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Best practices guide:

Management of inflow and infiltration in new urban developments

By Ted Kesik

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By Ted Kesik, University of Toronto

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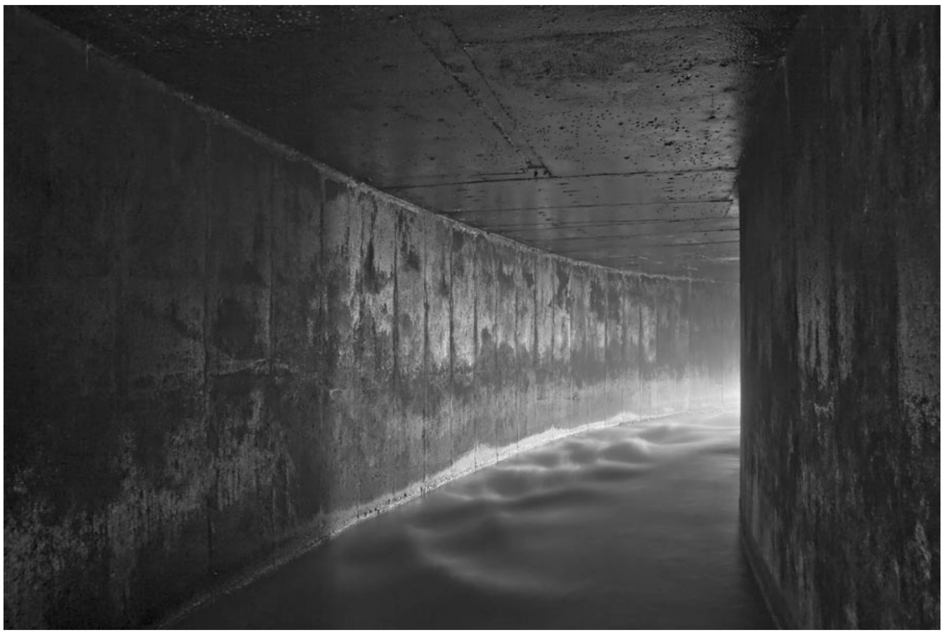

In many ways, inflow and infiltration in new sanitary sewer systems
are a barometer of the quality, care and stewardship
underlying the municipality, its system of governance,
the community's planning vision and its infrastructure engineering excellence.
What can be said about a 21st century civilization that
cannot properly design, construct and sustain its vital infrastructure?
Hopefully, it is a question that should not have to be answered
by future generations of Canadians.

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[Source: City of Halifax.]

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Foreword

As Canada's urban settlements intensify and expand their populations, the role of municipal infrastructure for the management of water, wastewater and stormwater will become ever more critical, potentially exerting unsustainable financial pressures on municipalities, while placing environmental stresses on our water resources and the ecosystem. Among the many problems confronting municipalities is the management of inflow and infiltration (I&I) into sanitary sewer systems. This uncontrolled migration of water causes problems such as the backup of sewers into the buildings they serve, and the need to treat higher volumes of wastewater that has become diluted and hence more costly to treat. For existing developments, both with combined and separated sewer systems, the inflow of stormwater and the infiltration of groundwater into sanitary sewers pose formidable challenges to municipal engineers seeking to remediate and rehabilitate existing infrastructure. Running in parallel are the new developments that are coming online to support a growing population and economy. Infrastructure serving these new developments may potentially exacerbate inflow and infiltration problems unless best practices are adopted. By properly managing I&I in new developments, limited resources may be allocated to improve poorly performing infrastructure inherited from previous generations. Existing infrastructure underpins the core of most communities and if its maintenance and rehabilitation continue to be deferred, then deterioration will accelerate, eventually leading to even more severe problems and the need for costly interventions. The adoption of best practices for the management of inflow and infiltration in new urban developments is a proactive and cost effective means of avoiding future expenditures and promoting sustainable development. The study leading to this best practices guide was commissioned by the Institute for Catastrophic Loss Reduction (ICLR) and involved a number of stakeholders in a collegial process of contribution, review and comment. Time, effort and knowledge were generously contributed by the numerous stakeholders acknowledged in this report. These individuals and organizations also reviewed drafts of this report and provided their comments. It was recognized from the outset this study would focus on collecting and synthesizing current best practices into a comprehensive and coherent framework rather than attempt to develop new approaches and technologies for I&I management. There is much evidence to suggest that virtually every measure for effectively managing I&I is already known and available to municipal engineers, hence the vision guiding this study was to connect the dots between the various measures so that municipal infrastructure in new urban developments could benefit from the best available knowledge and technology.

In conducting this study, it became obvious that numerous barriers to sustainable municipal infrastructure continue to compromise best practices. Beginning with legislation and standards, through to the organization of municipal governance and management of services, and across the entire life cycle of infrastructure planning, design, construction, quality assurance, commissioning, monitoring and maintenance, the biggest barriers are not related to technology. Instead, the harmonization of regulations, the coordination of municipal services, and the establishment of consensus performance indicators, when combined with diverse competing interests and human factors, pose the most significant barriers, not only to the management of I&I, but all aspects of municipal infrastructure. The management of municipal infrastructure and related services is not an established science, and municipalities are creatures of evolution and adaptation to political, cultural, economic and geographic realities. Therefore, it cannot be expected to forge a "one size fits all" approach to developing and implementing best practices for the management of I&I. However, this study aspires to establish a framework for better informed decision making by all of the players, and should be viewed as the departure point for a perpetual work in progress, just like our evolving municipal infrastructure.

Executive Summary

This study commissioned by the Institute for Catastrophic Loss Reduction has attempted to provide a best practices guide for the management of inflow and infiltration (I&I) in new urban developments. It is intended to serve as a knowledge map of sorts connecting relevant and authoritative sources of information. While the focus of the study is the Greater Golden Horseshoe, the findings are extensible to other regions of Canada and particularly relevant to areas experiencing rapid continued growth.

A premise of this study is that I&I in sanitary sewer systems is a barometer of the care and diligence exercised by public works organizations, and a direct reflection of the corporate culture of a municipal and/or regional government. After having put men on the moon and safely bringing them back almost half a century ago, it is not unreasonable to expect fully engineered municipal infrastructure to consistently achieve high performance. However, it is important to appreciate high performance infrastructure comes at a cost that comprises the initial expenditure and the ongoing operational and maintenance costs over the life cycle of the infrastructure asset. Willingness to pay combined with political will are viewed as among the most significant obstacles to delivering sustainable infrastructure to Canadians.

Research conducted by way of literature review and interviews with experts indicates virtually all of the prerequisite knowledge and expertise needed to effectively manage I&I in sanitary sewer systems exists today. However, it is widely dispersed among numerous organizations and has yet to be integrated and consolidated. Without a consistent knowledge base that is readily accessible, not only does each municipality have to develop its own standards, guidelines and protocols, but it is also difficult to effectively conduct training and education of design professionals, asset managers and skilled trades. It is time for municipal infrastructure to evolve from a collection of local prescriptive measures to an integrated system of performance-based technologies. Some jurisdictions have embraced this challenge and are demonstrating considerable success in achieving performance objectives.

Key findings of this study are summarized as follows:

- It is not for a lack of materials, methods and technology that I&I problems continue to be witnessed in sanitary sewer systems. The most significant barrier to implementing best practices for the management of I&I is the political will to pay the real cost of sustainable infrastructure and integrated water resources management.
- Additional challenges are posed by a web on contributing factors comprising: complexity of legislation; jurisdictional conflicts; development pressures; municipal infrastructure operation; engineering design standards; procurement policies and practices; construction industry and workforce; climate change and extreme weather events.
- Practically all of the technological innovations now exist to deliver watertight sewer systems and are cost effective on a life cycle basis. International best practices reported in the literature observe that maintenance hole inflows have been practically eliminated and I&I rates of less than 0.1 litres/second/hectare could be consistently achieved and maintained in practice.
- The traditional paradigm of designing stormwater management systems and sanitary sewer systems independently of one another is being challenged by climate change and intensified urban development. It is now widely recognized an integrated water resources management approach is needed to effectively tackle performance problems such as I&I.
- Further study of the impact of low impact development on mitigating I&I problems is needed. It is also critical to integrate LID planning and design methods within water resources engineering.
- It was commonly reported that most I&I problems originate from the private side, reinforcing the need to coordinate stormwater management, wastewater services, lot grading and building inspections. Harmonization of interrelated codes and standards among jurisdictions is essential.
- Experience has shown that constant vigilance must be exercised by municipalities to ensure that inflow and infiltration infractions on the private side of the sewer system are not allowed to become widespread, since the accumulated impacts and costs of remediation are significant.
- Continuous monitoring and proper maintenance enable early detection of I&I problems and timely remediation. I&I reinforce the view that "if you can't measure it, you can't manage it."

By implementing best practices for I&I management in new developments, municipalities will be able to direct scarce resources toward the remediation of I&I in older existing developments to better manage assets. Critical areas of future research, development and integration identified in this study include:

- Life cycle cost-benefit analysis to better understand the economics underlying integrated water resources management and sustainable municipal infrastructure, and to better inform appropriate land use planning and development strategies - this analysis would include I&I best management practices among a host of sustainability and resilience measures;
- Development of a comprehensive framework of policies, standards, guidelines and protocols for the integrated management of water resources coupled to a suite of planning, design and management tools;
- Integration and consolidation of all knowledge-based resources to be made readily available online through a central directory that is continuously maintained and updated;
- Formation of a national expert panel and municipal infrastructure roundtable to engage all of the stakeholders in a collaborative forum to gain consensus on relevant future research, development and integration initiatives that can be pursued for the benefit of all stakeholders.

This report provides a guiding framework for future initiatives that may address I&I management issues within the context of an integrated water resources management model. It represents an important first step towards cataloguing the current state of knowledge and identifying critical questions and issues.

[Source: The Vanishing Point - vanishingpoint.ca]

Long after the creation of our early 20th century municipal sewer systems, citizens discovered their inherited municipal infrastructure was either a legacy or a liability. Future generations will be able to devote their tax dollars toward aspects of civil society like education and healthcare, or they will have to dig up the past to rebuild a new future. What happens to our municipal infrastructure in the next few decades across many parts of Canada will greatly influence our nation's fiscal and environmental well being in the second half of the 21st century.

Introduction

Inflow and infiltration problems in sewer systems are not new and have long been recognized.[1] Yet best practices for the management of I&I in new urban developments do not exist within a comprehensive and integrated framework. They exist but are spread out among numerous publications, jurisdictions, municipalities and practitioners. Their effectiveness in different contexts has not been validated and when the most basic test about the degree of technology transfer for these best practices is applied, it reveals they are not commonly reflected in municipal engineering and technology curricula. It is fair to conclude that at present, these best practices are far from normative.

The term "new urban developments" refers to new developments that are serviced with sanitary and stormwater sewer systems, but are not interconnected with existing infrastructure, except at the trunk. Urban developments may also be taken to mean suburban developments and these would deploy the same municipal infrastructure, as distinguished from rural developments. Existing infrastructure may be practically defined as services that would fall under a previous official plan of development, or plan(s) of subdivision. Staged developments that may require several years or decades to be completed in phases or stages would fall under the new urban development classification. In practical terms, all new greenfield and brownfield developments that fall under the Places to Grow Act, 2005 in Ontario would be considered new urban developments, and this would also apply to most new urban developments across Canada, but be differentiated from any small scale infill development projects.

Inflow and infiltration (I&I) is a widespread problem affecting sanitary sewer systems across North America and around the world. Ideally, a sanitary sewer system would only convey sewage from connected laterals to the sewage treatment facilities and no external sources of water would inflow or infiltrate the wastewater conveyance network. In reality, a certain amount of I&I is unavoidable due to factors such as: 1) local climate, soil and groundwater conditions; 2) imperfect design, materials and workmanship; 2) the settlement and deterioration of piping, connections and maintenance holes; and 3) the connection of stormwater and foundation drainage sources to the sanitary system, unintentional and otherwise. Put simply, it is not practically possible to maintain a perfectly watertight sanitary sewer system over its life cycle. However, many jurisdictions have demonstrated it is possible to cost effectively manage I&I within acceptable limits.

Despite the relatively long history of I&I problems and the corresponding development of prevention and mitigation measures, the design of sanitary sewer systems remains, for the most part, a relatively routine process relying on standardized assumptions about I&I rates. All of the factors noted previously are seldom considered explicitly, yet the current state of the art in sewage system design, construction, commissioning and operation is quite capable of addressing I&I challenges. But it requires a greater degree of integration and sophistication than has traditionally been evidenced across most Canadian municipalities and their respective jurisdictions. This, in turn, demands the political will to pay the real cost of sustainability and resilience.

So what is a normal level of I&I? How much do I&I rates normally increase over the life cycle of a sanitary sewer system? If there is a significant increase, is it due to design standards, materials, workmanship and/or environmental factors such as local water tables, soils types and freeze/thaw action? In researching I&I issues during the development of this guideline, these and other related questions arose frequently among experts and professionals. Unfortunately, the answers to these questions are beyond the scope of this publication.

Fortunately, a great deal is known about the best practices for implementing preventive measures to manage I&I. There is no excuse not to apply what is known even if our knowledge and its application are imperfect. A complete and drastic overhaul of protocols may not be necessary, and a gradual adoption and implementation of best practices may in fact be more effective, simply because it is manageable and more easily monitored. A central idea advocated in this publication is that positive change can be realized by implementing one best practice at a time, provided these are properly prioritized and capable of building upon one another in an integrated fashion.

[1] Environmental Protection Agency. (1971). *Prevention and Correction of Excessive Infiltration and Inflow into Sewer Systems*. http://nepis.epa.gov/Exe/ZyPDF.cgi/9100WH40?Dockey=9100WH40.pdf

Overview
These best practice guidelines have been researched and developed with a view to providing readers with an up-to-date documentation of the various measures for the management of inflow and infiltration. The approach taken is holistic and advocates the crafting and implementation of appropriate measures based on an enhanced awareness and understanding of the following:

- I&I phenomena and their associated issues and impacts;
- The relationship between I&I best management practices and integrated water resources management;
- Emerging best practices for the effective management of I&I;
- Critical relationships underpinning an I&I best management practices framework; and
- The future of I&I control measures within an integrated water resources management model.

Measures and programs for the management of I&I cannot be separated from the larger context of water resources and municipal infrastructure. However, the diversity of urban and geographic contexts is too great to be examined comprehensively, hence a more focused approach was adopted.

Context
This best practices guideline is set within the larger context of Canadian municipalities, but focuses on the Greater Golden Horseshoe region where most of Canada's new urban development is expected to occur over the next several decades. Existing municipal infrastructure faces different I&I challenges than new infrastructure and once these have been appropriately addressed, the subject matter of these guidelines may be engaged.

Figure 1. The Greater Golden Horseshoe region forms the basis of this I & I study. It comprises areas where rapid growth is driving the design and construction of extensive municipal infrastructure. [Source: Neptis Foundation]

Scope and Intended Audience

The scope of these guidelines is confined to wastewater collection systems and does not include sewage treatment facilities. Wastewater collection systems include the sanitary sewer, maintenance holes, and service piping from connected buildings, intended, legal and otherwise. In most cases, the influence of the surrounding municipal infrastructure in which the wastewater collection system resides must also be considered. The intended audience for this publication includes:

- municipal infrastructure designers, engineers and technologists;
- municipal infrastructure operators and managers;
- municipal staff, officials and elected politicians;
- conservation authorities; and
- regulatory authorities and government agencies.

The training and education of municipal infrastructure constructors, their technicians and skilled workers is beyond the scope of this publication, but should not be ignored as a critical aspect of comprehensive I&I prevention measures. This guideline publication deals with the legislative, municipal and professional dimensions of I&I problems with the view that material and product suppliers and municipal infrastructure constructors will comply with design guidelines and standards of performance set out by municipalities.

This best practices guideline represents an exercise in knowledge mapping that attempts to connect the dots between human, technical and legislative aspects of the sustainable management of I&I in sanitary sewer systems. It is premised on observations drawn during the research that indicate practically all of the knowledge, technology, standards and legislative policies needed to manage I&I currently exist, albeit in a disaggregated form.

What is Inflow and Infiltration?

There are numerous definitions for inflow and infiltration found in engineering literature. It is interesting to note that the term "inflow and infiltration" is also interchangeable with "infiltration and inflow" and that these are abbreviated as both I/I and I&I. In this publication I&I refers to inflow and infiltration, and is confined to separated sewer systems servicing new urban developments.

In the simplest terms, inflow involves the entry of stormwater from rainfall and snowmelt events entering the sanitary sewer system directly from the surface or indirectly from stormwater drainage system connections to sanitary sewers. Infiltration involves the entry of groundwater into the buried sanitary sewer system. The more comprehensive definitions are provided below.

Inflow - Water, other than sanitary flow, that enters a sewer system intentionally or unintentionally from sources that include, but are not limited to: roof leaders; basement foundation drains and sumps; yard, area, driveway and garage drains; manhole covers; cross connections between storm sewers and sanitary sewers, including catch basins; and snowmelt, surface runoff and flooding. Note that in some cases, intentional conveyance of stormwater to the sanitary sewer system is referred to as an illegal connection where it is prohibited by codes, by-laws or design standards and guidelines.

Infiltration - Groundwater that enters a sewer system, directly or indirectly, through means such as: defective pipes; leaky pipe joints; connections between sewer system components; and damaged, deteriorated or defective maintenance holes.

When sanitary sewer systems, also known as wastewater collection systems, are put into service and begin the process of aging and inevitable deterioration, I&I phenomena are observed. Unless monitoring of the sewer system behaviour is implemented from the time it is commissioned, it is often very difficult to differentiate the contribution of inflow versus infiltration to excessive wastewater flows beyond the rates predicted at the design phase. Due to this uncertainty, the problem of periodically excessive flows is commonly referred to as I&I.

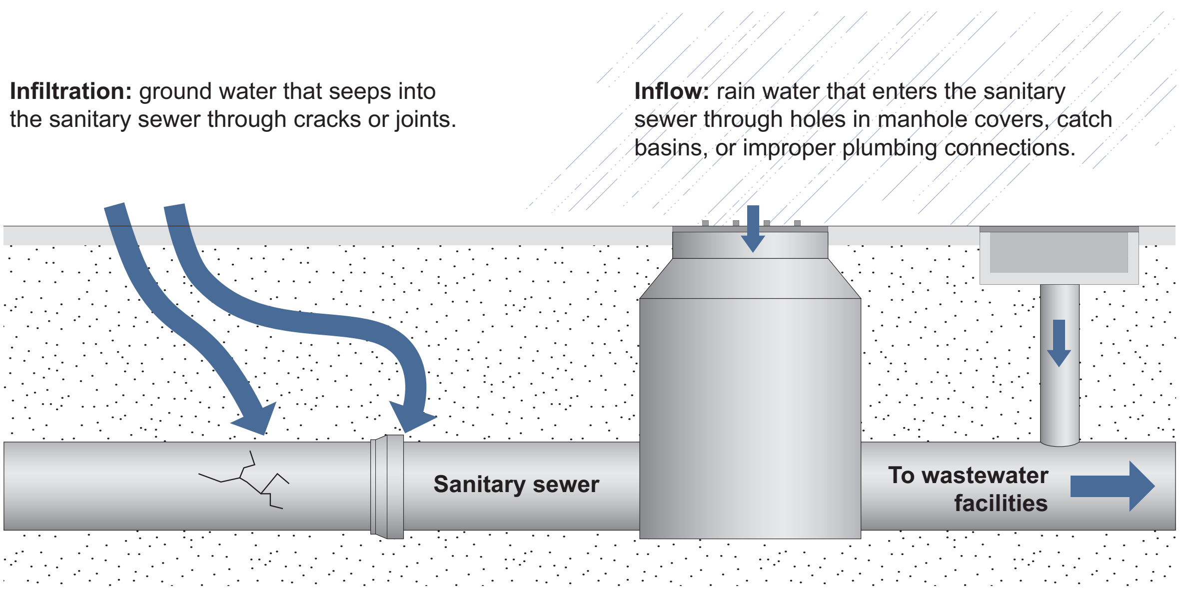


Figure 2. A simplistic depiction of I&I phenomena differentiates between surface water sources (inflow) and groundwater sources (infiltration).

