Developing an Efficient and Cost-Effective Inflow and Infiltration (I/I) Reduction Program

A Foundational Document
for the Development of a National Standard of Canada

By Barbara Robinson and Dan Sandink

June 2021

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Norton Engineering Inc. was established in 2015. Norton's primary area of interest is the phenomenon of inflow and infiltration (I/I) in new construction, a topic Norton's founder, Barbara Robinson, has been working on since the mid-2000s. Norton leads a variety of ongoing projects across Ontario and Canada looking at all aspects of this phenomenon. Every year, Norton delivers dozens of presentations, workshops, training and media spots on this and related topics. Norton staff chaired the CSA committee that developed *CSA Z800: Basement Flood Protection and Risk Reduction Guideline* (2018).

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Abbreviations

CCTV: Closed-circuit television

CIRC: Canadian Infrastructure Report Card

EA: Environmental assessment

EBMUD: East Bay Municipal Utility District

GWT: Groundwater table

I&IMPs: Inflow and infiltration master plans

I/I (also called I&I): Inflow and infiltration

LID: Low-impact development

MAMP: Municipal Asset Management Plan

MassDEP: Massachusetts Department of Environmental Protection

MECP: Ministry of the Environment, Conservation and Parks (Ontario)

MMAH: Ministry of Municipal Affairs and Housing (Ontario)

MMSD: Milwaukee Metropolitan Sewer District

MOE/MOECC: Ministry of Environment/Ministry of Environment and Climate Change

NSC: National Standard of Canada

OMWA: Ontario Municipal Water Association

RDII: Rainfall-derived inflow/infiltration

ROI: Return on investment

SBS: Sanitary building sewer

SDHI: Short-duration, high-intensity

SDO: Standards Development Organization

SPS: Sanitary pumping station

SSO: Sanitary sewer overflow

SWM: Stormwater management

WTP: Water treatment plant

WWTP: Wastewater treatment plant

WWPS: Wastewater pumping station

Definitions

Accessible dry weather flow: Flow observed during dry weather flow that is "accessible" for removal during an I/I reduction program (new term coined by Norton).

Base sanitary flow (BSF): A term previously used to describe the variable component of dry weather flow.

Clear-water waste: Wastewater with impurity levels that will not be harmful to health; may include cooling water and condensate drainage from refrigeration and air-conditioning equipment and cooled condensate from steam-heating systems, but does not include stormwater.[1]

Foundation drains: A system, typically composed of perforated pipe and granular material, designed to collect and convey subsurface water away from foundations.

Groundwater table (GWT) or water table: Upper level of an underground surface in which the soil or rocks are permanently saturated with water.[2]

Infiltration: Water other than sanitary wastewater that enters a sewer system from the ground through defective pipes, pipe joints, connections or maintenance holes; does not include inflow.[3]

Inflow: Includes sources of water that flow directly into sanitary sewer systems, such as residential roof downspouts, storm catch basins that have accidentally been connected to sanitary sewer systems, leaky sanitary sewer maintenance hole covers and basement stairwell drains, among other factors.[4]

Leak-acceptable flow: Flow observed in a newly constructed sewer that is at or near required new sewer leakage testing values.

Low-impact development (LID): Systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater to protect water quality and associated aquatic habitat.[5]

Persistent dry weather flow: Flow observed during dry weather that cannot (or should not) be removed from the wastewater system (new term coined by Norton).

Private-side lateral: The portion of the lateral that runs from the property line to the private building; typically referred to as the sanitary building sewer (SBS) in building codes.

Public-side lateral: The portion of the lateral that runs from the mainline sewer to the property line.

Rainfall-derived inflow and infiltration (RDII): I/I associated with wet weather, including both inflow (during the storm) and infiltration (continues after the storm has ended but the ground is still saturated).

Sanitary building drain (SBD): A building drain that conducts sewage to a building sewer from the most upstream soil-or-waste stack, branch or fixture drain serving a water closet.[6]

Sanitary building sewer (SBS): A building sewer that conducts sewage[7]; in engineering, this pipe is termed the "private-side lateral."

Seasonally high GWT: The highest elevation of the water table during the wettest season in a year of above-average precipitation.

Sewage: Any liquid waste other than clear-water waste or stormwater.[8]

Stormwater: Water that is discharged from a surface as a result of rainfall or snowfall.[9]

Windscreen inspection: Inspections conducted via drive-by observations of buildings, lots, surface drainage systems, etc.

Executive summary

Inflow and infiltration (I/I) refers to excess clean water that enters existing and new sanitary sewer systems. Excessive I/I has numerous negative consequences, including effects on the environment, public health and safety, as well as acute and ongoing financial impacts for municipalities, insurers, taxpayers and homeowners. Specifically, urban and basement flooding attributed to excessive I/I in sewer systems is a major cause of flood damage across Canada. The negative impacts of I/I are chronic and widespread across Canada and North America and are expected to worsen as a result of climate change. Further, recapturing capacity in existing sewer systems is increasingly important, as urbanized areas across Canada seek to expand outwards and/or increase infill development.

This report outlines an approach to developing an efficient and cost-effective I/I reduction program that continues throughout the life cycle of a sewer system. The content of the report is based on the extensive professional experience of the lead author and author team, an extensive review of the existing I/I management literature, and substantial input from the project's Expert Stakeholder Committee (ESC), composed of municipal and private-sector I/I experts from across Canada and the US.

The document is targeted at small and medium-sized municipalities, which may have limited internal resources to develop and conduct I/I management programs. It is expected, however, that all stakeholders involved in I/I management – including larger municipalities, consultants, and provincial and national regulatory agencies – will find value in the guidance provided here. The document focuses on separated and partially separated sewer systems and concerns I/I reduction both in municipal infrastructure and on private property.

The purpose of this guideline is to provide tools that allow municipalities to efficiently and cost-effectively understand the nature and extent of the I/I in their system *prior to investing large capital dollars on field investigations and rehabilitation*. The foundational work that the municipality will have done if these guidelines are applied will help guide the municipality toward a modern approach to I/I management, which is much more complex (and cost-effective) than a single I/I study.

Outcome of this project: A Foundational Document

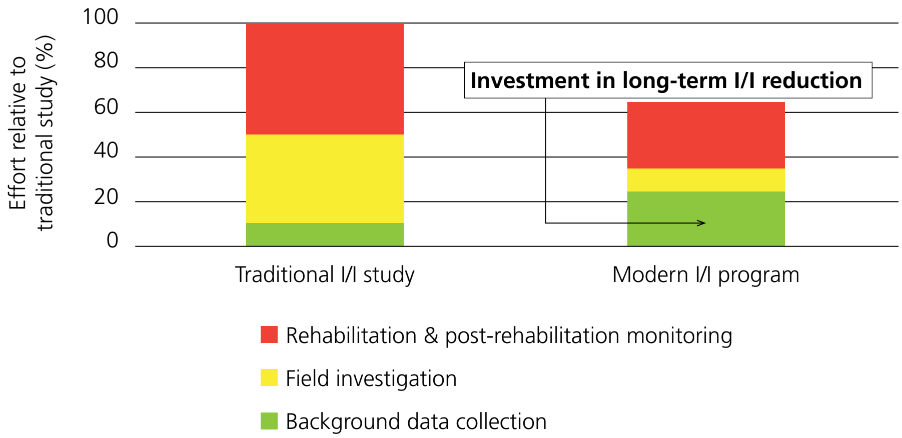
This report is a "Foundational Document," the purpose of which is to establish a foundation of knowledge and stakeholder insights for the eventual development of a National Standard of Canada (NSC). The findings of the report suggest that an NSC concerning I/I management programs should be developed for Canada. An NSC project would be pursued at the discretion of the Standards Council of Canada.

An efficient and cost-effective I/I program vs. traditional I/I study

This document provides a staged approach to developing an efficient and cost-effective I/I program, distinct from a traditional I/I study. Compared to a traditional study, the program approach involves much more background work to clearly understand all of the issues that contribute to I/I in a sewer system. An I/I program will advance the municipality from being "reactive" with respect to I/I to being "proactive" in managing the sewer system. It will provide a framework in which the causes of, and conditions that contribute to, I/I in a municipality can be systematically reduced and managed.

This “modern” approach to I/I invests in tasks that will result in long-term I/I reduction. The figure below depicts this concept graphically.

Figure ES-1: Visual representation of effort by task: I/I study vs. modern I/I program



I/I program development stages presented in this document include:

- *Stage 1: Understand wastewater flow and private-side I/I (Section 3)*
- *Stage 2: Develop an I/I reduction program (Section 4)*
- *Stage 3: Collect and assess existing data and develop a workplan (Section 5)*

Once these stages are completed, the municipality can proceed to any number of I/I studies, which will include the following stages:

- *Stage 4: Conduct flow monitoring and field investigations*
- *Stage 5: Identify deficiencies and develop a capital program for rehabilitation or replacement*
- *Stage 6: Undertake construction and post-construction monitoring*
- *Stage 7: Repeat for each drainage area selected in overarching I/I program*

Given the lack of guidance in the industry on how to undertake the early stages of work required to develop a successful I/I management program, this project focused on Stages 1 to 3. Considerable documentation and expertise on the components of I/I studies (Stages 4 to 7) already exist; therefore, these stages are not covered here.

Stage 1: Understanding wastewater flow

To reduce I/I, a clear understanding of its source is essential. Therefore, the first step in addressing inflow and infiltration in sewer systems is to understand sewage flow and each component that contributes to the flow. This work begins with a discussion of I/I values used in design, construction and acceptance.

Reducing the design peak I/I allowance (e.g., 0.28 L/s/ha), will have *absolutely no impact* on how much I/I will occur in the system.

Norton, Presentation to OMWA OJT, November 2020

Design of sanitary sewers and design I/I

Sanitary sewers are designed assuming a 75-year design life. Total design flow is calculated using an assumed average domestic flow (e.g., 300 L/c/d) with a peaking factor (Harmon's or other). A value for long-term peak I/I is then calculated. In sanitary design sewer sheets across Canada, this is done using an infiltration factor expressed in L/s/ha (e.g., 0.28 L/s/ha or other). The two long-term peak I/I values are summed, and the total peak flow is used to size the sewer. Necessarily, it is sized to convey peak I/I at year 75. The design stage of the sanitary sewer is the only occasion where the I/I value of 0.28 L/s/ha (or other) is meaningful.

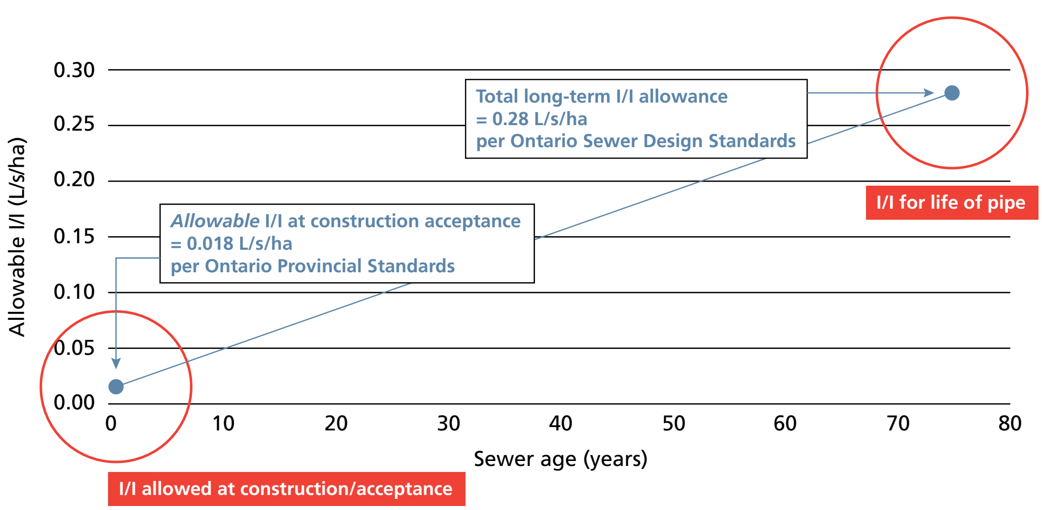
Sanitary sewer construction and acceptance I/I

Municipalities in Canada prescribe allowable I/I values (i.e., leakage) at acceptance in all construction specifications (for public side) and building codes (for private side). The sum of the allowable leakage in each component of a sewer system – on each of the public and the private sides – is the allowable leakage for the sewer system. New sanitary sewers must be confirmed to be leak-acceptable before they are assumed by the municipality. Leak-acceptable infrastructure meets acceptance testing when it is installed.

Use of I/I values

As presented in the previous two sections, an engineer needs to consider two I/I values: design I/I, and I/I at construction and acceptance. These values are distinct and unrelated. The figure below depicts these two I/I values that are used with sewer systems for a sample subdivision in Ontario (with a straight line degradation assumed over the life of the sewer). Peak long-term I/I (0.28 L/s/ha) should never be considered as allowable I/I at acceptance.

Figure ES-2: I/I values throughout the life of a sewer pipe



Persistent and accessible dry weather flow

Dry weather flow is flow measured in the sanitary sewer during a dry weather period and is typically associated with infiltration. The components of dry weather flow may be divided into two categories: *persistent* dry weather flow and *accessible* dry weather flow.

Persistent dry weather flow is flow that cannot be removed from the system (such as industrial nighttime flows, unmetered wastewater flow and design I/I). Accessible dry weather flow is flow that can be removed from the system (such as water leaks that end up in the sanitary sewer or most leaking pipes, joints and maintenance holes). It is necessary to understand these components when developing solutions to I/I issues.

Dry weather flow I/I is just as important as wet weather I/I because its constancy proves extremely expensive, and it also directly contributes to wet weather peaks and flooding.

Wet weather flow

Wet weather flow is the flow observed during and after rain and snowmelt periods. Essentially, it is the flow pattern observed when it is raining and for some time afterwards, when the sewer system is still responding to water in the ground. Wet weather flow includes both inflow and infiltration. Accessible wet weather I/I includes cross-connections between the sanitary and storm sewer systems, as well as illegal private-side connections.

Private-side I/I

Experts now believe that across North America, 50–60% of inflow and infiltration is generated on the private side of the property line. Indeed, in most collections systems, about half of the pipe length exists on the private side. In approximately the past five years, research has been undertaken to better understand the causes and conditions of private-side I/I, particularly as they occur during new construction. Any modern I/I program must carefully consider private-side I/I, whether it can be addressed in the program or not.

This guideline was written to reflect the fundamental importance of including the assessment of private-side I/I in any modern I/I program.

Managing I/I on the private side of the property line is a behavioural issue, as well as a physical, engineering, building/plumbing code and plumbing issue. Voluntary programs typically include a combination of educational initiatives, ranging from less intensive provision of websites and bill inserts with critical information to door-to-door visits and public open houses in flood-affected regions, as well as programs that financially subsidize private-side interventions.

Municipal programs often provide substantial subsidies and detailed homeowner guidance; however, uptake of lot-side I/I mitigation measures has been sporadic across the country, with many programs experiencing low uptake rates. These low uptake rates reflect the difficulty of addressing I/I and basement flood risks on the private side of the property line.

Other issues

The challenge of working in silos, widely reported by Canadian municipal staff, is exacerbated in two-tier sewer systems (i.e., where upper-tier and lower-tier municipal governments share responsibility for collection and treatment of wastewater). In research undertaken in 2015 and 2016, hundreds of municipal staff across Ontario were interviewed confidentially about their sewer systems and, specifically I/I, these staff expressed many problems, concerns and frustrations around trying to achieve effective I/I reduction in two-tier systems.

Inflow and infiltration is a long-term, systemic problem in sewer systems. Addressing these problems is complex and ideally becomes a proactive part of a municipality's sewer system program. The Water Environment Federation's (WEF) *Existing Sewer Evaluation and Rehabilitation: Manual of Practice* lists the following causes of I/I:

- Natural aging of sewer system,
- Lack of maintenance of sewer system,
- Uncontrolled stormwater,
- Poor construction methods, and
- Inadequate construction specifications or design.

Clearly, a one-time I/I study is inadequate to resolve most of these causes. Rather, a concerted, proactive program that considers all aspects of the sewer system is required.

Stage 2: Development of an inflow and infiltration reduction program

Once a municipality has carefully examined all of the background considerations associated with undertaking an I/I program, it can begin development on specific elements of the program.

Estimating the costs of I/I

An important early step in an I/I program is to estimate the actual costs of I/I since staff will likely be expected to justify the need for an I/I reduction program to their councils. As such, the existing true costs of I/I should be considered estimated costs for "measurable" items such as:

- Treatment of I/I (chemical and power),
- Opportunity costs associated with I/I (for example, lost development charges and property taxes if development freezes),
- Construction of new trunks to convey flow,
- Sanitary sewer overflows (SSO) and bypasses,
- Urban flooding costs (include/estimate both insured and uninsured damage, costs to institutions, businesses, households and local government),
- Staff costs associated with flooding, overflows and bypasses,
- Legal costs associated with SSOs, bypasses, flooding and sewer backup, and
- Potential increases in costs associated with the anticipated impacts of climate change.

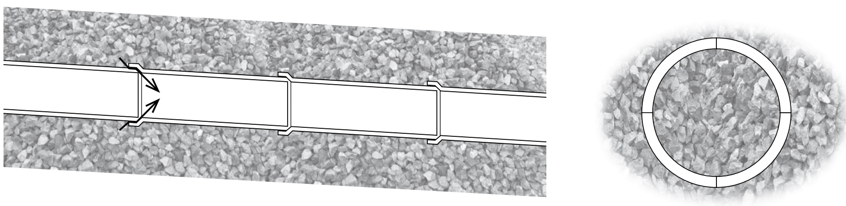
It is essential to also consider soft costs that may not be readily quantifiable, such as the reputation of the municipality, exposure to legal risks and impact on credit rating.

Another cost that is difficult to measure is the impact of poor construction on the useful life of a sewer. As stated in the *Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys* (Massachusetts Department of Environmental Protection – MassDEP, 2017): "Extraneous water from infiltration/inflow (I/I) sources reduces the useful life, and the capacity of sewer systems and treatment facilities to transport and treat domestic and industrial wastewaters."

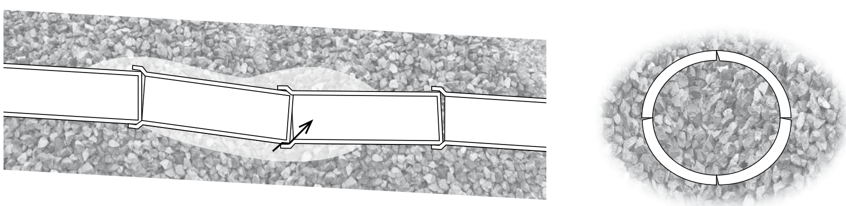
Figure ES-3 depicts the pipe settlement due to initial defect, and it is easy to see how I/I impacts the useful life of a sewer.

Figure ES-3: Pipe settlement due to initial defect

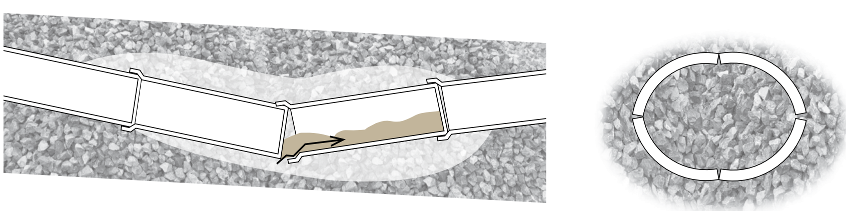
Stage 1: Initial defect, but sewer remains held in position by the surrounding soil.



Stage 2: Development of zones of loose ground or voids caused by the loss of ground into the sewer.



Stage 3: Pipe failure.



