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Inflow and Infiltration Management Plan Template

Final Report
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Prepared for:

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

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Revision History

Revision #	Date	Status	Revision	Author
A	January 10, 2022	Draft	Preliminary Draft – 60% Complete	CJ
B	March 1, 2022	Draft	Working Draft Report	CJ
C	May 3, 2022	Draft	Addressed Metro Vancouver Preliminary Comments	CJ
D	October 7, 2022	Final	Addressed Comments from REAC I&I Sub-Committee	CJ
0	December 2, 2022	Final Rev 1	Minor Changes	CJ
1	December 20, 2024	Final Rev 2	Revised and updated Appendix G, Table 4-2, Table 5-1	CJ

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Abbreviations

ADWF	Average dry weather flow
CCTV	Closed circuit television
CSO	Combined sewer overflow
GARR	Ground-Adjusted Radar Rainfall
GVS&DD	Greater Vancouver Sewerage and Drainage District
GWI	Groundwater infiltration. Extraneous flow from the ambient long-term water table, not influenced by individual rainfall events
I&I	Rainwater inflow and groundwater infiltration, generally expressed as flow per area (L/ha/d)
I&IMP	Inflow and infiltration management plan
IDF	intensity, duration, frequency: statistical graphs for rainfall
ILWRMP	Integrated Liquid Waste and Resource Management Plan: A Liquid Waste Management Plan for the Greater Vancouver Sewerage & Drainage District and Member Municipalities
LACP	Lateral Assessment Certification Program
LWMP	Liquid Waste Management Plan
MACP	Manhole (Maintenance Hole) Assessment Certification Program
MMS	Master Municipal Specifications
MWR	BC Municipal Wastewater Regulation
NASSCO	National Association of Sewer Service Companies
PACP	Pipeline Assessment Certification Program
PDWF	Peak dry weather flow
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PWWF	Peak wet weather flow
RDI&I	Rain derived inflow and infiltration
REAC	Regional Engineering Advisory Committee
REAC-LWSC	Liquid Waste Subcommittee of the Regional Engineering Advisory Committee
$RDI\&I_{RP}$	Rainfall-Dependant Inflow & Infiltration. Total peak rainfall-sourced extraneous flow averaged over short-terms ranging from 5 minutes to 24 hours depending on catchment characteristics. The RP subscript refers to the specific return period associated with the value.

RII_{RP} $RII_{RP\text{-}slow}$ $RII_{RP\text{-}fast}$	Rainfall-Induced Infiltration. Rainfall that follows a path to the sewer through the soil and/or from short-term, rainfall-based increases in water table elevation. Often occurs in two discernible components, slow and fast. The RP subscript refers to the specific return period associated with the value.
RP	Return Period. All of the rainfall-related parameters must be expressed with a return period if they have been derived from flow data or have been estimated with a hydrologic model. It may be appropriate to express the return period as 'major event' in some cases.
SII	Snowmelt-induced infiltration. Snowmelt that follows a path to the sewer through the soil.
SWI_{RP}	Stormwater Inflow. Rainwater that enters the sewer through direct (non-soil) connections to the runoff surface. RP refers to the specific return period associated with the value.
SMI	Snowmelt Inflow. Snowmelt that runs overland and enters the sewer through direct (non-soil) connections to the surface.
SDI&I	Snowmelt-Dependant Inflow & Infiltration. Total peak snowmelt-sourced extraneous flow averaged over short-terms ranging from 5 minutes to 24 hours depending on catchment characteristics.
SSO	Sanitary sewer overflow
USEPA	United States Environmental Protection Agency
WRC	Water Resources Centre
WWTP	Wastewater treatment plant

Executive Summary

Inflow and infiltration (I&I) in wastewater collection systems can have detrimental effects on social, economic, and environmental aspects of urban areas. Excessive flows as a result of I&I can result in health and environmental risks associated with sanitary overflows, increased operation and maintenance costs, and capacity limitations otherwise reserved in the existing wastewater system to serve future populations.

This report provides a template for managing I&I in Metro Vancouver. Most of the municipalities connected to the Greater Vancouver Sewerage & Drainage District's (GVS&DD) regional sewer system already perform many of the activities associated with I&I management including flow monitoring and pipeline condition assessments. Depending on the specific issues in a given collection system, additional measures that include more intensive I&I investigations and system rehabilitation may be recommended. There are some smaller areas in Metro Vancouver that have partially separated sewer systems, which includes cross-connected sub-surface drainage that causes I&I to increase substantially compared to other fully separated systems of similar age and pipe composition. Partially separated sewer systems will require a different approach to I&I management that may include stormwater improvements. A prescriptive certification program approach to managing I&I from private sewer laterals is also proposed.

The proposed I&I Management Plan template includes both City-wide Measures and Targeted Catchment Measures. New to the targeted measures is the concept of 'archetypal' collection system conditions, relying on data collected about system age, material, condition, and I&I rates. This works by plotting the 5-year, 24-hour I&I rate for any sewer catchment against an empirical curve showing the expected I&I rate based on its age. Depending on the catchment age and whether the I&I rate is 'above' the curve, an approximate budget for reducing I&I in that catchment can be made. This information can then be included with asset management planning to allow for sustainable funding of I&I management activities within sewer utility budgets.

To help with the execution of these activities, this report also contains a set of best practices and resources for planning flow monitoring and other field investigation programs and techniques for characterizing I&I. This includes both the I&I Envelope and RTK Methods for I&I characterization and quantification.