Rainfall Derived Inflow and Infiltration

In most cases, I&I problems are caused by rainfall events, and less frequently by snowmelt or fluctuating water tables. Rainfall-derived inflow and infiltration (RDII) into sanitary sewer systems is widely recognized as a source of operating problems in sanitary sewer systems. RDII is the main cause of sanitary sewer overflows (SSOs) to basements and water bodies. It can also create serious operating problems for sewage treatment plants. SSOs oftain contain high levels of pathogens, suspended solids, toxic pollutants, oils and grease, to name a few of the many dangerous contaminants contained in raw sewage. The potential health and environmental risks associated with these discharges are cause for concern and cannot be ignored.

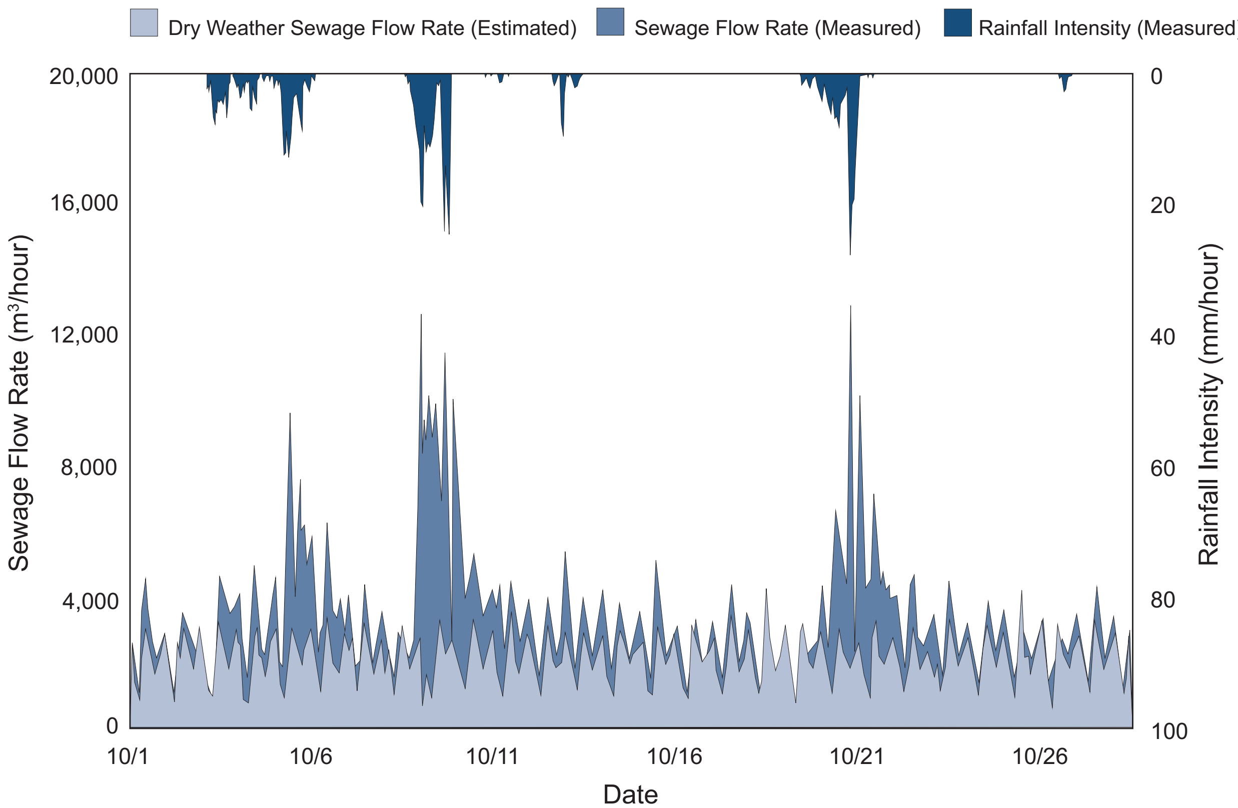


Figure 3. This example of monitoring data depicts how estimates of dry weather sewage flows reasonably predict actual flow rates, and then how rainfall events influence rainfall derived I&I rates. It is difficult and costly to implement monitoring that differentiates between I&I rates, but there now exist techniques for isolating each of these phenomena with a reasonable degree of accuracy.

RDII problems vary widely according to numerous factors. The local climatic conditions and the intensity, duration and frequency of extreme rainfall events play a significant role in the environmental stresses placed on the stormwater and sanitary sewer systems. Urban hydrology resulting from the surrounding geography, the existing municipal infrastructure, and the form, scale and density of new urban developments will affect groundwater, surface water accumulation levels, drainage rates and system loads. Soil conditions and related phenomena such as freeze-thaw action and expansive soils are known to cause differential settlement, active soil pressures on buried infrastructure, and damage due to adhesion freezing of components such as maintenance holes. Human factors pertaining to design, material selection, manufacturing and handling, quality of construction, and municipal operations (commissioning, monitoring, inspection, maintenance and repair) further influence the nature and magnitude of I&I problems. As a result, there is not a "one size fits all" solution to I&I problems.

Inflow and Infiltration Issues

Issues related to I&I problems are significant because they involve undesirable impacts. These are better appreciated by first gaining an understanding of the various I&I influences, and then connecting these to their related factors.

As noted earlier, this publication focuses on infrastructure serving new developments where sanitary and storm sewers are separated. Separated sewer systems have two individual pipes that are designed to convey only sanitary sewage and only storm sewage. The separation of the different types of sewage allows municipal engineers to direct sanitary sewage to treatment facilities, while storm sewage is allowed to flow into nearby lakes, streams and rivers with less intensive treatment.

Social, Economic and Environmental Impacts

Basement flooding due to sanitary sewer backup translates into significant social impacts for occupants of affected basement apartments or living areas. A flooded basement is a traumatic event that may force occupants out of their living spaces until the flooding subsides, damaged contents are removed and the basement area is sanitized. Each sewer backup episode may mean days or weeks of displacement.

Figure 4. A Toronto resident is seen drying out memorabilia following basement flooding due to sanitary sewer backup. These unintended consequences of I&I to sanitary sewer system disrupt the lives of residents and expose them to potential health risks. There may even be a certain degree of social stigmatization associated with occupants inhabiting chronically flood prone basements. [Source: CTV News, Toronto.]

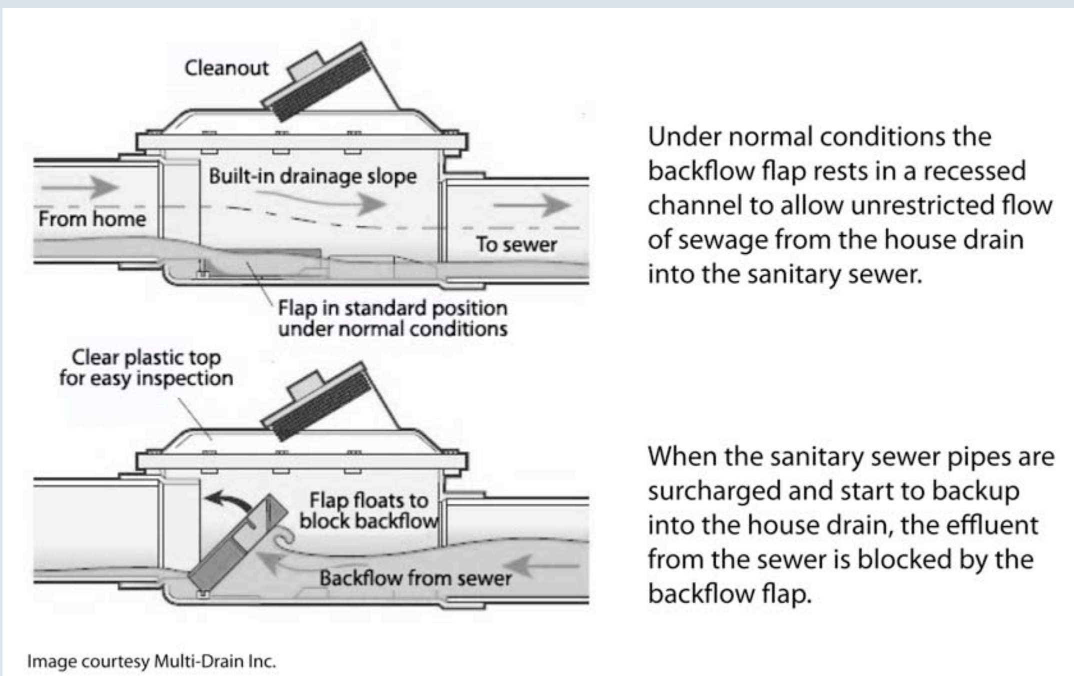
Sewer backup can happen when sanitary sewer systems receive more water than they can handle. Excess water due to I&I can cause the sewers to "surcharge," and push water backwards through home sewer laterals and cause sewage to backup into the home through basement floor drains, toilets and sinks. Excessive surcharge in the municipal sewer can create high pressures around basement floors and the foundation, which can cause structural damage to the home. For example, excess pressure in pipes beneath the home can result in heaving of basement floors, especially when improper backwater valves are used. When weeping tiles are connected to the municipal system through sanitary sewer laterals or storm sewer laterals, sewage can be forced back into the weeping tiles, resulting in possible structural damage to the home.

Sewer Surcharges and Backwater Valves

Climate change has led to the increased frequency and severity of extreme rainfall events. In many municipalities, sewer surcharges from separated systems in new developments have been know to occur simply because the system designs relied on traditional storm models that have since been significantly exceeded. The City of Ottawa is an example among numerous municipalities that have observed a sequential pattern of sewer surcharges. First, intense rainfall from convective storms overloads storm sewers leading to stormwater being backed up through the foundation drains to enter around the perimeter of the basement floor slab. This surcharge then enters the floor drains and flows into the sanitary sewer system causing further surcharges downstream. This is a phenomenon that has been addressed in Ottawa by requiring the installation of backwater valves in both the storm and sanitary connections across all new developments. There are some interesting insights to be gained from the Ottawa experience.

- Inflow and infiltration are not direct factors impacting sewer surcharges in new developments since these are relatively tight sanitary sewer systems - all observed surcharges stem from the stormwater system.
- In practical terms, this means that the management of I&I is no guarantee of dry basements and it may be cost effective to require backwater valves as an alternative to suffering basement flooding damages.
- It is much easier and less costly to install backwater valves at the time of new construction (or infill) than it is to retrofit existing buildings.
- Proper risk assessment and cost-benefit analyses are needed to make informed decisions. Engineers should investigate downstream system effects by modeling both the stormwater (major and minor systems) and sanitary sewer systems. Experience now indicates storm and sanitary systems cannot be viewed in isolation from one another.

Another issue that arises from backwater valves is the need for homeowner education regarding inspection and maintenance. There is also a need for municipalities to share backwater valve performance data among each other since many aspects of in-situ performance are not currently tested in product certification standards.



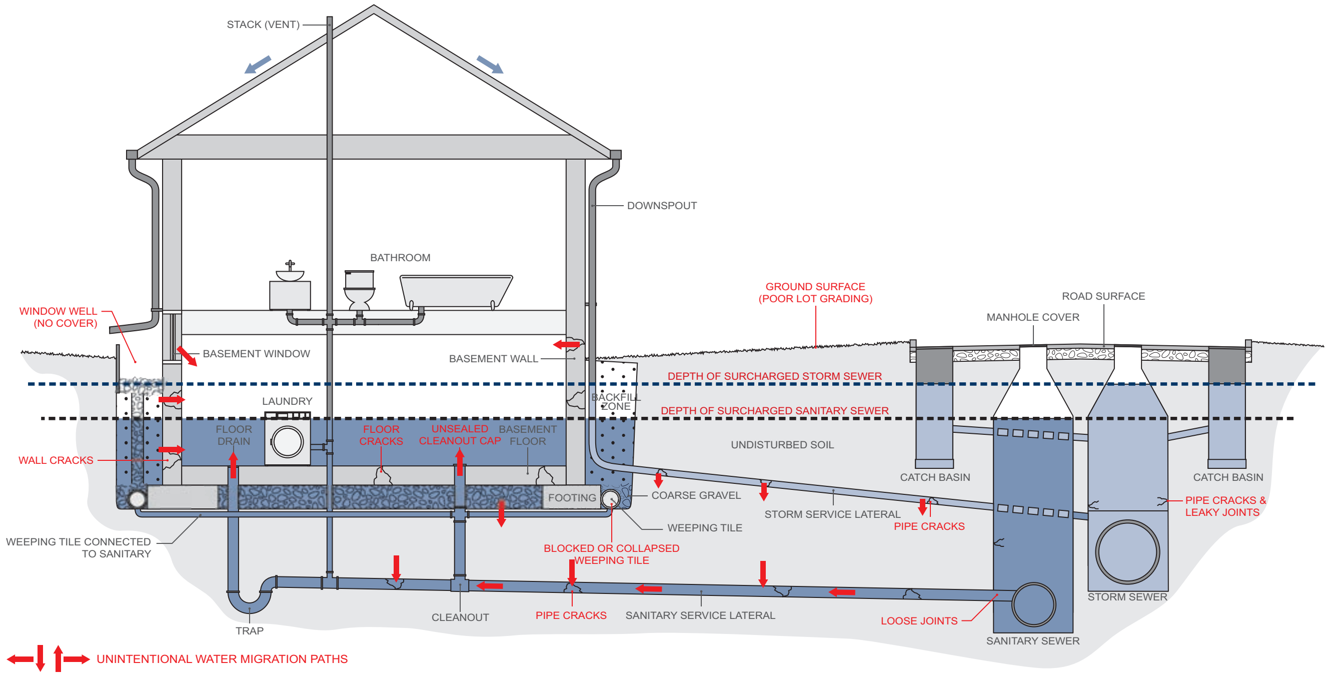


Figure 5. Sanitary sewer backup occurs typically during major rainstorm and/or snowmelt events, when I&I surcharge the sanitary sewers. With the effluent level in the sanitary sewers higher than the basement floor drain, sewage backs up into the basement through floor drains and other unintentional openings that develop in pipes and foundations. [Source: ICLR Handbook for Reducing Basement Flooding, 2009.]

Environmental impacts that are influenced by I&I may not be as noticeable as basement flooding due to sanitary sewer backup, but they are very much as serious. The two most significant phenomena that are aggravated by I&I are combined sewer over flows (CSOs) and sewage bypass. As this publication does not involve combined sewers, only sewage bypasses will be discussed.

Sewage treatment plants experience bypasses during wet weather such as heavy rainstorms or spring snowmelt. Bypasses occur when the treatment facility is overloaded and excessive sewage continues flowing into the treatment plant. To prevent possible upstream problems like basement flooding, some of the sewage flow is deliberately redirected and discharged into local water bodies with little or no treatment. Under Ontario law, it is not illegal to dump sewage via a bypass or overflow, if it is necessary to alleviate high flow volumes during wet weather. Provincial government guidelines are available that municipalities can follow, however these are not enforceable.[2] It is important to note that the annual frequency of bypasses across Ontario is quite high, but also dependent on the capacity of a sewage treatment plant - those with sufficient capacity can detain wet weather flows. However, a recent report cites the situation is becoming dire for the Great Lakes.

"The release of sewage into Ontario's waterways including the Great Lakes is an enormous problem that is not going to improve unless urgently needed investment is made from all levels of government in sewage infrastructure – including green infrastructure - to improve how we manage our sewage and reduce the amount of stormwater that enters the sewage system and causes CSOs and bypasses.

Inadequately treated sewage causes human health and environmental impacts that go far beyond beach closures. In both 2006 and 2007, raw or undertreated sewage was dumped more than 1,000 times by Ontario municipalities. The quantities are staggering, with billions of litres escaping full treatment each year.

[2] The Environmental Impacts of Sewage Treatment Plant Effluents.
http://www.ecoissues.ca/The_Environmental_Impacts_of_Sewage_Treatment_Plant_Effluents

Unfortunately Ontario does not publish information on sewage bypasses or combined sewer overflows, leaving most Ontarians in the dark over the extent of this colossal problem and their local community's contribution."[3]

The economic externalities associated with sewage bypasses in Ontario and across Canada are largely unknown,[4] but assuming an average sewage treatment rate applied to the quantity of bypassed sewage, hundreds of millions, if not several billions, of dollars of environmental damages, direct and indirect, result from sewage bypasses across Canada annually. The contribution of I&I is unclear based on the available data and literature review, but it is much more significant in municipalities with extensive combined sewer systems where major wet weather events cause both combined sewer overflows and bypasses at the sewage treatment plant.

Without attempting to factor in externalities and appreciating that most municipal water supply and sewage treatment costs are distorted,[5] data from a recent study were used to estimate life cycle costs imposed by I&I across the Greater Toronto Area (GTA). A number of simplifying assumptions were employed to arrive at an order of magnitude rather than a reasonably accurate estimate. It is important to appreciate these I&I costs stem mostly from older developments where combined sewer systems or partially separated sewer systems predominate, and represent the largest proportion of total I&I. The idea behind this simplified analysis was to assess the economic impact of failing to effectively manage I&I in new developments going forward.

First, annual I&I costs were based on 2007 data in *General Inflow and Infiltration Management Practices*, Ontario Centre for Municipal Best Practices, February, 2008. These costs have not been updated, escalated or deflated throughout the life cycle study period. Second, it was assumed I&I were directly proportional to population and occur at the present rate, however this may not be true in municipalities where best practices are employed such that new developments exhibit much lower than historical I&I rates. Third, the average per capita costs for I&I were applied without adjusting that average based on the predicted populations in each of Toronto and Durham, Halton, Peel and York regions. Fourth, the Modified Uniform Present Value method for calculating the net present value (NPV) of I&I assumed the escalation rate for I&I stays constant over the study period, even though it is most likely to increase as time goes on. Fifth, the model assumed population growth levels off in 2036 and there is negligible subsequent growth because the GTA has been intensified to its saturation point.