Source: Adapted from METHODS TO CONTROL LEAKS IN SEWER COLLECTION SYSTEMS. White Paper Prepared by C. Vipulanandan, Ph.D., P.E. and H. Gurkan Ozgurel. Center for Innovative Grouting Materials and Technology (CIGMAT), Department of Civil and Environmental Engineering, University of Houston Houston, Texas 77204-4003 October, 2004.

Norton Engineering has been advocating for the use of the actual residential sewer rates (e.g., $3.15/m in Kitchener, Ontario, in 2020) as the costs of I/I since these represent a direct application of what it costs the municipality to own, operate, maintain, repair and replace the sewer collection and treatment system in its entirety, including fixed and hidden costs.

The use of existing asset management data is encouraged in the development of an I/I program (this information may exist in a different "silo" at a municipality). The engineer should take care to understand the criteria used for assessing the condition of the system, as they may be different than those used in an I/I study (e.g., the use of "age" and "pipe material" as an indication of I/I status is inadequate). However, if an asset management plan exists, it will be useful in determining "level of service" for the sewer system.

Level of service for sanitary sewers

An essential step in developing an efficient and cost-effective I/I program is to develop the appropriate target level of service (LOS) for the wastewater collection system. LOS for wastewater collections systems are difficult to quantify. LOS may be attained from a sewer system master plan, if available. Due to the complex nature of I/I, it may not be possible to directly link sewer deficiencies to flood risk, for example (management of flood risk could be an LOS target). In two-tier municipal governments, establishing LOS is particularly challenging.

Specific hard targets may be appropriate for determining LOS, such as:

- Volume reduction,
- Peak reduction,
- SSO/bypass reduction,
- Capacity recapture,
- Private property flooding risk reduction,
- Staying within sewer design capacity, and
- Legal risk reduction (for municipality).

Most municipalities, however, will find it difficult to define LOS precisely, given the complexity of I/I. Many municipalities have found that a softer approach to LOS targets is necessary. An I/I program should define LOS in some way so that funding can be allocated appropriately and results can be measured against a target.

Investigate the willingness of the municipality to undertake private-side work

Private-side I/I is now well understood to be an important part of an overall I/I reduction program, and it should be considered indispensable. It is most efficient and cost-effective for the I/I team to determine early in I/I program development whether the municipality is willing to conduct private-side work.

Determining whether private-side work is to be conducted is largely a political, not a technical, issue. Strong communication and buy-in with the public are important for private-side programs to be successful. Innovative programs, such as time-of-sale private-side lateral inspections, have been applied successfully in the US, and several jurisdictions in North America are increasing legislative support for addressing private-side I/I sources. Exterior pipe and interior plumbing insurance programs, offered through partnerships with municipalities and private insurers, offer a further innovative approach that may assist in managing I/I on the private side by bringing residents' attention to the fact that they own a part of the sewer. Proactive enforcement of sewer use bylaws to remove illegal foundation drain connections is also an option for municipalities.

Information from the private side is essential in a modern I/I program, whether it is to be addressed in the program or not.

What is acceptable I/I in an existing system?

To date, while some efforts have been made, no useful overall acceptable I/I targets have been developed, due to the immense complexity of I/I, the vast differences in how I/I is tracked at each municipality, site conditions, construction methods across sewer systems, etc. It is not expected that this will change.

Metro Vancouver has undertaken a thorough investigation of acceptable I/I design allowances as part of its *Integrated Liquid Waste Resource Management Plan* and concluded:

> It is evident that irrespective of whether the I&I design allowance is 11,200 L/ha·d (or 22,400 L/ha·d [0.28 L/s/ha]) excessive I&I must be reduced. Based on I&I design values from across Canada, it appears that all I&I rates above 25,000 L/ha·d can be regarded as excessive.

Jurisdictions continue to carefully consider what is economically feasible. MassDEP, for example, considers the following I/I sources as excessive and in need of elimination: infiltration sources that can be cost-effectively removed from the sewer system and all public and private inflow sources, unless existing conditions render such removal technically infeasible or cost-prohibitive.

Municipalities may need to consider that "acceptable" I/I in their sewer systems may relate more to what remains once the I/I that can be addressed in a cost-effective manner is removed, rather than an absolute value.

Summarize goals and objectives

After completing the abovementioned tasks, the municipality should have a good understanding of the overarching goals and objectives of the I/I reduction program. These should be clearly articulated in writing and shared with senior staff, council and the public. The next step is to collect and assess the existing data within the framework established through the foundational steps outlined above.

Stage 3: Collection and assessment of existing data and development of a workplan

"One Water" approach

The "One Water" lens helps program developers consider the full water cycle in all its forms: drinking water, wastewater, rainwater, surface water and groundwater. Sanitary sewers, storm sewers and water mains are connected as far as I/I is concerned. Defects in water distribution systems and storm sewers may have a direct impact on I/I in sanitary sewers; both systems lose water and leaking storm infrastructure is likely to increase I/I in the sanitary sewer, due to the interconnection of utility trenches and sanitary sewers typically being located deeper than other conveyance systems. In addition, there is always competition for budget dollars. Therefore, a One Water lens is essential in the context of I/I management.

Data identification, assembly and organization

The first tasks in understanding and managing existing data are to gather and classify all available information, and to manage and store the resulting data in a readily available and easily retrievable manner for the purposes of I/I work. Thorough data collection will likely result in a variety of data types, sources, formats, accuracies and ages. Some care and thought will need to go into determining how to assemble this data into a useful database/package/format/group.

Managing the often-extensive data collected in the study phase of a sewer system evaluation is a major challenge but a necessary component of an effective I/I management program. Because each municipality differs vastly in how it collects, stores, maintains and retrieves data, this task needs to be tailored to each one.

Water and wastewater plant data

Examining the relationship between the water treatment plant (WTP) and the wastewater treatment plant (WWTP) is a valuable exercise in I/I investigation work. These are data sources that are readily available and provide useful insights into I/I in a system. The WWTP data alone can be collected at various levels of detail and used to study the system's response to various events, for example, wet weather events.

Public-side sewer system data collection

Relevant public-side data is available from many diverse sources (beyond the engineering department), both within a municipality and beyond it. The engineer should consider each source carefully and include a discussion of potential limitations in the proposed I/I program documentation.

Private-side sewer system data collection

Understanding the contribution of the private side to I/I in a municipality is essential since this will inform the most efficient and cost-effective reduction program. Private-side data is more difficult to obtain, but many indicators may help to provide information. These indicators include the age of homes, drainage cards, flooding data, sewer backup data and operations staff experience. In particular, orphaned laterals should be investigated, as these can be significant and silent sources of accessible I/I.

Sewer system operations data

Operators typically have invaluable and difficult-to-access information on sewer systems. An effective I/I program must include sewer system operators and their thorough understanding of sewer system operations in all I/I discussions. Research undertaken since 2015 has revealed that operations staff expertise is widely ignored during traditional I/I studies.

Planning data

Staff working on the I/I program should ensure that they coordinate with planning departments to understand the municipality's official plan and approved or draft approved development, infill development policies, protected areas, growth areas, etc., as these will affect capacity requirements and, thus, I/I decisions. In particular, the impacts of intensification due to rezoning changes and provincial direction need to be considered, as servicing capacity needs to be adequate to allow for additional population density.

Identify data gaps and update data collection methods as required

The municipality is likely to identify data gaps during the process of data collection. A gap analysis should be performed to determine what essential data, if any, is missing or if information needs to be collected a different way or by a different department.

At this point in the I/I program development, the engineer will likely have a good idea of the data that will be essential. Data collection, management, storage and updates can be costly. Data gaps and format inconsistencies make tracking I/I difficult, so it is recommended that steps are taken to improve or update data collection to ensure better I/I tracking and understanding moving forward (i.e., moving from reactive to proactive mode). This aspect of program development will likely take concerted effort.

Desktop analysis of existing conditions

After data gaps have been resolved, the engineer should be in a position to undertake a thorough desktop analysis of existing conditions in the sewer system. It should be noted that analysis to characterize I/I is more like detective work than a science. The engineer must always keep in mind the myriad of variables that affect I/I. In particular, the engineer needs to clearly understand the components of wastewater and how each contributes to total flow. It has been common in the industry to characterize all "base flow" as infiltration, when in fact some of this base flow is persistent dry weather flow that is not infiltration.

A great deal of information about how to analyze data to evaluate I/I is publicly available. The engineer is presumed to access outside sources as required to analyze specific combinations of data sets. The following sources are recommended:

- *Guide for Estimating Inflow and Infiltration*, USEPA, 2014
- *Infraguide Assessment and Evaluation of Storm and Wastewater Collection Systems*, 2003
- *Guidelines for Performing I/I Analyses and Sewer System Evaluation*, Massachusetts Department of Environmental Protection, 2017
- *Guide for Evaluation Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems*, USEPA, 2005

Summarize findings and develop a workplan

Once the data have been analyzed, the engineer should be in a good position to summarize findings and determine the appropriate next steps. Preliminary findings and probable issues, sources, opportunities and constraints should be summarized in a written report. The report should re-examine I/I reduction goals and identify whether opportunities exist to achieve these goals.

The municipality now has a framework within which to proceed with I/I studies in specific drainage areas. It should be possible for municipalities to establish reasonably accurate timelines, budgets, staffing requirements, etc. for these studies.

I/I studies, which will be ongoing, will generally include the following next stages:

Stage 4: Inflow and infiltration study phase (flow monitoring and field investigations)

Stage 5: Identify deficiencies and targets and develop a capital plan for rehabilitation or replacement

Stage 6: Undertake construction and post-construction monitoring

Stage 7: Repeat

The tasks required for I/I studies are generally well understood, and extensive public information is available on how to perform these studies, so they do not form part of this document.

1. Introduction

1.1. What is inflow and infiltration, and why is it problematic?

Inflow and infiltration (I/I: see side box) and its negative impacts have become chronic problems across North America. Excessive I/I has numerous negative consequences, including impacts on the environment, public health and safety, as well as acute and ongoing financial impacts for municipalities, insurers, taxpayers and homeowners.[10] The negative impacts of I/I are expected to intensify in many regions under projected changes in extreme rainfall due to climate change. Further, recapturing capacity in existing sewer systems is becoming increasingly important, as highly developed urban areas across Canada continue to emphasize infill development.[11]

The potential impacts of climate change on I/I in separated sewer systems are increasingly recognized in national climate change assessment reports and climate change adaptation–related guidance documents.[12] While it is widely acknowledged that the projected impacts of climate change will have direct implications for stormwater management systems, sanitary systems are also expected to experience impacts associated with I/I.[13] The interconnectivity between storm and sanitary trenches[14] (storm generally being at a higher elevation) makes these impacts inevitable. In general, rainfall-derived I/I (RDII) is expected to increase with higher rainfall intensity/accumulation,[15] and short-duration, high-intensity (SDHI) rainfall events are expected to increase in frequency and severity under changing climate conditions.[16]

Inflow/Infiltration (I/I)

Inflow/Infiltration is an industry term that refers to clean water that enters sanitary sewer systems. I/I may affect both existing and new sewer systems. The US Environmental Protection Agency defines I/I as follows:

Inflow – Water other than sanitary wastewater that flows directly into sanitary sewer systems and includes sources such as residential roof downspouts, storm catch basins that have been accidentally connected to sanitary sewer systems, leaky sanitary sewer maintenance hole covers and basement stairwell drains. Inflow does not include infiltration.

Infiltration – Water other than sanitary wastewater that enters a sewer system from the ground through defective pipes, pipe joints, connections or maintenance holes. Infiltration does not include inflow.

Source: USEPA. 2014. Guide to I/I Reduction.

A number of other potential climate change impacts may also exacerbate or otherwise affect I/I. Because frozen ground is less conducive to infiltration, reduced periods of frozen ground due to higher temperatures may result in increased infiltration during the winter.[17] Coastal regions may also face increasing risk of I/I, as sea level rise increases groundwater table levels, and saltwater intrusion may compromise system integrity.[18] Changing climate conditions may also affect antecedent conditions (i.e., rainfall and moisture conditions before/between SDHI events), with further implications for RDII.[19] As RDII increases, there is also the risk of increasing frequency and volume of combined and sanitary sewer overflows.[20]

1.2 I/I and flood damages in Canada

Urban/basement flooding[a] associated with short-duration, high-intensity (SDHI) rainfall events is one of the most significant drivers of disaster loss in Canada.[21] The vulnerability of urban communities was highlighted following the July 8, 2013, urban flood event in the Greater Toronto Area. At over $1 billion (2019 CAD) in insured losses, this event remains the most expensive insured loss event in Ontario's history and the most expensive urban SDHI flood event in Canada's history.[22] Though multiple flood drivers contributed to damage, including a combination of insured and uninsured storm/overland flow, sewer backup, infiltration flooding and various household-scale plumbing issues, insurance industry loss data indicated that over 60% of the insured losses and 70% of the claims were attributed to sewer backup and water damage in residential buildings.[b]

Sewer backup in residences typically contributes more than half of total insured losses during major urban flood events.

[a] These terms are described later in this section.

[b] Note that insurance coverage for typical residential overland/stormwater flood damage was not introduced in Canada until 2015.

Table 1: Major urban flood events in Canada that included major/regional sewer backup losses*

Event location and date, insured loss (2019 CAD, if published)	Details
Peterborough, ON, July 15, 2004 Insured loss: $113 M	~80 mm in 1 hr, ~260 mm in 24 hrs[23]
Toronto/GTA, ON, Aug. 19, 2005 Insured loss: $795 M	132 mm in 2 hrs, 12 hr accumulation of 149 mm (Toronto/North York)[24]
Hamilton, Ottawa, ON, July 2012 Insured loss: $104 M	116 mm to 140 mm in 3 hrs in Hamilton area
Toronto, ON, July 8, 2013 Insured loss: $1.024 B	102 mm in 2 hrs, 6 hr accumulation of 126 mm (Toronto/Pearson International Airport)[25]
GTA, ON., Aug. 2014 Insured loss: $84 M	150 to 200 mm in Burlington
Saskatoon, SK, to Thunder Bay, ON, June 2016 Insured loss: $40 M	50 mm (up to 90 mm total) in 3 hrs (Thunder Bay, ON), 44 mm (Estevan, SK), 140 mm, 303 mm/hr (West Hawk Lake, MB), 104 mm (Killarney, MB), 60 mm (Grandview, MB)
Estevan, SK, to Edmonton, AB, July 8–11, 2016 Insured loss: $59 M	~130 mm in 2 hrs (Estevan, SK), 49 mm (Clearwater, MB), 86 mm (Lloydminster, SK), 89 mm (Yorktown, SK area)
Windsor/Tecumseh, ON, Sept. 28, 2016 Insured loss: $165 M	195 mm (total), 100–110 mm in 5 hrs in Tecumseh, 115–230 mm in Windsor (24 hrs)[26] ~80% of insured losses attributed to residential sewer backup/water damage
Southern ON and QC, April 5–7, 2017 Insured Loss: $116 M	30–40 mm (parts of S. ON/QC, Apr. 4), 50–85 mm (parts of S. ON/QC, Apr. 5–7), 70–85 mm in Montreal
Windsor/Tecumseh/Essex, ON, Aug. 28–29, 2017 Insured loss: $177 M	290 mm in LaSalle, +220 mm in Windsor, 190 mm in Essex ~70% of insured losses attributed to residential sewer backup/water damage
ON/QC, Oct. 2017 Insured loss: $104 M	Remnants of Tropical Storm Phillipe (112 mm in Ottawa, 74 mm in Kingston)
Eastern Canada winter flooding, Jan. 2018	Max rain: 127.5 mm, Mechanic Settlement, NB. Losses also associated with high wind
Southern ON and QC flooding, Feb. 2018	Max rain: 76 mm, Lucknow, ON. Additional losses due to freezing rain
Toronto SDHI flooding, Aug. 2018	Max rain: 72 mm
QC and Maritimes flooding and wind, Jan. 2019	Losses also attributed to freezing rain and wind
ON and QC, early Feb. thaw, 2019	Water and freezing rain–related losses
Southern ON and QC snowmelt and rain, March 2019	Losses attributed to snowmelt, rain and high wind
Eastern Canada flooding, March 2019	Max rain: 62.2 mm, Duncan Cove, NS
ON, QC and NB spring flooding, April–May 2019 Insured loss: $272 M	Losses attributed to flood and high wind
Eastern Canada rain and windstorm, Oct.–Nov. 2019 Insured loss: $256 M	Max rainfall: 109 mm, Stratford, QC. Losses also attributed to high wind and snow
ON and QC winter storm and flooding, Jan. 2020	Max rainfall 82 mm, Wellesley, ON. Losses also associated with freezing rain and high wind

* Includes events where at least 20% of total losses were attributed to property sewer backup.

Sources: Unless otherwise indicated, damage drivers and rainfall accumulation were sourced from CatIQ. 2018, 2019, 2020. Catastrophe Bulletins. Toronto: CatIQ. City of Windsor. 2017. Special Meeting of City Council. Agenda. January 23, 2017. Windsor: City of Windsor. Unless otherwise indicated, insured loss amounts sourced from Insurance Bureau of Canada. 2020. Facts of the Property and Casualty Insurance Industry in Canada. Toronto: Insurance Bureau of Canada. Town of Tecumseh. 2016. Town of Tecumseh Flooding Event. News Release, September 29, 2016.

Aside from property damage, impacts of sewer backup flooding include health risks associated with flooded basements (e.g., mould, introduction of raw sewage into homes),[27] reduced livability of homes and loss of irreplaceable and sentimental items, among other effects. Households may also experience negative impacts on insurance coverage conditions and availability for future events.[28] Examples of municipal impacts include damage to infrastructure, operational costs and threats of lawsuits following SDHI-related flood events.[29]

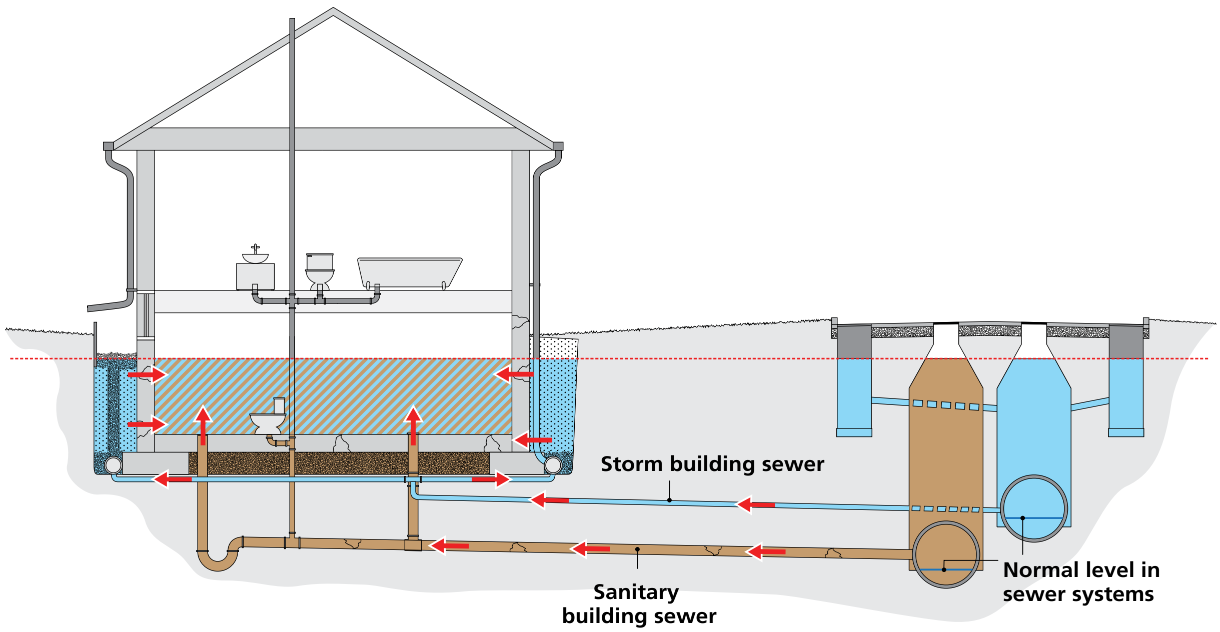
A 2017 review of climate change adaptation for the built environment by the Infrastructure and Buildings Working Group (part of Canada's Adaptation Platform) indicated that municipalities in many regions of Canada are concerned that the risk associated with urban and basement flooding will intensify as a result of increasing urban development and density, aging private- and municipal-side infrastructure, sewer construction issues, and increasing frequency and intensity of extreme rainfall events associated with climate change, among other factors.[30] As discussed later in this guideline, homeowner behaviour (e.g., lack of maintenance) and building designs that result in use of basements as living space may be additional factors that increase basement flood risk.[31] A general trend toward using basements as living space and the related trend toward deepening of basements to increase livability further increase vulnerability of buildings and households to significant flood damages.