Also included in this report is an updated Sewer Condition Reporting Template, which is intended for member municipalities to use in their Liquid Waste Management Plan Biennial Reports. This introduces the Pipeline Assessment Certification Program (PACP) into the template, and although this has become the de facto condition assessment standard in Metro Vancouver, it has not been formally included in previous documents.

As the proposed I&IMP template is a new approach for Metro Vancouver, municipalities will be encouraged to test it and report back on experiences and potential room for improvements.

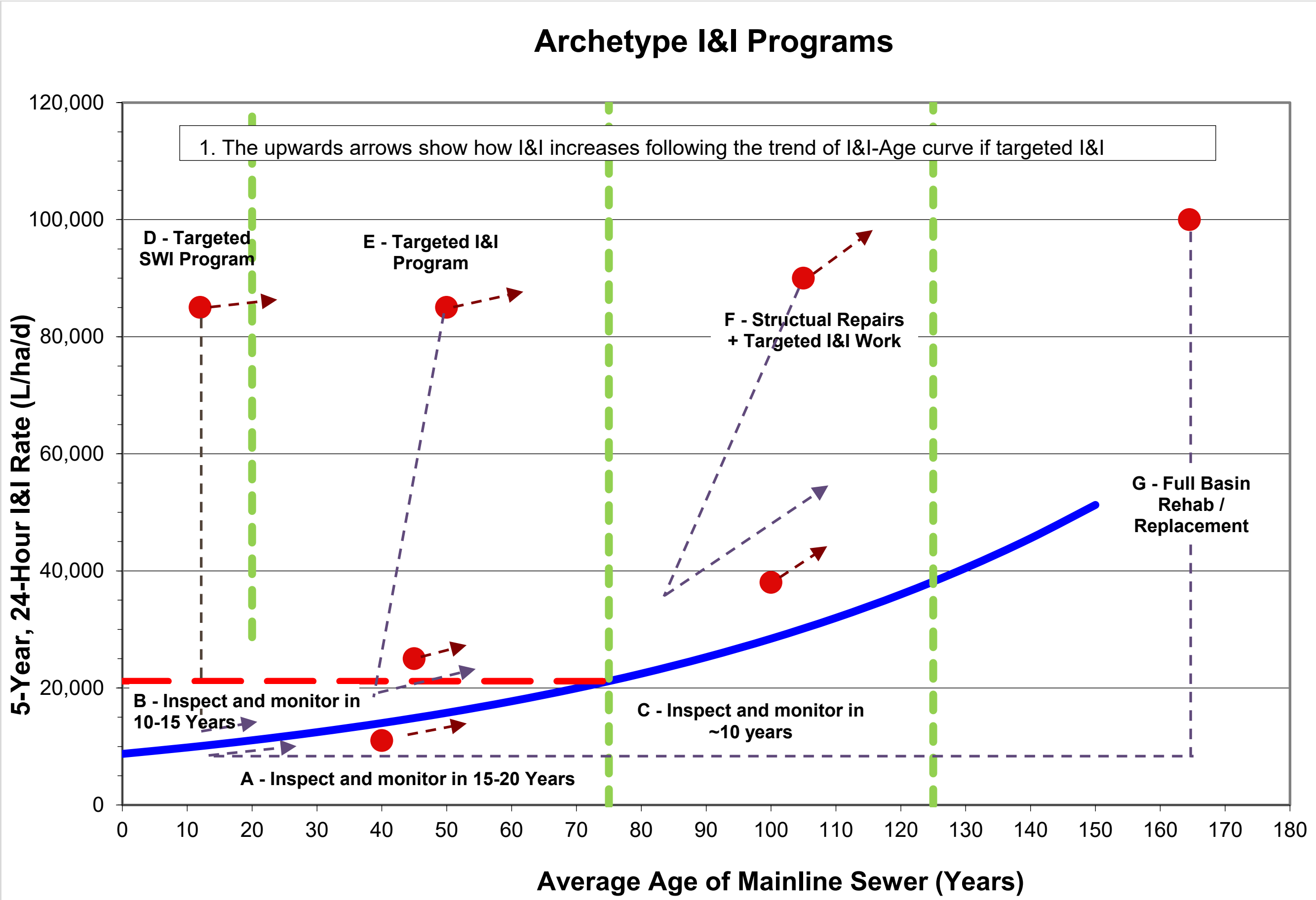

Figure E-1: I&I Archetype Program Identification Diagram

1. Background

1.1 Purpose

Uncontrolled rainwater inflow and groundwater infiltration (I&I) in sanitary sewer systems can have detrimental effects on social, economic, and environmental aspects of urban areas. Excessive flows as a result of I&I can result in environmental and health risks associated with sanitary sewer overflows (SSOs), increased operation, capital, treatment, and maintenance costs, and capacity limitations otherwise reserved in the existing sanitary sewer system to serve future populations and cope with climate change.

As I&I becomes a significant component of sanitary flow, it may be cost-effective to reduce I&I rather than upgrade infrastructure to convey additional flows. The literature shows that success reducing I&I has been mixed, and that a well-planned I&I management plan is required to achieve satisfactory I&I control with the limited infrastructure funds available. [1]

Traditionally, most I&I reduction efforts have been targeted at rehabilitating public-owned sewer infrastructure. Dealing with private service laterals for I&I reduction now occupies a sizable space at most international sewer collection system conferences. To achieve an effective I&I reduction, it is becoming recognized that a complete and multi-pronged approach to managing the entire sanitary sewer system (regional trunk sewers, municipal collectors, and private laterals) is necessary. Expanding programs to include service laterals is now gaining momentum throughout North America as many cities are arriving at the same conclusion. [2]

In the meantime, sanitary sewer overflows are numerous in Metro Vancouver's regional and municipal systems and exceed regulatory limits. Figure 1-1 shows flow monitoring results from the 2021 ILWRMP Biennial Report. The figure only shows SSOs from the regional (Metro Vancouver) system. Many more SSOs occur on the municipal systems as well.