Despite these simplifications, looking at the data in Table 1 under the high interest and escalation rate scenario, the average per capita NPV of increased costs due to I&I is $271 over a 50-year study period. This translates simply into $5.42 per year per person living in the GTA over the next 50 years. Even if the price distortions approach a 50% threshold of undervaluing sewage treatment, doubling the annual cost increase for I&I per person to roughly $10 does not adversely impact most households across the GTA. But when viewed from a societal perspective, the net present value across the entire GTA under the high interest and escalation rate scenario is roughly $907.7-million. Assuming best practices can reduce I&I rates to one-third of what they were reported in 2007, then the present value of better practices is about $600-million. In practical terms, moving towards best practices is cost effective if over the next 50 years, the net present value of these best practices does not exceed $600-million, notwithstanding the value of avoided costs and externalities.

[3] MacDonald, E., Podolsky, L., Roberts, J., and Brus, K. (June 2009, Revised July 2009). *Flushing out the Truth: Sewage Dumping in Ontario*. Ecojustice, Toronto, Ontario, Canada. http://www.ecojustice.ca/publications/reports/flushing-the-truth

[4] Renzetti, S. and Kushner, J. (2004). *Full Cost Accounting for Water Supply and Sewage Treatment: Concepts and Case Application*. Canadian Water Resources Journal Vol. 29(1): 13–22 (2004). http://www.tandfonline.com/doi/pdf/10.4296/cwrj13

[5] Renzetti, Steven. (1999). *Municipal Water Supply and Sewage Treatment: Costs, Prices and Distortions*. Canadian Journal of Economics, 32(2): 688–704. http://spartan.ac.brocku.ca/~srenzetti/327/Renzetti_CJE.pdf

Life Cycle Cost Analysis of I&I for Selected Ontario Municipalities

Annual I&I costs based on 2007 data in *General Inflow and Infiltration Management Practices*, Ontario Centre for Municipal Best Practices, February, 2008.
GTA population based on 2006 census data.
Predicted GTA population growth based on *Ontario Population Projections Update, 2011–2036*, Ontario Ministry of Finance, Spring 2012.
Life cycle costing analysis based on Modified Uniform Present Value method with escalation.
Avoided costs for related I&I impacts (e.g., basement flooding, pollution control) not included.
Input data obtained from study. Variable parameters input by user.

Economic Assessment Parameters

Two interest (discount) rate and sewage treatment cost escalation rate scenarios are considered in this analysis.
Three life cycle study periods are considered, corresponding to normative planning horizons.

	Current	*High*
Interest Rate	1.5%	3.0%
Escalation Rate	2.5%	6.0%
Study Period (yrs)	10	
	25	
	50	

	Annual I&I Volume (ML)	Annual I&I Cost*	NPV of Inflow & Infiltration *Current*	*High*
Durham Region	27,101.85	$2,048,088	$21,624,139	$24,065,881
584,400	per capita	$3.50	$58,307,593	$75,971,137
	per ML	$75.57	$132,810,067	$231,698,397
Halton Region	1,374.00	$179,841	$1,898,799	$2,113,206
457,800	per capita	$0.39	$5,119,944	$6,670,966
	per ML	$130.89	$11,661,948	$20,345,254
Peel Region	25,798.95	$2,001,357	$21,130,743	$23,516,772
1,213,400	per capita	$1.65	$56,977,195	$74,237,712
	per ML	$77.58	$129,779,754	$226,411,760
Toronto	192,891.45	$16,193,263	$170,971,836	$190,277,537
2,610,600	per capita	$6.20	$461,010,558	$600,667,845
	per ML	$83.95	$1,050,066,376	$1,831,929,624
York Region	1,044.00	$197,992	$2,090,441	$2,326,488
931,900	per capita	$0.21	$5,636,690	$7,344,253
	per ML	$189.65	$12,838,965	$22,398,661
Average NPV per capita			$25	$28
			$68	$89
			$155	$271
Average NPV per ML			$1,178	$1,310
			$3,175	$4,137
			$6,027	$12,617
NPV of Increased Cost of I&I Across GTA			$84,716,344	$94,282,296
(assuming constant per capita I&I rates)			$228,430,189	$297,630,211
			$520,306,654	$907,718,973

GTA Population 2006	5,798,000
Predicted GTA Population 2036	9,151,800
Predicted Growth by 2036	3,353,800

* Does not include cost of expanding sewage treatment facilities or externalities.

Table 1. A life cycle cost analysis across the GTA projecting population growth and per capita I&I rates reveals that given sewage treatment price distortions, and in the absence of externalities and avoided costs, I&I is not viewed as a major economic burden. (Note: Approximately 80% of the sewage treated at the Duffin Creek plant in Durham originates in York Region.)

I&I economics must be viewed in a proper context. Ontario's water and wastewater assets are worth an estimated $72-billion and include treatment plants, distribution systems and collection systems, that will demand tens of billions of dollars in expenditures for capital renewal, including deferred maintenance, and growth. In the City of Toronto alone, the sewer system consists of 10,561 km of pipe, ranging in size from 100 mm to 5,500 mm, with an estimated total system replacement cost of approximately $13.3-billion.[6] An interesting perspective on Ontario's water infrastructure is provided below.

[6] City of Toronto. (2008). *Toronto Water's Infrastructure Renewal Backlog*.
http://www.toronto.ca/legdocs/mmis/2008/ex/bgrd/backgroundfile-16566.pdf

"*Much of the decision-making regarding what to build, where to build it and at what level of service to build it at has been associated with government and governance at all levels. In terms of financing, all of this water infrastructure had to be paid for, is paid for and will have to be paid for by all levels of government and users. In addition, all of these systems had to be planned and designed, and many of them have undergone or will undergo rehabilitation, replacement and/or expansion. The history of Ontario's water infrastructure can be relayed as a tale of these three components (governance, financing and engineering) and how the interplay between them has led to what we know today as Ontario's water infrastructure*."[7]

And what is true in Ontario is just as true across Canada.

"*Canadian municipalities build, own and maintain most of the infrastructure that supports our economy and quality of life. Yet for the past 20 years, municipalities have been caught in a fiscal squeeze caused by growing responsibilities and reduced revenues. As a result, they were forced to defer needed investment, and municipal infrastructure continued to deteriorate, with the cost of fixing it climbing five-fold from an estimated $12 billion in 1985 to $60 billion in 2003. This cost is the municipal infrastructure deficit, and today it has reached $123 billion.*

The upward trend of the municipal infrastructure deficit over the past two decades points to a looming crisis for our cities and communities and ultimately for the country as a whole. The deficit continues to grow and compound as maintenance is delayed, assets reach the end of their service life, and repair and replacement costs skyrocket. When compared with earlier estimates, the $123-billion figure clearly shows the municipal infrastructure deficit is growing faster than previously thought."[8]

Viewed from these perspectives at a larger system scale, the economic impacts of I&I do not appear significant to the average citizen or policy maker, but they are very compelling at the individual or household level once basement flooding damages have been suffered. A 2007 Institute for Catastrophic Loss Reduction (ICLR) report noted:

"*Locating property in basements is a significant contributing factor in excessive basement flood damages. Previous research has revealed that average insurance claims for sewer backup damages in Canada were approximately $3,000 to $5,000. The 2005 GTA storm, however, resulted in an average insurance claim of $19,000 and the 2004 storms in Edmonton saw an average of over $15,000. Further, previous research estimated total yearly insurance claims for basement flooding at $140 million, however, sewer backup damage insurance payouts from the August, 2005 GTA storm were $247 million. These values suggest that property people are placing in their basements may be significant in both quantity and value. Findings in this study revealed that the majority of sewer backup positive homeowners did not choose to remove their important or expensive items from their basements to reduce damage risk. Homeowners should be made to understand if they choose to locate expensive or important items in flood prone basements, they do so at a risk*."[9]

Municipalities are under pressure to address I&I issues because climate change and the changing use of basements as livable spaces make chronic sanitary sewer backups socially and economically unacceptable. It is highly likely that valuation of the externalities associated with sewage treatment plant bypasses would make I&I unacceptable on environmental grounds as well.

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[7] Swain, H., Lazar, F., and Pine, J. (2005). *Watertight: The Case for Change in Ontario's Water and Wastewater Sector*. Report of the Water Strategy Expert Panel, Queen's Printer for Ontario, Toronto, Ontario, Canada.
http://www.probeinternational.org/EVfiles/Watertight-panel_report_EN.pdf

[8] Mirza, Saeed (November 2007). *Danger Ahead: The Coming Collapse of Canada's Municipal Infrastructure*. Federation of Canadian Municipalities. Ottawa, Ontario, Canada.
https://www.fcm.ca/Documents/reports/Danger_Ahead_The_coming_collapse_of_Canadas_municipal_infrastructure_EN.pdf

[9] Sandink, Dan (November 2007). *Sewer Backup: Homeowner perception and mitigative behaviour in Edmonton and Toronto*. Institute for Catastrophic Loss Reduction. Toronto, Ontario, Canada.
http://iclr.org/images/ICLR_Report_sewer_backup.pdf

Severe Weather, Flooding of Property and Insured Damages in Canada

Damage caused by severe weather has emerged in recent years as the leading cause of property insurance claims and now exceeds fire damage in some regions of the country. Environment Canada reports that extreme weather events that used to happen every forty years can now be expected to happen every six. The resulting increase in insured losses (losses covered by insurance) from natural catastrophes is not a short-term phenomenon. Payouts from extreme weather have more than doubled every five to ten years since the 1980s. For each of the past four years, they have been near or above $1-billion in Canada. And in 2013, losses were a historic $3.2-billion, as a result of floods in Alberta and Toronto. By comparison, total insured losses averaged $400-million a year over a 25-year period from 1983 to 2008.*

Looking at some recent severe weather events in the Greater Golden Horseshoe area as reported by the Insurance Bureau of Canada:

- July 15, 2004, Peterborough, Ontario, flooding, $102.4-million.
- August 19, 2005, various Ontario locales, wind/rainstorm, $717.7-million.
- July 8-9, 2013, Toronto and southern Ontario, $995.5-million. In July, a severe thunderstorm with heavy rainfall caused flash flooding in the Toronto area. With estimated losses of almost $1 billion, the storm set an Ontario record for insured losses arising from a single natural disaster.
- August 4, 2014, Burlington, rain/flooding, $90-million. Insurance Bureau of Canada (IBC) reports that the preliminary estimate for insured damage caused by heavy rains and flooding in the Burlington, Ontario area in early August was just over $90-million, according to Property Claim Services (PCS). "This was a horrible situation, but unfortunately one that we are seeing far too often," said Ralph Palumbo, Vice-President, Ontario, IBC. "The insurance industry continues to study the impact of severe weather on our communities and advocates for the need to update infrastructure. We continue to engage consumers on how to protect themselves and their properties and we work with all levels of government to help develop, promote and implement adaptation measures," added Palumbo. On August 4, Environment Canada issued a series of severe thunderstorm warnings and watches for parts of southern Ontario, including Burlington. During the storm, Burlington received so much rainfall that local highways had to be closed because of flooding in some places, as creeks and rivers throughout the city were inundated and crested at the same time.**

Residential insurance coverage for overland flooding is not available in Canada, hence the reported damages are due for the most part to basement flooding via sewer backups. Severe weather is stressing the current property insurance framework across Canada.

"*Flood-related losses are often directly attributable to under-investment in public infrastructure, poor asset management, obsolete building codes and ineffective land use planning. Unless governments fulfil their obligations for better risk planning and mitigation, flood insurance will remain commercially unviable.*" ***

Inflow and infiltration play a difficult to exactly quantify role in basement flooding, but most experts agree the management of I&I is a prudent and cost effective best practice.

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* Insurance Bureau of Canada. *2014 Facts of the Property & Casualty Insurance Industry.* http://assets.ibc.ca/Documents/Facts Book/Facts_Book/2014/IBC_2014_Factbook_English.pdf

** Insurance Bureau of Canada News Release, September, 2, 2014. *Burlington flooding insured damages estimated at $90 million*. http://www.ibc.ca/qc/resources/media-centre/media-releases/burlington-flooding-insured-damages-estimated-at-$90-million

*** Insurance Bureau of Canada, May 2014. The Financial Management of Flood Risk. An International Review: Lessons Learned from Flood Management Programs in G8 Countries. http://assets.ibc.ca/Documents/Natural Disasters/The_Financial_Management_of_Flood_Risk.pdf

Factors Contributing to Inflow and Infiltration

There are a number of interrelated factors that contribute to I&I problems and they involve social, economic and environmental dynamics intersecting with technology. In conducting this study, it was discovered that in many ways, I&I in new developments serve as a barometer of how well a municipality can juggle the numerous factors impacting the performance of its infrastructure.

In terms of the most significant factors, these are listed below, not in priority of significance, rather in a phenomenological sequence based on how the entire process unfolds. It begins with a legislative and jurisdictional framework that ultimately produces municipal infrastructure that is tested by climate change through extreme weather events. The key factors include:

- **Complexity of Legislation** - barriers to innovation and integrated water resources management;
- **Jurisdictional Conflicts** - region versus city/town and building code versus municipal works;
- **Development Pressures** - implications of sprawl versus intensive development;
- **Low Impact Development Measures** - sustaining water quality and the environment;
- **Municipal Infrastructure Operation** - the need for comprehensive, integrated management;
- **Engineering Design Standards** - life cycle performance versus first costs;
- **Procurement Policies and Practices** - optimizing engineering design and construction quality;
- **Construction Industry and Workforce** - training, succession and evolution of capable hands; and
- **Climate Change and Extreme Weather Events** - designing for risk, consequences, uncertainty.

These factors interact with various stakeholders to produce a web of interactions that is becoming increasingly diverse and fiscally challenged due to factors such as deferred maintenance deficits and an aging infrastructure.

Figure 6. If I&I problems were largely caused by material selection, these would have been solved decades ago. The complexity and diversity of the factors contributing to I&I problems is a significant problem that is only now becoming addressed in a systematic fashion. [Source: JM Eagle.]

The following parts of this publication examine each of the key factors impacting I&I problems.

Complexity of Legislation

The framework of legislation, policies and guidelines impacting the management of I&I in Ontario is complex and undergoing a process of evolution. It is informative to review the provincial regulatory structure around water to gain an overview of the context within which the management of I&I operates. There is a discussion of the issues arising from legislative and jurisdictional intersections following the outline presented below.

Water Related Legislation in Ontario	
Acts Regulating Water Directly - Administered by the Ontario Ministry of the Environment	
Ontario Water Resources Act (1990)	The Ontario Water Resources Act is the most important law governing water quality and quantity in the province. It is a general water management statute whose origins date back to the 1950s. It applies to both groundwater and surface water. Administered by the Ministry of the Environment, the Ontario Water Resources Act contains a number of important mechanisms that protect water resources.
Environmental Protection Act (1990)	The Environmental Protection Act is the principal pollution control statute in Ontario. It is used interchangeably with the Ontario Water Resources Act to address sources of water pollution. The Act contains a number of general provisions that can be used to protect surface water and groundwater against contamination.
Environmental Assessment Act 1990)	The Environmental Assessment Act is Ontario's primary environmental planning statute. The general rule is that public sector undertakings (such as provincial or municipal projects) are caught by the Environmental Assessment Act unless exempted. Conversely, private sector undertakings are not caught by the Environmental Assessment Act unless they are specifically designated by regulations as undertakings to which the Act applies. For example, private proposals to establish or expand waste disposal sites are typically designated under the Act.
Municipal Water and Sewage Transfer Act (1997)	Transferred ownership of some 230 provincially-owned water and wastewater plants from Ontario Clean Water Agency (OCWA) to municipalities. With the transfer, virtually all water and wastewater systems in Ontario are now owned and controlled by the municipality in which they are situated. At the time of the transfer, many municipalities chose to continue to use OCWA for operations.
Safe Drinking Water Act (2002)	The purpose of the Safe Drinking Water Act is to protect human health through the control and regulation of drinking water systems and drinking water testing. Building on existing policy and practice in Ontario's treatment and distribution of drinking water, the Safe Drinking Water Act requires that all municipal drinking water systems obtain an approval from the Director of the Ministry of the Environment in order to operate. Operators are required to be trained and certified to provincial standards. The Act also provides legally binding standards for testing of drinking water and requires that testing be done in licensed and accredited laboratories.
Sustainable Water and Waste Water Systems Improvement and Maintenance Act (2010) - Intended to replace Sustainable Water and Sewage Systems Act (2002)	Sustainable Water and Sewage Systems Act, 2002 (SWSSA) was passed in 2002 but never proclaimed. Its regulations would have required municipalities to develop full-cost recovery plans and set their water and wastewater rates accordingly. These were to be based on asset management plans, but this Act was never proclaimed. Instead drinking water financial plans are required under 2007 regulations passed under the Safe Drinking Water Act. In addition, new legislation (the Ontario Water Opportunities and Water Conservation Act) passed in 2007 includes authority to develop regulations for municipal water sustainability plans which would be broader than the SDWA financial plans and which would be required to include wastewater and storm water in addition to drinking water financial and asset planning.
Nutrient Management Act (2002)	The Nutrient Management Act, 2002 and its regulations require farm operators to develop nutrient management strategies as part of source water protection. Large livestock operators in Ontario had to be in compliance with the Act by the end of 2005. The legislation, and source protection in general, has an impact on the quality of water that municipalities draw, and therefore on their costs to treat it.
Clean Water Act (2006)	Ontario's Clean Water Act helps protect drinking water with a multi-barrier approach that stops contaminants from entering sources of drinking water - lakes, rivers and aquifers.