A variety of mechanisms commonly result in flooding of buildings during SDHI rainfall events, including:[32]

- Seepage of ground and surface water (water seeps into ground beside foundation walls causing water to enter through cracks, loose joints, etc. in basements, and/or groundwater enters homes through cracks in foundations),
- Sewer backup (water/sewage backs up into underground storm or wastewater sewer connections), and
- Overland flow of stormwater (stormwater surface flow enters buildings through aboveground openings).

Many additional factors may affect flood occurrence in a particular home, including sump pump failure, improperly installed or maintained flood protection devices, blocked sewer connections and poor construction.[33] Figure 1 (page 14) depicts the hydraulics of a sewer backup, showing the flooding mechanisms.

Figure 1: Sewer backup, exemplified in a separate sewer system



Source: Robinson, B., Sandink, D., and Lapp, D. 2019. Reducing the Risk of Inflow/Infiltration (I/I) in New Sewer Construction: A Foundational Document. Toronto/Ottawa: Institute for Catastrophic Loss Reduction/Standards Council of Canada; adapted from Sandink, D. 2009. Handbook for Reducing Basement Flooding. Toronto: Institute for Catastrophic Loss Reduction; and CSA. 2019. CSA Z800-18: Basement Flood Protection and Risk Reduction. Toronto: CSA.

From January 2016 to December 2019, more than $1.1 billion in losses were directly attributed to residential flooding associated with sewer surcharge, causing backup of sewage into residential basements across Canada. Over $400 million of these losses occurred in 2019 alone. Details on recent major urban flood insured catastrophe events are provided in Table 1. Note that events listed in this table have minimum 20% insured loss attributed to residential sewer backup. The remaining losses are attributed to flood damage to automobiles, commercial buildings and commercial contents. As reported by CatIQ, the major catastrophe reporting agency in Canada, sewer backup typically contributes more than half of total insured losses during major urban flood events.[34]

1.3 Preliminary definitions

Many concepts will be discussed in detail in this report; a preliminary description of "sewers" and "flooding" are presented here to provide context for the rest of the section.

1.3.1 Types of sewers

There are only four or five main types of sewers, but numerous combinations of sewers may exist within individual municipalities, especially in older communities. Table 2 provides a simple summary of sewers based on the type of flow they convey.

Table 2: Sewer types by flow source[35]

Flow source	Sewer type				
	Sanitation function				
		Drainage function			
	Separated	Partially Separated/ Semi-Combined[1]	Combined	Storm	3rd pipe[2]
Domestic Sewage	x	x	x		
Roof Leaders		x	x		x
Foundation Drains		x	x		x
Stormwater runoff			x	x	

Source: Norton Engineering. 2020. Presentation to OMWA, November 19, 2020; research ongoing.

Note 1: In Ontario, the common term is partially separated; in BC, the common term is semi-combined.
Note 2: Third pipe systems are used in Ontario. They do not appear to be as common in BC.

Separated sewer systems include those where purpose-built, separate storm and sanitary sewer conveyance systems are found on the municipal side of the property line. On the private side of the property line, homes are serviced by a sanitary sewer and may also be serviced by a storm or "third pipe" foundation drain and/or downspout collector. In fully separated systems, only household wastewater (i.e., soil and waste, blackwater, greywater) is discharged to the sanitary sewer. No "clean" stormwater or groundwater – such as that associated with eavestrough downspouts, foundation drains, area drains, etc. – is purposely discharged to the sanitary system.

Semi-combined (or partially separated) systems are legacy systems where separated sanitary sewers exist on the municipal side of the property line, but household foundation drainage systems, eavestrough downspouts, area drains, etc. are connected to sanitary sewers on the private side of the property line. These flow sources can contribute significant excess water to sanitary sewers, resulting in overwhelmed wastewater treatment infrastructure and sewer backups into buildings.

Experts consulted in the preparation of this report noted a lack of clarity with respect to the definition of "separated" sewer systems. In many Canadian municipalities, connecting foundation drainage to sanitary sewers was common practice in many separated sewer areas until the mid-to-late 20th century. While sewer systems in these areas include separate underground pipes for sanitary sewage and stormwater, sanitary systems in these instances convey significant amounts of rainfall and groundwater-derived I/I as a result of foundation drain connections. Thus, these types of systems cannot be accurately described as fully separated systems but are called "partially separated" or "semi-combined."

As reported by Metro Vancouver's Liquid Waste Services Department (2016):

> Semi-combined sewer systems were once common in new construction across Canada as a means to provide foundation and basement drainage without requiring the construction of storm sewers. As a result, semi-combined sewers are sanitary sewers receiving combined private sewer laterals or that have extensive private-side cross-connections. They are believed responsible for chronic elevated I&I rates in many neighbourhoods serviced before their prohibition.[36]

In reality, sewer systems frequently combine the sewer types illustrated in Table 2. Effort was made by the project team and ESC to agree on standard definitions during the preparation of this document, but consensus was not reached. Further:

> Related to [sewer types] are the truly separated systems which are impacted by years of DIY repairs, lateral pipe deterioration and poor lateral construction which can result in a checkerboard of separated sanitary and semi-combined sewer connections. This is difficult to identify and manage.[37]

1.3.2 Types of flooding related to I/I

Flooding is referred to many times in this guideline. There are two major categories of flooding that relate to I/I in inland (non-coastal) areas:

1. Riverine (receiving water) flooding
2. Urban flooding

Riverine flooding is associated with the hydraulic grade line of a nearby receiver that exceeds typical values and causes backup into storm and sanitary sewer systems, resulting in flooding. If I/I is higher than it should be, riverine flooding may affect more properties than is necessary since the hydraulic grade line in the sewer is starting from a higher point. This issue is largely masked during a major riverine flooding event.

Urban flooding is associated with any other cause of flooding, including:

- Lot-level issues, such as overland flow due to drainage issues, a defect with a privately owned sewer or protective plumbing equipment, and
- Municipal issues, such as overloaded sewer systems, pumping station failure or poor maintenance.

I/I *in general* (not just in the case of SDHI or RDII events) is also responsible for flooding. If the hydraulic grade line of the sewer increases because of I/I, then the I/I directly causes flooding. This is an important concept for the purposes of this report and for identifying and managing the different kinds of I/I.

It is beyond the scope of this guideline to describe all the different possible flooding scenarios (e.g., coastal, groundwater). Municipalities are assumed to be familiar with the general causes of any type of flooding they experience and to develop I/I reduction programs accordingly.

This document only addresses the issues associated with urban flooding. Readers should refer to *CSA Z800-18: Basement Flood Protection and Risk Reduction* for extensive information on the causes and conditions of urban flooding.

1.4 Purpose and scope of this guideline

The purpose of this guideline is to provide tools to allow municipalities to efficiently and cost-effectively understand the nature and extent of the I/I in their system *prior to investing large capital dollars on field investigations and rehabilitation*. The foundational work that the municipality will have done if these guidelines are applied will help guide the municipality toward a modern approach to I/I management, which is much more complex (and cost-effective) than a single I/I study.

This guideline is focused specifically on separated and semi-combined systems as generally defined in Table 2. Storm and combined sewer analyses are fundamentally different. Both separated and combined sewer systems experience I/I, and both types of sewer systems respond to runoff events and may have return periods associated with their flows.

In any case, the rehabilitation techniques that are required to address I/I in either separated or combined systems are essentially the same, although alternatives for combined systems will include an assessment of stormwater outlet options.

This guideline was written to reflect the fundamental importance of including the assessment of private-side I/I in any modern I/I program.

This report focuses largely on urban areas of southern Canada. It does not, in its current form, provide initial guidance related to regions of northern Canada that may be vulnerable to changes in permafrost conditions.

1.5 Target audience for this document

The proposed target audience includes:

- Small and medium-sized municipalities,
- Legal agencies and authorities with responsibility for sanitary sewer systems, and
- Consulting engineers.

This document recognizes that most of the systems in Canada that have older fully combined sewers in Canada are operated by large urban municipalities that have extensive staffing, resources and, likely, in-house I/I expertise. The proposed target audience for this guideline is the remaining municipalities that do not necessarily have access to such expertise, although larger municipalities will also benefit from this information.

The primary target user is a municipal engineer interested in implementing I/I reduction strategies for their municipality. However, because very few guidance documents exist in this space, guidance at both municipalities and consulting companies is needed.

The term "engineer" is used to denote the person likely to be developing an I/I reduction program, though it is understood that this person could have a different professional designation (e.g., may not be P.Eng. or equivalent).

1.6 Primary documents consulted for this guideline

Very few comprehensive and current documents that guide the development of a modern I/I reduction program exist. Most documents were published more than 10 years ago. However, the fundamental nature of I/I has not changed, and much of this information remains valuable. The following documents were widely consulted in the preparation of this guideline and are recommended for further information:

- *Infraguide on Assessment and Evaluation of Storm and Wastewater Collection Systems*, Issue No. 1.0, 2004, Federation of Canadian Municipalities and National Research Council (Infraguide).
- *Infraguide on Infiltration/Inflow Control/Reduction for Wastewater Collection Systems*, Issue No 1.0, 2003, Federation of Canadian Municipalities and National Research Council.
- *Infraguide on an Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks*, Issue No. 1.0, November 2003, Federation of Canadian Municipalities and National Research Council.
- *Existing Sewer Evaluation and Rehabilitation*, WEF Manual of Practice No. FD-6, ASCE/EWRI Manuals and Reports, Water Environment Federation and the American Society of Civil Engineers/Environmental and Water Resources Institute.
- *Guide for Evaluating Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems*, USEPA, January 2005.
- *Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys*, Massachusetts Department of Environmental Protection, 2017.
- *Assessing Local Mandatory Measures To Reduce Flood Risk and Inflow & Infiltration in Existing Homes*, ICLR, 2017.
- *Controlling Inflow and Infiltration in the Metro Vancouver Area*, Liquid Waste Subcommittee of the Regional Engineers Advisory Committee, 2019.
- *Guide for Estimating Infiltration and Inflow*, USEPA, June 2014.
- *Best Practices Guide: Management of Inflow and Infiltration in New Urban Developments*, ICLR, 2015.

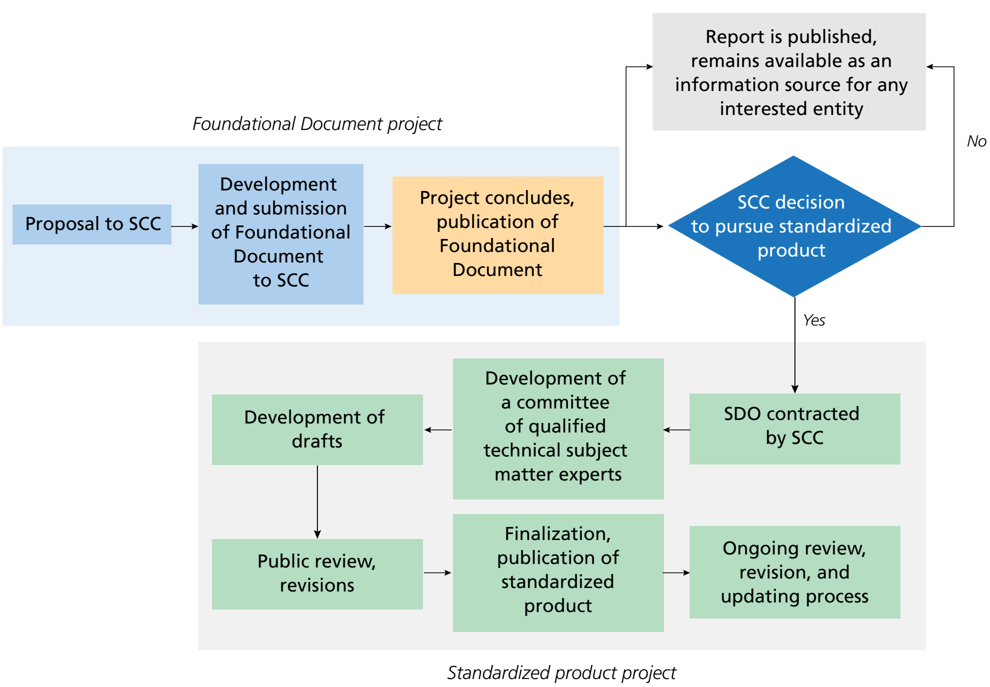
1.7 The Foundational Document and the NSC development process

The current project concerns the development of a "seed" or "foundational" document, the purpose of which is to establish a foundation of knowledge and stakeholder insights for the eventual development of a standard. Technical topics have been flagged in the report for the purposes of setting the basis for further discussion.

While the document is a source of useful information, it cannot be used for certification, verification or regulatory purposes. No part of the Foundational Document should be considered prescriptive or adopted as a vetted best practice by any agency. Development of an NSC would be conducted in a separate and distinct project managed by SCC. NSC development is likely to incorporate the following steps (see Figure 2):

- Creation of a request for proposals by SCC, which would be distributed to accredited standards development organizations (SDOs),
- Selection of an experienced SDO to undertake the project,
- Formation of a technical committee (TC) by the SDO to support development of the NSC, using a TC membership matrix to ensure broad representation from industries and stakeholders across Canada,
- Development of several drafts of the NSC,
- A formal public review and comment period for the draft NSC,
- Revision of the NSC based on feedback received during the formal public comment period,
- Finalization and publication of the NSC, and
- An ongoing revision process (e.g., re-formation of the TC and revision every five years).

Figure 2: Foundational Document in relation to National Standard of Canada development process



National webinar

An open, national webinar was held on November 10, 2020. The webinar was intended to notify stakeholders of the Foundational Document project and to invite feedback from a large audience.

A total of 122 participants from British Columbia, Ontario, Nova Scotia, Alberta, New Brunswick, Newfoundland and Quebec attended the webinar. Participants represented the following industries and sectors: municipal utilities, regional municipalities, lower-tier and single-tier municipalities, provincial agencies, engineering consultants, Indigenous communities, manufacturers and industry associations.

1.8 Stakeholder consultation and input process

The stakeholder consultation and input process associated with developing a Foundational Document for the Standards Council of Canada includes the following components:

- Establishment of an Expert Stakeholder Committee (ESC) by the project team, including:
  - Highly experienced individuals and technical experts representing a number of sectors, including engineering practice, municipal administration, consulting, sanitary sewer systems and I/I programs.
  - Nationally representative membership, with experts from all relevant regions of Canada: BC, Prairies, Ontario, Quebec and Atlantic regions.
- Extensive consultation with the ESC over an 18-month period, including a web-based meeting, two formal reviews of draft documents and follow-up one-on-one discussions between the ESC and project team members.
- Consultation with wider stakeholder audience via a national webinar (see side box) and one-on-one discussions.
- Adjustment and revisions of multiple drafts of the report to account for stakeholder input and feedback.

1.9 Guiding principles

As outlined in this document, minimizing the risk of excess I/I in existing sewer systems represents good engineering practice. It has multiple benefits, including reducing costs, limiting risk of property damage, extending infrastructure life and limiting restrictions on development capacity. Though climate change is expected to increase the frequency and severity of extreme rainfall events, measures presented in this document are applicable independent of the impacts of climate change.

To be included in the standard or guideline, I/I management measures should:

- **Protect public health**. Ultimately, the goal of sewer systems is to protect public health. This concept should also be carried forward when making important decisions about I/I.
- **Support or fill gaps in existing codes and standards**. Provinces and municipalities across Canada publish standards for sewer design, construction and inspection. The standard should seek to apply these existing best practices where relevant and should provide a basis to increase application of construction standards through administrative procedures (e.g., inspections, information sharing and coordination between relevant decision-makers) where appropriate.
- **Be flexible**. Proposed measures should provide for flexibility and emphasize process- and objective-based elements in place of prescriptive measures wherever possible. Measures should also reflect administrative environments and existing standards, codes and guidelines in place in municipalities and local authorities responsible for sanitary sewer systems.
- **Be data- and evidence-based**. Proposed measures should be based on the best available information on I/I management.
- **Be effective**. Measures should have demonstrated effectiveness and measurable reduction in I/I in sanitary sewer systems.

- **Have ROI that reflects life cycle phase**. Life cycle phase should be considered when assessing ROI of specific I/I management methods. ROI of many of the most effective measures for managing I/I risk will vary based on infrastructure life cycle phase. For example, measures related to pipe material and construction will have limited ROI during retrofit, but a good ROI when incorporated in new construction, substantial renovations or redevelopments.
- **Be practical.** To the extent possible, measures should be practical, and implementation should be administratively straightforward.

This guideline proposes that I/I programs need to be *efficient and cost-effective*, including components of the following:

- The taxpayer investment in the I/I program (including both staffing and capital costs) appears to justify the results (i.e., the approach is efficient).
- The approach to the I/I reduction program focuses on cooperatively involving all stakeholders to maximize results (i.e., the approach is efficient).
- Leading-edge approaches to I/I reduction programs are being studied, piloted and implemented, understanding that not all approaches work for every municipality (i.e., the approach is cost-effective).
- Program findings and results are shared publicly for the benefit of all (i.e., the approach is efficient from a societal point of view).

The above principles also reflect requirements for technical items to be included in a national SCC standard, as described in the next section. Cost-effectiveness for I/I programs is not defined here, but in its purest form, cost-effectiveness would be represented by the total program cost per L/s of I/I removed.

This document further considers I/I throughout the life cycle of a sewer system (from installation to decommissioning).

2. Managing I/I throughout the life cycle of a sewer system

2.1 Background

Identifying and reducing I/I can be long, costly and frustrating processes. Many municipalities report investing large capital dollars on I/I reduction with few, if any, positive and measurable results. In addition, the following issues contribute to the difficulty in achieving a successful I/I reduction program:

- Lack of in-house technical expertise,
- Staffing changes,
- Decision-makers lacking understanding of the correlation between flooding, costs, etc. of I/I,
- Lack of appropriate information gathering to support reduction programs,
- Council term limits and, therefore, council/councillor priorities,
- The budgeting process and competing priorities, and
- Fatigue resulting from slow progress.

Clearly, a more efficient and cost-effective approach to I/I reduction is needed.

This section describes the approach taken in this document. The goal is not simply to advise municipalities on how to undertake an I/I study and rehabilitation program, but rather to encourage municipalities to think about managing I/I throughout the life cycle of a sewer system (from installation to decommissioning).