The BC Municipal Wastewater Regulation (MWR) dictates that SSOs can not occur as a result of events with less than a 5-year return period. As shown in Figure 1-1, many locations are overflowing more frequently than that interval.

1.2 Regulatory Context

It is Metro Vancouver's members who determine and fund their I&I management programs while it is the effectiveness of these programs that determines the costs members contribute to supporting the Greater Vancouver Sewerage and Drainage District's (GVS&DD) storage, conveyance, and treatment of excessive I&I.

Since the mid-1990s, Metro Vancouver and its GVS&DD members have collaborated to understand I&I issues and develop cost-effective I&I management solutions. In 2002, GVS&DD members made commitments to the Ministry of Environment on I&I reduction and management. However, over the last two decades I&I management efforts and reductions have been mixed. Municipal I&I that is substantially in excess of the regional I&I allowance of 11,200 L/ha/d continues to contribute to sanitary sewer overflows from Metro Vancouver's sewers and continues to consume conveyance and treatment capacity provided for population growth by unnecessarily conveying and treating rainwater and groundwater.

[1] Controlling Inflow and Infiltration in the Metro Vancouver Area, March 2019, Metro Vancouver

[2] Study of Effectiveness of I&I Reduction Measures, Final Report, July 2008, KWL

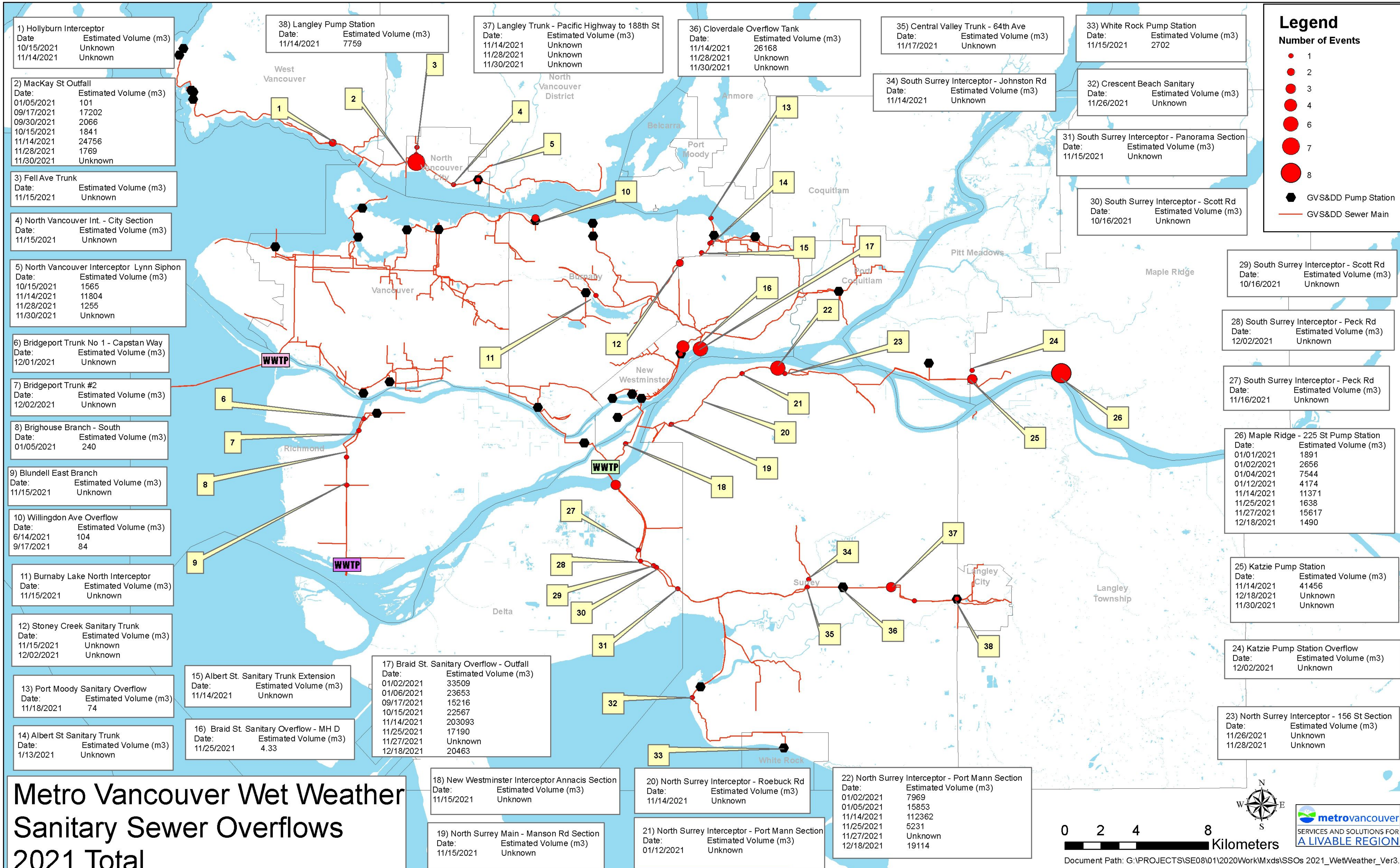

Figure 1-1: Sanitary Sewer Overflows in 2021

The following table summarizes the 2010 Integrated Liquid Waste and Resource Management Plan (ILWRMP) commitments current to the preparation of this report:

