www.bealeader.ca.

CVC and TRCA. 2010. "Low Impact Development Stormwater Management Planning and Design Guide Version 1.0." www.bealeader.ca.

De Loë, Rob, and Dan Murray. 2012. "Governance for Source Water Protection in Canada Synthesis Report. Waterloo, ON: Water Policy and Governance Group." www.governanceforwater.ca.

De Loë, Rob, Georgia Simmins, and Deb Lightman. 2010. "Tools and Approaches for Source Water Protection in Canada. Governance for Source Water Protection in Canada, Report No. 1. Waterloo, ON: Water Policy and Governance Group." www.governanceforwater.ca.

Dobbie, Meredith Frances, Katie Louise Brookes, and Rebekah Ruth Brown. 2014. "Transition to a Water-Cycle City: Risk Perceptions and Receptivity of Australian Urban Water Practitioners." Urban Water Journal 11 (6): 427–43. doi :10.1080/1573062X.2013.795235.

Engle, Nathan L., Owen R. Johns, Maria Carmen Lemos, and Donald R. Nelson. 2011. "Integrated and Adaptive Management of Water Resources: Tensions, Legacies, and the next Best Thing." Ecology and Society 16 (1): 19.

Farrelly, Megan, and Caitlin Davis. 2009. "Demonstration Projects: Case Studies from Melbourne, Australia." www.urbanwatergovernance.com.

Federation of Canadian Municipalities. 2011. "Building Canada's Green Economy: The Municipal Role." www.fcm.ca.

Ferguson, Briony C., Rebekah R. Brown, Niki Frantzeskaki, Fjalar J. de Haan, and Ana Deletic. 2013. "The Enabling Institutional Context for Integrated Water Management: Lessons from Melbourne." Water Research 47 (20): 7300–7314. doi:10.1016/j.watres.2013.09.045.

Ferguson, Briony C., Niki Frantzeskaki, and Rebekah R. Brown. 2013. "A Strategic Program for Transitioning to a Water Sensitive City." Landscape and Urban Planning 117 (September): 32–45. doi:10.1016/j.landurbplan.2013.04.016.

Floyd, Joshua, Benjamin L. Iaquinto, Ray Ison, and Kevin Collins. 2014. "Managing Complexity in Australian Urban Water Governance: Transitioning Sydney to a Water Sensitive City." Futures 61 (September): 1–12. doi:10.1016/j.futures.2014.04.002.

Henderson, David, and Nicholas R. Parker. 2012. "The Blue Economy: Risks and Opportunities in Addressing the Global Water Crisis." Blue Economy Initiative.

Huppé, Gabriel A., Heather Creech, and Doris Knoblauch. 2012. The Frontiers of Networked Governance. International Institute for Sustainable Development. http://www.ecologic.eu/files/attachments/Publications/2012/frontiers_networked_gov.pdf.

IBC. 2014. "IBC Facts: Canada's P&C Insurance Industry, All Sectors." http://www.ibc.ca/en/Need_More_Info/Facts_Book/.

IPCC. 2012. Summary for Policy Makers In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds)]. A Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

Maas, Carol, and Sarah E. Wolfe. 2012. "Building Professional Capacity for a Water-Sensitive Future in Ontario." POLIS Project on Ecological Governance. http://books.scholarsportal.info/viewdoc.html?id=578471.

Martin-Downs, Deborah. 2010. "One Water: Supporting Watershed Management and Green Infrastructure in Ontario Policy." Ontario Water Conservation Alliance. http://books.scholarsportal.info/viewdoc.html?id=380004.

Means III, Edward, Maryline Laugier, Jennifer Daw, Laurna Kaatz, and Marc Waage. 2010. "Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning." Water Utility Climate Alliance.

Millenium Ecosystem Assessment. 2005. "Ecosystems and Human Well-Being: Synthesis." Island Press, Washington, DC.

Mirza, Saeed. 2007. Danger Ahead the Coming Collapse of Canada's Municipal Infrastructure. Ottawa, Ont.: Federation of Canadian Municipalities. http://www.deslibris.ca/ID/250220.

Mitchell, Bruce, Charles Priddle, Dan Shrubsole, Barbara Veale, and Dan Walters. 2014. "Integrated Water Resource Management: Lessons from Conservation Authorities in Ontario, Canada." International Journal of Water Resources Development 30 (3): 460–74. doi:10.1080/07900627.2013.876328.