Water Opportunities and Water Conservation Act (2010)	The purposes of the Act are: (a) to foster innovative water, wastewater and stormwater technologies, services and practices in the private and public sectors; (b) to create opportunities for economic development and clean-technology jobs in Ontario; and (c) to conserve and sustain water resources for present and future generations.
Acts Regulating Water Directly - Administered by the Ontario Ministry of Natural Resources	
Lakes and Rivers Improvement Act (1990)	The purposes of this Act are to provide for: (a) the management, protection, preservation and use of the waters of the lakes and rivers of Ontario and the land under them; (b) the protection and equitable exercise of public rights in or over the waters of the lakes and rivers of Ontario; (c) the protection of the interests of riparian owners; (d) the management, perpetuation and use of the fish, wildlife and other natural resources dependent on the lakes and rivers; (e) the protection of the natural amenities of the lakes and rivers and their shores and banks; and (f) the protection of persons and of property by ensuring that dams are suitably located, constructed, operated and maintained and are of an appropriate nature with regard to the purposes of clauses (a) to (e).
Conservation Authorities Act (1990)	Empowers the 36 Conservation Authorities to establish and undertake programs designed to further conservation, restoration, development and management of natural resources other than gas, oil, coal, and minerals, such as drinking water.
Public Lands Act (1990)	Applies to Crown land use planning, lands management, sales, development etc.
The MNR is an integral partner in administering these Acts along with other Provincial Ministries or Federal Departments:	The Ontario Water Resources Act, the Planning Act, the Safeguarding and Sustaining Ontario's Water Act, the Clean Water Act, the Emergency Management and Civil Protection Act, Federal Fisheries Act, and the Navigable Waters Protection Act.
Miscellaneous Acts Regulating Water Indirectly	
Planning Act (1990)	A wide-ranging Act, the scope of which includes the supply, efficient use and conservation of energy and water; the protection of ecological systems, including natural areas, features and functions; the protection of the agricultural resources of the Province; the conservation and management of natural resources and the mineral resource base; and the adequate provision and efficient use of communication, transportation, sewage and water services and waste management systems. This Act allows the promulgation of Provincial policy statements and also allows the Province to delegate its powers to lower-tier governments.
Development Corporations Act (1990)	Established the Walkerton Clean Water Centre under O. Reg. 304/04.
Building Code Act (1992)	Water is indirectly regulated through provisions in the Ontario Building Code that govern foundation and roof drainage, and plumbing. Private sewer laterals and private sewer and water systems are also regulated under the Ontario Building Code.
Environmental Bill of Rights (1993)	The purposes of this Act are: (a) to protect, conserve and, where reasonable, restore the integrity of the environment by the means provided in this Act; (b) to provide sustainability of the environment by the means provided in this Act; and (c) to protect the right to a healthful environment by the means provided in this Act.
Capital Investment Plan Act (1993)	Created the Ontario Clean Water Agency (OCWA), which took over the Provincial Ministry of Environment's role as direct owner and operator of water systems. The Act also prevents a municipality from transferring ownership of water-related assets to anyone but another municipality without repaying provincial subsidies for all of its water-related assets.
Savings and Restructuring Act (1995)	This Act brought about the amalgamation of many municipalities. In most cases, this has led to a parallel consolidation of the ownership of water and wastewater systems, although not necessarily the consolidation of operators or the integration of water operations with wastewater operations.

Energy Competition Act (1998)	This Act had the indirect effect of uniting the water and wastewater functions in municipalities in which a public utilities commission (PUC) had previously provided electricity distribution and drinking water. The Act required municipal councils to set up electricity distribution companies, which resulted in the disbandment of almost all PUCs. Municipalities generally decided to re-integrate water treatment into the municipal structure, with some choosing to contract out service delivery.
Municipal Act (2001)	In this Act (and other Acts), the Province of Ontario gave municipalities in the province powers and duties to regulate with regard to matters under their jurisdiction. Municipal jurisdiction includes public utilities, and the health and environment of the municipality. The powers granted under the Act include the ability for municipalities to finance their water systems through the use of debentures and reserves.
Places to Grow Act (2005)	Directs communities to develop in ways that should help to prevent the further development of small, scattered low-density communities that are costly to service.
Greenbelt Act (2005)	Encourages more compact land use by creating a "greenbelt" in the Greater Golden Horseshoe (the area extending from the Niagara River around western Lake Ontario to Peterborough and Cobourg). Like the Places to Grow Act, this should help prevent the further development of small, far flung communities that are costly to serve.
Water Regulation under the Health Protection and Promotion Act	
Health Protection and Promotion Act (1990) See also the Ontario Public Health Standards	The guiding purpose of the HPPA is to: provide for the organization and delivery of public health programs and services, the prevention of the spread of disease and the promotion and protection of the health of the people of Ontario. Specific Sections that are relevant to drinking water are: Part III (Community Health Protection), Part IV (Communicable Diseases), and Part VI.1 (Provincial Public Health Powers)
HPPA O. Reg. 318/08 – Transitional – Small Drinking Water Systems	This regulation laid out the standards governing the maintenance and testing of the following systems during the period of transition to O. Reg 319/08: 1. Large municipal non-residential systems; 2. Small municipal non-residential systems; 3. Non-municipal seasonal residential systems; 4. Large non-municipal non-residential systems; and 5. Small non-municipal non-residential systems.
HPPA O. Reg. 319/08 – Small Drinking Water Systems	This regulation lays out a new schema of standards and tests that apply to Ontario's small drinking water systems: 1. Large municipal non-residential systems; 2. Small municipal non-residential systems; 3. Non-municipal seasonal residential systems; 4. Large non-municipal non-residential systems; and 5. Small non-municipal non-residential systems.
Source: *Fact Sheet: What is the provincial legal structure around water in Ontario?* Erica Stahl, Canadian Environmental Law Association, 2012. http://www.cela.ca/sites/cela.ca/files/FactSheet-DrinkingWaterLegislation2012.pdf	

Table 2. Summary of water related legislation in Ontario.[10]

[10] Adapted from**:** *Fact Sheet: What is the provincial legal structure around water in Ontario?* Erica Stahl, Canadian Environmental Law Association, 2012.
http://www.cela.ca/sites/cela.ca/files/FactSheet-DrinkingWaterLegislation2012.pdf

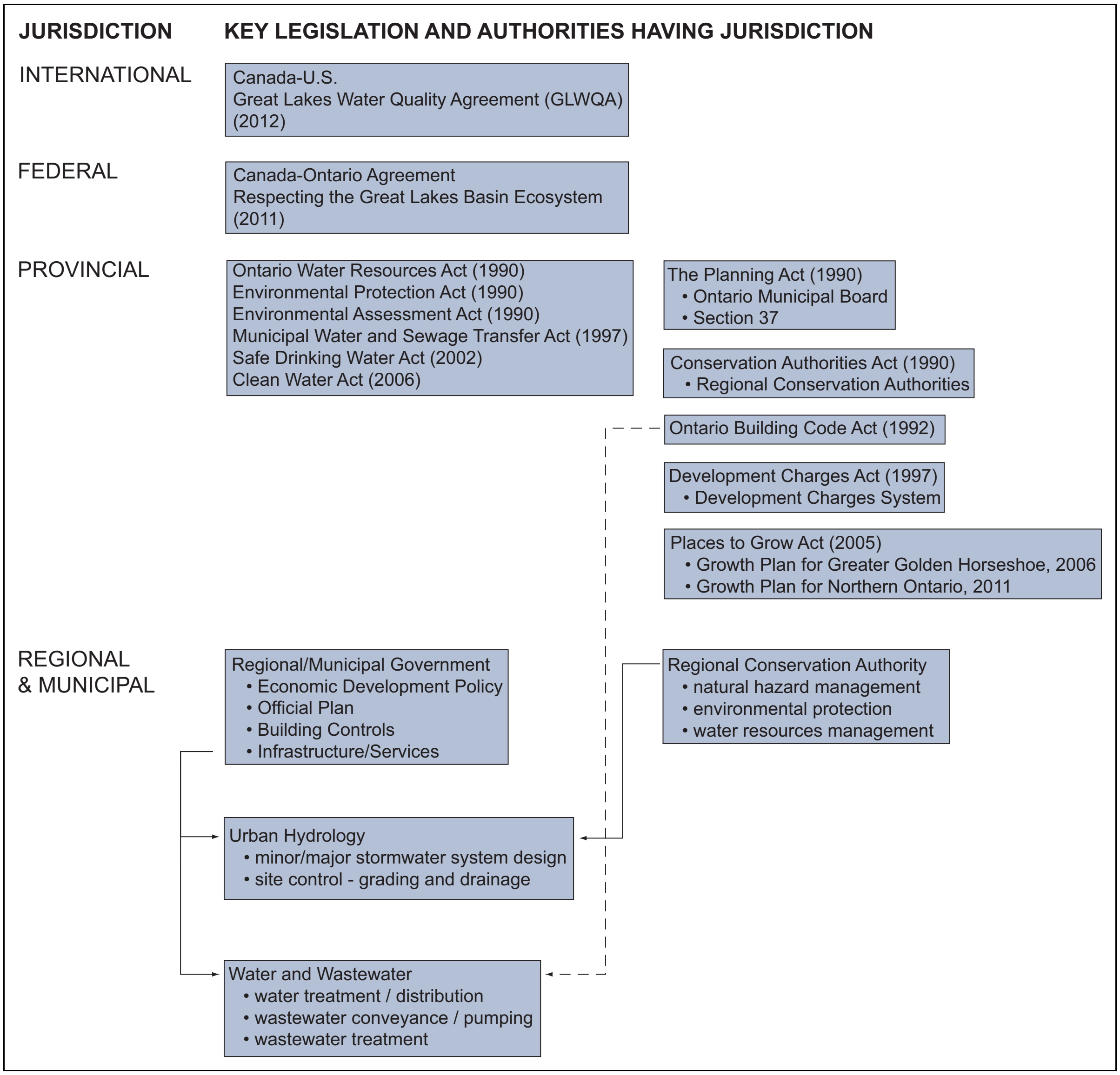

Figure 7. The key legislation and jurisdictions involving Ontario's water resources are extensive and complex. Noteworthy interactions are the impact of plumbing and drainage requirements in the Ontario Building Code on municipal stormwater and sanitary systems, and the relationship between regional conservation authorities and municipal planning of urban hydrology.

The number of agencies involved with water resources in Ontario makes even routine development and implementation of many programs cumbersome. Communications between the various players and stakeholders is difficult to coordinate and as a result the degree of responsiveness is less than optimal. Building code inspectors need to be trained in the proper enforcement of sewer use by-laws. Going forward with integrated water resource management strategies across the various regions of Ontario will be hindered unless protocols can be streamlined. The impact of legislative and jurisdictional complexity on the management of I&I is largely indirect, simply because the additional effort and human resources needed to deal with the current framework detract from those needed to implement best practices in a comprehensive fashion.

Jurisdictional Conflicts

Municipal infrastructure falls under the jurisdiction of public works according to all pertinent regulations and standards, but the plumbing and drainage connecting to sewers falls under the Ontario Building Code. This situation may not appear to be difficult to reconcile, but it typically involves different municipal departments and a different set of construction industry players.

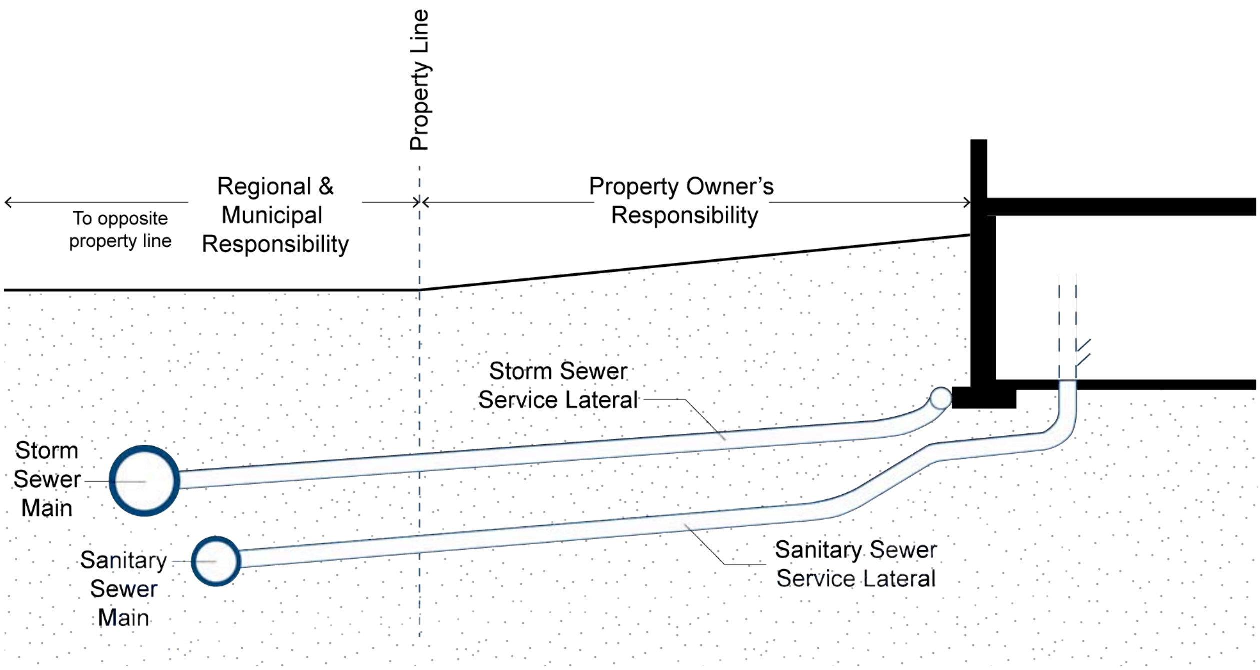

Figure 8. Sanitary plumbing, foundation and site drainage on private property fall outside the design, construction, quality assurance and commissioning procedures associated with the delivery of municipal infrastructure.

A lack of harmonization between the enforcement of building codes and municipal infrastructure design guidelines can develop into situations impacting I&I through inappropriate connections and substandard quality of sanitary sewer laterals on private property.

In order to appreciate the importance of maintaining consistency between the enforcement of sewer use by-laws and building code requirements, there are many existing developments with separated sewer systems where the connection of foundation drains to the sanitary sewer was permitted. The result of this practice is referred to as a partially separated sewer system since some stormwater has been diverted to the sanitary sewer. At the time, it was assumed very little stormwater percolating through the soils surrounding basements would enter the sanitary sewer system. In some cases, downspouts from eavestroughs were also connected to the foundation drain and this led to many cases of extreme inflow volumes during storm events. Many municipalities subsequently implemented downspout disconnection programs, and while a significant reduction of inflow was achieved, the foundation drains could not always be so easily disconnected because there were no stormwater laterals provided in many of these older developments.[11]

The City of Ottawa has reported that some 58,000 homes fall under this situation and that at an average cost of $11,000 per home, this represents a total cost of some $630-million. Assuming a remediation rate of 500 homes per year, this process would require some 110 years to complete. The lesson to be learned from this example is that getting things right and keeping them that way is far more cost effective than remediation of dysfunctional infrastructure. This underlines the importance of the proper enforcement of sewer use by-laws by building inspectors and clearly communicating vital information to developers, builders and their trades.

[11] City of London (2013). *Weeping Tile Disconnection to Reduce the Impact of Basement Flooding*. http://www.iclr.org/images/Kyle_Chambers.pdf

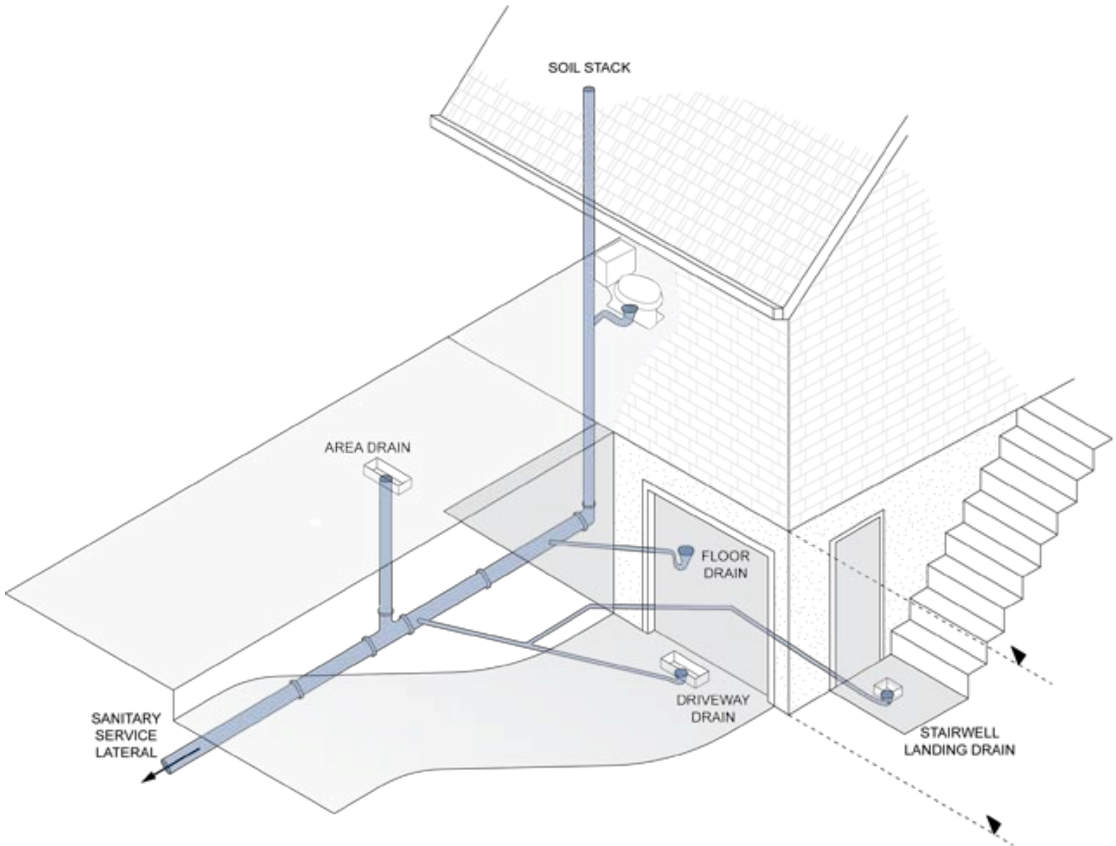

Figure 9. Connections of stormwater drains to sanitary sewer systems on private property are not explicitly prohibited in building codes, and these can overload sanitary sewer systems during extreme weather events when accumulations of runoff overwhelm these drains and subsequently the sanitary sewer system that receives these unforeseen inflows.

Integrated Water Resources Management

One of the significant observations made during the course of this study is the number and variety of legislation, authorities having jurisdiction, and levels of government involved with the management of water resources. Seldom do the jurisdictional boundaries coincide with watersheds, and rarely are the operational responsibilities harmonized to deal with water inputs and outputs holistically. There is an emerging awareness that this fractionation of responsibilities often leads to gaps and contradictions in water resources management practices and policies. The following definitions are useful in bringing important challenges into sharper focus.

- ***Watershed*** *is the area of land that contributes runoff to a lake, river, stream, wetland, estuary, or bay. Integrated watershed management is the comprehensive process of balancing water and land use planning within a watershed to promote sustainable social, ecological and economic outcomes. The watershed is considered an effective planning unit because it represents a boundary within which all ecological activities are sustained by the watershed*.
- ***Integrated water resources management:*** *The management of all water within a watershed taking into account all impacts on water quality and quantity. From a municipality's perspective, this includes drinking water, wastewater, stormwater and natural water courses and any infrastructure or operational services necessary to provide sustainability of the watershed.*

By taking these definitions into serious consideration, it is possible to formulate better legislation, policies, guidelines and protocols for the development of land and the stewardship of precious water resources. It is now obvious end of the pipe solutions are failing and there is a growing recognition that "going with the flow" is the only sustainable path to our common future.

Development Pressures

The dynamics of development under *Places to Grow* in Ontario involve rapid growth, increasingly marginal lands and the need to provide services to relatively low density development.