Table 1-1: ILWRMP Commitments for Sanitary Sewer Systems

Metro Vancouver Commitments	Municipal Commitments
1.1.6 Develop a template to guide the preparation and implementation of inflow and infiltration management plans as part of broader asset management plans and to support sanitary sewer overflow reduction strategies. *2011* 1.1.7 Work with the real estate industry and their regulators, and the municipalities to develop and implement a process for the inspection and certification of private sewer laterals being in good condition as a required component of real estate transactions within Metro Vancouver. *2011* 1.1.8 Develop and implement inflow and infiltration management plans that identify reduction strategies and timelines to ensure wet weather inflow and infiltration are within targeted levels. *2012* 1.1.9 Work with municipalities to review historical data and adjust as necessary the average inflow and infiltration allowance for regional trunk sewers and wastewater treatment plants and develop associated target allowances for municipal sewer catchments associated with a 1:5-year return frequency storm event for sanitary sewers to a level that ensures environmental and economic sustainability. *2013* 1.1.11 Enhance enforcement of sewer use bylaw prohibition against the unauthorized discharge of rainwater and groundwater to sanitary sewers. *2010* 1.1.18 Develop and implement inflow and infiltration management plans, using the Metro Vancouver template as a guide, to ensure wet weather inflow and infiltration volumes are within Metro Vancouver's allowances as measured at Metro Vancouver's flow metering stations. *2012*	1.1.19 Enhance enforcement of sewer use bylaw prohibition against the unauthorized discharge of rainwater and groundwater to sanitary sewers. *2010* 1.2.4 Work with municipalities to develop and implement municipal-regional sanitary overflow management plans which will: prevent sanitary overflows resulting from heavy rain and snowmelt occurring less than once every five years (for a 24 hour duration event); reduce emergency overflows due to power outages; and identify locations and schedules for appropriate system capacity improvements, wet weather containment, and point treatment and discharge to receiving waters of chronic overflows, including Cloverdale Pump Station, Katzie Pump Station, Lynn Pump Station. *2013* 3.1.6 Assess the performance and condition of municipal sewerage systems by: (a) inspecting municipal sanitary sewers on a twenty-year cycle; (b) maintaining current maps of sewerage inspection, condition, and repairs; and (c) using the Metro Vancouver *Sewer Condition Reporting Template Standard Report*, November 2002 as a guide to ensure a consistent approach to sewer system evaluation and reporting. 3.1.8 Develop and implement asset management plans targeting a 100-year replacement or rehabilitation cycle for municipal sewerage infrastructure and provide copies of such plans to Metro Vancouver. *2014 for plans*

Biennial ILWRMP Reporting

As part of the ILWRMP compliance, biennial reports are produced by Metro Vancouver with information supplied by municipalities. The reporting includes details on I&I investigation and reduction activities. Significant I&I monitoring, investigation, and rehabilitation has been undertaken by most member municipalities in the past five years. However, as mentioned above, the latest 2021 reporting is still showing that SSOs are occurring in several locations resulting from rainfall with less than a five-year return period. See Figure 1-1 for a summary of SSOs in 2021.

1.3 Existing I&I Management Programs

In 2019, the Regional Engineering Advisory Committee's Liquid Waste Sub-Committee (REAC-LWSC), reviewed the last two decades of I&I management programs in Greater Vancouver and observations from other jurisdictions and produced a report entitled *Controlling Inflow and Infiltration in the Metro Vancouver Area, Metro Vancouver, March 2019.*

The report concludes that the tools and know how to control and manage I&I have been available to GVS&DD members for several decades. The report suggests that the primary challenge for local governments in controlling I&I appears to be a broad perception that I&I management is a lower municipal priority and the costs of unmitigated I&I on the regional sewer system are disconnected from the impacts to municipal finances.

The report then recommended the following actions to address I&I:

Table 1-2: Recommended Actions to Address I&I

1.	That GVS&DD members continue to use the Envelope method or the RTK method to estimate sewer catchment I&I. [1]
2.	That by July 2019, GVS&DD members review their I&I management plans to contribute and develop a regional (Metro Vancouver-wide) list of municipally prioritized and targeted catchments that may be contributing to excessive I&I.
3.	That by December 2019, GVS&DD members and Metro Vancouver evaluate members' inspection practices for the new construction of sewers and public and private laterals and identify recommendations for improvements to bylaws, policies and procedures that will reduce I&I in new construction.
4.	That by December 2019, GVS&DD members and Metro Vancouver identify suitable strategies for sewer lateral I&I management based on local work and North American case studies.
5.	That by July 2020, GVS&DD members and Metro Vancouver identify guidelines for annual municipal sewer programs needed to address excessive I&I in prioritized and targeted catchments.
6.	That by July 2020, GVS&DD members develop implementation options for private lateral I&I management to reduce excessive I&I.
7.	That by December 2020, GVS&DD members and Metro Vancouver establish a coordinated strategy and implementation timeline for municipal I&I management priorities that will reduce the occurrence of wet weather SSOs and prioritize members' I&I reduction efforts.
8.	That by December 2020, GVS&DD members and Metro Vancouver develop a public education strategy and program blueprint to support private lateral I&I management.