2.2 Approaches to developing an I/I program

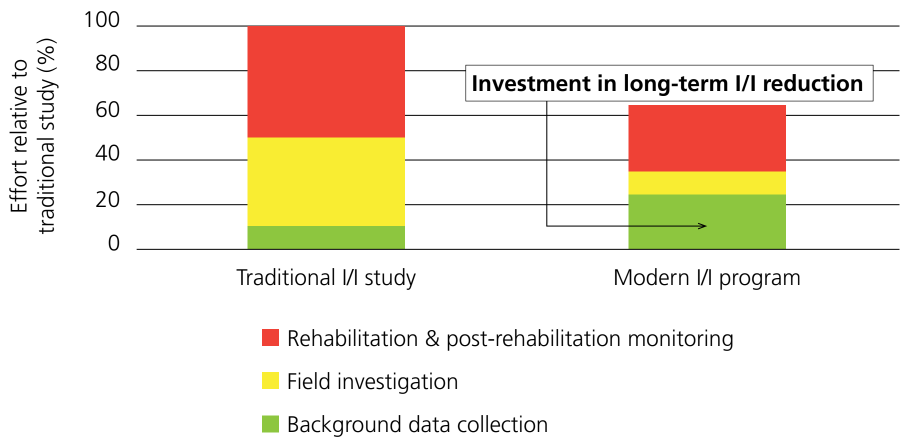
An I/I study will inevitably involve background review, identification of problem areas, field investigation to confirm and identify I/I sources, and rehabilitation and post-rehabilitation monitoring. In traditional I/I studies, flow monitoring of large sewersheds is often undertaken early in the study to start identifying problem areas. While this will indeed identify problem areas, it does not return information that will allow the municipality to "know" the nature and type of I/I. This information is typically too broad to be actionable.

The approach proposed by this document, called an I/I program, includes all the same tasks, but more effort is invested early in the process to target problem areas more closely before undertaking costly field investigations.

This approach proposes that municipalities first do the necessary groundwork, including thoroughly understanding the system, establishing goals, costs and private-side approach, prior to implementing detailed I/I studies in specific drainage areas (which includes field investigation and rehabilitation and post-rehabilitation monitoring). This careful investigation is expected to reduce, perhaps substantially, the effort (hence, budget) spent on rehabilitation, since it optimizes information *already available within the municipality*.

This systematic approach to evaluation and rehabilitation of sewer systems uses all available resources. Figure 3 graphically depicts the conceptual difference between a traditional I/I study and a modern I/I program.

Figure 3: Visual representation of effort by task: I/I study vs. modern I/I program



Source: Norton Engineering. 2020. Presentation at Master Municipal Construction Documents (MMCD) AGM, November 20, 2020.

Flow monitoring will likely be an essential component of an I/I program, but it can be costly and the data can quickly become overwhelming. Careful, informed and effective selection of monitoring sites can save municipalities a great deal of time and money. Moreover, the approach avoids the unfortunate scenario of collecting significant quantities of flow monitoring data that the municipality may not have the capacity nor the expertise to process, monitor, understand and utilize. Municipalities across Canada, particularly larger ones with extensive flow monitoring programs, report struggling to keep up with analysis, even to the point of not using the data effectively at all.[38]

As this document will make clear, reducing I/I involves all aspects of managing sewer systems. While it is well beyond the scope of this work to discuss in detail the components of sewer system management that go beyond strictly I/I management, other issues are presented for consideration, and readers are referred to other documents for more information.

This document proposes a systematic approach that uses all available resources as essential to ensuring an efficient and cost-effective I/I reduction program.

2.3 An efficient and cost-effective I/I program vs. traditional I/I study

This document provides a step-by-step approach to developing an efficient and cost-effective I/I program distinct from a traditional I/I study. The program approach involves more background work in clearly understanding all of the issues that contribute to I/I in a sewer system. An I/I program will advance the municipality from being "reactive" with respect to I/I to being "proactive" in managing the sewer system. It will provide a framework in which the causes and conditions that contribute to I/I in a municipality can be systematically reduced and managed.

Following completion of these stages, the municipality will have identified gaps, summarized findings and developed a workplan for targeted and specific I/I studies. The following tasks in the development of an I/I program are presented in this document:

Stage 1: Understand wastewater flow and private-side I/I (Section 3)

Stage 2: Develop an I/I reduction program (Section 4)

Stage 3: Collect and assess existing data and develop a workplan (Section 5)

Once the program is established, I/I studies can proceed. The studies will be designed to specifically locate the I/I that the municipality is willing or able to address. Small catchment flow monitoring and intensive I/I source detection techniques, such as smoke/fog testing and dyed water (flood) testing, will be undertaken. These tasks are essential to determining the exact sources of I/I so that appropriate rehabilitation techniques can be selected and implemented. However, these techniques are very costly. Results are only useful to the municipality if they are actionable (e.g., if a municipality finds defects on private property but is unwilling to take steps to correct them, the effort may be futile). Valuable capital dollars are better spent looking for I/I that the municipality can and will correct by way of an I/I program.

Following the establishment of the I/I program, the municipality can undertake any number of I/I studies that will generally include the following:

Stage 4: Conduct flow monitoring and field investigations

Stage 5: Identify deficiencies and develop a capital plan for rehabilitation or replacement

Stage 6: Undertake construction and post-construction monitoring

Stage 7: Repeat

I/I studies are obviously essential to correcting I/I. They are not particularly technically difficult to implement, and there are many guidance documents on each specific component (e.g., how to undertake flow monitoring, CCTV inspection, fog and dye testing). Further, rehabilitation techniques to correct I/I are well understood and constantly changing as new products are brought to market.

Given the general lack of guidance in the industry on how to undertake the early stages of work required to develop a successful I/I management program, this project focused on Stages 1 to 3. Considerable documentation and expertise on the components of I/I studies (Stages 4 through 7) already exist.

Finally, the tasks described in this section can be organized a variety of ways (e.g., there may be a need to advance flow monitoring in the process), but the main conclusion is that a municipality needs to consider a great deal *prior* to undertaking costly field work. Indeed, to achieve efficient and cost-effective I/I reduction, a great deal of careful consideration should be taken. The program will identify many factors that affect I/I, and many of them are non-technical, as presented in the next sections.

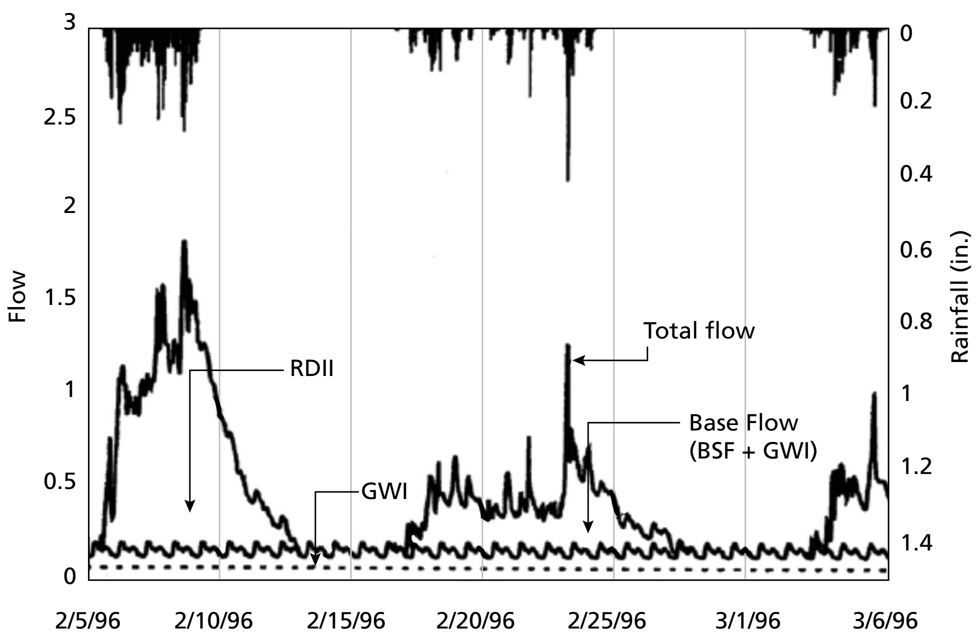
3. Stage 1: Understanding wastewater flow

3.1 General discussion of wastewater flows

The first step in addressing inflow and infiltration in sewer systems is to understand flow monitoring results and each component that contributes to flow (since to reduce I/I, a clear understanding of its source is essential). When analyzing total wastewater flows to find sources of I/I that can be reduced, all components of the flow should be considered.

Figure 4 illustrates the way wastewater flows have typically been depicted in I/I reference documents. While correct, it oversimplifies the components that make up this flow, particularly on the private side, which is less well understood. This section will describe these components in more detail.

Figure 4: Typical depiction of wastewater flow graph in I/I reference documents



Source: WEF (Water Environment Federation). 1999b. Using Flow Prediction Technologies to Control Sanitary Sewer Overflows. Monograph, Alexandria, VA.

As shown in Figure 4, base flow is defined as base sanitary flow (BSF) and groundwater infiltration (GWI). This is the flow seen during dry weather. Rainfall-derived inflow and infiltration (RDII) is all of the I/I associated with wet weather, including both inflow (during the storm) and infiltration (continues after the storm has ended but the ground is still saturated). Many terms are used to describe I/I, some of which are not particularly meaningful in an actual I/I study.

Wastewater flow is typically considered under two conditions: dry weather and wet weather. The components that comprise BSF, GWI and RDII are described in detail in the next sections.

3.2 Design and construction of sanitary sewers

To understand the types of I/I that exist in sewer systems, an understanding of the essential concepts in sanitary sewer design and construction is needed. This section briefly describes the basics of design, construction and acceptance of sanitary sewer systems; these comments are expanded upon later in the report (Section 4.7).

3.2.1 Design of sanitary sewers

As discussed throughout this report, sanitary sewers deteriorate with age and are typically assumed to have a design life of 75 years, at which time the system is presumably taken out of service. At the end of 75 years, the sewer should still be capable of conveying the peak domestic flow and the peak long-term I/I allowance. For this reason, when designing sanitary sewers, an allowance for peak, long-term I/I is included in the calculations for pipe sizing. Across most of Canada, a value of 0.28 L/s/ha (also expressed in other units) is used (however, BC uses half this value). Table 3 depicts a typical Ontario sanitary sewer design sheet. BC uses a similar template.

Table 3: Typical sanitary sewer design sheet used to size pipes (excerpt)

City of XXX • Sanitary sewer design

Location:	Trunk Sewer	Design Flow Factor, F=	0.00417 L/s (equivalent to 360 Lpcd)
Project #:	Consulting Engineer	Infiltration Factor Fi=	0.28 L/s/ha
Checked by:	ABC	Maximum Allowable Flow=	100 % of sewer's design capacity
Computed by:	DEF	Maximum Velocity=	3.0 m/s
Date:	xxx	Minimum Velocity=	0.6 m/s

Location		Area Number	From MH	To MH	Pop Density (pers/ha)	Area (ha)		Population		Peaking factor	Sanitary Flow (L/s)		Peak I/I Flow (L/s)	Additional Flow (L/s)	Total Flow (L/s)	Proposed Sewer Design			
						Incr.	Cum.	Incr.	Cum.		Average	Peak				Dia. (mm)	Velocity (m/s)	Qd Full (L/s)	% Capacity
1	A	AM11	PS02	L002	0	0.001	0.00	0	0	5.00	0.00	0.00	0.00	60.80	60.80	200	0.90	28.43	214
2	B	AM10	A002	A001	62	10.53	10.53	653	653	5.00	2.72	13.61	2.95	0.00	77.36	250	1.15	56.46	137
3	"	AM10	A001	A001	62	0.96	11.49	60	712	5.00	2.97	14.85	3.22	0.00	78.87	250	1.03	50.50	156
4	"	AM10	A001	A002	60	3.32	14.81	199	912	5.00	3.80	19.01	4.15	0.00	83.95	300	0.80	56.23	149
5	"	AM10	A002	A003	60	0.78	15.59	47	958	5.00	4.00	19.98	4.37	0.00	85.15	300	0.93	66.46	130
6	"	AM10	A003	A004	60	0.77	16.36	46	1005	5.00	4.19	20.93	4.58	0.00	86.31	350	1.31	126.43	68
7	"	AM10	A004	A005	60	0.62	16.98	37	1042	4.96	4.34	21.54	4.75	0.00	87.10	350	1.38	133.21	65
8	"	AM10	A005	A001	60	12.66	29.64	760	1801	4.44	7.51	33.39	8.30	0.00	102.49	525	1.22	263.59	39

Source: Norton Engineering. 2020. Presentation to Metro Vancouver REAC Liquid Waste Subcommittee, September 2020.

As shown in Table 3, the assumed average day flow (360 L/c/d in this case) is multiplied by a domestic peaking factor (Harmon's factor is used here) to calculate peak sanitary flow (see right-most yellow column in Table 3). Then peak I/I flow is calculated separately, typically by multiplying the area in hectares by 0.28 L/s/ha to arrive at design peak I/I allowance (see green column in Table 3). The sum of these values (pink column in Table 3) is the peak flow that is used to size the sanitary sewer. The sewer must carry the peak I/I at year 75.

Importantly, the peak long-term I/I allowance is distinct from the allowable leakage in new sewers at acceptance.[39] Furthermore, reducing the design peak I/I allowance (e.g., from 0.28 L/s/ha), will have absolutely no impact on how much I/I will occur in the system. This value, which is used at acceptance, is described in the next section.

Reducing the design peak I/I allowance (e.g., 0.28 L/s/ha), will have absolutely no impact on how much I/I will occur in the system.

Norton, Presentation to OMWA OJT, November 2020

3.2.2 Construction and acceptance of sanitary sewers

There are allowable I/I values (e.g., leakage) at acceptance prescribed in all construction specifications (for public side) and building codes (for private side) in Canada.

The National Plumbing Code defines the allowable leakage on the private side as "zero." Provincial specifications, such as Ontario Provincial Standards and BC Master Municipal Construction Documents (MMCD) define allowable leakage for both new pipes and maintenance holes.

What is leak-acceptable infrastructure?

Leak-acceptable infrastructure is infrastructure that meets acceptance testing when it is installed. This is the sum of acceptable leakage on the public and private sides. This value can be calculated for each sewershed based on area, number of houses or pipe length.

The sum of the allowable leakage in each component of a sewer system (on both the public and the private sides) is the allowable leakage for the subdivision. The term "unacceptable"[40] is used when the I/I has been compared to allowable and exceeds it (see box).

The term "unacceptable" has a specific meaning in the context of a modern I/I program. I/I is unacceptable when the amount of I/I exceeds the amount allowed at inception, as calculated per existing standards, codes and guidelines.

Acceptable I/I for an existing sewer system is discussed in more detail in Section 4.7.

3.2.3 Use of I/I values

As presented in the previous two sections, an engineer needs to consider two I/I values, but they are distinct and unrelated. Correct use of I/I values in the industry is essential and currently not well understood. Figure 5 depicts the two I/I values that are used with sewer systems – allowable I/I at acceptance and the long-term I/I allowance – for a sample subdivision in Ontario.

Figure 5: I/I values throughout the life of a sewer

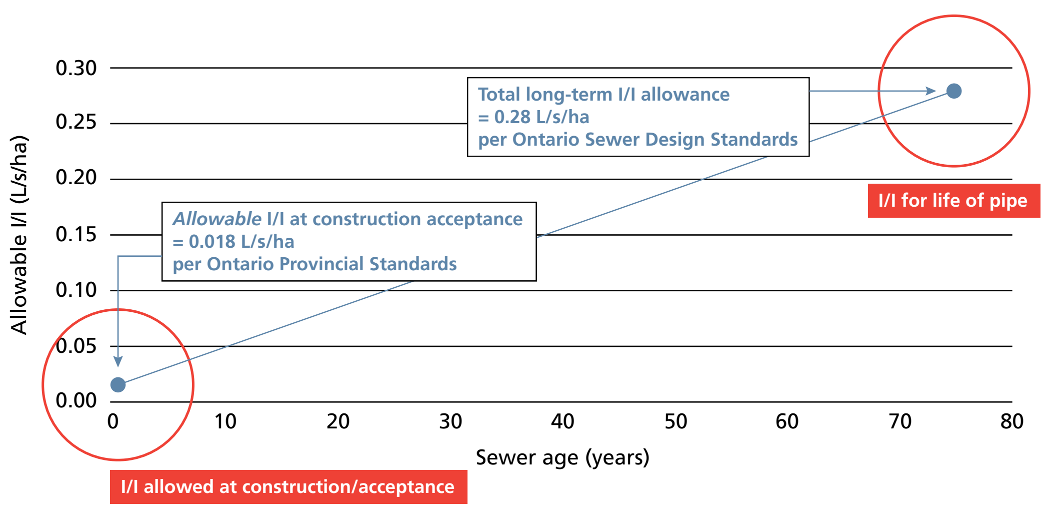


Figure 5 depicts a straight-line degradation of the sewer system, but any other assumption could be made. Peak long-term I/I (0.28 L/s/ha) should *never* be considered allowable I/I at acceptance.

3.3 Dry weather flow

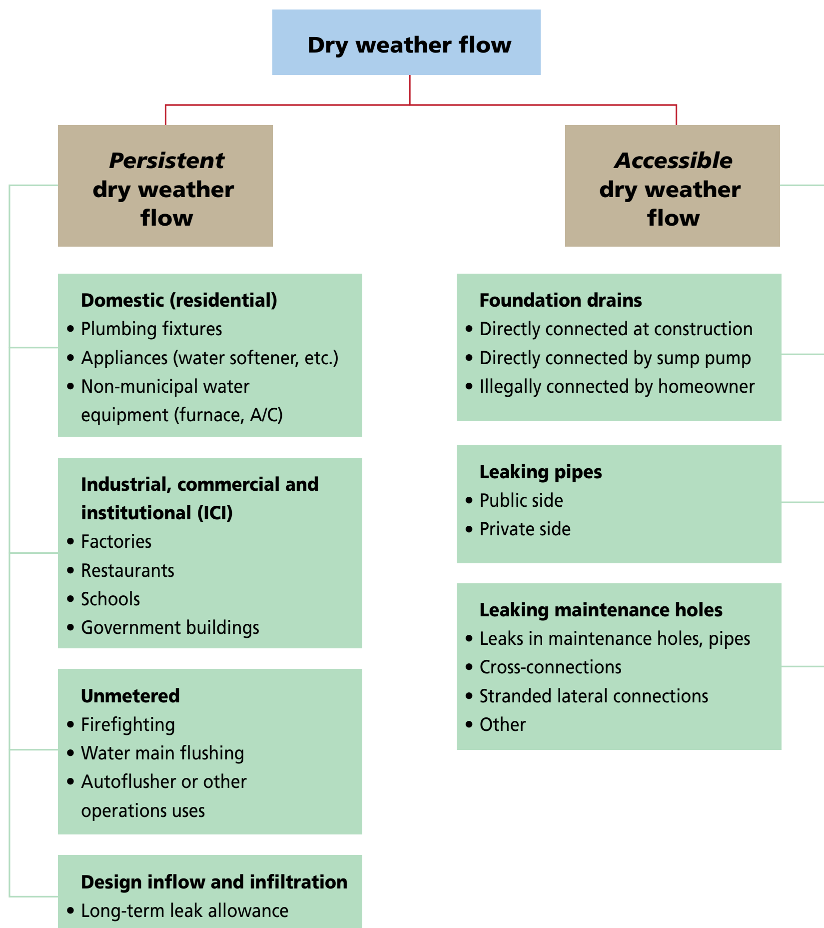
Dry weather flow is defined as the flow measured in the sanitary sewer during a dry weather period.[41] It is essentially the flow pattern observed when it has not been and is not raining. Dry weather flow may contain both inflow and infiltration but is more typically associated with infiltration.

The components of dry weather flow may be divided into two categories: *persistent*[c] dry weather flow and *accessible*[d] dry weather flow. Flow monitoring graphs themselves do not identify the source of the flow, although the shape of the graph assists in its identification.