"If we continue to consume land for urban development at the rate we have been for the past three decades, we will jeopardize the financial, social and environmental factors that make the region so attractive to new residents and new economic growth. Business-as-usual development will consume 1,000 sq km of primarily agricultural land by 2031, an area twice the size of Toronto." [12]

This problem is not unique to the Greater Golden Horseshoe of Ontario. The tendency for new development to expand into the peripheries of suburban areas is predominant in many regions. Despite concerns for paving over prime agricultural land, the evidence in Ontario suggests these concerns are not being considered.[13] Low density development that is typical of single-family detached housing subdivisions demands proportionately more piping to service on a per-household basis than medium to high density development. This does not suggest that high density development around the centres of formerly "quaint" communities is not without its challenges. In the case of such developments, the existing infrastructure did not foresee such concentrated sanitary sewage loads, and accommodating enlarged piping configurations to handle the population density within a crowded public services right of way involves special design and logistics to maintain quality.

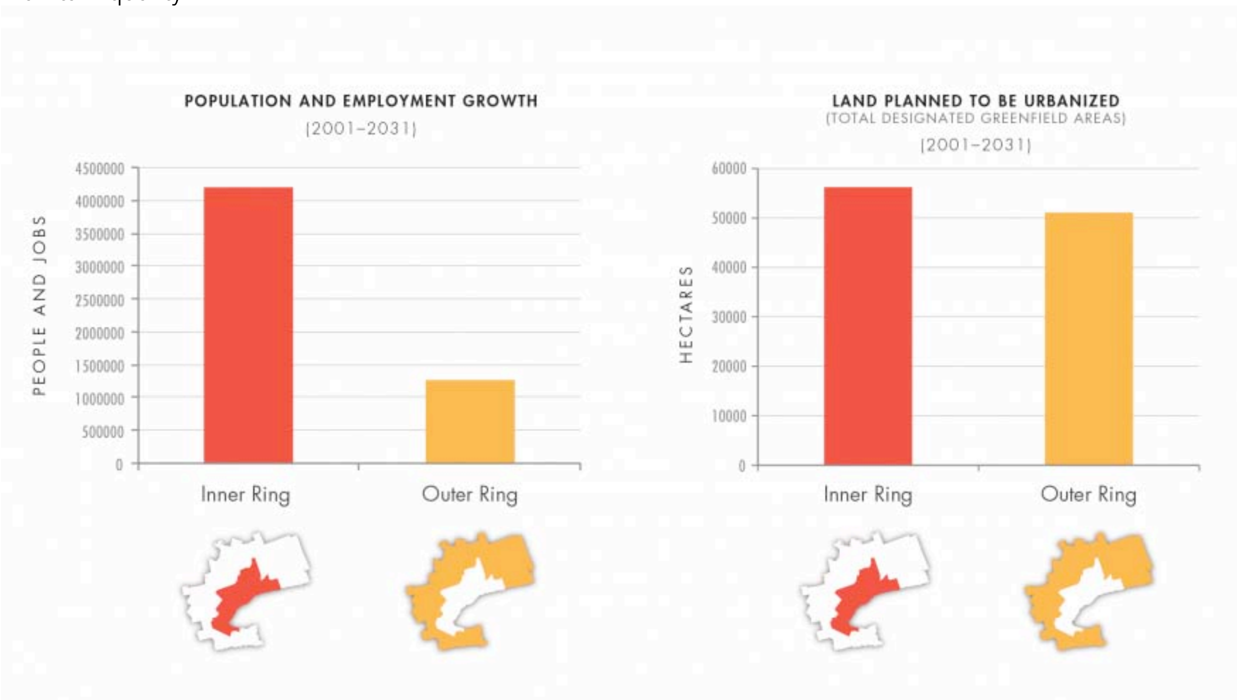

Figure 10. Low density development in the outer ring of the Greater Golden Horseshoe translates into more buried infrastructure per capita than in areas with higher development densities. Source: [Allen and Campsie, 2013.] [14]

Municipalities wishing to attract development are conflicted between advocating best practices for a sustainable life cycle of the municipal infrastructure or adhering to 'business as usual' to avoid disincentives to developers. There remains a delicate balance between sustainable development and the economically sustainable integration of responsible water resources management.

[12] Government of Ontario. (2004.) *A Growth Plan for the Greater Golden Horseshoe: Discussion Paper*. https://www.placestogrow.ca/images/pdfs/PTG_DiscussionPaper.pdf
[13] Ontario Greenbelt Alliance and Environmental Defence. (2009) *Places To Sprawl: Report on Municipal Conformity with the Growth Plan for the Greater Golden Horseshoe.* http://environmentaldefence.ca/reports/places-sprawl
[14] Allen, R., and Campsie, P. (October 2013). *Implementing the Growth Plan for the Greater Golden Horseshoe*. Neptis Foundation, Toronto, Ontario, Canada. http://www.neptis.org/sites/default/files/growth_plan_2013/theneptisgrowthplanreport_final.pdf

The Relationship of Compact Development to Infrastructure Costs

Urban sprawl and low density development have frequently been characterized as unsustainable. There is often an insufficient critical mass needed to support public transit and social services, leading to incomplete communities where people cannot live, work and play within walking distance of their homes. In many new suburban developments, it is not even possible to walk a reasonable distance to access public transportation that will connect residents to recreation centres, public services and their places of employment. Low density developments served primarily by the automobile are also criticized for their adverse impacts on human health since residents are discouraged from walking, a vital form of exercise for good health. The costs associated with urban sprawl are seldom fully assessed by urban planners, but there are aspects related to infrastructure costs that are much better understood by municipal engineers.

To municipal engineers designing sewer and water works, it has long been apparent that the length of piping per capita in low density developments is significantly higher than compact developments. Some engineers have expressed the concern that in low density developments where water conservation has been implemented, there may be insufficient sewage volumes to promote proper conveyance in sewers that are sized using traditional per capita water usage, peaking factors and I&I rates (i.e., pipes are grossly oversized representing unnecessarily higher capital costs).

From the perspective of developers, municipalities and tax payers, compact development represents better returns on investment, lower operating and maintenance costs, and lower tax increases, respectively. Recent studies on compact developments and intensification indicated these are preferable alternatives to greenfield urban sprawl.

- Studies undertaken by the cities of Calgary, Canada and Los Cabos, Mexico identified significant savings on infrastructure costs could be achieved through more compact growth. Savings of 33% and 38% were identified for the capital cost of roads, transit, water and other infrastructure for Calgary and Los Cabos, respectively. Savings on operational costs were 14% for Calgary and 60% for Los Cabos.*
- A study undertaken by the City of Brantford, Ontario found that intensification was a preferred alternative to new development sites across all forms of urban infrastructure, especially stormwater management, sanitary sewers and water.**

Compact development, coupled to low impact development strategies, has the potential to dramatically reduce life cycle costs associated with sewer infrastructure and stormwater management. Related benefits are extended to social, environmental and economic factors stemming from complete compact communities embracing green design principles.

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* Sustainable Cities Institute (September 2012). *Infrastructure Costs and Urban Growth Management*.
http://www.sustainablecities.net/our-work/services/infrastructure-costing

** AMEC (2012). *Intensification/Infill Study Background Report - Water, Wastewater and Stormwater Management*. City of Brantford.
http://www.brantford.ca/Projects Initiatives Intensification Strategy/Amec - Servicing Report (March 2012).pdf

Low Impact Development Measures

Traditionally, stormwater management has been based on the notion of conveyance, moving rainwater and snowmelt away from the site as quickly and efficiently as possible. Various stormwater management measures were used to regulate peak flow impacts on receiving waters, but for the most part, these practices did not completely address water quality and aquatic and riparian habitat degradation issues.

By contrast, the low impact development (LID) approach is not based on conveyance, rather it is a series of measures for source control and infiltration. LID techniques seek to maximize the area available for infiltration so that runoff volume and pollutant concentrations are reduced. This is achieved through a variety of site design and engineered infiltration techniques.

There are many benefits associated with LID measures, and most notably, these include groundwater recharge through infiltration, improved surface water quality, and protection of streams and lakes from large volumes of polluted runoff.

Figure 11. The construction of bioswales is a highly effective low impact development measure for managing stormwater on site. Properly situated, these measures can manage runoff from adjacent hard surfaces, such as roadways and parking lots. [Source: Toronto and Region Conservation Authority]

Industry experts were interviewed to determine if there was any documentation about the relationship between LID measures and higher local water tables that may place increased hydrostatic pressure on sanitary sewer laterals and piping connected to the laterals, including illegal connections. There is no indication LID measures have any adverse impacts on I&I. It is generally acknowledged LID measures have the potential to reduce impacts on I&I, provided the measures are properly designed, constructed, commissioned and maintained. LID measures can achieve their desired performance, without compromising the sanitary system, which is supposed to be designed to be watertight and capable of resisting groundwater pressures. Like climate change, LID measures are here to stay and they can positively contribute to integrated water resource management without compromising sanitary sewer system performance, but further long term studies are needed.

Low Impact Development Challenges and Opportunities

Unlike conventional development approaches that impose buildings and infrastructure on a landscape in patterns that do not always reflect its intrinsic ecological carrying capacity, low impact development is premised on the stewardship of water resources.

Low impact development (LID) is a stormwater 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 flow.

Despite the numerous environmental and economic advantages of low impact development, it faces numerous challenges.

- LID best management practices (BMPs) are widely documented, readily accessible and have been successfully demonstrated in a number of jurisdictions but they have not been fully integrated into normative engineering practice. Qualified LID designers are not as abundant as traditional water resources engineering personnel. The pre-qualification of LID contractors remains a significant challenge in most parts of Canada.
- Increasingly, properties available for development are marginal in that they comprise poor draining soils and/or high seasonal groundwater tables (1.5 metres or less below grade). These sites cannot be adequately serviced with LID measures and even their development using conventional infrastructure is questionable in the long term.
- The stewardship and maintenance requirements of LID BMPs are not well understood by municipal operation personnel. As a result, the full performance potential of these measures may not be realized over time.

Low impact development practices can significantly reduce initial and ongoing life cycle costs associated with the management of stormwater, while enhancing the environmental performance of new developments. They also offer opportunities for savings to be invested in high performance sanitary sewer systems that provide enhanced resilience in the face of climate change. Mainstreaming LID practices hinges on adopting integrated water resources management policies.

Municipal Infrastructure Operation

Planning, design, construction, quality assurance, commissioning, monitoring and maintenance comprise the facets of municipal infrastructure operation, using this term in its holistic sense.

A number of issues related to municipal infrastructure operation may impact I&I problems. At the highest level, the delineation of responsibilities for stormwater management versus sewer and water can result in situations where one aspect of municipal infrastructure is the purview of a regional government and the other aspect the sole responsibility of the municipality within a region. These types of relationships, often referred to as "silos" in organizational jargon, can hinder effective communication and an integrated approach to water resources management.

In municipal infrastructure, planning is typically driven by a higher level of decision making that sets out the official plan for a municipality and/or region. This establishes the future growth patterns and the intensity of development. A failure to consider integrated water resources management when developing an official plan can often impair municipal infrastructure planning. The design of municipal infrastructure in response to the official plan is greatly influenced by design standards and the procurement of design services when this process is outsourced. Sections on engineering design standards and procurement follow this present discussion.

Quality assurance and commissioning are aspects of operations that are highly dependent on the quality of workmanship - a factor that is related to procurement protocols as well as the available construction industry bidders pool. Suburban sprawl will incur higher quality assurance and commissioning costs than compact development simply because of the higher length of collection system pipes.

Figure 12. Regular cleaning of sanitary sewers to avoid blockages and backups not only maintains proper performance, but also enables the proper monitoring of infiltration. [Source: Town of Yorkton, Saskachewan.]

Monitoring and maintenance ensure the performance of the sewer system is sustained over its useful service life. I&I are generally found to increase as a system ages and regardless of the quality of design, materials and workmanship, proper monitoring and maintenance are key to fixing small problems before they become big problems. Municipal infrastructure operation is analogous to a chain where the performance and sustainability of the entire system are only as reliable as the weakest link.

Engineering Design Standards

Design standards for stormwater management and sewage systems are not consistent across municipalities. An examination of design guidelines across a handful of Ontario and Canadian municipalities confirmed what was commonly reported in interviews with industry experts. There are several critical issues that stem of this lack of consistency.

Beginning with the fundamentals of urban hydrology and stormwater management, the design of minor and major systems varies widely and this has been known to translate into higher levels of runoff accumulation in streets and low lying areas of new developments during extreme events, leading to increased inflow stresses. In some cases, the use of less sophisticated simulation methods combined with inappropriate allowances for climate change effects has exacerbated such situations. The design of sanitary sewer systems without knowing how the major stormwater management system will behave can lead to additional problems, such as incorrectly locating maintenance holes in areas where they are submerged in surface water during extreme rainfall events. When sanitary conveyance system designers assume constant I&I rates in situations where inflow potential has not been properly assessed, it is possible for the capacity of sewers to become exceeded, thus leading to sanitary sewer backup problems. The traditional paradigm of designing stormwater management systems and sanitary sewer systems independently of one another is being challenged by climate change and intensified urban development.

Another issue associated with differences in engineering design standards among municipalities is that constructors are not following a consistent set of specifications, materials and methods. While this may not be critical when a better practice is carried out through habit, the results may not be so desirable when a lesser practice is inadvertently executed.

Figure 13. Municipalities cannot rely on material and component manufacturers to uphold a minimum standard reflecting best practices across their line of products. This example of a pre-benched maintenance hole base with gasketed connections represents current best practices, but lesser quality products are both still available, being manufactured and installed in many parts of Canada. [Source: Langley Concrete Group, Chilliwack, BC.]

Standards and specifications for inspection, testing, monitoring and the eventual acceptance of municipal infrastructure in new developments must be carefully coordinated to manage I&I. While a system of provincial standards has been in place for some time in Ontario,[15] and notwithstanding numerous past and ongoing collaborative initiatives for advancing and sharing best practices, there is no central repository of best practices and model design guidelines, standards and specifications available to Canadian municipalities. It is also important to recognize that the effective application of engineering design standards requires considerable experience. Given the demographics of Ontario's water resources and municipal infrastructure engineers, unless much of this wisdom is captured, distilled and conveyed as part of a succession plan, the future quality of municipal infrastructure may suffer considerable setbacks.

[15] Ontario Provincial Standards for Roads and Public Works
http://www.raqsb.mto.gov.on.ca/techpubs/OPS.nsf/OPSHomepage

International Perspectives on Sewer System Best Practices

Inflow and infiltration issues are common to sewer systems around the world and have been widely recognized and understood for well over half a century. I&I only became viewed as a problem when ecologists recognized the environmental impacts associated with combined sewer overflows and sewage treatment plant by-passes. Since that time, numerous jurisdictions have attempted to rectify I&I problems in existing developments, and even more progressive jurisdictions have sought to develop and implement best practices for the management of inflow and infiltration in new developments. The common rationale underlying these various best practice strategies was to contain I&I rates and prevent them from escalating so that they would not exacerbate the current situation, thereby capping the extent of rehabilitation across existing sewer infrastructure systems.

The literature reports that among the consistently lowest I&I rates are being realized in Sydney, Australia by Sydney Water, where this has been accomplished through the introduction of two innovations: 1) leak tight sewers; and 2) low infiltration sewer systems.* By adopting these new sewer systems, it is possible to significantly reduce inflow and infiltration by utilizing improved or alternative approaches in the design and construction of pipes, fittings and maintenance structures.

Sydney Water aims to eliminate rainfall ingress to new sewerage systems in growth areas (new developments) to not more than 1% for Leak Tight Sewers and not more than 2% for Low Infiltration Sewers for a period of more than 30 years after completion. It is believed that these objectives can be achieved through improvements to: design; construction; quality assurance; and maintenance.

- Among the many innovations piloted by Sydney Water is the use of cast in place maintenance holes with square walls, where the benching is a "scooped out" monolithic pour onto and around the inlet and outlet pipes, all of which are placed with a pull-tested collar.
- High density polyethylene (HDPE) maintenance shafts feature fully welded connections to the HDPE inlet and outlet pipes so that this juncture would in effect have no seams.
- Whenever possible, maintenance structures are spaced no less than 400 metres apart to reduce costs and the likelihood of infiltration at connections.

A comprehensive technical specification for these types of systems has been developed.** Its continued evolution is being guided by pilot projects which have to date evidenced virtually no measureable rainfall ingress.

The innovative approaches adopted by Sydney Water may not be entirely suitable to Canadian conditions where winter and freezing temperatures, along with factors such as the cost of skilled labour, require rapidly installed technologies such as precast concrete piping and maintenance structures. It is nevertheless encouraging to see that innovation is being championed on the basis of life cycle cost, and that acceptable performance is being confirmed through monitoring.

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* Sydney Water, Australia (October 2011). *Leak Tight and Low Infiltration Sewer Systems Overview*. (Presentation to External Industry.)
https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq2/~edisp/dd_046110.pdf

** Sydney Water, Australia (December 14, 2012). *Technical Specification For Low Infiltration Sewer Systems*.
https://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq2/~edisp/dd_046421.pdf

Procurement Policies and Practices

The procurement of goods and services associated with municipal infrastructure in many ways determines the quality of design, materials and construction. Ideally, procurement policies are implemented to provide a framework to support open, fair, transparent and accountable purchasing processes, and also to ensure procurement processes are consistently managed. In order to have an effective and efficient procurement program, especially related to the purchase/construction of large capital assets, the procurement policy can include clauses to protect the municipality, as well as assist in receiving competitive responses. Examples include:

- Criteria to determine the type of competitive process to be followed (i.e. tender, RFP, RFQ);
- Circumstances when sole sourcing, negotiation, and/or in-house Bids can be considered;
- Methods used for advertising a competitive process;
- Direction for purchasing in cases of emergency;
- Guidelines for procurement as part of a co-operative purchasing group;
- Requirements related to bid deposits or other financial security;
- Non-discrimination policy and notification that any bid can be rejected by the municipality; and
- Reasons for terminating a contract with a supplier/contractor.

As part of the continuous asset management update process, it is recommended that the municipality's procurement policies and procedures be reviewed and compared against procurement best practices to ensure resources are being allocated in an efficient manner.

Section 270(1) of the Municipal Act, S.O. 2001, provides that municipalities (and local boards) shall adopt and maintain policies with respect to its procurement of goods and services, but it does not stipulate the nature of these policies. With respect to municipal infrastructure, it does not require pre-qualification of consulting engineers and contractors to ensure they are capable of properly carrying out the work. There is also nothing restricting the exclusive use of low bidder criteria when awarding contracts. This has had many consequences, among them a lowering of the quality of expertise, materials and workmanship for delivering municipal infrastructure. An excerpt from a recent seminar on municipal finance and governance summarizes the current state of affairs in Ontario and many other parts of Canada.

"*The history of water in the province has also affected engineering practice. Tighter provincial and municipal budgets over the years have led to a practice of price-based selection (PBS) in the procurement of public infrastructure projects, which is often referred to as low-cost bidding. With PBS, price considerations enter in the engineering consulting firm selection process early for a given project. Price has a significant influence on the chosen firm for the project and these prices typically only include up-front costs and not full life-cycle costs. Alternatively, qualifications-based selection (QBS) requires that the initial selection of the firm be based on the firm's qualification and project proposal. In QBS, price negations occur after joint project scoping with the client and life-cycle costs are considered in this process (Infraguide 2006)*[16].