1. See Sections 1.5, 3.3.2 and 3.3.3 and Appendix D of this document for details about these methods.

Based on the above, the purpose of this report is to update Metro Vancouver's 2011 I&I Management Plan Template using the recommendations above but keeping with the original commitments in the 2010 ILWRMP. In addition, clarification and further refinements will be developed through interviews with municipalities and the REAC-LWSC. [3]

[3] Inflow and Infiltration Management Plan Template, Working Draft, January 2011, KWL

1.4 Roles and Responsibilities

It is estimated by Metro Vancouver that the length of installed linear sanitary infrastructure is ± 12,530 km. This infrastructure is distributed as follows: [4]

- Metro Vancouver: 4.2%
- Municipalities: 50.3%
- Laterals (estimated as 80% on private property and 20% public): 45.5%

A 2008 study had identified that private connections (laterals) collectively account for over 50% of the length of the region's wastewater system, and that up to 91% of catchment I&I may be attributable to semi-combined private laterals. [5, 6]

Key roles in determining the sources of I&I and managing the overall integrity of the sanitary sewer collection system include the following:

- Metro Vancouver: Facilitates regional benchmarking of I&I sources, sets regional targets to protect trunk sewers, WWTPs, and minimize SSOs to meet ILWRMP targets, creates REAC-LWSC working groups to address I&I management and SSOs, and develops public education programs for the region;
- Member Municipalities: Largest role. Responsible for I&I source identification through asset management and detailed I&I investigations leading to I&I reduction, rehabilitation, and renewal programs. As well, member municipalities are responsible for implementing bylaws and inspection programs for rehabilitation and renewal of private sewer laterals; and
- Private Property: where Municipalities are conducting I&I investigations, most sewer bylaws require residents and business owners to allow access to private property for inspections. Also, owners are required to follow all sewer bylaws, and building/plumbing codes.

Generally, roles in determining sources of I&I are dependent upon the nature of the I&I investigation being conducted.

As a general statement, regular inspection and maintenance is performed only on collector and trunk sewers that account for 49.7% of the sewer system. The remaining 50.3% of the system – the small diameter sewer connections – have not been assessed, reconditioned, or replaced except in small number of pilot projects or after failure.

[4] Controlling Inflow and Infiltration in the Metro Vancouver Area, March 2019, Metro Vancouver

[5] Private Sewer Lateral Programs: A Study of Approaches and Legal Authority for Metro Vancouver Municipalities, 2008, The Sheltair Group and West Coast Environmental Law

[6] Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source, June 2016, Metro Vancouver

1.5 Previous Work

The following documents have been issued by Metro Vancouver relating to the development of the I&I Management Plan Template.

Sewer Condition Reporting Template Standard

In response to 2002 Liquid Waste Management Plan (LWMP) commitments C19 and C23, a common reporting standard for Metro Vancouver member municipalities was developed. [7] The reporting standard ensures that biennial LWMP progress reports submitted by the member municipalities are consistent. The 2010 ILWRMP extends the biennial reporting requirement, and the Sewer Condition Reporting Template Standard continues to be a tool used by municipalities to report their infrastructure management progress.

Original 2011 I&I Management Plan Template[8]

A key strategy in the 2010 ILWRM plan was the reduction of wet weather sewer overflows through regional and municipal asset management, and co-ordinated planning. To implement this, several actions have been required to reduce and control inflow and infiltration (I&I) into the sanitary sewer system through ongoing management of the sewer collection system using formalized Inflow and Infiltration Management Plans (I&IMPs).

The 2011 I&IMP template was developed with the intent to guide GVS&DD and its member municipalities in the preparation of I&IMPs as identified by ILWRM Actions 1.1.8 and 1.1.18. The purpose of the 2022 update is to replace the 2011 Management Plan Template with information and experience gained over the last decade by Metro Vancouver and the member municipalities.

I&I Envelope Methodology

The I&I Envelope method was identified in the Sewer Condition Reporting Template Standard (2002) as an economical and practical method of standardizing I&I analysis in Metro Vancouver. It is a graphical method based on a summary of rainfall and sewer flow data from flow monitoring. By plotting these results, a relationship between rainfall and rainfall dependent I&I (RDI&I) can be developed. It is then possible to develop 'return-period' design values for RDI&I, based on the rainfall analysis.

The I&I Envelope method is relatively easy to apply to collected data and provides a means for normalizing I&I results measured both within a municipality and across the wider Metro Vancouver area.

Study of Effectiveness of I&I Reduction Measures

A 2008 study for Metro Vancouver looked at two subjects: the work conducted to reduce I&I upstream of two historic SSO locations identified in the 2010 ILWRMP, and the effectiveness of various I&I reduction measures employed across North America. [9]

The study found the highest reductions have been achieved where entire systems including public and private sewers were rehabilitated. The next highest I&I reductions were noted where only the private laterals were rehabilitated.