Persistent dry weather flow is flow observed during dry weather that belongs in the wastewater and cannot (and should not) be removed from the wastewater system. This flow is not from I/I, but from a variety of sources that are not available for removal in an I/I reduction program.

Accessible dry weather flow is flow observed during dry weather flow that is "accessible" for removal during an I/I reduction program. That it is accessible for removal does not mean that it *should* be removed, but rather that it *could* be. Examples of accessible dry weather flow are infiltration associated with leaking maintenance holes, orphan lateral connections or illegal connections to the sanitary sewer. Many factors will determine which components of accessible dry weather flow should be removed, including feasibility, practicality, location (e.g., public or private side) and cost. Figure 6 depicts the categories of dry weather flow and the components that make up each.
These components are described in detail in the next section.

Figure 6: Components of dry weather flow



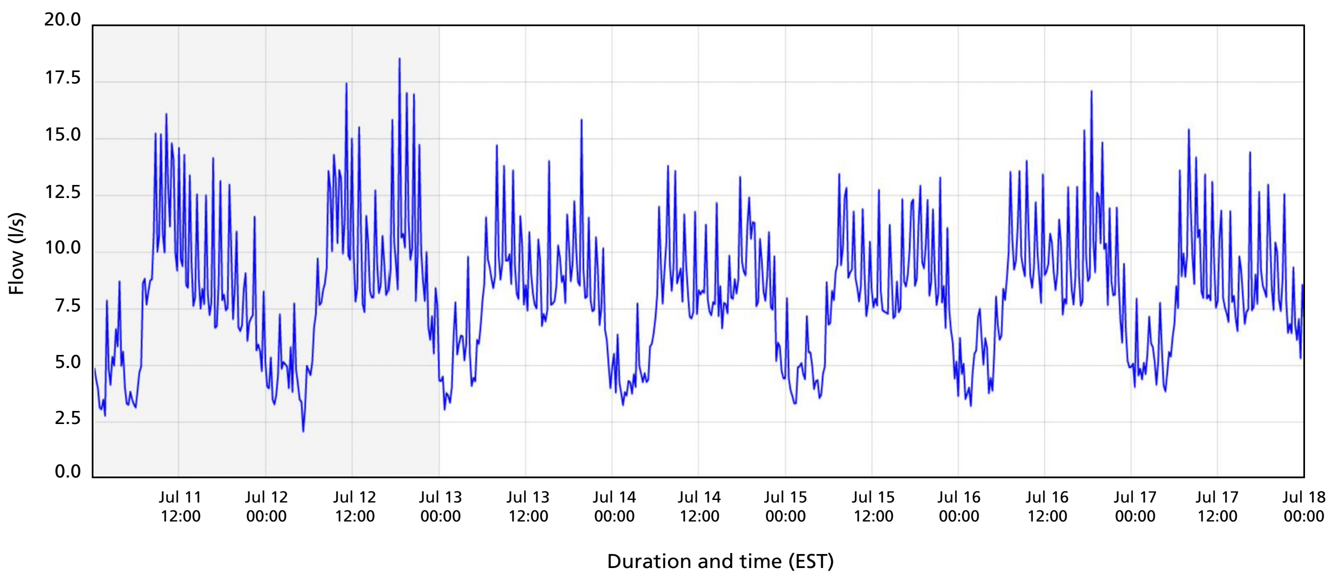
[c] Term coined by Norton.

[d] Term coined by Norton.

3.4 Persistent and accessible dry weather flow

Figure 7 depicts a dry weather flow period. These flows were monitored from an existing system in 2020 for one week, including a weekend (start of graph, shaded). The graph clearly shows that both peak flow and base flow vary, even across a single week and in dry weather conditions. Over a year, even omitting spring conditions that often demonstrate higher flows, the peak and base flows can vary. Actual flows are somewhat different from what is typically depicted in I/I manuals (e.g., as shown in Figure 7). The fundamental variability of wastewater flow needs to be considered when undertaking I/I analysis.

Figure 7: Dry weather wastewater flow monitoring results



Source: AMG Environmental, unidentified site.

The base flow visible on dry weather flow graphs is from a variety of sources, not all of which are BSF and GWI, as is commonly reported on simplified graphs (such as Figure 4). This is a very important concept to understand when analyzing wastewater flow data. The next sections delineate dry weather flow into its two main components: persistent (permanent) dry weather flow, and accessible (removable) dry weather flow.

3.4.1 Persistent dry weather flow

Persistent dry weather flow includes the following components:

- Domestic (residential) flow,
- Industrial, commercial and institutional (ICI) flow,
- Unmetered wastewater flow, and
- Design inflow and infiltration.

All these components of dry weather flow, which are described in more detail below, represent flows that are persistent and are not available for removal from the system. This concept must be understood when looking to reduce I/I from an existing system.

Domestic (residential) flow

Domestic wastewater flow includes flows that originate from the municipal water system and sources that originate from processes in the home, including:

- Plumbing fixtures in the home (sinks, toilets, showers, washing machines, dishwashers, etc.)
- Appliances in the home that use domestic water, for example:
  - Water softeners, which typically run for a two-hour window overnight. The amount of water generated varies depending on the water hardness and how much the home uses. It is difficult to estimate the amount of water generated, but a book value of about 100 L/d may be considered.
- Equipment in the home that generates water not originating in the municipal water system:
  - High energy furnaces, which generate a small amount of water while running; this flow may vary if heat is turned down during the day or overnight.
  - Air conditioners, which generate a small amount of water; this flow may also vary during the day or overnight (estimate ~20 to ~75 L/d; Hunker.com, 2017).

Industrial, commercial and institutional (ICI) flow

ICI flow comprises a portion of dry weather wastewater flow. This flow includes flow from industry (e.g., factories), commercial establishments (e.g., restaurants, stores, attractions, campgrounds) and institutions (e.g., schools, government buildings, jails). These flows can vary widely. Water use data can be used to capture the potential wastewater generation rates. However, many industries use water that is not returned to the wastewater system (e.g., canning operations). Book values on various ICI sources are often available in water design guidelines.

Unmetered wastewater flow

Unmetered wastewater flow includes treated water that is taken from the water system but not flow-monitored. This can include firefighting, watermain flushing and some construction/operations activity (e.g., water system bleeds at dead ends) that is ultimately discharged to the sewer system. Awareness of firefighting and watermain flushing is important when analyzing small sewershed flows. For example, a large unexplained peak in dry weather flow on a single day may be a result of any of these sources; they can often be identified as such and removed from consideration as an I/I source during a specific period.

Acceptable inflow and infiltration

Dry weather flow also contains inflow and infiltration that is allowable and a normal part of sanitary sewer flow. Sanitary sewers are never leak-free, and leakage is expected to slowly increase as the sewers age. Acceptable I/I should be considered part of dry weather flow. New sewers should be determined to be "leak-acceptable"[42] when they are constructed (see Section 3.2.2).

3.4.2 Accessible dry weather flow

Accessible dry weather flow is flow observed during dry weather that is "accessible" for removal during an I/I reduction program, including:

- Foundation drains,
- Leaking pipes, both sanitary and storm (public side and private side),
- Leaking joints (public side and private side), and
- Leaking maintenance holes.

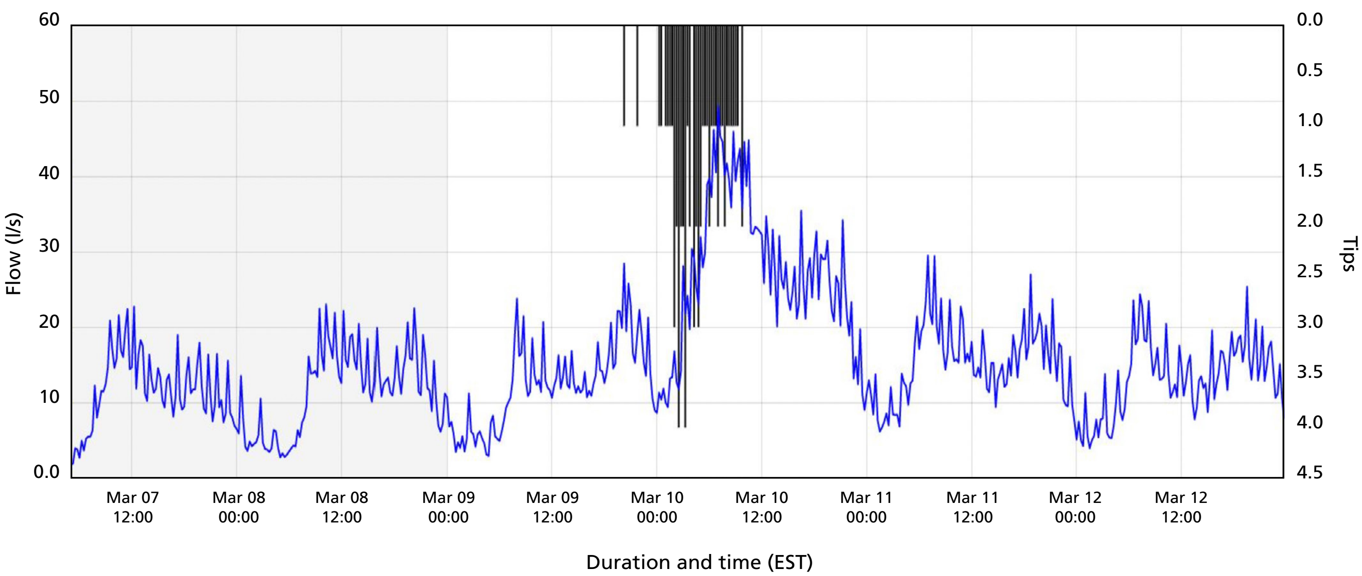
Flow from these sources appears in the sanitary sewer during dry weather conditions.

3.5 Wet weather flow

Wet weather flow is defined as flow observed during and after rain and snowmelt periods. Essentially, it is the flow pattern observed during rain and for some time afterwards, when the sewer system is still responding to water in the ground. Wet weather flow includes both inflow and infiltration.

Figure 8 depicts a one-week wet weather flow period (shaded area is the weekend). Flows are relatively consistent at the start of the week (dry weather flow), but as it begins to rain, flow in the sewer starts to increase. In this case, the elevated peak flows are relatively short-lived, but the base flows remain elevated for several days. This increase in flow during and after a rainfall is described as RDII. The concept of RDII appears to be well understood by engineers.

Figure 8: Wet weather wastewater flow monitoring results



Source: AMG Environmental, unidentified site.

3.5.1 Accessible wet weather flow

Accessible wet weather flow is flow observed during wet weather that is "accessible" for removal during an I/I reduction program. Accessible wet weather flow may include:

- Foundation drains,
- Leaking pipes, both sanitary and storm (public side and private side),
- Leaking joints (public side and private side),
- Leaking maintenance holes,
- Poorly located maintenance holes, and
- Cross-connections with the storm sewer system.

Flow from these sources appears in the sanitary sewer during wet weather conditions.

3.6 Private-side inflow and infiltration

Experts now believe that across North America, 50–60% of inflow and infiltration is generated on the private side of the property line. In most collections systems, about half of the pipe length exists on the private side. In approximately the past five years, research is being undertaken to better understand the causes and conditions of this I/I, particularly as they occur during new construction.[43]

Any modern I/I program must carefully consider private-side I/I, whether it can be addressed in the program or not. As Metro Vancouver reported:

> …addressing excessive inflow from private laterals must be a key component of municipal I&I reduction programs. Such programs will take time and require a long-term commitment with respect to funding and resources; their initiation and continuation cannot be deferred if I&I is to be controlled to minimize SSOs and ensure that conveyance capacity is available for community growth.[44]

This section describes some of the recent findings regarding I/I on the private side.

3.6.1 Private-side inflow and infiltration

Multiple agencies have developed estimates that indicate the potential private-side contribution of I/I to municipal sanitary systems. In 2015, Kesik reported that "most I/I problems originate from the private side."[45] Private-side lateral programs have been a concern of I/I management in Metro Vancouver, as approximately 50% of the total length of sewer pipe is located on the private side of the property line.[46]

A pilot study in London, Ontario, indicated that disconnecting foundation drainage systems had a substantial impact on managing I/I in a subdivision previously affected by basement flood hazards.[47] In another study, Jiang et al. (2019) closely examined the manner in which RDII enters the system through private-side connections and demonstrated that weeping tiles are a substantial contributor to private-side sanitary sewer flow during rainfall events, contributing up to 85% of rainfall-derived inflow. Disconnecting the weeping tiles at the study site reduced inflow volume by 78% and duration by 32%.[48]

International studies have also indicated high rates of I/I originating on the private side of the property line. For example, a survey of 58 US agencies conducted by the Water Environment Research Foundation revealed that all but one agency considered I/I into sanitary systems a problem. In addition, 26 of these agencies provided estimates for private-side contributions to overall I/I, ranging from 7–80%, with an average estimation that 24% is contributed from private-side laterals.[49]

A 2005 report from Columbus, Ohio, indicated that 55% of I/I originated from the private side of the property line.[50] An additional 2014 study focusing on Columbus, Ohio, by Pawlowski et al. (2014) indicated that residential I/I sources accounted for 35% of total I/I for SDHI rain events (with dry antecedent conditions) and 7% of total I/I under low-intensity, long-duration rainfall events with wet antecedent conditions. Private-side downspouts and laterals accounted for 98% of private-side I/I contributions.[51] A 2007 report prepared for the Neponset River Watershed Association (Massachusetts, US) reported that as much as 40% of sewer system infiltration originates on the private side of the property line.[52] A recent report from China, conducted in new residential development in the city of Jiaxing, found that 30% of the total rainfall from a precipitation event entered the city's sewer system and was directly attributed to "illicit" private-side connections.[53]

I/I is often related to connection of downspouts and/or foundation drains to municipal sanitary sewer systems in "partially separated" or "semi-combined" sewer areas.[54] Municipalities across Canada have developed municipal and private-side programs to mitigate I/I. For households, critical I/I management options include downspout and foundation drain disconnection from sanitary sewers, as well as maintenance and repair of sewer connections.[55]

CSA Z800-18: Guideline on Basement Flood Protection and Risk Reduction includes a variety of figures depicting private-side plumbing of various types, along with potential interconnections between sanitary and storm systems on the private side.

I/I rates in sanitary sewer systems are generally expected to increase as the physical condition of systems deteriorates over time.[56] Factors influencing deterioration include physical defects, design flaws, illicit connections, root penetration, corrosion, soil conditions and aggressive groundwater.[57] As a result, when sanitary sewers are designed, an allowance for peak long-term I/I is included in pipe sizing (a typical value of 0.28 L/s/ha).

Abandoned and/or orphan laterals (which can be classified as either municipal or private side) have long been identified as sources of I/I. Recent work[58] has identified that many municipalities do not have a formal process in place to track and arrange to decommission abandoned or orphaned laterals, potentially leaving large sources of I/I connected to the sewer system.

This document was written to reflect the fundamental importance of addressing private-side I/I.

3.6.2 Resident behaviour, voluntary and mandatory household programs

Managing I/I on the private side of the property line is a behavioural issue, as well as a physical, engineering and plumbing issue. Critical aspects of resident behaviour concerning mitigation of basement flooding and I/I are outlined in Table 4.[59]

Table 4: Behavioural and physical adjustments to reduce risk from overland, infiltration and sewer backup flooding associated with extreme rainfall events in Canada

Adjustment		**Flooding type**			**Function**	
		O*	I**	SB†	Private-side risk reduction	Private-side I/I reduction
Behavioural	Seek out/read information on urban flood reduction	x	x	x	x	x
	Inform municipal government about flood experiences	x	x	x	x	x
	Plumbing and drainage investigation	x	x	x	x	x
	Review insurance coverage			x	x	
	Avoid pouring FOGs down drains			x	x	
	Keep storm sewer grates cleared of debris, blockages	x			x	x
	Reduce home water use during heavy rainfall events			x	x	x
	Maintain eavestroughs and downspouts		x	x	x	x
	Change use of basement to reduce exposure to flood damages	x	x	x	x	
Physical	Seal cracks in foundation walls, basement floors		x		x	
	Identify/seal overland flood entry points	x			x	
	Extension of downspouts/splash pads		x	x	x	x
	Lot grading/backfilling/swales	x	x	x	x	x
	Backflow protection device(s)			x	x	
	Sewage ejector/overhead sewer system			x	x	
	Maintenance, repair of sewer laterals			x	x	x
	Window wells/well covers	x			x	
	Downspout disconnection from municipal			x		x
	Weeping tile disconnection			x		x

Individual measures may address one or more of the various types of flooding that homes may experience by either reducing the risk that water will enter a home (private-side risk reduction) or by limiting the home and property's contribution to municipal inflow/infiltration (private-side I/I reduction).

FOG: fats, oils and grease.

* Stormwater overland flooding
** Infiltration flooding
† Sewer backup flooding

Source: Sandink, D. 2016. Urban flooding and ground-related homes in Canada: an overview. *Journal of Flood Risk Management*, 9(3): 208-223.

In many instances, it is technically possible for municipalities to apply mandatory measures (for example, through bylaw enforcement) for households to engage in interventions such as cross-connection inspection, disconnection of sump pumps from sanitary sewer connections, maintenance of private-side sewer laterals and related measures. However, administrative, physical/plumbing and political complexities may limit willingness of local authorities to engage in these types of regulatory or mandatory approaches.[60] As a result, many basement flood and I/I mitigation programs with private-side components focus on voluntary adaptation of I/I management interventions at the private side of the property line.

The Capital Region District in Victoria, BC, has a well-established engagement process regarding private laterals and considers windows of opportunity when the lateral condition becomes known and/or important to the homeowner, including:

- Time of sale/purchase,
- Time of permit/renovation, and
- Time of failure/blockage.

Allies in this effort include realtors, mortgage brokers/lenders, plumbers, home inspectors and insurers. Awareness among this group will inform and educate property owners. This approach is socially led rather than technically led and should be considered in more jurisdictions.

Introducing a two-tier or dual-rate sewer use fee, which includes a lower fee for certified laterals and higher fee for uncertified laterals (the default fee), may be valuable. This approach would essentially charge sewer users for the discharge of I/I (drainage water) unless their lateral was certified to be free of defects and cross-connections. The certification could last about a decade and be provided by a certified plumbing contractor. This could incentivize private lateral management while recognizing that there may be instances that lateral repairs or replacement may not be practical.[61]

MassDEP, which regulates sewer systems in Massachusetts, includes the following statement in its *Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys* (2017):

> MassDEP acknowledges the difficulties in addressing private inflow sources to public sewer systems. While all sewer use regulations must prohibit connection of inflow sources, as per 314 CMR[e] 12.03(5), approaches to identifying and removing existing private inflow connections can and should consider the role of private inflow sources in creating SSO risks; the costs to the utility and/or property owner of removing private inflow connections; and the potential for any adverse impacts such as increased flooding or icing of surfaces.

Voluntary programs typically include a combination of educational initiatives, ranging from less intensive provision of websites with critical information to door-to-door visits and public open houses in flood-affected regions, as well as programs that financially subsidize private-side interventions.

Municipal programs often provide substantial subsidies and detailed homeowner guidance; however, uptake of lot-side mitigation measures has been sporadic.[62] An aggressive pilot program in London, Ontario, focused on disconnection of foundation drainage systems from sanitary sewers. The program included comprehensive property evaluation, full subsidization for mitigation measures and $1,000 remittances for future maintenance, and it resulted in 37 of 65 eligible homes participating.[63]

[e] State legislation.