Morrison, K. E, M. W Parkes, L. H Hallström, R. C Neudoerffer, M. J Bunch, and H. D Venema. 2012. Ecohealth and Watersheds Watersheds as Settings for Health and Well-Being in Canada. Winnipeg, Man.: Network for Ecosystem Sustainability and Health (Publication Series No. 3) and the International Institute for Sustainable Development, Winnipeg, MB. http://www.iisd.org/pdf/2012/ecohealth_watersheds_canada.pdf.

Munang, Richard, Ibrahim Thiaw, Keith Alverson, Musonda Mumba, Jian Liu, and Mike Rivington. 2013. "Climate Change and Ecosystem-Based Adaptation: A New Pragmatic Approach to Buffering Climate Change Impacts." Current Opinion in Environmental Sustainability 5 (1): 67–71. doi:10.1016/j.cosust.2012.12.001.

NASA. 2013. "Climate Risk Management Plan & Report."

Norman, Emma, Karen J Bakker, Christina Cook, Gemma Dunn, and Diana Allen. 2010. Water Security: A Primer. Vancouver, B.C.: Program on Water Governance, University of British Columbia. http://site.ebrary.com/id/10425633.

Parkes, Margot W., Karen E. Morrison, Martin J. Bunch, Lars K. Hallström, R. Cynthia Neudoerffer, Henry D. Venema, and David Waltner-Toews. 2010. "Towards Integrated Governance for Water, Health and Social–ecological Systems: The Watershed Governance Prism." Global Environmental Change 20 (4): 693–704. doi:10.1016/j.gloenvcha.2010.06.001.

Porter-Bopp, Susanne, Oliver M. Brandes, and Calvin Sandborn. 2011. Peeling Back the Pavement: A Blueprint for Reinventing Rainwater Management in Canada's Communities. Victoria, B.C: POLIS Project on Ecological Governance. http://books.scholarsportal.info/viewdoc.html?id=413105.

Pralle, Sarah. 2006. "The 'mouse That Roared': Agenda Setting in Canadian Pesticides Politics." Policy Studies Journal 34 (2): 171–94.

Rankin-Gouthro, Erin E., and Gail Krantzberg. 2011. "The Lorax Can Win: Using Scenario Building to Create A New Vision and Invigorate An' Activist' Agenda for the Great Lakes St. Lawrence Basin." Electronic Green Journal 1 (31). https://escholarship.org/uc/item/3s20t46r.

Rupert, Allen. 2010. "Water and the Future of the Canadian Economy." Innovolve Group. http://books.scholarsportal.info/viewdoc.html?id=547954.

Salamon, Lester M. 2002. "The Tools of Government: A Guide to the New Governance." Oxford University Press.

Sandford, Bob. 2011. "Climate Change Adaptation and Water Governance: Summary for Decision Makers." Simon Frazer University. http://books.scholarsportal.info/viewdoc.html?id=499060.

Schoeman, Jess, Catherine Allan, and C. Max Finlayson. 2014. "A New Paradigm for Water? A Comparative Review of Integrated, Adaptive and Ecosystem-Based Water Management in the Anthropocene." International Journal of Water Resources Development 30 (3): 377–90. doi:10.1080/07900627.2014.907087

Schreier, Hans. 2012. "Innovative Storm Water Management: Translating Science into Actions." Canadian Water Network.

United Nations. 1987. "Report of the World Commission on Environment and Development: Our Common Future."

Vabo, Signy Irene, and Asbjørn Røiseland. 2012. "Conceptualizing the Tools of Government in Urban Network Governance." International Journal of Public Administration 35 (14): 934–46. doi:10.1080/01900692.2012.691243.

Vander Ploeg, Casey G. 2011. "Water Pricing: Seizing a Public Policy Dilemma by the Horns." Canada West Foundation. http://books.scholarsportal.info/viewdoc.html?id=412502.

Voora, Vivek, and Henry D. Venema. 2008. "An Ecosystem Services Assessment of the Lake Winnipeg Watershed." International Institute for Sustainable Development. http://books.scholarsportal.info/viewdoc.html?id=31700.

Winz, Ines, Sam Trowsdale, and Gary Brierley. 2014. "Understanding Barrier Interactions to Support the Implementation of Sustainable Urban Water Management." Urban Water Journal 11 (6): 497–505. doi:10.1080/1573062X.2013.832777.