Applying PBS to the selection of engineering consulting firms for water infrastructure projects leads to commoditization of the engineering consulting profession. Commoditization is a process wherein a market based mainly on the matching of the unique skills of a given firm with a given project transitions into a commodity/price-based market, where firms are chosen mainly on their ability to provide the lowest price for a given project.

[16] Infraguide. (2006). *Selecting a Professional Consultant*. Federation of Canadian Municipalities, No. 11, Ottawa, Ontario.
http://www.docstoc.com/docs/57535860/Selecting_Profess_Consultant

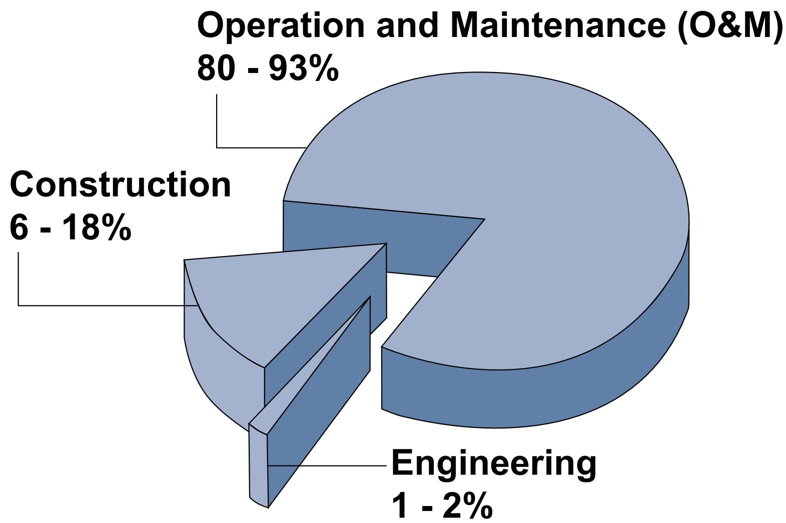

Figure 14. The typical breakdown for total life cycle costs associated with municipal infrastructure projects indicates increasing investments in engineering design services is an effective means of leveraging savings in operation and maintenance costs. [Source: Infraguide, 2006.]

"PBS is a short-term-thinking way of approaching infrastructure projects because this selection process does not explicitly consider the life-cycle costs of a project (e.g., pumping energy costs, treatment chemical costs). As shown in the pie chart above (Infraguide 2006), when life-cycle costs of Canadian and US infrastructure projects are considered, the engineering and design costs are quite low (1-2%), but engineering design affects construction costs and operations and maintenance costs, which account for a majority of the total life-cycle costs of a project. By investing more up-front in engineering expertise, more value can be realized from the project over its lifetime. Such value allows municipalities to do much more with less over a longer period of time with relatively little up-front engineering consulting investment.

If PBS dominates the selection of engineering consulting firms for municipal water projects in the province, the engineering consulting market may become increasingly commoditized. With commoditization (Capelin 2005)[17]*:*

- *Projects may exhibit poorer long-term planning due to the lack of long-term life-cycle costing.*
- *There may be less innovation in design because the need to provide the lowest cost can limit time spent on a project, thus limiting creative output.*
- *Fees tend to be lower because the need to provide the lowest cost to win a project may lead to unrealistically low bids, requiring cost-cutting on the part of firms.*
- *It may eventually be difficult to attract talent to the profession due to lower salaries and a diminishing ability to contribute to innovation in design."* [18]

Procurement policies and practices can act as filters that screen out life cycle cost effectiveness in favour of affordable first costs. There is nothing that prevents them from fostering best practices, premised on bringing value and quality to municipal infrastructure. In conducting this study, it was encouraging to discover an increasing number of municipalities inform their decision making with life cycle cost-benefit analysis, but it must become far more widely adopted before it can be considered a mainstream practice supporting procurement policies.

[17] Capelin, J. (2005). *Confronting Commoditization*. Design Intelligence. http://www.di.net/articles/confronting-commoditization/

[18] Herstein, Lesley (2012). *Adding Value: Recognizing the Link Between Engineers and Municipal Finance and Governance*. 2012 Graduate Fellowship Seminar Series, Institute on Municipal Finance and Governance, Munk School of Global Affairs, University of Toronto, May 10, 2012. http://munkschool.utoronto.ca/imfg/uploads/200/imfg_adapted.pdf

Construction Industry and Workforce

One of the most frequently cited factors impacting I&I problems is the dichotomy between the municipal infrastructure construction industry working in the public right-of-way versus the various trades and workers operating on the private side of the property line.

Ontario's municipal infrastructure construction industry is both sophisticated and diverse and ranks highly on an international basis. Opportunities for persons to obtain training and education in areas such as civil engineering technology and civil infrastructure design are available through community colleges, universities and various associations. For example, the Ontario Good Roads Association offers municipal infrastructure training courses on a variety of subjects related to water resources, such as watermain design, storm sewer design, sewer and watermain construction inspection, stormwater management and sanitary sewer design.[19]

Based on interviews with industry experts, it was discovered the training and education resources to prepare the workforce to deliver high quality municipal infrastructure exist, but are not always easily accessible. Similarly, highly skilled and experienced contractors are not distributed uniformly across all regions of Ontario. All contractors are beginning to face a demographic shift in their workforce as experienced personnel age. According to the Ontario Sewer and Watermain Construction Association (OSWCA), the average age of equipment operators is approaching 50 years. The forecast municipal growth across Ontario and particularly the Greater Golden Horseshoe region will challenge the construction industry to find sufficient numbers of appropriately qualified personnel.

Going forward, Ontario lacks a formal contractor qualification and workforce certification process, with some notable exceptions for water and sewage treatment plant operators, heavy equipment operators and specialized trades required to perform critical work, such as pipe fitters, electricians, welders, millwrights, etc. Various municipalities have established their own contractor pre-qualification criteria, but there is no assurance the "A-team" will form the contractor's crews assigned to a particular project.

Despite these challenges, the consensus among experts interviewed was that quality assurance and field inspection were indispensable tools to ensuring high quality municipal infrastructure, but that the extent of this effort, and hence its cost to the municipality, was strongly correlated to the qualifications of the contractors. There is considerable interest in monitoring how the quality of municipal works evolves given the demographics of the workforce and the rapid rates of growth across municipalities.

Moving to the private side of the property line, there is typically much less inspection of how sanitary and storm piping is configured and possibly interconnected, intentionally or otherwise. While the sanitary system plumbing is normally tested by inspectors from a municipality's building department, varying degrees of inspection and quality assurance are associated with weeping tiles and sump pumps.

While sanitary plumbing is installed by licensed plumbers or apprentices working under their supervision, the same cannot be said of the foundation and area drainage works. When low impact development measures are deployed, such as infiltration pits, bio-swales, etc., it is not always clear as to what constitutes appropriate workforce qualifications, and field inspection protocols. Further, the site drainage control for surface runoff is not always conducted by skilled personnel and compliance with the site grading plan is seldom fully enforced on an ongoing basis beyond initial construction. As noted earlier,
this issue is related to the jurisdictional conflicts between the municipal works and the Ontario Building Code. Some municipalities have made special efforts to coordinate between the building controls and municipal works divisions so that I&I problems originating from the private side of the property line are properly managed.

Quality of workmanship and the knowledge and expertise needed to properly execute sanitary and stormwater drainage systems on both sides of the property line have always been assumed as being adequate, but in future certification of individuals and organizations may need to be established.

[19] Ontario Good Roads Association. *Municipal Infrastructure Training Program*.
http://www.ogra.org/Education/CoursesandWorkshops/MunicipalInfrastructureTrainingProgram.aspx

Climate Change and Extreme Weather Events

As most I&I are derived from rainfall events, climate change leading to an increase in extreme weather events is a major factor that must be carefully considered.

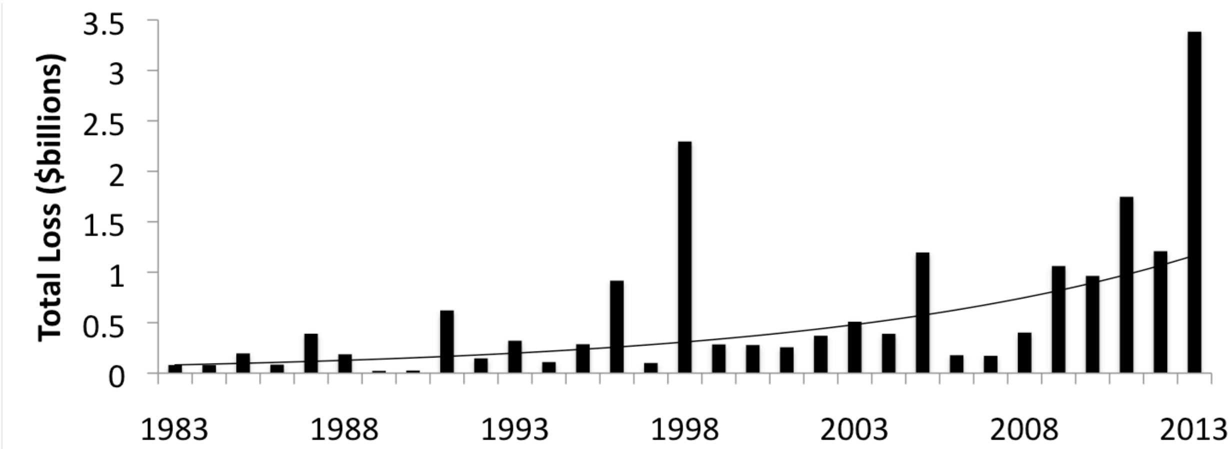

Figure 15. Catastrophic losses in Canada from 1983 to 2013 indicate an escalating trend. Insurance claims for the severity and frequency of weather related losses are highly correlated to sanitary sewer backups associated with I&I.
[Source: Insurance Bureau of Canada, http://assets.ibc.ca/Documents/Facts Book/Facts_Book/2014/IBC_2014_Factbook_English.pdf]

The expected outcomes of climate change in all of Ontario and most regions of Canada are as follows:[20]

- Increase in average annual temperature
- More frequent and intense extreme events
- Increase in annual precipitation (more rain and less snow)
- More extreme heat days and fewer extreme cold days
- Increased variability of wet and dry periods (duration, timing, severity)

Figure 16. Extreme rainfall events are now a common occurrence across Canada and accumulations of water on streets have caused an increase in the rates of inflow to sanitary sewer systems. [Source: CTV News, Toronto.]

Municipalities that have implemented best management practices for I&I in new developments reported negligible impacts associated with extreme weather events. However, conventional sanitary sewer design in new developments continue to experience I&I issues. Environmental stresses affecting I&I may be expected to increase significantly in the next several decades and it is important for municipalities to adopt appropriate adaptation strategies for their sewer system infrastructure.

[20] Environmental Commissioner of Ontario. (2014). *Sink, Swim or Tread Water? Adapting Infrastructure to Extreme Weather Events*. Toronto, Ontario, Canada.
http://www.eco.on.ca/uploads/Reports-GHG/2014/GHG2014 Section 4.pdf

Inflow & Infiltration Best Management Practices Framework

The establishment of a best practices framework for the management of I&I is the first step toward sustaining the life cycle performance of municipal infrastructure. As noted earlier in this publication, the numerous best practices are disaggregated and have never been collected and made available as a single cohesive source of authoritative information. This best practices guide attempts to do so in the manner of a 'knowledge map' linking various sources of information and making them readily accessible to the user.

Web of Municipal Infrastructure Interactions

The best practices framework responds to the web of infrastructure interactions depicted below. This web connects government, public and private stakeholders, and technology and it is noteworthy every part of the web is connected to every other part, both directly and indirectly.

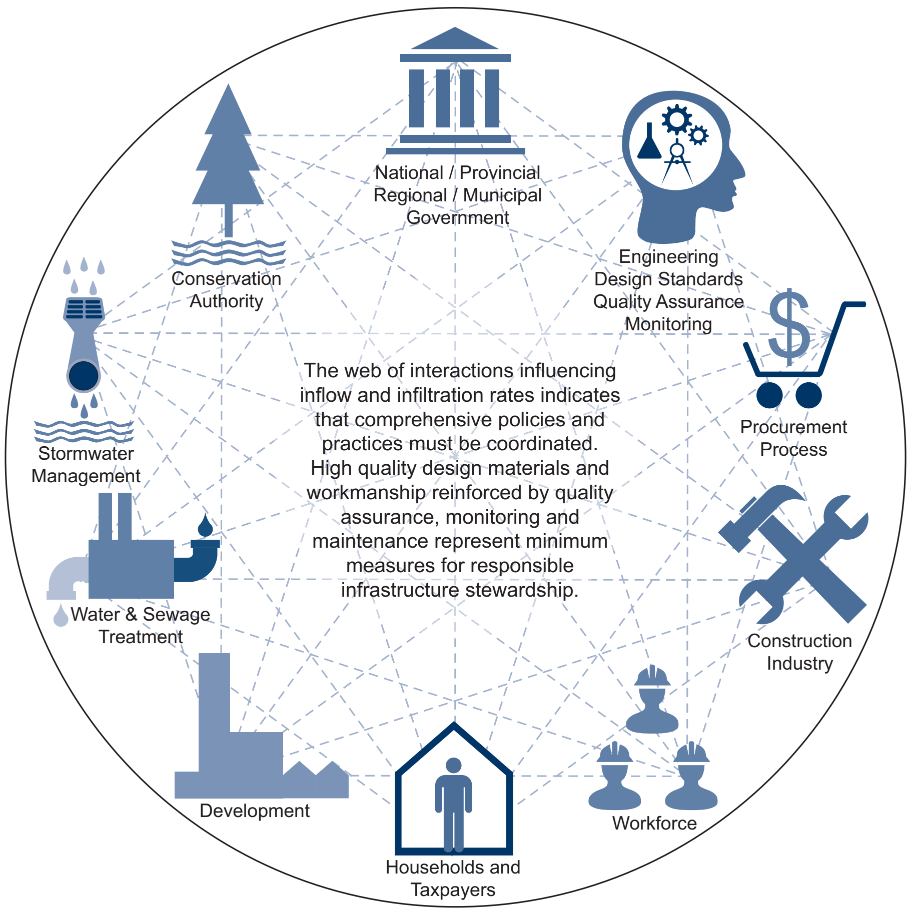

Figure 17. The web of interactions between municipalities and their stakeholders is made more complicated by legislative, jurisdictional and political dynamics. It is the underlying processes that shape this web of interactions.

The best practices framework is described in the section that follows and it assumes that mechanisms, such as procurement policies and practices, are congruent with delivering high performance infrastructure over its life cycle. This reasoning is consistent with the notion of integrated water resources management.

Inflow and Infiltration Management Best Practices

The following collection of I&I best management practices is based on a review of contemporary literature as well as a series of interviews with industry experts. It is important to recognize that at present, there is no formal consensus across Canada's water resources management community about best practices for the management of I&I.

Urban Hydrology Design Practices

Interestingly, the management of I&I to sanitary sewers begins with urban hydrology design practices because it is the stormwater that is unintentionally entering the sanitary sewer system. The potential hydrostatic pressures exerted on the buried infrastructure are not entirely dependent on urban hydrology since groundwater levels and soils are also important factors. However, since groundwater and soil conditions are typically beyond the control of system designers, stormwater management represents a variable that can be effectively addressed by municipal engineers.

Stormwater management begins with the design of urban drainage which normally consists of the minor and major drainage systems. The minor drainage system comprises roof gutters, rainwater leaders, service connections, swales, street gutters, catchbasins and storm sewers. It is designed to convey runoff from frequent storms (i.e., 2 to 5 year return period storms). The chief purpose of the minor system is to minimize stormwater ponding at roadway intersections which may cause inconvenience to both pedestrians and motorists, hence it is sometimes referred to as the "convenience" system.

The major drainage system comprises the natural streams, ravines, valleys and man-made streets, swales, channels and ponds. It is designed to accommodate runoff from less frequent storms (i.e., 50 to 100 year return period storms, also known as regional storms). The main objective in major systems design is to reasonably eliminate the risk of loss of life and property damage due to flooding. This major system exists whether or not it has been planned or designed, and this becomes evident during extreme weather events.

Major and minor stormwater drainage systems design is being challenged by climate change and an increase in the frequency and severity of extreme rainfall events. It is seldom possible or feasible to revisit the minor and major system designs inherited from out existing urban developments, but it is possible to apply more sophisticated design tools to the design of new urban developments. It is important to recognize that new criteria now govern stormwater management and these have been developed for most regions of Canada.[21]

I&I concerns will not drive minor/major system design, rather it is important that the forecast behaviour and performance of these systems be shared with sanitary sewer system designers so they can better anticipate the amount and duration of runoff accumulations over top of buried infrastructure and how water will migrate based on the hydraulic conductivity of the soil. In the same way that structural engineers need to understand the loads on their structures, sanitary sewer system designers need to appreciate the hydrological context of their municipal works.

In conducting this study, it was discovered that in some parts of Ontario, a regional government may deal exclusively with stormwater management, while a town or municipality will deal with sanitary sewer system design, independent of another. Best practices require that urban drainage and sanitary sewer systems be designed through an integrated process.[22] It is only by dealing with the composite behaviour of all buried municipal infrastructure that appropriate measures be adopted in design guidelines and standards.

[21] Toronto and Region Conservation Authority. (August 2012). *Stormwater Management Criteria (Version 1).*
http://sustainabletechnologies.ca/wp/wp-content/uploads/2013/01/SWM-Criteria-2012.pdf
[22] A good example of a recent set of municipal standards for drainage covering all aspects of drainage and conveyance may be found in: City of Edmonton. 2012. *Design and Construction Standards, Volume 3, Drainage*.
http://www.edmonton.ca/business_economy/documents/PDF/Volume_3_Drainage_.pdf

Low Impact Development Practices

In many ways, low impact development (LID) practices are a return to the way stormwater was managed before communities could afford large scale engineering interventions. Since those times, the increase in impermeable surfaces and the rapid conveyance of stormwater through pipes, culverts and channels caused municipal infrastructure to go beyond convenience to environmental threat. Landscape based stormwater management, termed low impact development to distinguish it from conventional practices, is now recognized as a best practice, provided its implementation accounts for the specific context in which it is situated. What works in one climatic and/or geographic zone may not work in another.

Figure 18. Examples of bioswales used to sequester runoff from a parking lot (left image) and both roadway and parking lot (right image). The detention of runoff manages both stormwater volumes and water quality in aesthetically pleasing landscape features. [Source: Credit Valley Conservation Authority, Ontario.]

Low impact development best management practices are well documented in the Ontario context.[23] However, these various measures have not been in service for a sufficient period of time to be able to determine long term performance and the requirements for routine maintenance.[24] As such, a great deal of performance evaluation needs to be conducted so that stormwater management system designers can better calibrate their simulations models, and municipal works operators can address maintenance of LID features.