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[7] Sewer Condition Reporting Template Standard, Working Draft Reporting, Nov 2002. KWL and Earth Tech

[8] Inflow and Infiltration Management Plan Template, 2011, KWL

[9] Study of Effectiveness of I&I Reduction Measures, Final Report, July 2008, KWL

Private Sewer Lateral Rehabilitation

The 2008 Sheltair and West Coast Environmental Law report provides a synopsis of the range of private lateral I&I reduction programs that have been carried out in other jurisdictions, analyzes these options within the context of the Metro Vancouver regulatory environment, and provides recommendations/pathways for moving forward. The approaches include: [10]

- incentive-based approaches: grants or rebates for inspection, repair, or replacement, and / or deferred payment programs (low or no-interest loans);
- enforcement-based approaches: time of sale requirements for lateral certification before transfer of title is granted, non-compliance fines on utility bills, and/or termination of services for non-compliance; and
- agency-driven approaches: identification of problems through sewer system evaluation by an agency, funding by agency for repair of identified problems, and/or incentive or regulatory mechanisms to have homeowners repair identified problems.

Ultimately, to effectively reduce I&I from private laterals, the report recommends that Metro Vancouver, including member municipalities, take a region-wide approach for policy, endorsement, public education, and potentially even industry-professional training on expectations and standards. Note that there are a number of legal issues that municipalities must consider before developing a private sewer lateral program. Similarly, there are potential liabilities and costs associated with inaction on the issue of private laterals. The 2008 report discusses these topics in Sections 3 and 4, respectively.

I&I Response Relative to Catchment Age

A CRD study in 2005 demonstrated that older sewer catchments tend to have higher I&I rates. [11] A relationship between sewer catchment ages and I&I rates can be developed to demonstrate, on average, how I&I rates in a typical catchment will change over time. This relationship is a useful tool to identify practical I&I reduction targets as part of broader I&I management practices.

Private Sewer Lateral Certification Through Real Estate Transactions

A study by Pinna Sustainability Inc. in 2013 reviewed the municipal authority and programmatic steps necessary to implement a private sewer lateral certification program at the time of real estate transactions, with a focus on North Shore municipalities, but broadly applicable to Metro Vancouver municipalities. The report identifies a process for implementing a private sewer lateral certification program that utilizes real estate transactions as a circumstance for requiring private property owners to prove the sewer lateral is in good condition, highlights key engagement activities for successful implementation and estimates potential resource requirements. [12]

[10] Private Sewer Lateral Programs: A Study of Approaches and Legal Authority for Metro Vancouver Municipalities, 2008, The Sheltair Group and West Coast Environmental Law

[11] I&I Rates and Sewer Infrastructure Age: Is There a Strong Correlation? Water Environment Federation (WEF) Collections System Conference, Boston 2005, Johnston et al.

[12] An Approach Towards Private Sewer Lateral Certification in Real Estate Transactions for Metro Vancouver, 2013 Pinna Sustainability Inc.

Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source

In June 2014, Metro Vancouver completed a report that investigated the influence of semi-combined sewers (i.e., partially separated sewers) on inflow and infiltration. [13] Semi-combined sewers were identified as an unrecognized type of sewer system through discussions at the National Water and Wastewater Benchmarking Initiative's I&I Task Group. Semi-combined sewer systems were once common in new construction across Canada 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 to be responsible for chronic elevated I&I rates in many neighbourhoods serviced before their prohibition.

The findings from this study support the belief that rainwater inflow from foundation drains could also be a key contributor to high I&I rates in many catchments locally. A testing methodology was developed and can help assist municipalities to better understand I&I issues and lead to better approaches to dealing with legacy semi-combined sewer systems.

Controlling Inflow and Infiltration in the Metro Vancouver Area

A 2019 Metro Vancouver study for the Regional Engineering Advisory Committee's Liquid Waste Sub-committee (REAC LWSC), (Metro Vancouver, March, 2019) reviewed the last two decades of I&I management programs and practices in Greater Vancouver as well as observations from other jurisdictions. [14]

The report concluded that the tools and know-how to control and manage I&I have been available to GVS&DD members for several decades. The report continues by stating that the primary challenge for local governments in controlling I&I appears to be a broad perception that I&I management is a lower municipal priority and the costs of unmitigated I&I on the regional sewer system are disconnected from the impacts to municipal finances.

The recommendations of the report have been included in a summary of issues to be addressed below.

1.6 Summary of Issues to be Addressed in I&I Management Plan Update

Based on the sections above, the following key issues have been developed to guide the update procedure in this 2022 I&I Management Template Update:

1. **Sewer Laterals:** A program of renewal and rehabilitation needs to be implemented region-wide through the updating and enforcement of sewer bylaws. An inspection program also needs to be developed;
2. **Condition Reporting:** The 2002 Sewer Condition Reporting Template previously used the Water Resources Centre (WRC) coding system that is now out of date. It will be replaced with the generally accepted Pipeline Assessment Certification Program (PACP) system;
3. **I&I Metrics and Analysis:** Significantly more monitoring data is now available since the 2011 I&I Management Plan Template was initiated. The update will summarize the data to date to highlight trends related to pipe material and age;

[13] Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source, June 2016, Metro Vancouver

[14] Controlling Inflow and Infiltration in Metro Vancouver Area, Metro Vancouver, March 2019

4. **I&I Reduction Program Costs:** Even though unit costs are available for most types of investigation and rehabilitation work, it can be difficult to budget for annual I&I reduction programs on a catchment basis as the extent and application of rehabilitation methods within a basin can vary widely based on the I&I severity and sources. It has been recommended that the I&I unit costs be updated and a system of estimating budgets for I&I catchments based on grouping be developed;
5. **Prioritizing I&I Catchments:** Understanding which catchments to prioritize and what degree of rehabilitation to undertake can be difficult. A prioritization system that aligns with established asset management programs for renewal should be recommended. The update will propose a system for prioritization of catchments;
6. **Clear Pathway of I&I Program Development:** Provide a more streamlined and 'automatic' system of addressing public and private service I&I reduction; and
7. **Partially Separated (Semi-Combined) Private Laterals:** Acknowledge that there are many older areas in Metro Vancouver that have partially separated sanitary services. These services may have subsurface drainage and wastewater leaving the property in the same pipe, which is prohibited by many sewer use bylaws. They usually exist due to an inadequate public storm sewer system in the area (storm sewer too high or non-existent). The I&I rehabilitation program for these areas will be different than the other areas and will start with the construction of a proper storm sewer system.