Some programs have achieved less than 10% uptake, while others, including those that have emphasized multiple notifications to homeowners and potential penalties for non-compliance, have achieved higher uptake rates.[64]

Many of Canada's larger insurers are now also offering direct financial subsidies for private-side basement flood interventions, including those related to I/I mitigation. Insurers may, for example, provide reduced premiums and/or increased payout caps for policyholders in regions prone to basement flood risk who have implemented I/I and basement flood protection measures. Incented measures typically include foundation drain disconnection or sump pump installation and sewer backflow protection. In some cases, basement flood protection measures may be a condition for insurability of basement flood damage.[65] Several of Canada's larger insurers have also engaged in direct subsidies to assist households in implementing basement flood–related interventions after sewer backup claims have been made.

An important factor that has been associated with limited uptake of voluntary programs is that residents may be asked (or required) to engage in interventions that are viewed as undesirable. For example, residents may be encouraged to correct cross-connections, repair or replace sewer laterals, or install sump pump systems to protect downstream regions from I/I and flooding, despite having never experienced flooding themselves. Some measures, including installing sump pumps, require ongoing maintenance and introduce the potential for additional energy costs for households, further reducing willingness of households to engage in I/I and basement flood risk reduction.

The lessons from the above-mentioned programs indicate that a range of strategies is likely required to effectively manage I/I, including interventions on the private sides of the property line.

Despite the above-mentioned limitations to mandatory private-side initiatives, mandatory approaches have been applied in several jurisdictions. For example, the City of Surrey, BC, requires inspections and replacement of private sewer laterals under specific scenarios when lots are redeveloped or buildings are substantially renovated. In the Maizerets neighbourhood of Québec City's Limoilou district, the local authority achieved high uptake rates for a downspout disconnection program by progressing from a voluntary to mandatory approach, which included $300 fines for households that did not comply.[66]

Local interpretations of construction codes – specifically articles related to 2.4.6.4. of the National Plumbing Code – have also been applied to require interventions to protect homes from sewer backup associated with excessive I/I, including in many jurisdictions in Ontario and Saskatchewan.[67]

Reverse-slope driveways have the potential to introduce substantial quantities of water into basements and homes during extreme rainfall events.[68] This water can then enter sanitary sewer systems through basement floor drains and other connections, significantly exacerbating I/I at the regional scale. Application of zoning bylaws and lot-grading and drainage requirements – both under local municipal control – have also been applied to restrict use of reverse-slope driveways, including in Toronto, Pickering and Markham, Ontario.[69]

3.6.3 The impact of two-tier governments on ability to address I/I

Many of the largest municipalities in Canada have a two-tier model that governs the responsibility for stormwater and wastewater. It is important to include stormwater in this discussion because the two systems are connected. These models vary, but generally, the lower-tier municipality is responsible for sewage collection and the upper tier is responsible for treatment (with wastewater pumping stations belonging to either). Stormwater is frequently the responsibility of the lower-tier municipality.

Municipalities that were formerly two-tier and have amalgamated (e.g., Hamilton, Toronto, Ottawa), have inherited a variety of grandfathered guidelines, standards, record keeping, etc., making understanding these wastewater and stormwater systems complex.

Since the upper-tier municipality is typically responsible to regulators for treatment and overflows (more common in combined systems), but the lower-tier municipality is the only one that can actually effect change at the lot level, two-tier systems can be problematic (see side box).

If I/I is problematic in a system, the upper-tier municipality may want the lower-tier municipality to fix it. However, the lower-tier municipality may want the upper tier to deal with the problem at the WWTP (e.g., by installing equalization or storage tanks). Each tier of government reports to their own council and voters and has different budgets, priorities, pressures and timelines.

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 the regional government and the other aspect is the sole responsibility of a 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.

Source: Kesik, T. 2015. Management of Inflow and Infiltration in Urban Developments. Toronto: Institute for Catastrophic Loss Reduction.

In research undertaken in 2015 and 2016, hundreds of municipal staff across Ontario were interviewed confidentially about their sewer systems, specifically I/I. They expressed many problems, concerns and frustrations around trying to achieve effective I/I reduction in two-tier systems.

The Metropolitan Milwaukee Sewer District (MMSD), however, has been successful in managing I/I as a two-tier jurisdiction. MMSD is an upper-tier municipality with 28 lower-tier jurisdictions. An essential feature of the program is the Technical Advisory Team (TAT) – a committee composed primarily of public works directors, city engineers or other representatives from the 28 satellite agencies that advises MMSD staff on technical matters. Originally established in 1995, the TAT has developed into an essential component of MMSD’s I/I reduction program.

The MMSD TAT meets monthly and is a forum for ideas, lessons learned, challenges, etc. Through the TAT, MMSD has demonstrated to the satellite agencies that they are credible and transparent and will follow through with their commitments. Trust has been established, and in several cases agencies that previously were detractors of the program have become champions. This is a best-in-class approach to managing I/I within a two-tier system since it is likely that both efficiency and cost-effectiveness increase when cooperation and trust are high. More information on MMSD’s program is presented in Section 4.6.1.

MassDEP, a state agency, also takes an approach that endeavours to work cooperatively with the agencies it regulates. MassDEP publishes I/I guidelines with the intent to:

> ...aid communities in performing infiltration/inflow (I/I) analyses by providing a systematic, comprehensive approach for conducting sewer system evaluations; and to provide information to assist sewer system authorities with fulfilling the requirements of the [applicable legislation]…

In addition, the Massachusetts Water Resources Authority (MWRA) has a grant/loan program for its 43 member communities specifically to identify and remove I/I. This certainly has been helpful and has been accessed by all MWRA members.[70] The guidelines recognize the challenges with reducing I/I and provide the overall framework for performing the required work, while recognizing that "site-specific conditions may warrant different approaches."

The *National Guide to Sustainable Municipal Infrastructure*[71] (InfraGuide, 2001) identified a two-tier structure for sewer systems as problematic for infrastructure in general. However, the kind of cooperative, practical support that some jurisdictions have provided to local municipalities trying to achieve I/I reduction targets is essential to achieving an efficient and cost-effective I/I reduction program.

To this point, this document has established the pressing need to reduce I/I and some of the challenges associated with doing so. The next sections describe how to systematically develop an efficient and cost-effective I/I reduction program.

4. Stage 2: Development of an inflow and infiltration reduction program

This section specifically addresses Stage 2 as presented in Section 2.3 – development of an I/I reduction program – outlining the various issues a municipality will need to consider as it develops an efficient and cost-effective I/I reduction program.

4.1 Inflow and infiltration study vs. program

Inflow and infiltration is a long-term, systemic problem in sewer systems. Addressing I/I is complex and ideally becomes a proactive part of a municipality's sewer system program (as discussed in Section 2). Many factors contribute to I/I, not all of them related to aging pipes. The Water Environment Federation (WEF)'s *Existing Sewer Evaluation and Rehabilitation: Manual of Practice*[72] lists the following causes of I/I:

- Natural aging of sewer system,
- Lack of maintenance of sewer system,
- Uncontrolled stormwater,
- Poor construction methods, and
- Inadequate construction specifications or design.

Clearly, a one-time I/I study is inadequate to address all of these causes (see side box). Municipalities, particularly small to medium-sized ones, have reported that I/I studies (typically undertaken by consultants) are often not useful because staff are unable to implement recommendations due to lack of resources, staff changes, or I/I being overlooked in favour of other priorities.

Furthermore, managing I/I efficiently and cost-effectively over the long term requires that a municipality consider much more than a one-time effort. Municipalities must continually prioritize the capacity, management, operation and maintenance (known as CMOM in the US) of the sanitary sewer collections system. It involves an ongoing, concerted effort by the entire organization (see box below). This concept is described in detail in this guideline.

I/I study and rehabilitation are not one-time events. A regular maintenance program, including pipeline and maintenance hole inspections, cleaning, root treatment and inflow source identification/removal, is critical to maintaining the integrity of a collection system.

Source: MassDEP. 2017. Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys.

The CMOM approach helps municipal wastewater utility operators provide a high level of service to customers and reduce regulatory noncompliance. CMOM can help utilities optimize use of human and material resources by shifting maintenance activities from "reactive" to "predictive" – often leading to cost savings through avoided overtime, emergency construction costs, increased insurance premiums, and the possibility of lawsuits. CMOM information and documentation can also help improve communications with the public, other municipal works and regional planning organizations, and regulators.

Source: USEPA. 2005. Guide for Evaluating Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems.

4.2 Define goals

Municipalities should carefully define the goals for their I/I reduction program since these will have a direct impact on the solutions that the municipality develops. The goals will help establish whether the focus will be on inflow, infiltration or both.

To establish goals, staff will need to understand the current costs, consequences and liabilities of existing I/I, have an idea of what is acceptable I/I for them, and consider whether work on the private side is feasible. Setting goals for I/I removal may need to take place later in the I/I program process, once the nature and extent of the I/I is better understood. However, an I/I program is likely being proposed because of a known issue in the system.

Defining goals is much more difficult for two-tiered systems where there is a regional utility and local municipal sewer systems connected to it. The I/I costs are often directly borne by municipalities, whereas the consequences of excessive I/I may be borne by the regional utility in the form of SSOs and elevated conveyance and treatment costs. Costs and benefits for different solutions often sit on the same ledgers; therefore, the causes and effects of I/I management actions are less easily rationalized between the two-tiers of utility service.[73]

Provincial authorities that approve major sewer and WWTP upgrades are starting to attach I/I reduction requirements prior to approval. It is recommended that users of this guideline keep this longer-term approach in mind as they develop the goals and objectives for I/I management programs.

4.3 Calculate the current costs of I/I in your system

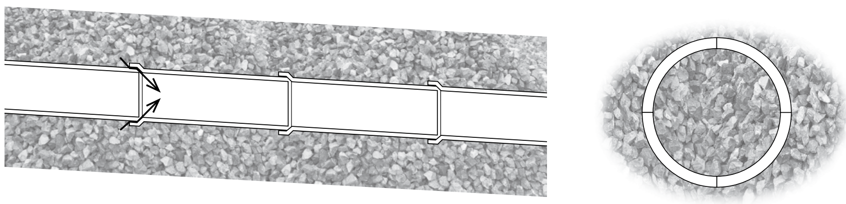
It has been traditional in engineering to consider only the "chemical and power" costs at the WWTP when calculating the costs of I/I, but this is an inadequate measure of the true cost of I/I and needs to be reconsidered. Norton Engineering has been advocating for the use of the actual sewer use charges (e.g., \$3.15/m^3 in Kitchener, 2020)[74] since these represent a direct application of what it costs the municipality to own, operate, maintain, repair and replace the sewer collection and treatment system in its entirety, including fixed and hidden costs. While this has not been widely accepted, it is at least site-specific.

Another cost that is difficult, if not impossible, to estimate is the cost of needing to replace sewers long before their estimated service life (normally taken to be between 75 and 100 years). In 2019, City of Kitchener staff reported to council that sewers needed to be replaced after about 40 years,[75] not 75 years, and requested substantial budget increases to undertake rehabilitation and replacement programs. Sewer replacements fall under capital programs, so will never be attributed as an I/I cost, even though they may be directly related to I/I. That is one reason that the *actual cost of providing sewer services* should be used when calculating I/I costs.

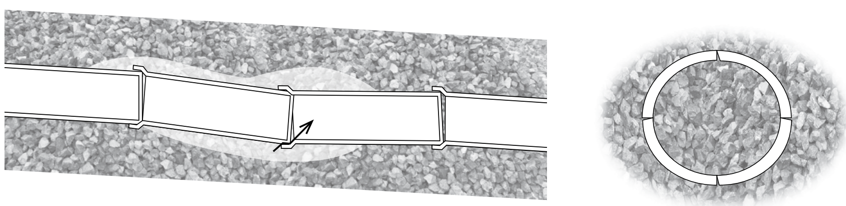
Figure 9 depicts how infiltration affects the pipe bedding over time, resulting in premature pipe failure.

Figure 9: Pipe settlement due to initial defect

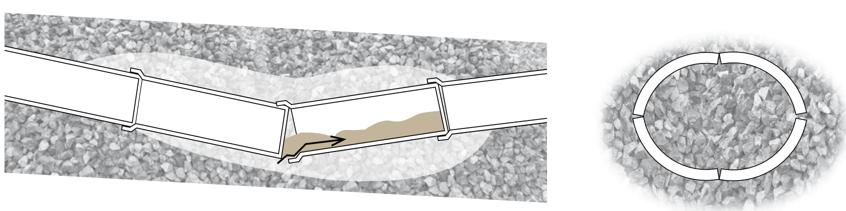
Stage 1: Initial defect, but sewer remains held in position by the surrounding soil.



Stage 2: Development of zones of loose ground or voids caused by the loss of ground into the sewer.



Stage 3: Pipe failure.



Source: Adapted from METHODS TO CONTROL LEAKS IN SEWER COLLECTION SYSTEMS. White Paper Prepared by C. Vipulanandan, Ph.D., P.E. and H. Gurkan Ozgurel. Center for Innovative Grouting Materials and Technology (CIGMAT), Department of Civil and Environmental Engineering, University of Houston Houston, Texas 77204-4003 October, 2004.

MassDEP, when describing the impact of I/I on sewer systems, starts with the fact that I/I reduces the useful life of sewers:

> Extraneous water from infiltration/inflow (I/I) sources reduces the useful life, and the capacity of sewer systems and treatment facilities to transport and treat domestic and industrial wastewaters.[76]

Municipal staff will likely be expected to justify the need for an I/I reduction program to their councils. As such, they should consider the existing true costs of I/I. This information may not be available at the start of an I/I program (before field investigations), but some high-level estimates should be possible. Estimated costs for "measurable" items should consider costs such as:

- Treatment of I/I (chemical and power),
- Opportunity costs associated with I/I (for example, lost development charges and property taxes if development freezes),
- Construction of new trunks to convey flow,
- SSOs and bypasses,
- Urban flooding costs (include/estimate both insured and uninsured damage, costs to institutions, businesses, households and local government),
- Staff costs associated with flooding, overflows and bypasses,
- Legal risk associated with SSOs, bypasses, flooding and sewer backup, and
- Potential increases in costs associated with impacts of climate change.

In an unpublished study for a major southern Ontario municipality, an effort was made by a consultant to quantify all of the above costs to estimate the actual costs of having roof leaders connected to sanitary sewers in the city (whose collection system eventually discharges to a combined sewer trunk prior to reaching the WWTP). They found that a single roof leader cost the city between $6,000 and $11,000 *per year*. The study necessarily required many assumptions, but even if these assumptions were incorrect by an aggregate 100 or 200%, the study demonstrates the substantial costs of permitting connected roof leaders to persist.

Where possible, it is also valuable to include soft costs that may not be readily quantifiable, such as the reputation of the municipality, exposure to legal risks and impact on credit rating. Insurers actively underwrite based on historical and potentially future exposure to insured flood losses, and households in high-risk areas may be exposed to higher premiums and lower insurance payout caps (e.g., capping to $10,000 or $15,000 for sewer backup flood coverage – a small fraction of total potential flood damages to a standard finished basement), and households may not be able to purchase flood coverage in high-risk areas. Insurers are also starting to take an interest in mapping loss data over municipal sewer data to better define risk (Norton Engineering, private client, 2017).

As Metro Vancouver concluded,

> The continuation and updating of municipal Inflow and Infiltrations Master Plans (I&IMPs) will also be required to prevent new I&I problems and contain long-term sewerage infrastructure costs.

Municipal staff will need to develop a means of adequately quantifying the real costs of I/I to taxpayers to attract the support, funding and approval that will be required to implement and maintain a long-term I/I program.

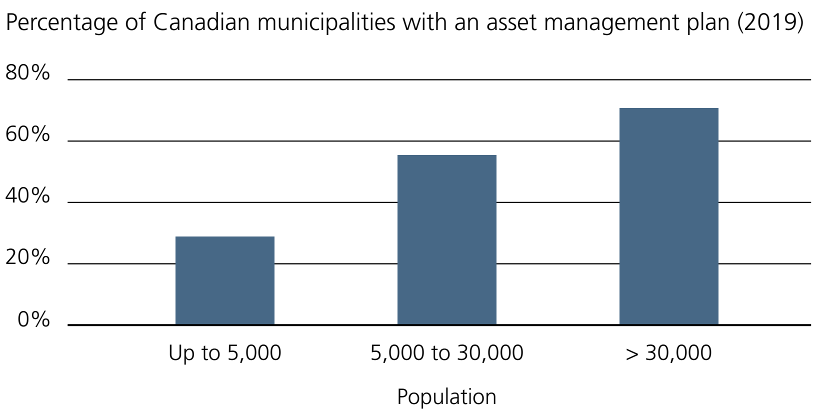
4.4 Existing asset management data

The development of asset management plans (AMPs) has become more common in Canadian municipalities in recent years. Indeed, in 2016 the Federation of Canadian Municipalities (FCM) launched FCM's Municipal Asset Management Program (MAMP) – an eight-year, $110 million program funded by Infrastructure Canada. MAMP offers funding, training and resources to help Canadian municipalities improve their asset management practices. Note that 82% of the municipalities that have received funding to date have populations less than 15,000, which likely reflects smaller municipalities being much less likely to develop MAMP without additional support. As shown in Figure 10, smaller municipalities are much less likely to have MAMPs than larger ones.

Through better data about assets, municipalities can plan for community service needs, respond to climate change, and deliver the best, most cost-effective outcomes for their communities.

Source: MAMP. 2018/2019. Supporting Sustainable Infrastructure Management in Canadian Communities.

Figure 10: Availability of asset management plan by size of municipality



It is beyond the scope of this document to discuss AMPs in any detail. However, the 2016 Canadian Infrastructure Report Card (CIRC) noted that "for linear assets, proxy information (age, pipe material) was the most common source of condition information indicated by 27 to 43% of respondents." This information was not updated in the 2019 CIRC.

The use of "age" and "pipe material" to indicate I/I status is inadequate. Municipalities should review asset management criteria, as they may differ from those that an I/I program needs to consider. For example, in an AMP, the worst condition for a sewer is likely "at risk of collapse," but for an I/I study, a sewer in very poor shape but not at risk of collapse may also be of great interest.

Age of pipe plus CCTV inspection to a known standard (e.g., Pipeline Assessment Certification Program or PACP[77]) may be used to assess I/I status; however, the standard may not be calibrated to I/I, but rather to catastrophic failure (typically, structural collapse of the pipe).

If an AMP exists, it should be used to inform I/I data collection, with the caveat that the criteria used be examined for adequacy in an I/I reduction program. The engineer should examine how the asset management group prioritizes infrastructure projects; I/I itself may not be considered a driver for replacement. It may be necessary for the purposes of an I/I reduction program to reassess the asset management data (e.g., CCTV) from an I/I, capacity or flood risk perspective (or whatever priorities are important to the I/I program).

If a MAMP exists and it establishes "level of service" (LOS) goals for the sanitary sewer system, these should be incorporated into the I/I reduction program goals.

4.5 Level of service for sanitary sewers

4.5.1 Background

An essential step in the development of an efficient and cost-effective I/I program is to develop the appropriate target level of service (LOS) for the wastewater collection system. LOS for wastewater collections systems are difficult to quantify. Due to the complex nature of I/I, it may not be possible to directly link sewer deficiencies to flood risk, for example (management of flood risk could be an LOS target). In two-tier models, establishing levels of service is particularly challenging.

Laws or regulations from municipal, provincial or federal authorities and industry standards already define and limit certain criteria (e.g., Ontario's F-5-5 Criterion for Combined Sewers), but municipalities can select more stringent and/or additional criteria (e.g., related to flooding) to address their specific needs.

Specific hard target goals may be appropriate, such as:

- Volume reduction,
- Peak reduction,
- SSO or bypass reduction,
- Capacity recapture,
- Private property flooding risk reduction,
- Staying within sewer design capacity, and
- Legal risk reduction (for municipality).