[23] Credit Valley Conservation. (2011). The Low Impact Development (LID) Stormwater Management Planning and Design Guide (Version 1.0).
http://www.creditvalleyca.ca/low-impact-development/low-impact-development-support/stormwater-management-lid-guidance-documents/low-impact-development-stormwater-management-planning-and-design-guide/

[24] Appendix A - Low Impact Development Stormwater BMP Fact Sheets
http://www.creditvalleyca.ca/wp-content/uploads/2012/02/cvc-lid-swm-guide-appendix-a1.pdf

A significant issue associated with low impact development measures is elevated groundwater levels. From an integrated water resources management perspective, this is a positive outcome, but municipal engineers are unclear as whether or not this leads to higher than normally expected hydrostatic pressures on buried infrastructure - particularly piping that is located on private property, and having an undetermined watertightness. Interviews with experts did not reveal evidence of such problems occurring during extreme rainfall events in new subdivisions incorporating LID measures. Only through the ongoing performance monitoring of LID measures can impacts on local water tables be evaluated, and then it may be determined if there are any associated factors to consider in sanitary sewer system design.

Figure 19. Infiltration basins located away from buried infrastructure may represent preferred low impact development measures in areas where the hydraulic conductivity of the local soils causes infiltration stresses on sanitary sewer pipes and maintenance holes. [Source: Construction Specifier Magazine, Canada.]

Another difficult challenge with low impact development is its relative novelty and a lack of successful precedents that have embraced LID on a broad scale. An important best practice for municipal engineers engaging LID measures is to stay abreast of the most recent research and field investigations for new LID technologies, such as porous pavements.[25] It is also prudent to keep up with the latest literature in the field.[26] LID is here to stay and municipalities have to engineer responsive solutions that fit within an integrated water resource management model.

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[25] Drake, J., Bradford, A., Van Seters, T. and MacMillan, G. (December 2012). *Evaluation of Permeable Pavements in Cold Climates - Kortright Centre, Vaughan*. Toronto and Region Conservation Authority. http://sustainabletechnologies.ca/wp/wp-content/uploads/2013/02/KPP-Final-2012.pdf

[26] Struck, S. and Lichten, K., Editors. (2010). *Low Impact Development 2010: Redefining Water in the City.* American Society of Civil Engineers. http://dx.doi.org/10.1061/9780784410998

Sanitary Sewer System Design Practices

The design practices associated with sanitary sewer systems encompass design methods and the specification of materials and components comprising the conveyance system. An emerging issue in many municipalities is the limited capacity of sewage treatment plants and the need to extend the available capacity to accommodate growth. Innovative practices, such as using the conveyance system for storage and detention, are being developed but as yet are not well documented in the literature. Methods for the design of sanitary sewer systems are fairly consistent across Ontario and most of North America and there are several recent guidelines to assist designers.[27,28] Additionally, many municipalities have developed their own guidelines, presumably tailored to suit the particular geographic and hydrological conditions in their locales.

There are several significant aspects to all of the existing design standards that require further consideration. First, many of the guidelines cite a constant I&I rate of 0.28 litres/second/hectare, along with 0.4 litres/second per manhole located in low lying areas - these are to be considered in sizing the conveyance system. Given the dramatic difference in the hydraulic conductivity of soils and groundwater levels within a region of Canada, sometimes within a municipality, this approach seems to lack the sophistication associated with stormwater management system design. Second, there is no mention of expected useful service life in the guidelines, and only recently, as the result of various municipalities addressing I&I problems in existing developments, have thresholds for excessive I&I been established. If a performance based set of sanitary sewer design guidelines were to be developed, a threshold for I&I over a specified useful service life (e.g., 50, 75 or 100 years) would provide designers and municipal operation staff some idea if a catchment area was failing with respect to I&I.

A review of the literature could not find any large scale studies correlating I&I rates with the age of a sanitary sewer system. Interviews with industry experts did not yield any reasonable estimates since it was reported that better than two-thirds of I&I problems are caused on the private side of the property line, and hence factors like deteriorating laterals and illegal connections over time often obscure the performance of the public side of conveyance system. To use the analogy of creep in structural engineering, there is no normal deterioration rate ascribed to I&I management in sanitary sewer systems.

Further complicating the design process is that the useful life of the infrastructure typically exceeds the service careers of municipal engineers. The general response to this situation is to use the best available technology when designing conveyance systems and specifying their constituent materials, components and methods of installation and connection. It will take some time to discover how these innovations perform in the long term, however, it was generally reported that maintenance hole inflow could be practically eliminated and I&I rates of less than 0.1 litres/second/hectare could be consistently achieved.

Among the innovations commonly reported during interviews are:

- Advances in pre-cast concrete maintenance holes and appurtenances, the most notable being pre-benched and pre-lined maintenance holes (internal liner) or external sealing (membrane wraps);
- The use of leak-free frame and cover systems to eliminate inflow to maintenance holes;
- The incorporation of neoprene seals at all connection points to accommodate minor movement without compromising watertightness;
- The provision of prefabricated standard tees for sanitary sewer pipes to avoid the increasingly outdated practice of breaking into sewer mains to connect laterals; and
- The addition of waterproof membranes covering joints in pipes and sections of maintenance holes to better resist water leakage associated with movement and/or lack of fit.

An important issue that was repeatedly raised during interviews was the need to properly evaluate the suitability of new materials and product innovations. Performance problems associated with new and unproven products do not become apparent for some time and the cost incurred to remediate inferior products is prohibitive. This explains the glacial diffusion rates for technological innovation in the municipal infrastructure sector.

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[27] Ontario Ministry of the Environment. (2008). *Design Guidelines for Sewage Works 2008*. http://www.ontario.ca/environment-and-energy/design-guidelines-sewage-works

[28] Environmental Protection Agency. (January 2008). *Review of Sewer Design Criteria and RDII Prediction Methods*. http://nepis.epa.gov/Adobe/PDF/P1008BP3.pdf

Pre-benched precast concrete maintenance hole.

Rubber seals for watertight connections.

Waterproof membranes over sewer pipes.

Waterproof membranes at maintenance hole joints.

Figure 20. Best practices for sewer system components are intended to reduce infiltration by maintaining a watertight system that can resist minor movement. Pre-benched maintenance holes reduce blockages and the potential for backups. Sources: TOP - Munro Ltd.; BOTTOM - City of Halifax.]

High performance sanitary sewer systems are feasible and cost effective, but minimum standards and construction methods have not always kept pace with material and component innovations.

Durability, Robustness and Resilience of Sewer System Infrastructure

Throughout the course of this study, interviews with industry experts revealed that the adoption of innovative technologies is often based on an ad hoc approach. Full scale, in-situ testing of emerging products and techniques by manufacturers is seldom conducted, and in reality the installed municipal works assume the role of a living test laboratory. Some of the observations gained during this study are summarized below.

- A key criterion of durability is service life and it appears this is largely a notional concept for buried infrastructure. Should all components of a sewer system provide 50, 75, 100 or more years of service without the need for significant maintenance? The practical reality is how does a municipality make a warranty claim on substandard materials and components that do not deliver the stipulated service life? Is it possible to clearly differentiate between the contribution of materials versus workmanship to observed performance problems? Who pays?
- An increasing number of municipalities are moving towards the specification of gaskets, membranes and various joint sealants to keep conveyance systems watertight, but there is little third party information available regarding the service life and robustness of these products. How much movement due to settlement or adhesion freezing can these sealants tolerate? Are they robust in terms of delivering performance across a wide range of installation quality? How does an engineer writing a technical specification identify forgiving products and techniques that do not depend on surgical skills for their proper installation?
- Remedial and rehabilitative technologies such as epoxy injections and grout linings are not considered resilient by many municipal engineers who stated they prefer investing more in quality assurance to minimize defects than dealing with them afterwards using products and techniques that are less durable and robust than the base technology.
- The adoption of new sewer technologies is often based on references from other municipalities that have ventured to adopt innovations. While there are material testing standards in place, there is no third party certification process for the "system" as a whole. Actual municipal projects become the test bench for emerging technologies and this remains a barrier to establishing confidence in the adoption of technological innovation.

The general state of "sewer science" is that it is a fragmented and inconsistent body of knowledge that remains guided for the most part by heuristics. Municipal engineers continue to rely on an informal network of colleagues to filter out products and techniques. It was not possible at the outset of this study to locate a central repository that listed proven versus unproven technologies, and provided third party performance ratings across a range of key criteria. As the study proceeded, invaluable insights were gained, but these were based exclusively on expert opinion. A major challenge going forward is how to prudently foster innovation in municipal infrastructure and to share both reliable and unreliable performance data among practitioners.

Lot Level Measures

Best practices associated with lot level measures focus on site grading and drainage as well as the proper construction and maintenance of private sewer laterals. Beginning with site grading and drainage, it is important for municipalities to harmonize these requirements with the larger stormwater management plans and associated low impact development measures.

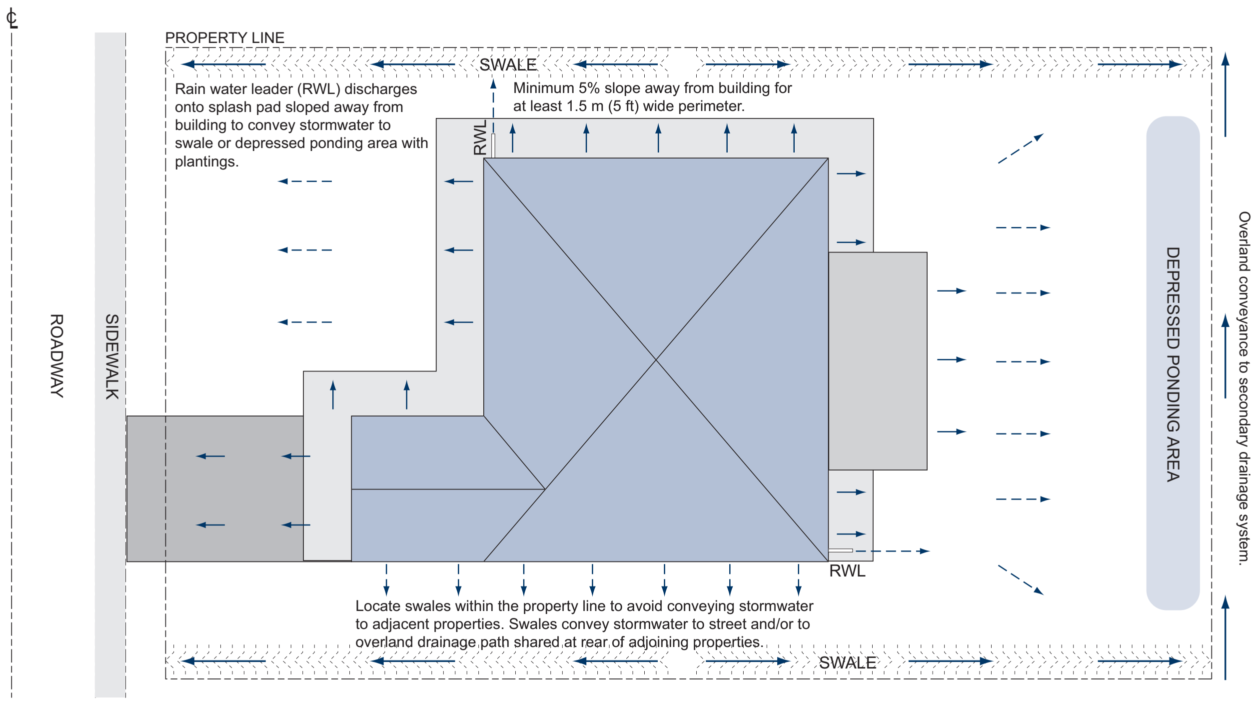

Figure 21. Best practices for site grading and drainage assume frequent light rainfalls can be contained on site through infiltration and that extreme events will see water conveyed away from the buildings and to the street as part of a minor/major system design strategy. [Adapted from: Swinton, M. and Kesik, T. (2008)][29]

Then it is necessary to harmonize municipal infrastructure design with the drainage and sanitary plumbing serving connected buildings. This is a significant factor influencing I&I rates, especially when stormwater drainage from eavestroughs, area drains, foundation drains and sumps is conveyed to the sanitary sewers, unintentionally or otherwise. This best practice involves technical and administrative coordination between the municipal operation and the building code enforcement staff.

As a failsafe strategy, municipalities such as Ottawa, Ontario are requiring the provision of backflow protection on both sanitary and storm laterals in all new developments. While this does not address the root cause of sanitary sewer surcharges, it provides property owners with a measure of protection against basement flooding.

[29] Swinton, M. and Kesik, T. (2008). *Site Grading and Drainage to Achieve High-Performance Basements*. National Research Council of Canada.
http://www.nrc-cnrc.gc.ca/ctu-sc/files/doc/ctu-sc/ctu-n69_eng.pdf

Best practices for ongoing management of lot level measures include periodic reviews of policies governing lot grading, drainage and alterations.[30] This can be reinforced by implementing by-laws governing the certification of private sewer laterals.[31,32] It has been reported that most I&I problems originate on the private side of the property line, hence best practices for managing lot level measures is critical.

Reviewing Lot Grading, Drainage and Site Alteration Policies

Cities like Hamilton, Ontario discovered that a patchwork of policies and practices needed to be completely overhauled in order to become better harmonized with integrated water resource management. Key aspects identified in the 2011 City of Hamilton's *Lot Grading, Drainage and Site Alteration – Comprehensive Policy Review* included:

- Need for additional staff to administer, inspect and enforce policies and by-laws;
- Development of a clear and consistent grading approval process (standards and requirements);
- Public education to avoid adverse site alterations; and
- Enforcement mechanisms that are fair and manageable.

Specific considerations by any municipality recognizing a need for a comprehensive review include:

- an increase in lot grading security deposits to incentivize developers, builders and/or owners to call for inspections to ensure compliance before releasing refunds;
- a mandatory second lot grading inspection no sooner than six months after the initial inspection, only after which security deposits are refunded providing the lot grading is in compliance;
- clarification of design parameters for lots created under severance applications;
- specific standards for grading of lands outside the urban area;
- requirements for constructors to provide an as-built grading plan to demonstrate conformance with the grading policy;
- the retention on title of approved grading plans of all newly created lots; and,
- formalizing of 'Lot Grading Approval Process' to clearly identify the municipality's requirements for release of securities.

In municipalities where low impact development measures are deployed at the individual lot level, these should also be reviewed, inspected and clearly documented in grading plans.

The process of implementing lot level policies and measures should be recognized as having the potential to deliver gradual improvement for the management of I&I and inflow in existing subdivisions, but a significant preventive strategy if implemented in new subdivisions due to coverage of the entire development at one point in time. It is likely easier to implement as part of subdivision agreements since it only involves dealing with a single entity - the developer.

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[30] City of Hamilton (June 7, 2011.) *Lot Grading, Drainage and Site Alteration – Comprehensive Policy Review.* http://www.hamilton.ca/NR/rdonlyres/2B87A6B1-66D3-4C03-ABCE-D31CD917DEDF/0/Jun07EDRMS_n176733_v1_8_4__PED10091_b_.pdf

[31] Sheltair Group (December 2008). *Private Sewer Lateral Programs: A Study of Approaches and Legal Authority for Metro Vancouver Municipalities*. Metro Vancouver, BC, Canada. http://www.metrovancouver.org/about/publications/Publications/Study-Legal Approaches-MVMunicipalities09-07-13.pdf

[32] Garratt, C., Rutherford, S. and Macdonald, R. (February 12, 2013). *An Approach Towards Private Sewer Lateral Certification in Real Estate Transactions for Metro Vancouver*. Metro Vancouver, BC, Canada. http://www.metrovancouver.org/about/publications/Publications/PrivateSewerLateralCertification-2013-02-12.pdf

Quality Assurance, Inspection and Commissioning Practices

A high quality set of design drawings and specifications is a necessary but insufficient condition for the delivery of high performance municipal infrastructure. Without a consistent and comprehensive approach to quality assurance, inspection and commissioning, it is possible to fall short of the intended level of performance. There are several factors to consider regarding quality assurance and inspections of municipal works.

First, the training and education of qualified personnel is essential for proper inspection and commissioning of the work. Quality assurance protocols, similar to design drawings and specifications, assume an entry level of knowledge and minimum competency.

Second, the period of time during which the constructor and suppliers are liable for defective workmanship and/or materials cannot be extended indefinitely. Normally, it takes between 5 and 10 years for a municipality to assume buried infrastructure. A majority of defective or substandard work that is not corrected during construction is identified during the commissioning of the systems prior to the development being occupied. Problems can usually be remediated at this time provided they are not extensive. As it is not feasible to have inspection staff on site throughout the construction process, acceptable performance is achieved by a combination of constructor experience/qualifications, and contractual provisions that assign liability during this critical period. Procurement, contractual arrangements and quality assurance protocols are key to obtaining the best possible performance.

Third, the final approval of the infrastructure, whereby all the work is assumed by the municipality, is a final opportunity to ensure performance problems that may arise due to settlement, deterioration, etc., are fully rectified by the constructor.

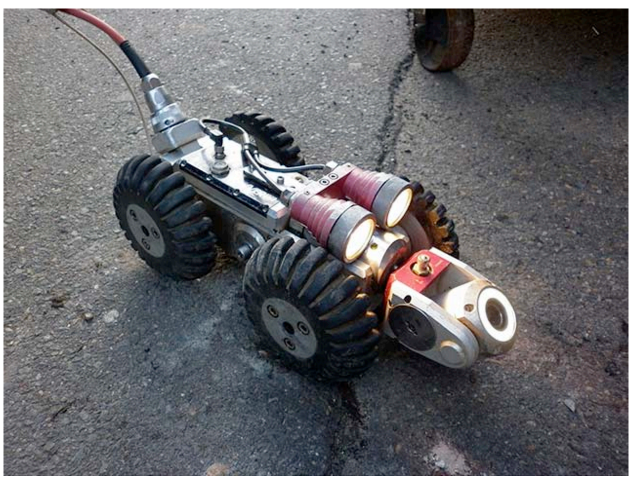

Figure 22. A remote controlled tractor with an articulating closed circuit television (CCTV) camera is able to detect defects such as leaks at joints, as well as any defects or deterioration of materials. [Source: Online Pipe and Cable Locating.]

There are numerous test standards and procedures available ranging from air testing for leaks, mandrel testing for excessive pipe deflections, and closed circuit television (CCTV) scans of the interiors of sewer pipes and their connections. Guidelines have been developed by many jurisdictions and these are shared online.[33] The cost of quality assurance, inspections and commissioning will vary with the scope and complexity of the work, but it is generally appreciated this is much less than the cost of premature remediation and rehabilitation of defective infrastructure.