1.7 Report Outline

This report comprises the following four sections:

1. **Section 2: I&I Management Principles:** This section summarizes the overall objectives of what is trying to be achieved by the I&I Management Plan Template and I&IMPs in general. It also highlights the key principles on which the template is based;
2. **Section 3: Data Collection and Analysis Methods:** This section reviews the procedures to collect sanitary sewer flow and rainfall data as well as the collection of field data. It also reviews the proposed I&I analysis methods;
3. **Section 4: I&I Management Programs:** This section proposes programs and techniques for managing I&I on both private and public property. The section also presents cost information for rehabilitation methods; and
4. **Section 5: I&I Prioritization, Costing, and Evaluation:** This section proposes a new method of prioritizing I&I catchments to focus efforts. The section also provides guidance on developing cost estimates for budgeting.

The sections are supported by Appendices that provide more detail on the analysis approach.

There is also an appendix containing a template example of how the sections can be pulled together in a reporting format.

2. I&I Management Principles

This section summarizes the overall objectives of what is trying to be achieved by the I&I Management Plan Template and I&IMPs in general. It also highlights the key principles on which the template is based.

2.1 Guiding Principles

When developing the Action and Implementation section of an I&IMP, the following Guiding Principles can be considered:

Metro Vancouver

- Minimize the occurrence of SSOs.
- Delay or eliminate the need for capacity upgrade of conveyance and treatment facilities due to I&I.
- Reduce or eliminate the need for on-site storage/treatment of SSOs through I&I reduction.

Municipalities

- Minimize the occurrence of SSOs.
- Reduce or eliminate the need for on-site storage/treatment of SSOs through I&I reduction.
- Design a program to meet ILWRMP and Metro Vancouver targets.
- Clearly define responsibility for removing I&I from municipal sewers and private sewer laterals.
- Develop a cost-effective program.
- Ensure there are enforceable legal means for actions/methods to address private service lateral I&I (i.e., municipal bylaw and within scope of powers granted to municipalities under the *Local Government Act, Vancouver Charter and/or Community Charter*).
- Employ actions/methods that are measurable.
- Promote public acceptance of the I&IMP.

2.2 Importance of Repeatable I&I Analysis Methods

I&I quantification begins with accurate, reliable, and repeatable sewer flow data. Flow data is defined as continuously recorded, electronic, time-series sewer flow. Depending on the metering technology, other parameters including level and velocity may also be recorded at the same time. Figure 2-1 shows a sample of typical sewer flow monitoring data plotted along with rainfall data.

Each rainfall event produces a unique sewer flow monitoring result depending on a number of variables including soil composition and water saturation levels, pipe materials and construction methods, adequacy of the existing drainage/stormwater conveyance system, etc. It is important for the professional undertaking an I&I investigation program to use analysis methods and procedures that make multi-year flow comparisons as reproduceable as possible.

Section 3 and Appendices A through D of this report re-confirm the use of analysis methods developed as part of the original Sewer Condition Reporting Template in 2001 coupled with additional guidance to address the above.