However, most municipalities will find it difficult to define LOS so precisely, given the complexity of I/I.

An approach to LOS for the wastewater collections system that involves "softer" targets, such as those that are socio-economic, environmental, or financial in nature rather than technical, may be required. Readers are referred to the *Infraguide Assessment and Evaluation of Storm and Wastewater Collection Systems* for more detailed information on this issue.

The target LOS for sanitary sewers may already have been established in a municipality's AMP or possibly in a wastewater master plan. It is important that the I/I program align with the proposed LOS for the sewer system. Costs of I/I are directly related to the LOS that residents expect from a municipality, as the LOS concern issues like SSOs, bypasses and occurrence of sewer backup flooding. The City of Toronto has a well-defined LOS model for basement flooding protection.

Given the importance of defining LOS to achieve a successful, efficient and cost-effective I/I reduction program, this document includes four different approaches to LOS to assist municipalities in considering their own.

4.5.2 Level of service: USEPA

The USEPA suggests the following potential goals (e.g., levels of service) for an I/I reduction program:[78]

- Reduce ratepayer costs for transporting and treating wastewater by implementing all cost-effective I/I reduction projects within 10 years.
- Minimize liability from water pollution and public health risks by eliminating sanitary sewer overflows in storm events.
- Eliminate enough I/I to avoid the capital costs of wastewater treatment plant capacity expansion in anticipation of 10% population growth over the next 20 years.
- Eliminate enough I/I to avoid the capital costs of interceptor expansion, which will be needed to support the build-out of certain neighbourhoods.
- Eliminate enough I/I to offset the environmental and regulatory impact of sewer system expansion and increased water demand over the next 15 years.

4.5.3 Level of service: City of London (Ontario)

The City of London has defined LOS based on the asset management requirements set out in Ontario's new asset management (AM) legislation (O. Reg. 588/17). London's approach has applied the requirements of the AM legislation, which has specifications for developing an AM plan, into wastewater LOS, under the categories of both "customer" and "technical" metrics. Figure 11 describes how these are set out by the City (please refer to the full documents for details).

Figure 11: City of London level of service metrics for wastewater

O. Reg. 588/17 requires legislated community levels of service (LOS) for core assets. Community levels of service use qualitative descriptions to describe the scope or quality of service delivered by an asset category. Examples of legislated community levels of service include a map showing areas of the municipality that are serviced by the water and wastewater system. In this example, a map provides an illustrative view of the extent of the services provided through the infrastructure assets.

O. Reg. 588/17 also requires legislated technical levels of service for core assets. Technical levels of service use metrics to measure the scope or quality of service being delivered by an asset category. Examples of technical levels of service include the percentage of urban properties serviced by the municipal water and wastewater system. Technical levels of service for core assets are provided below.

The following are performance measures in the LOS Table that are O. Reg. 588/17 requirements for wastewater (or sanitary) assets. References are provided to show where O. Reg. 588/17 requirement has been attained:

Table 5.2 O. Reg. 588/17 Levels of Service Metrics for Wastewater – Sanitary services

Customary Level of Service	Technical Level of Service
• Description, which may include maps, of the user groups or areas of the municipality that are connected to the municipal wastewater system. **(Table 5.3)**	• Percentage of properties connected to the municipal wastewater system. **(94%, Table 5.3 and Figure 5.4)**
• Description of how combined sewers in the municipal wastewater system are designed with overflow structures in place which allow overflow during storm events to prevent backups into homes. **(Table 5.3)**	• # of events per year where combined sewer flow in the municipal wastewater system exceeds the system capacity compared to the total number of properties connected to the municipal wastewater system. **(Table 5.3)**
• Description of the frequency and volume of overflows in combined sewers in the municipal wastewater system that occur in habitable areas or beaches. **(Table 5.3)**	• The number of connection-days per year due to wastewater backups compared to the total number of properties connected to the municipal wastewater system. **(Table 5.3)**
• Description of how stormwater can get into sanitary sewers in the municipal wastewater system, causing sewage to overflow into streets or backup into homes. **(Table 5.3)**	• The number of effluent violations per year due to wastewater discharge compared to the total number of properties connected to the municipal wastewater system. **(Table 5.3 and Table 5.4)**
• Description of how sanitary sewers in the municipal wastewater system are designed to be resilient to avoid events described in the previous paragraph. **(Table 5.3)**	
• Description of the effluent that is discharged from sewage treatment plants in the municipal wastewater system **(Table 5.3)**	

Source: http://www.london.ca/city-hall/master-plans-reports/reports/Documents/CAMPlan-2019-Section5.pdf

4.5.4 Level of service: Metro Vancouver, BC

Metro Vancouver has set goals for its liquid waste management program (LWMP), its term for storm and sanitary sewage management. These goals are essentially LOS; they are goals with strategies, but they do not define specific performance levels. Figure 12 describes these goals. Although Metro Vancouver has comprehensive I/I programs, after extensive effort it has determined that it was unable to establish numerical I/I reduction goals due to the complexity of its system and its two-tier structure with 19 member municipalities.

Figure 12: Metro Vancouver's integrated liquid waste resource management plan goals

Goal 1: Protect public health and the environment

Public health and the environment are protected by managing sanitary sewage and stormwater at their sources, and providing wastewater collection and treatment services protective of the environment.

Goal 2: Use liquid waste as a resource

Energy will be recovered from the heat in the sewage and from biogas generated in the treatment process. Materials which have nutrient value will be recovered from wastewater treatment plants. Water will be recovered from the wastewater treatment process and stormwater.

Goal 3: Effective, affordable and collaborative management

Monitoring, maintaining and investing in liquid waste infrastructure are essential to ensuring effective system performance and preventing costlier repairs. Innovative alternative approaches to traditional treatment systems will be explored. Opportunities for positive synergies with other utilities and regional management systems will be pursued – such as integrated stormwater management plans. Sources of risk will be identified and mitigated.

Source: http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/IntegratedLiquidWasteResourceManagementPlan.pdf

4.5.5 Level of service: City of Lethbridge, Alberta

The City of Lethbridge defines LOS objectives that combine soft and hard targets, described in Figure 13. Lethbridge's LOS includes a hard target associated with surcharging that causes sewer backup (99.5% of homes protected). This approach directly links the relationship between I/I and basement flooding, which, though difficult to quantify, is direct and absolute.

Figure 13: City of Lethbridge level of service objectives

Level of service requirements have been defined based on a customer focus group formed during the 2000 Underground Infrastructure Master Plan. The City of Lethbridge Wastewater Utility has adopted a set of level service requirements and as such they will form a basis for these principles of functionality. The following level of service objectives have been set:

- Provide sewage collection adequate to meet the dry weather demand of the proposed development with appropriate allowances made for wet weather inflows based on current sanitary sewer construction practices.
- Provide sanitary sewer capacity so that surcharging does not occur for design dry weather peak flows and so 99.5% of homes are protected from sewer backup during peak wet weather flow events.
- No additional or new homes will be added to the "at risk" list as a result of any new development. "At risk" is defined as locations where surcharging of the sanitary sewer occurs to a level less than 2 m below the manhole rim for the design wet weather event.
- Limit wet weather inflows to less than 5% of the total volume of rainfall in the system during wet weather periods.

Defined levels of service, expressed as soft or hard criteria, are essential to a modern I/I reduction program.

4.6 Investigate willingness of municipality to undertake private-side work

The amount of I/I that can be removed from a sewer system will directly depend on whether private-side I/I is addressed. Private-side I/I reduction is much more complex than public-side since it relies on resident willingness and behaviour (see Section 3.6.2). The success in implementing private-side I/I reduction, however, may also depend on the extent to which the municipality has corrected I/I deficiencies on the public side.

Indeed, there are great potential synergies between the public- and private-side portions of the lateral since they are essentially the same pipe. CCTV investigation and repairs would most efficiently be done on the public and private sides at the same time.

Strategies for addressing private-side I/I, discussed below, have gained a lot of attention in recent years.

4.6.1 Private-side I/I reduction: Lateral inspection at time of sale

One approach to reduce private-side I/I is a concept called lateral inspection at time of sale. This is a leading-edge, cost-effective approach that requires private-side sewer owners to be responsible for their sewer performance. This approach to private-side I/I reduction is highly recommended for the following reasons:

- Requiring the owner of the sewer (the property owner) to be responsible for sewer performance returns the risk to the property owner, where it belongs.
- Implementing such a requirement at time of sale likely increases residents' willingness to pay, since a home purchase is already an enormous investment with a variety of ancillary costs that homebuyers are already familiar with.
- Having such a program in place puts private-side sewers top-of-mind for society in general.

Implementing such a program is a great challenge; however, it must be considered as an efficient and cost-effective strategy in a modern I/I program.

Currently, the East Bay Municipal Utility District (EBMUD) near San Francisco is a leading jurisdiction in using lateral inspection at time of sale to address private-side I/I. Affected property owners must obtain a certificate from EBMUD certifying that all of their private sewer laterals are leak-free when selling their home, requesting a building permit for work over $100,000 or changing the water meter size.

After many years of attempting to reduce sewer overflows, in 2009 EBMUD was compelled to implement a Regional Private Sewer Lateral (PSL) ordinance beginning in 2011. EBMUD has now moved its entire I/I reduction program to the PSL ordinance program. Politically, this is more achievable in the US because of the EPA's use of "Consent Decrees" (essentially a legal tool) that involve hefty fines for lack of compliance.

EBMUD is a regional municipality with seven local municipalities, like the model found across Canada. The regional municipality is responsible for trunk sewers and treatment, while the local municipality is responsible for local sewers and dealing directly with the homeowners. After years of working with the EPA and the local municipalities, the EPA's Consent Decree *named the local municipalities along with EBMUD* as responsible parties. This resolves the impact of two-tier governments on I/I reduction programs as discussed in Section 3.6.3.

In Canada, lateral inspection at time of sale has not yet been implemented. However, Metro Vancouver has demonstrated an excellent approach to this concept by proactively investigating private sewer lateral certification in real estate transactions for a decade (see *An Approach Towards Private Sewer Lateral Certification in Real Estate Transactions for Metro Vancouver*, Pinna Sustainability Inc., 2013).

4.6.2 Private-side I/I reduction: Other municipal approaches

Jurisdictions in the US have made great strides with private-side I/I reduction strategies (made possible, in part, because of the EPA's ability to issue Consent Decrees as discussed above). Examples are provided in this section.

Milwaukee Metropolitan Sewer District (MMSD; an upper-tier jurisdiction) provides funding and support for design, planning and investigation by the satellite municipalities for private property I/I remediation.[79] In order to establish the private property I/I program, MMSD obtained a legal opinion in May 2011 that identified the potential legal issues associated with a private property program. Generally, it was determined that MMSD had reasonable legal grounds to undertake the program to ensure the public health, safety and welfare of its residents.

The program requires that satellite agencies submit workplan requests for funding to MMSD. These requests are evaluated against a set of agreed-upon criteria. Upon approval, funding is provided exclusively for the removal of private property sources of I/I.

By 2015, the program had changed focus to be largely private property–based. Activities on private property eligible for funding include:

- Foundation drain disconnection,
- Rehabilitation or replacement of lateral sewers,
- Installation of new stormwater lateral sewers,
- Inspection and investigation costs, such as smoke and dye testing, CCTV, etc.,
- Professional services (planning, design, preparation of tender documents),
- Construction inspection services, and
- Public education and outreach.

Many other jurisdictions in the US are implementing similar programs.[80]

4.6.3 Private-side I/I reduction: Legislative authority approaches

It is becoming increasingly clear that addressing private-side I/I is essential but that municipalities sometimes find it challenging to gather the collective political, technical and practical support required to implement programs on their own. Another approach that is being taken across North America is for regulators to start providing legislative support or actual requirements to ensure its implementation.

In published documents, MassDEP states that all public and private inflow sources are considered excessive and need to be eliminated unless existing conditions render such removal technically infeasible or cost-prohibitive.[81] This is an example of a state agency establishing the essentiality of private-side work. It provides extensive guidance to the local municipalities on how to approach this work.[82]

In Ontario, the Ministry of Environment, Conservation and Parks (MECP) has recently been developing new sewer design standards ("Consolidated linear infrastructure wastewater collection ECA template and design criteria") that are currently under review. Although changes proposed by MECP apply largely to new construction, they demonstrate how regulators can directly influence efficient and cost-effective I/I prevention.

The new sewer design standards, which will allow municipalities to pre-approve new infrastructure if specific requirements are met, focus on I/I prevention as an integral part of the design of new sanitary sewers. As summarized by MECP:

> We are proposing to modernize Ontario's environmental approval process for low-risk municipal sewage works by implementing a Consolidated Linear Infrastructure Permissions Approach. The proposed approach will consolidate and update the approvals process for these types of works and incorporate measures that will enhance environmental protection.[83]

The draft standards include a number of requirements concerning I/I risk reduction. This approach will ensure that municipalities no longer see I/I as a nuisance but rather a fundamental problem.

4.6.4 Private-side I/I reduction: Private lateral insurance implemented by the municipality

In an innovative approach, several jurisdictions in Ontario, including Peel and Hamilton, have recently developed and implemented the "Exterior Pipe and Interior Plumbing Coverage for Homeowners." This is a program in which the municipality, in cooperation with a private insurance company, endorses optional and voluntary insurance coverage programs for homeowners with broken pipes. As stated on Peel's website,

> The Region of Peel is responsible for the maintenance and repair of municipal water and sanitary sewer (wastewater) pipes only. If a pipe on your property fails, it is your responsibility to pay for these repairs, which can cost hundreds to thousands of dollars, depending on the type of work. This can put you in a financial bind, especially when it's unexpected.[84]

This insurance program covers items not typically included in home insurance policies, even those in which riders for overland flooding are available, such as optional exterior water, sewer/septic line and interior plumbing and drainage coverage.

One of the advantages of this kind of approach is that it helps homeowners recognize that they own part of the sewer system and that it is their responsibility. This is an excellent approach to addressing I/I on the private side.

In summary, management of I/I on the private side will likely be an ongoing discussion with senior management and council. It is recommended that municipal staff start considering private property issues early in the process of developing the I/I program. The decision whether to work on the private side will have significant impact on program development; it is most effective to establish that discussion early. In any event, information from the private side will need to be collected, whether it is to be addressed or not.

4.7 What is acceptable I/I in an existing system?

4.7.1 Book values for acceptable I/I

In Canada, we have specified allowable I/I rates at construction, and we use an I/I allowance at design, as described in Section 3.2. Thus, a book value to calculate allowable I/I could be numerically defined assuming a linear degradation of the sewer over its life. In the absence of other information, specified I/I rates and linear degradation may be good places to start.

4.7.2 Estimating acceptable I/I in sewers across Canada

Existing sewer systems in Canada are combinations of many different sewershed collection systems, built at different times to different specifications in different conditions. The National Water and Wastewater Benchmarking Initiative (NWWBI) has made efforts to track I/I metrics in Canada. However, the information collected on I/I was necessarily high-level and non-specific, such that it could not be used to establish meaningful benchmarks.

MassDEP acknowledges the difficulty in defining excessive I/I into sewer systems. While a number of benchmarks have been developed, they are often too simplistic to account for sewer system responses over a range of precipitation events differing in intensity and depth, along with varying groundwater levels at the time of the event.

Source: MassDEP. 2017. Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys.

Thus far, establishing I/I metrics has proved elusive. MassDEP has also recognized this challenge (see side box).

Metro Vancouver published a thorough investigation of I/I design allowances and concluded:

> It is evident that irrespective of whether the I&I design allowance is 11,200 L/ha·d or 22,400 L/ha·d (0.28 L/s/ha) excessive I&I must be reduced. Based on I&I design values from across Canada, it appears that all I&I rates above 25,000 L/ha·d can be regarded as excessive.[85]

To date, no useful overall I/I benchmarking data has been published due to the complexity of I/I and the vast differences in how I/I is tracked, if indeed it is tracked, at each municipality, site conditions, construction methods across sewer systems, etc. It is not expected that this will change.

However, jurisdictions continue to carefully consider what is economically feasible. MassDEP, for example, considers the following I/I sources as excessive and in need of elimination:

- Infiltration sources that can cost-effectively be removed from the sewer system.
- All public and private inflow sources, unless existing conditions render such removal technically infeasible or cost-prohibitive.[86]

Municipalities may need to consider that "acceptable" I/I in their sewer system may relate more to what remains once the I/I that can be removed in a cost-effective manner is removed, rather than an absolute value.

4.8 Summarize goals and objectives

After assembling the information outlined above, the municipality should have a good understanding of what the overarching goals and objectives of the I/I reduction program are. These should be clearly articulated in writing and shared with senior staff, council and the public.

The engineer should now be able to establish preliminary timelines and budgets for the I/I reduction program development. The engineer may need to make budget requests, which can be prepared at this stage of the work. It is recommended that municipal staff plan for a multi-year project with permanent funding to proactively address I/I.

Municipalities may wish to hire an engineering consultant to undertake an I/I reduction program, but it is important that municipal staff understand their system so that knowledge gained from the program is not lost externally. This has been identified as an issue by municipalities in Ontario that have undertaken consultant-led I/I studies.[87]

5. Stage 3: Collection and assessment of existing data (desktop assessment)

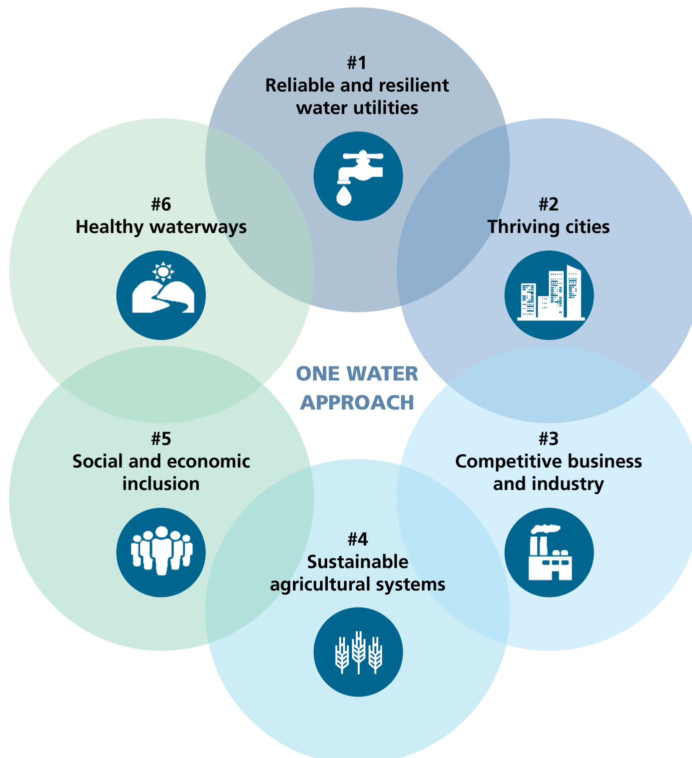
A great deal of information that is relevant to I/I is available in most municipalities already. However, the data may reside in many different formats and departments and may not be readily available. This section provides some guidance on how to locate and assemble available data. Mining existing data sources is an important foundational step in developing an efficient and cost-effective I/I reduction program.

5.1 "One Water" approach

"One Water" looks at the full water cycle in all its forms – drinking water, wastewater, rainwater, surface water and groundwater – and it treats all water as a resource to be protected. It recognizes that changes to one portion of the urban water cycle affect all of the other portions (see side box). Regulatory, financial and governance structures have put water into separately managed silos for drinking water, wastewater and stormwater. In the 21st century, this is no longer adequate.

Municipalities across Canada (particularly the large ones) have started to plan infrastructure according to One Water principles (e.g., City of Vancouver, Region of Niagara, Halifax Water).