[33] York Region. (October 2011). *Sanitary Sewer Inspection, Testing and Acceptance Guideline (Formerly Commissioning Guideline)*.
https://www.york.ca/wps/wcm/connect/yorkpublic/dafe2e9b-a11a-42d8-bd59-adf48322cc92/sanitary_sewer_inspection__testing_and_acceptance_guideline_2011.pdf?MOD=AJPERES&CACHEID=dafe2e9b-a11a-42d8-bd59-adf48322cc92

Management, Monitoring and Maintenance Practices

Sustaining the performance of municipal infrastructure is a formidable challenge in the Canadian climate and given a less than robust economy. A 2002 study provided an in-depth review of Canadian municipalities' management and maintenance practices for storm and sanitary sewer systems.[34] Interviews with industry experts suggest most of the findings remain valid and it was also noted that adequate technologies for testing and monitoring I&I are available across Canada through specialized engineering service providers.

Method	Applications	Advantages	Disadvantages
In-Sewer Flow Monitoring	Used for initial assessment of high flow areas. Most effective when combined with rainfall monitoring.	Good as an initial and cost effective analytical approach to determining areas with high I/I.	Covers large areas only. Is an indicator only - Does not identify specific defects or connection points.
Visual Inspections	Used for the location of likely inflow sources such as manhole covers, etc.	Simple. Quick. Can be done by water agency staff.	Significant private property access may be required.
Smoke Testing	More useful for Inflow detection. Its use for identifying infiltration depends on depth of asset, soil type and the water table level.	Quick and simple. Minimizes time spent on private properties.	Effectiveness can depend on climatic conditions and soil moisture levels when considering laterals. Does not necessarily locate point of connection.
Dye Testing	Used to confirm inflow sources identified by smoke testing or cross connections between stormwater and sewerage system.	Simple. Can be done by water agency staff.	Significant private property access required.
Closed Circuit Television (CCTV)	Used for location of infiltration sources as well as structural condition assessment in both public and private sewers.	Useful for structural assessment location of infiltration. Locates point of connection.	Difficulty using with high flow. Infiltration sources are less visible in dry soil conditions. Subject significantly to operator skill and consistency in coding defects. Flow diversion, cleaning, root cutting may be required.
Electro Scan	A new technology that can be used to assess the likely leakiness of public and private sewers with non-conductive pipes.	Locates the leak. Can be used in surcharge conditions. Likely to pick up more defects than CCTV.	New technology, few experienced operators Limited track record. Cannot be used for conductive pipes.
Hydrostatic Isolation Testing	Used to give qualitative indication of likely extent of infiltration and exfiltration in both public and private sewers.	Provides easy indication of the leakiness of pipes, either exfiltration or infiltration potential.	Requires isolation of section of sewer to be tested (i.e. bypass pumping etc. may be required). Does not reliably quantify likely exfiltration or infiltration levels. Does not pin point location or nature of defects.
Lateral Surface Flood Testing	Can provide an indication of likely infiltration rates in shallow house laterals.	Gives an indication of likely infiltration rates in private sewers in saturated soil conditions.	Time consuming. Need to isolate the house lateral under test. Difficult to measure flows

Table 3. Comparative analysis of various sanitary sewer I&I testing and monitoring techniques.[35]

Detailed guidelines for developing and implementing sewer system management plans are also available to interested organizations.[36] The only barriers to best practices are fiscal exigency and political will.

[34] Allouche, E. N. and Freure, P. (April 2002) *Management and maintenance practices of storm and sanitary sewers in Canadian Municipalities*. Institute for Catastrophic Loss Reduction, Toronto, ON, Canada.
http://www.iclr.org/images/Management_and_maintenance_practices.pdf

[35] Carne, S. (2013). Cost-effective and Reliable Inflow-Infiltration Reduction - Have They Got It Right Down-Under? GHD Limited, Auckland, New Zealand.
http://www.ghdcanada.com/pdf/Cost-effective_and_Reliable_II_Reduction.pdf

[36] San Francisco Bay Regional Water Quality Control Board, in cooperation with Bay Area Clean Water Agencies. (July 2005). *Sewer System Management Plan (SSMP) Development Guide*.
http://www.waterboards.ca.gov/rwqcb2/docs/SSMP_Development_Guide_Final.pdf

Organizational Sustainability and Succession

Nothing lasts forever, and this is especially true of human organizations. One of the hallmarks of the baby boomer generation has been a reluctance to retire and hand over the reigns to the upcoming generation, but there is also a justified concern there is a shortage of qualified personnel to fill critical roles. Looking at Canada's overall employment statistics and job skills, the concern stems from what is now recognized as decades of inadequate training and education of technical personnel, largely due to insufficient employment opportunities to justify investments in developing knowledge and expertise. Now that rapid growth across Canada is coupled to aging municipal workforce demographics, municipalities will be challenged to replace retiring staff in key positions, and the same will hold true for the construction industry. According to a recent industry survey, "*Engineering and related occupations, such as engineering technologists and technicians, were ranked as fields in which workers were most difficult to recruit*."[37] Deliberate efforts and policies will be needed to reverse the hollowing out of municipal engineering and operation departments.

"*Coaching, mentoring, shadowing, training and challenging assignments for the "rising stars" in a public works department can be key elements of a succession plan. Selecting those promising individuals can be the result of evaluating performance appraisals, consulting with other department management staff, and looking closely at productive division heads, creative key staff personnel and those who have shown an aptitude for doing very thorough work and going the extra mile on day-to-day tasks. And always, listening to be aware of those who want to move up, expand their job tasks and grow with the organization*."[38]

Without opportunities for advancement and growth, and meaningful feedback on individual contributions to advancing the common good, it will prove difficult to recruit and retain the best and the brightest. Critical initiatives to address this situation include:

- Fostering an organizational culture of continuous improvement;
- Conducting regular, periodic performance reviews offering constructive feedback and guidance and surveying job satisfaction and associated workplace issues;
- Promoting continuous learning opportunities for technical competence and personal growth;
- Holding retreats to engage open "blue sky" sessions to explore alternatives to the status quo;
- Benchmarking sanitary sewer system performance and I&I management programs, and relating these to the individual staff member's contributions;
- Commissioning best in class reviews so personnel appreciate how their divisions rank regionally, nationally and internationally.

Business as usual is no longer an alternative for organizations, especially municipalities who are responsible to a tax payer base that is demanding more for less. Public education about municipal infrastructure, investments, risks and consequences is a necessary outreach effort to avoid compromising the long term sustainability of assets and services.

[37] Canadian Council of Chief Executives (March 2014). *Second survey report: skills shortages in Canada*.
http://www.ceocouncil.ca/wp-content/uploads/2014/03/Second-survey-report-skills-shortages-in-Canada-13-March-20141.pdf

[38] Hellbusch, R. (December 2004). *Succession in Management Planning*. American Public Works Association.
http://www.apwa.net/Resources/Reporter/Articles/2004/12/Succession-management-planning

Future Research, Development and Integration

It has been stated earlier that municipal engineering possesses all of the knowledge and technology needed to adequately manage I&I in sanitary sewer systems. However, there remains a great deal of research, development and integration that needs to be addressed in order to situate I&I best practices within a more sustainable water resources management framework, and to better anticipate future needs and issues.

Leaving aside future research into new materials and innovative technologies, some important questions emerged from this study that need to be investigated within the area of I&I:

- On a life cycle basis, is water conservation more cost effective than I&I mitigation, in terms of offsetting costs and environmental impacts?
- As water conservation becomes more widely adopted and water use targets become more aggressive, is there a risk of insufficient water to convey solids, and if so, how should sanitary sewer design criteria be revised?
- What is the normal increase in I&I rates associated with the aging and deterioration of sanitary sewer systems (i.e., long term I&I rates)?
- Given the uncertainties about extreme weather events associated with climate change, combined with the implementation of low impact development techniques, is it prudent to provide backwater valves on both sanitary and storm laterals, and should this be a requirement in building codes?

From a development perspective, there is a need to evaluate:

- The need for consistent and comprehensive policies, criteria and guidelines for the integrated management of water resources, since the current approach to having each municipality duplicate these efforts is problematic;
- Proper training, education and qualifications for technical, fiscal and managerial personnel engaged in all aspects of municipal infrastructure and water resources management; and
- Adequacy, accessibility and effectiveness of planning, design and management tools needed to sustain municipal infrastructure.

In terms of the need for integration, it is apparent there is an emerging need for:

- Integrated water resources management planning policies and protocols that are organized around watersheds rather than political boundaries;
- Inclusion of stormwater management performance targets accounting for I&I impacts within environmental regulations so that the relationship between asset management, risks and consequences is harmonized across all aspects of an integrated water resources management plan; and
- Development, publication and rationalization of regional best practices for the management of I&I that are compatible with an integrated water resources management plan. These should readily accessible and continuously updated to reflect state of the art knowledge and expertise.

In the absence of a formalized expert panel and municipal infrastructure roundtable to engage all of the stakeholders in a meaningful dialogue, the advancement of knowledge, expertise and executive capacity is greatly impaired in Ontario and across most parts of Canada. It is acknowledged there are numerous water resources based networks, coalitions and consortiums that are active across Canada, but there is no central guiding body or repository of knowledge based resources. Given the normal turnover of personnel coupled to the continual reorganization of governmental bureaucracies, there is no constant hand steering municipal infrastructure research, development and integration across Canada. The risks and consequences associated with a failure to engage meaningful stewardship are rapidly becoming too severe to endure or ignore.

Synopsis

The last study commissioned by the Institute for Catastrophic Loss Reduction in this subject area was conducted in 2002 on the related subject matter of management and maintenance practices of storm and sanitary sewers in Canadian municipalities.[39] Since that time, many of the findings remain valid, but other issues that were not explored have emerged and become more prominent.

Among these is the recognition of a need to develop integrated water resource management plans that will sustain municipal infrastructure while enhancing environmental protection and water quality.[40] There is also a keen awareness that wastewater infrastructure in many municipalities across Canada is aging and in need of rehabilitation and replacement. A recent initiative by the Ontario Coalition for Sustainable Infrastructure, the Wastewater Infrastructure Needs Assessment project, is attempting to assist Ontario municipalities better understand and implement risk assessment based models to inform capital investments and management plans.[41]

The fundamental problem of continuous learning and improvement coupled to organizational maintenance and succession is beginning to impact municipal works organizations and the civil construction industry. There is a considerable challenge that parallels a period of unprecedented growth forecasts for the Greater Golden Horseshoe that is extended to other regions of Canada that are enjoying, but also struggling with, rapid growth. The bottleneck is the knowledge and expertise needed to implement frameworks for the stewardship of sustainable municipal infrastructure.

A window of opportunity to meet this challenge exists but is relatively narrow. Over the next decade, industry, government, professions and skilled trades will be pressed to implement a framework of best practices that is presently dispersed among a number of organizations and stakeholders. The task of integrating and implementing such a framework is not considerably lessened by virtue of the fact virtually all of the components are developed and accessible. Integration and consolidation remains a difficult task because it is rooted in human factors, chiefly among them an expectation by the average citizen that Canada is a modern country with relatively new municipal infrastructure, hence taxes supporting municipal works should remain relatively low. This is simply not so. Even if funding for municipal infrastructure is made abundant, it may then be the human resources capacity of government and industry that becomes the weak link in the municipal infrastructure value chain.

There remains good cause for optimism since a great deal of excellent work in formulating best practices has been performed and is readily accessible online. Just about everything there is to know about effectively integrating and managing our water resources, including I&I and its attendant problems, is known. Materials and technologies for achieving high performance are available and cost effective. But the kickstart needed to overcome decades of deferred maintenance and neglect cannot be underestimated, and the social and political inertia with respect to municipal infrastructure investments continues to plague so many Canadian municipalities that deny the real cost of sustainable infrastructure.

In many ways, I&I in new sanitary sewer systems are a barometer of the quality, care and stewardship underlying the region/municipality, its system of governance, the community's planning vision and its infrastructure engineering excellence. What can be said about a 21st century civilization that cannot design, construct and sustain its vital infrastructure? Hopefully, it is a question that should not have to be answered by future generations of Canadians.

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[39] Allouche, E. N. and Freure, P. (April 2002) *Management and maintenance practices of storm and sanitary sewers in Canadian municipalities*. Institute for Catastrophic Loss Reduction, Toronto, ON, Canada.
http://www.iclr.org/images/Management_and_maintenance_practices.pdf

[40] Canadian Municipal Water Consortium (2014). *2014 Canadian Municipal Water Priorities Report*.
http://www.cwn-rce.ca/assets/resources/pdf/2014-Canadian-Municipal-Water-Priorities-Report_web.pdf

[41] Ontario Coalition for Sustainable Infrastructure (November 2014). *When the Bough Breaks: Helping municipalities prioritize infrastructure investment to build resilient wastewater and stormwater systems*.
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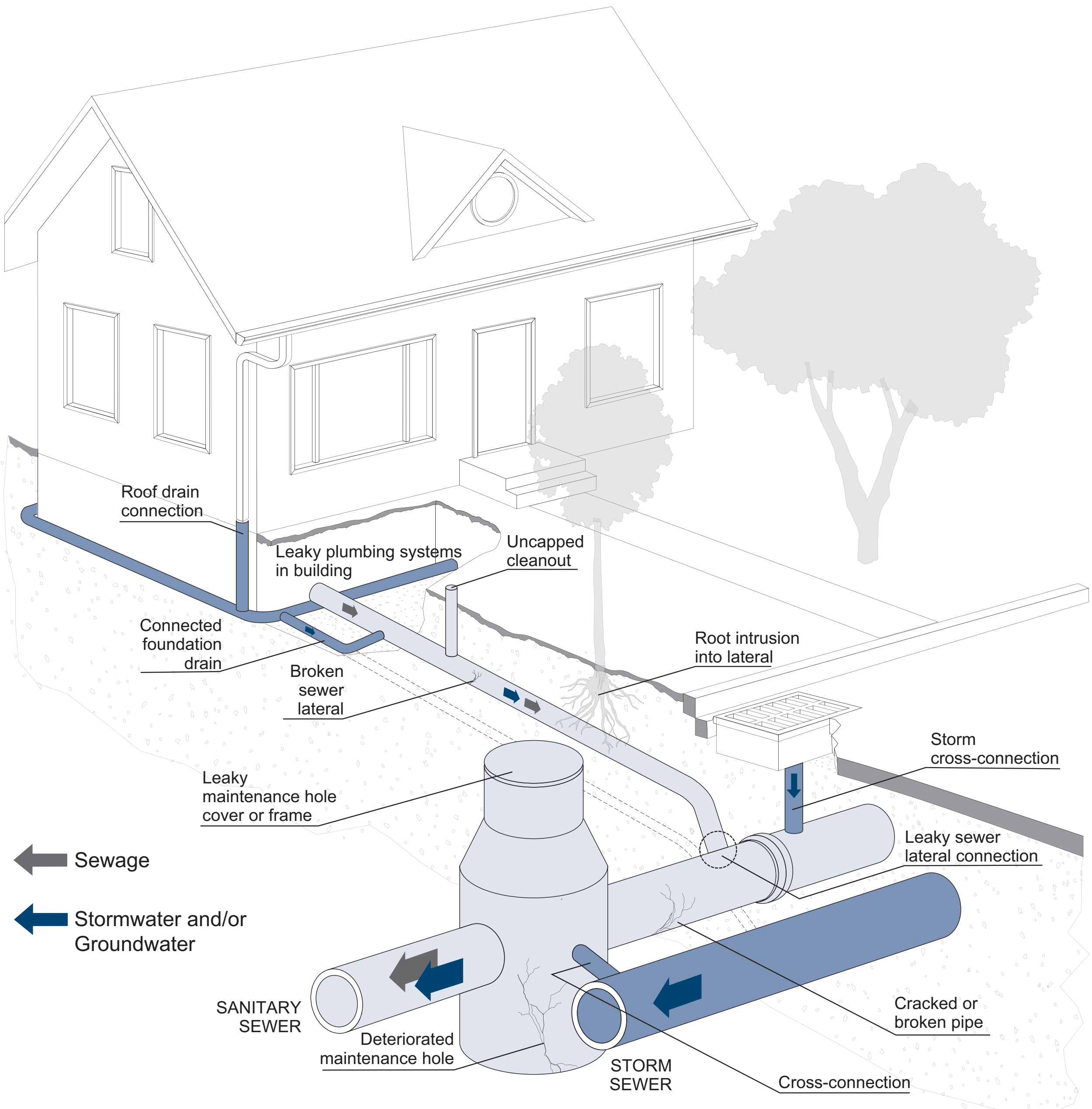

Figure 23. The causes of I&I are almost entirely due to human factors related to design, construction, quality assurance, inspection, monitoring and maintenance. Performance problems can be also be further exacerbated by environmental factors such as soils and groundwater conditions, as well as the quality of materials. It is not for a lack of materials, methods and technology that I&I problems continue to be witnessed in sanitary sewer systems, rather it is a failure to account for all of the factors impacting performance and then to address them in an effective manner.

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Appendix A

Bibliography of I&I-Related Literature

This bibliography has been arranged <u>chronologically</u> and represents authoritative sources of information pertaining to the management of inflow and infiltration, and some of the larger surrounding issues. Appendix C cites the same bibliography but is arranged <u>topically</u> for the convenience of readers.

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Appendix B

Best Practices Checklist

This checklist provides an outline of the critical aspects of municipal sewer system stewardship that represent the minimum standard of diligence needed to achieve integrated water resources management. For each of the checklist items, regional and municipal governments should be able to furnish policies, guidelines, standards and protocols that have been developed in house, or reference documentation from other best-in-class jurisdictions. The goal is to ensure that a consistent and comprehensive suite of best practices is properly contextualized to support local social, environmental and economic aspirations.

- ❑ Harmonized Municipal Governance, Policies, By-Laws and Practices
  - ❑ Economic Development Policy
  - ❑ Official Plan and Development Charges
  - ❑ Building Controls + Infrastructure/Services
  - ❑ Procurement Policy and Practices

- ❑ State of the Art Engineering Design Guidelines and Standards
  - ❑ Minor/Major Stormwater System Design
  - ❑ Site Control - Grading and Drainage
  - ❑ Low Impact Development Measures
  - ❑ Sanitary Sewer System Design
  - ❑ Review/Updating of Design Standards and Specifications

- ❑ Watershed-Based Jurisdictional Harmonization
  - ❑ Liaison with Conservation Authorities to Develop Integrated Water Resources Management Plan
  - ❑ Reconcile Conflicting Requirements Between Building Code and Municipal Works
  - ❑ Review of Lot Grading, Drainage and Alterations Policies

- ❑ Integrated Municipal Infrastructure Management
  - ❑ Benchmarking / Best In Class Review
  - ❑ Asset Management and Risk Assessment
  - ❑ Quality Assurance Guidelines and Protocols
  - ❑ Inspection Guidelines and Protocols
  - ❑ Coordination with Building Controls and Inspections
  - ❑ Monitoring and Maintenance

- ❑ Organizational Sustainability and Succession
  - ❑ Continuous Improvement Program
  - ❑ Lifelong Learning Policies and Initiatives
  - ❑ Operational Review Process
  - ❑ Recruitment, Retention and Advancement Policies/Programs

Appendix C

I&I Best Practices Knowledge Map

This appendix provides references and links to authoritative documentation and web sites that are directly or indirectly involved with best practices for the management of I&I. It is organized by topics that represent key aspects of integrated water resource management.

Integrated Watershed / Water Resources Management

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