Zubrycki, Karla, Dimple Roy, Henry D. Venema, and David Brooks. 2011. "Water Security in Canada: Responsibilities of the Federal Government." International Institute for Sustainable Development. http://books.scholarsportal.info/viewdoc.html?id=399590.

APPENDIX A

Impact of Land Urbanization

Land urbanization changes the precipitation proportion infiltrating into the ground, and evaporates into the atmosphere to enter drainage features as runoff because of land use change.

Ecosystem responses to urbanization (Source - CVC and TRCA 2010)

Results of Increased Imperviousness	Resulting Impacts					
	Flooding and Altered Stream Flows	Habitat Loss	Erosion and Sedimentation	Channel Widening	Streambed Alteration	Water Quality
Increased Flow Volume	x	x	x	x	x	x
Increased Peak Flow	x	x	x	x	x	x
Increased Peak Duration	x	x	x	x	x	x
Increased Stream Temperature		x				x
Decreased Base Flow	x	x				x
Sediment Loading Changes	x	x	x	x	x	x

Major sources of common stormwater pollutants (Source - CVC and TRCA 2010)

Common Constituents	Major Sources Related to Urban Land Use
Sediment and Particulates	Construction, winter road sanding, vehicle emissions, pavement weat
Hydrocarbons (PAHs)	Spills, leaks, dumping, vehicle emissions, asphalt breakdown, wood preservatives
Pathogens (Bacteria, Viruses)	Illicit connection of septic system to storm sewers, poor housekeeping (animal feces bird feces from rooftops)
Chloride, Sodium, Calcium	De-icing salt applications
Cyanide	Anti-caking agent in de-icing salts and sa;t/sand mixtures
Nutrients (N, P)	Illicit connection of septic systems to storm sewers, detergents (car washing), lawn fertilizers
Cadmium	Tire wear, insecticides, wood preservatives
Zinc	Galvanized building materials, tire wear, motor oil, grease
Lead	Motor oil, lubricants, batteries, bearing wear, paint, vehicle exhaust
Copper	Wear of moving engine parts, metal plating, fungicides and insecticides
Manganese	Wear of moving engine parts
Nickel	Vehicle exhaust, lubricants,, metal plating, wear of moving parts
Chromium	Metal plating, wear of moving parts
Iron	Steel structures, rusting of automobile bodies
PCBs	Leaks from electrical transformers, spraying of highway right of ways, catalyst in tire constrcution.

APPENDIX B

Ecosystem services with contextual relevance to Southern Manitoba

Ecosystem Services Examined (Voora and Venema 2008)

Contextual Reference	Ecosystem Service	Descriptor (Function)
Water Quantity and Quality - Lake Winnipeg Eutrophication	Water Regulation	Regulation of water flows, which entrains pollutants and purifies water (Regulating).
	Water Supply	Filtering, retention and storage of fresh water (Provisioning)
	Erosion control and sediment retention	Maintains arable land and prevents water silting by lowering soil losses by wind and runoff (Regulating)
	Waste Treatment	Removal breakdown or abatement of pollutants (Regulating)
Climate Change	Atmospheric regulation	Regulation of atmospheric compositions by various processes such as carbon sequestration (Regulating)
	Climate regulation	Influence of land covers on climate (temperature, precipitation, etc.) (Regulating)
Biodiversity	Biological control	Control of populations, pests and diseases through tophic-dynamic processes (Regulating)
	Habitat/Refugia	Suitable living space for species to evolve and breed (Supporting)
Material Benefits	Food production	The conversion of solar energy into edible plants and animals suitable for human consumption (Provisioning)
	Raw materials	Conservation of solar energy into materials suitable for construction (Provisioning)
	Genetic resources	Genetic evolution in plants and animals (Provisioning)
Social Well-being	Disturbance prevention	Dampening of environmental disturbances such as storm protection and flood prevention (Regulating)
	Recreation	Opportunities for recreation, relaxation, and refreshment (Recreation)
	Cultural	Spiritual, religious, historical and symbolic values (Cultural)
Environmental Integrity	Soil formation	Rock weathering and organic matter accumulation leading to the formation of productive soils (Supporting)
	Nutrient cycling	Storage processing and acquisition of nutrients within the biosphere (Supporting)
	Pollination	Movement of plant genes for reproduction (Supporting)

APPENDIX B (con.)