One Water approach



Source: US Water Alliance. 2016.

The US Water Alliance[88] describes the sustainable management of "life's essential resource" as follows:

> The idea of an integrated systems approach to water is not new. Its full-scale implementation, however, has yet to be realized. There are many signs that water management in the US is entering another great era of change and innovation. All around the country we are seeing silo-busting examples of integrated and inclusive approaches to water resource management. These approaches exemplify the view that all water has value and should be managed in a sustainable, inclusive, integrated way. **We call this perspective One Water. And while our focus is water, our goals are thriving local economies, community vitality and healthy ecosystems.**

Sanitary sewers, storm sewers and water mains are all connected as far as I/I is concerned. Defects in water distribution systems and storm sewers may have a direct impact on I/I, since both lost water and leaking storm infrastructure are likely to result in increasing I/I in the sanitary sewer, due to the interconnection of utility trenches.

Furthermore, and importantly, capital programs are budgeted yearly at the municipal level. The ability to develop capital project plans for I/I reduction needs to be done in the context of other infrastructure needs and priorities on an annual basis, further supporting viewing I/I management through a One Water lens.

Underground linear infrastructure that are the sewers, waterlines and utility ducts servicing communities create an extensive French drain system when trench backfill and pipe bedding are permeable materials. Permeable utility trenches drain their service area, conveying rainwater runoff and groundwater to the lowest trench points. As sanitary sewer trenches are typically constructed lower than other utility trenches, the other trenches will drain to the sanitary sewer and cause sanitary sewer pipes, joints, tie-ins and laterals to become submerged in trench groundwater – I/I will then enter sanitary sewers through any open defect.

Source: US Environmental Protection Agency. 1990. Rainfall Induced Infiltration into Sewer Systems: Report to Congress. Office of Water. Washington: United States Environmental Protection Agency.

A discussion of integrating I/I reduction activities with other municipal infrastructure needs is beyond the scope of this document. Readers are directed to *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* (InfraGuide, 2003a) and *Coordinating Infrastructure Works* (InfraGuide, 2003d) for more information.

5.2 Data identification, assembly and organization

This first tasks of data collection are to gather and classify all available information and to manage and store the resulting data in a readily available and easily retrievable manner. A thorough data collection exercise will likely result in a variety of data types, sources, formats, accuracies and ages. Some care and thought will need to go into determining how to assemble this data into a useful database/package/format/group. Managing the often-extensive data collected in the study phase of a (sewer) system evaluation is a major challenge.[89]

Ideally, the data inventory for each system should be collected in a way that will permit cross-referencing among the systems. The inventories should also be linked to a geographic information system (GIS) to facilitate spatial analysis if possible. The format and content of the inventories will vary among municipalities. However, each municipality should adopt a plan for data collection and storage that will eventually allow the municipality to manage its systems proactively and in an integrated manner.

Data identification, assembly and organization will be an iterative process. Each municipality's approach will necessarily be unique.

When collecting data, it will be important to identify the date the data was logged and the confidence level in the data if these are available. Refer to *Best Practice for Utility Based Data* (InfraGuide, 2003b) for a discussion on data management.

In the case of municipal water, wastewater, and stormwater utilities, there are literally hundreds of processes that cover a broad spectrum of service, technical and business activities. All these processes require information and data that can include locations, dates, times, descriptions and many different types of measurements. However, there are no commonly accepted information and data management standards or practices for municipal utilities to consult. As a result, many municipalities are storing these data in a wide variety of means and processes.

Source: Federation of Canadian Municipalities. 2003. Infraguide: Best Practice for Utility-Based Data.

5.3 Water and wastewater plant data

Examining the relationship between the WTP and the WWTP is a valuable exercise in I/I investigation work. Specific sources of data that would provide insights on I/I include:

- WTP data (pumped and billed, if available),
- WWTP data (including bypass information),
- WWPS data (the use of pump station run-time records should not be used as the principal method because of the possibility of time lags or event masking due to wet wells),[90]
- Sewershed areas and connected population for each plant and pumping station,
- Chemical parameters such as biological oxygen demand, suspended solids or total phosphorous strength (weaker strength can indicate I/I),
- Frequency, severity and duration of overflows and bypasses,
- Frequency and severity of surcharge causing flooding, and
- Change in data over time.

The engineer should carefully consider the quality of all data being examined (e.g., when the pumps at the WTP and WWTP were last calibrated).

5.4 Public-side sewer system data collection

The engineer should briefly discuss each data source, including discussion of potential limitations, in documentation concerning the proposed I/I program. Data may be available from the following sources:

- Base mapping/GIS, including how many different systems the engineer has access to and the degree to which they are compatible,
- Property fabric layers/maps,
- Type and age of sewer lines and maintenance holes,
- Condition of existing facilities,
- Sewershed areas and delineations,
- As-recorded data, including how frequently GIS is updated,
- Age of sewer,
- CCTV inspection,
- Customer service calls,
- Groundwater level,
- Land use and environmental designations,
- Location and extent of any underdrain systems,
- Drainage patterns,
- Number and frequency of overflows, bypasses and surcharging in the system,
- Previous problems, I/I investigations and rehabilitation in the system,
- Location of any permanent metering equipment in the system,
- Database or other of abandoned laterals,
- Soils data, including soils reports undertaken for design and construction projects for groundwater table elevations,
- Background information included in environmental assessments,
- Capacity studies,
- Existing computer models of the collection system,
- Existing streamflow monitoring level data, and
- Tidal charts for areas suspected to be influenced by tidal infiltration.

One of the challenges when collecting data for an I/I program is that sewer system information is likely housed in different departments (or even an upper-tier municipality) and may be challenging to access (e.g., development, design and construction, stormwater, asset management). Silos are common at municipalities. Where regional and local governments share responsibility for some assets, silos can be even more challenging.

Another anomaly concerning private-side data collection is information on the experience of flooding, which is generally handled by staff that work on the public side. In some cases, residents deal directly with an insurance company without contacting the municipality, so no record of flooding exists within the municipality.

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.

Source: Kesik, T. 2015. Management of Inflow and Infiltration in Urban Developments. Toronto: Institute for Catastrophic Loss Reduction.

For example, a 2011 survey of a flood-affected neighbourhood in London, Ontario, indicated that nearly half of respondents did not report sewer backup flooding to the municipality.[91] To get true flooding numbers in a community, improved data-sharing between insurers and municipalities would be beneficial, as would structured or formal data gathering from potentially affected residents.

5.5 Private-side sewer system data collection

Data concerning private-side sewer systems will likely be much more difficult to obtain than public-side data. However, this data is important, even if work on private property is not feasible for the municipality, and planning concerning the development of I/I programs should account for private-side conditions and the data that is available.

Information that is valuable for I/I investigations may include:

- Age of homes,
- Local policies concerning connection of foundation drains, area drains, catch basins, downspouts, etc. on the private side,
  - It may be useful to determine when the discharge of foundation drains and roof leaders to the sanitary system became illegal in the municipality. That date can be used as a proxy to estimate which neighbourhoods are likely to still have these connections.
- Drainage cards or other records of laterals,
- Flooding data, including:
  - Records of homeowner complaints,
  - Responses from surveys following flood events (if available),
  - Site inspections or survey information (if available),
  - Insurance data (where available – include discussions with local insurance brokers and agents where possible),
- Sewer backup data (likely available from operations staff and departments),
- Operations staff knowledge of areas where sump pumps and/or foundation drain connections, downspout, area drains and catch basins to sanitary sewers are present,
- Flow monitoring data (if available),
- Records, policies, etc. indicating whether sump pumps are present in homes, and where possible, discharge locations from pumps,
- Records, policies, etc. indicating whether eavestrough downspouts are connected to sanitary sewers,
- Windscreen (e.g., drive or walk-by) inspections undertaken for other reasons (roof leaders, age of home),
- Records, CCTV recordings, etc. of house-by-house plumbing inspections if available.

In addition, the engineer should identify whether the municipality or local government maintains a database of abandoned (orphan) laterals, as these can be substantial sources of I/I. Local plumbers and restoration contractors are also great sources of information on private-side plumbing configurations and common issues in the area.

Local authorities must understand private-side factors, even where private-side I/I management is considered impractical. To develop cost-effective solutions, knowledge of private-side discharges from foundation drains and roof leaders is essential (for example, if flowing laterals are a result of connected foundation drains and not public-side deficiencies, public-side capital works will not reduce I/I).

5.6 Sewer system operations data

Operators are the experts on the sewer system, and an effective I/I program requires that sewer system operations and available data be carefully considered. One of the challenges of collecting operations data is that each municipality collects data differently, and the programs used to collect and house data may vary between departments in the same municipality. Moreover, operations departments often do not keep records of maintenance activities/blockages/backups in a format that would permit this information to be readily examined for I/I purposes. Operations data is frequently lost because it is not tracked.

With the advent of mobile work order capabilities, capturing operations and public works data should become more streamlined, and the data should be easier for the I/I team to access. Meanwhile, collecting operations data will continue to be a challenging, but essential, part of the I/I program.

Useful data on sewer system operations may include:

- Interviews of operations staff to collect anecdotal information (including areas requiring frequent flushing or areas with known sags or backups),
- Regular maintenance hole inspection program results,
- Regular flushing program (include details of the flushing program, such as frequency and efficacy), identifying especially problematic areas,
- Stormwater management (SWM) pond management practices (determine whether these represent an I/I risk to the municipality); if SWM ponds are not cleaned regularly, they may not provide the design LOS and, therefore, may represent an I/I risk to sanitary sewers,
- CCTV inspections, and
- Confirmation that the municipality is operating facilities according to engineering design recommendations (this is not always the case).

5.7 Planning data

Municipal staff working on the I/I program should ensure that they coordinate with planning departments to understand the official plan and approved or draft approved development, infill development policies, protected areas, growth areas, etc., as these will affect capacity requirements and, thus, may impact I/I decisions. In particular, the impacts of intensification due to rezoning changes and provincial direction need to be considered, as servicing capacity must be adequate to allow for additional population density.

Background information about the municipal sewer system may also be available from planning documents. If necessary, book values for sewage generation rates may be used to calculate flows that are not yet available from planning documents.

5.8 Identify data gaps and update data collection methods as required

During the process of data collection, the municipality is likely to identify data gaps, which may fall into several categories:

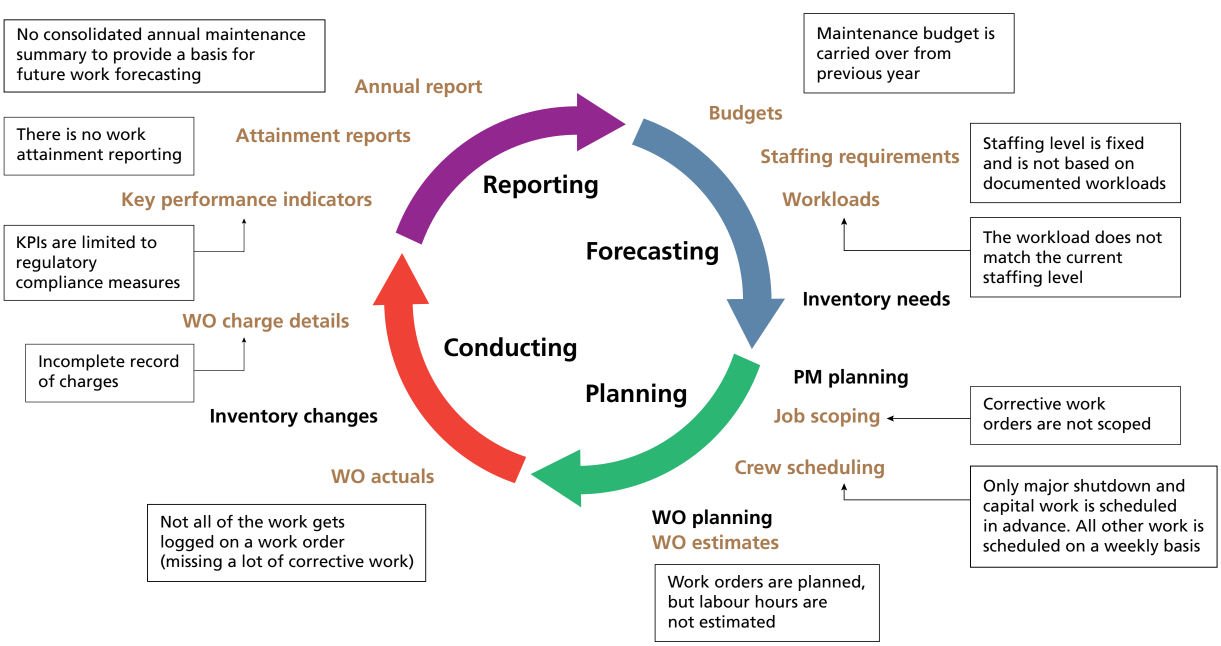
- The information is not collected,
- The information is collected but is not stored,
- The information is collected but stored as paper or another type of record that is difficult to operationalize,
- The information is collected and stored but in a way that is incompatible with other data being used.

At this point in the I/I program development, the engineer will likely have a good idea of what data is going to be essential for the program. Data collection, management, storage and update can be costly, and data gaps and format inconsistencies make tracking I/I difficult. Municipalities should take steps to improve and update data collection to ensure better I/I tracking and understanding moving forward. This is likely to take concerted effort.

Figure 14 shows a visual representation of a typical gap analysis. The Regional District of Nanaimo, BC, undertook an overall gap analysis for the systems supporting their efforts to study, conduct, monitor and repeat (Stages 1 to 7 as defined in this report). As shown in Figure 14, the gap analysis also identifies the process and data collection gaps that prevent the District from having a full understanding of their systems. This analysis gives the District an opportunity to improve the background data collection in support of improved understanding of their system.

Figure 14: Visual representation of a gap assessment[92]

Regional district of Nanaimo WWWTP business model gap assessment



Continuous improvement in sewer system management, tracking and follow-up will likely improve overall system performance and reduce costs and flood risk.

The data gap assessment will assist the engineer in determining the best course of action. A risk assessment approach should be considered, taking into account various aspects such as cost, safety and performance. Costs associated with improving the available data in the system should be considered and weighed against the risks of doing nothing. Since, ideally, the costs of I/I were developed earlier in the program, preliminary cost analysis should be straightforward.

This guideline recommends a desktop analysis, which was discussed in the previous section, and a preliminary assessment based on existing data, prior to initiating costly and time-consuming flow monitoring and field assessments (see side box). They may well be required, but a targeted approach in specific sewersheds is much more cost-effective and much more likely to result in actionable results at a sub-sewershed level.

To depict the actual condition of a system accurately, the database must be kept current with the addition of new sewers as the system expands. It is also necessary to include condition information obtained from inspection programs and during day-to-day operation and maintenance activities. Municipalities should establish an ongoing information updating procedure aimed at constantly collecting and updating system data.

Source: National Guide to Sustainable Infrastructure. 2003. Assessment and Evaluation of Storm and Wastewater Collection Systems.

5.9 Desktop analysis of existing conditions

The analysis of existing system data can yield a great deal of information about wastewater collection system performance.

Analysis to characterize I/I is more like detective work than a science. The engineer must always consider the myriad of variables that affect I/I. In particular, the engineer needs to clearly understand the components of wastewater and how each contributes to total flow. The industry has commonly characterized all "base flow" as infiltration, when in fact some of this base flow is persistent dry weather flow that is not infiltration (as described in Section 3).

A great deal of information about how to analyze available data to evaluate I/I is publicly available. It is presumed that the engineer will access outside sources as required to analyze specific combinations of data sets. The following sources are recommended:

- *Guide for Estimating Inflow and Infiltration*, USEPA, 2014
- *Infraguide Assessment and Evaluation of Storm and Wastewater Collection Systems*, 2003
- *Guidelines for Performing I/I Analyses and Sewer System Evaluation,* Massachusetts Department of Environmental Protection, 2017
- *Guide for Evaluation Capacity, Management, Operation, and Maintenance (CMOM) Programs at Sanitary Sewer Collection Systems*, USEPA, 2005

The purpose of the inventory of existing conditions is to gather information on the sewer system to better understand system assets and operation for the purpose of developing the flow monitoring program. The inventory is the first major work task in an I/I analysis and should be performed prior to any significant field investigations.

Source: MassDEP. 2017. Guidelines for Performing Infiltration/Inflow Analyses and Sewer System Evaluation Surveys.

5.10 Summarize findings and develop a workplan

At this point in I/I program development, the engineer should be in a good position to summarize the findings to date and determine the most appropriate next steps. The engineer should summarize preliminary findings and probable issues, sources, opportunities and constraints in a written report. The report should re-examine I/I reduction goals and identify whether opportunities exist to achieve these goals.

During the preliminary I/I analysis based on existing data, some specific problem areas that need additional investigation may have been identified. If that is the case, these problem areas can be selected directly for further investigation. Next steps may include:

- Flow monitoring,
- Groundwater monitoring,
- Rainfall monitoring,
- Hydraulic modeling,
- Public information sessions around private-side I/I,
- Source detection programs (known as Sanitary Sewer Evaluation Surveys –SSES):
  - Maintenance hole inspection,
  - CCTV inspection of sewers (public and/or private side),
  - Smoke (fog) testing,
  - Dyed water (flood) testing (public and/or private side), and
- Proceeding directly with rehabilitation.

At this stage, it should be possible to establish timelines and budgets for future investigative work. Budget requests should be made if necessary. Required staffing levels to manage the program and data should be estimated and funded. If a consultant is to be retained, the engineer should have sufficient information to be able to develop a robust request for proposal. The municipality now has a framework with which to proceed with additional work, and the program workplan may be presented to council for approval and to the public.

6. Summary and next steps

The purpose of this guideline is to provide tools to allow municipalities to efficiently and cost-effectively understand the nature and extent of the I/I in their system *prior to investing large capital dollars on field investigations and rehabilitation*. The foundational work that the municipality will have done if these guidelines are applied will help guide the municipality toward a modern approach to I/I management, which is much more complex and cost-effective than a single I/I study.

The preparation of this seed guideline and the associated background research have generated substantial and sustained interest across Canada, not only from municipal staff, but also from consultants, developers, and provincial and national government agencies.

The findings of this project indicate that a National Standard of Canada, *Guideline to Developing an Efficient and Cost-Effective I/I Program*, should be developed as soon as possible. Given the sometimes-political nature of this kind of research, it is further recommended that special care be taken in selecting the experts who will draft the final document to ensure that they represent a range of interests and perspectives but none of them dominates.

Section 2 presented the next three steps in an I/I program, which are beyond the scope of this guideline. They include:

Stage 4: Conduct flow monitoring and field investigations (inflow and infiltration study phase)

Stage 5: Identify deficiencies and develop a capital plan for rehabilitation or replacement

Stage 6: Undertake construction and post-construction monitoring

Stage 7: Repeat

If Stages 1 to 3 are completed as outlined in this guideline, the municipality should be able to develop an efficient and cost-effective I/I study (Stage 4). The municipality will understand how much I/I can (or should) be targeted, where this I/I is generally occurring, and what opportunities exist to remove it (e.g., is the municipality willing to work on the private side). This understanding will allow the municipality to develop a focused I/I study that will look for I/I that is *actually available to be removed*. This is an important concept.

Stages 4 to 5 are the type of straightforward technical exercises at which engineers excel, and many resources exist to assist municipalities with these technical exercises. Stage 6, construction and post-construction monitoring, is also a straightforward technical exercise well understood by engineers. And Stage 7, of course, represents the "Program" aspect of this work, as it needs to be ongoing. Findings of this project indicate that consideration be given to developing an updated, modern companion seed document, *Guideline to Implementing an Efficient and Cost-Effective I/I Reduction Program*, to cover the final four stages of the I/I program.

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