Summary of the current and pre-settlement landscape ecosystem service values by land cover and contextual relevance in 2007 billion CDN $/year (Voora and Venema 2008)

Land Cover and Contextual Relevance (ESV ranges in CDN $/hectare/year)	Current Land-scape	Pre-Settlement Landscape 1	Pre-Settlement Landscape 2	Pre-Settlement Landscape 3
Forests (65.15 - 677.43)	0.05 - 0.54	0.12 - 1.21	0.14 - 1.46	0.10 - 1.08
Wetlands (939.10 - 1,567.47)	0.21 - 0.35	1.06 - 1.76	0.47 - 0.78	0.33 - 0.55
Water Bodies (0.00)	0.00	0.00	0.00	0.00
Praries (25.17 - 50.61)	0.03 - 0.06	0.06 - 0.11	0.06 - 0.12	0.07 - 0.13
Agricultural Land (12.59 - 25.31)	0.04 - 0.08	0.00	0.00	0.00
Built-up (0.00)	0.00	0.00	0.00	0.00
Other (0.00)	0.00	0.00	0.00	0.00
Land Cover Type Total	**0.33 - 1.03**	**1.23 - 3.08**	**0.67 - 2.37**	**0.50 - 1.75**
Water Quantity and Quality (923.75 - 985.23)	0.21 - 0.23	1.04 - 1.11	0.46 - 0.49	0.33 - 0.35
Climate Change (49.88 - 662.26)	0.08 - 0.56	0.08 - 1.17	0.09 - 1.41	0.08 - 1.05
Biodiversity (27.29 - 301.85)	0.02 - 0.08	0.05 - 0.36	0.06 - 0.20	0.01 - 0.15
Material Benefits (3.29 - 323.29)	0.00 - 0.12	0.01 - 0.37	0.01 - 0.20	0.01 - 0.15
Social Wellbeing (37.80 - 48.30)	0.02 - 0.04	0.05 - 0.07	0.05 - 0.07	0.04 - 0.06
Environmental Integrity (0.00)	0.00	0.00	0.00	0.00
Contextual Relevance Total	**0.33 - 1.03**	**1.23 - 3.08**	**0.67 - 2.37**	**0.50 - 1.75**

APPENDIX C

Barrier Strength Calculations:

The PTS comprises of an upper and lower catchment areas where the later consists of native forest regeneration and semi-pastoral land use whilst the former contains low-medium density residential areas together with commercial land use. This is a case study of an environmental restoration and stormwater management project whose aim was to strengthen communities by reconnecting residents with their local environment. Forty-five barriers were identified and grouped into 11 categories.

A pair-wise comparison between the individual barriers was done to determine the influence strengths between barrier categories which was calculated as a percentage and ranked as shown in the following table (source - Winz et al. 2014):

%	Rank	Category Pair	%	Rank	Category Pair	%	Rank	Category Pair
100	1	Political to legal	55	18.5	Internal to Education	35	35	Financial to Political
92	2	Legal to Structural	55	18.5	Resource to Structural	34	36	Internal to Resource
83	3	Communication to Legal	54	20	Internal to Political	33	37	Resource to Legal
81	4	Structural to Communication	53	21	Political to Internal	30	39.5	Education to Resource
80	5.5	Communication to Resource	50	23	Communication to Structural	30	39.5	Resource to Financial
80	5.5	Resource to Education	50	23	Education to Political	30	39.5	Resource to Internal
75	7.5	Education to Communication	50	23	Technical to Structural	30	39.5	Political to Financial
75	7.5	Political to Communication	47	25	Legal to Resource	29	42	Financial to Internal
70	9	Resource to Communication	45	26	Political to Structural	25	45	Structural to Financial
67	10	Structural to Legal	44	27.5	Resource to Political	25	56	Internal to Financial
65	11	Communication to Political	44	27.5	Political to Resource	25	56	Structural to Political
63	12	Education to Structural	43	29	Internal Communication	25	56	Financial to Legal
60	13.5	Legal to Political	42	30	Legal to Communication	25	56	Legal to Financial
60	13.5	Structural to Resource	40	31	Political to Education	20	48	Financial to Resource
57	15.5	Education to Internal	39	32	Communication to Internal	0	50	Internal to Physical
57	15.5	Technical to Internal	38	33.5	Financial to Structural	0	50	Structural to Physical
56	17	Communication to Education	38	33.5	Structural to Education	0	50	Education to Legal

Normalizes % of barrier interactions between two categories
= Existing interactions/All possible interactions
e.g. Financial = 4 & Political = 5

- There are 20 possible directions in one direction.
- Only 7/20 are considered
- Interaction strength = 35%

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