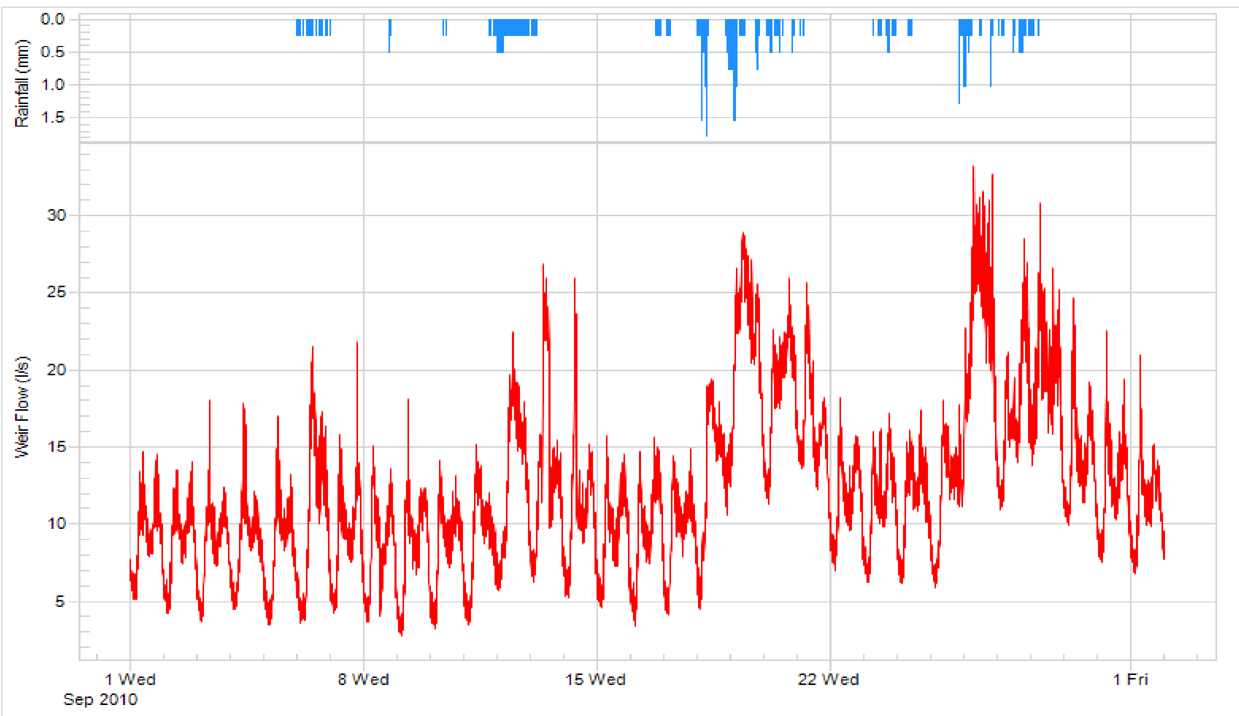

Figure 2-1: Typical Sewer Flow Monitoring Data Plot

2.3 Approach to Public Property I&I Investigation

It is recommended that Public Property I&I Reduction Plans are consistent with the systematic approach noted in the Infraguide for *Infiltration/Inflow Control/Reduction for Wastewater Collection Systems*. [15] This infraguide provides a proven framework for carrying out specific I&I reduction work in catchments (see Figure 2-2). The guide proposes that I&I reduction programs be divided into the following three phases:

Phase 1: Data Collection

- Create catchments with background data for each catchment.
- Flow monitor catchments and analyze for I&I, etc.

Phase 2: Investigation

- May include manhole inspections, dye testing, smoke testing, camera inspections (CCTV) of mains, CCTV of laterals, drainage system assessment, subcatchment flow monitoring, etc. (see Appendix A for details.)

Phase 3: Rehabilitation

- Interpret investigation data and prepare summaries/summary drawings.
- Develop rehabilitation plans.
- Carry out rehabilitation.
- Determine effectiveness of rehabilitation and adjust as required.

Phase 1 is discussed in more detail in Section 3. Phases 2 and 3 work will be discussed in detail in Section 4.

2.4 Importance of Private Sewer Programs

Studies show that approximately half of all I&I originates on private property. [16, 17] Like the mainline sewers on public property, I&I is generally highest in areas with older sewers due to general deterioration; construction practices and materials used at the time of installation; and the reality that property owners rarely maintain their laterals.

The Insurance Bureau of Canada recently announced that sewer back-up claims already exceed fire claims and are expected to become even more significant problem due to climate change.

Often property owners are not aware of their responsibility to maintain the sewer laterals. As a result, they rarely maintain them.

It is extremely important that municipalities have strong bylaws in place to address the renewal of private sewers. It is also important to have a have a test or certification for older services that may not have reached the end of their service life but require rehabilitation.

Metro Vancouver and the member municipalities have explored a number of programs over the years and further study and discussion is required. Section 4 of this report proposes options to be incorporated as part of the management plan.

[15] *Infiltration/Inflow Control/Reduction for Wastewater Collection Systems,* Infraguide, Federation of Canadian Municipalities and National Research Council, March 2003

[16] Controlling Inflow and Infiltration in the Metro Vancouver Area, March 2019, Metro Vancouver

[17] Private Sewer Lateral Programs: A Study of Approaches and Legal Authority for Metro Vancouver Municipalities, 2008, The Sheltair Group and West Coast Environmental Law

2.5 Partially Separated Private Service Connections

Partially separated sewers, also known as semi-combined sewers, were once common to new construction across Canada as a means to provide foundation and basement drainage without requiring the construction of storm sewers, and have since become a legacy issue with respect to I&I. Even as storm sewers were added in the form of ditch enclosure projects, the storm sewers were installed to drain the road surface and were not deep enough to service the building foundation. Partially separated sewers have been identified as an unrecognized type of sanitary sewer system receiving flows from combined private sewer laterals or extensive private-side cross-connections. They are believed to possibly be responsible for chronic elevated I&I rates in some local neighbourhoods that were serviced prior to their prohibition; findings support the belief that rainwater inflow from foundation drains is a key contributor to I&I. [18] Interviews with the City of North Vancouver and the City of Burnaby support these findings.

Recognizing this, in June 2016 the REAC-LWSC made three recommendations regarding identification and reporting of semi-combined sewers to help municipalities better understand how I&I from legacy semi-combined sewers contribute to the flows in their overall sewer system. Summarized versions of these recommendations, found in the same 2016 Metro Vancouver report, are: [19]

1. specified, established methodology in the development of I&IMPs;
2. sanitary sewer catchments with excessive I&I rates should apply the methodology of Recommendation 1 to priority areas to help identify private-side I&I source; and
3. share the findings of Recommendation 2 with Metro Vancouver and each other via sewerage area technical committees.

Ultimately, if an adequate municipal storm sewer system is not provided for a private lateral connection at a suitable elevation, it is not recommended to try to rehabilitate this type of catchment to address and reduce the I&I contribution, but rather to first construct a new and improved storm sewer or drainage system to which the flows would be directed. As stated above, critical to this approach is to identify where these areas exist. Once a proper drainage system exists, I&I rehabilitation programs can be re-established.

[18] Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source, 2016, Metro Vancouver

[19] Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source, 2016, Metro Vancouver.

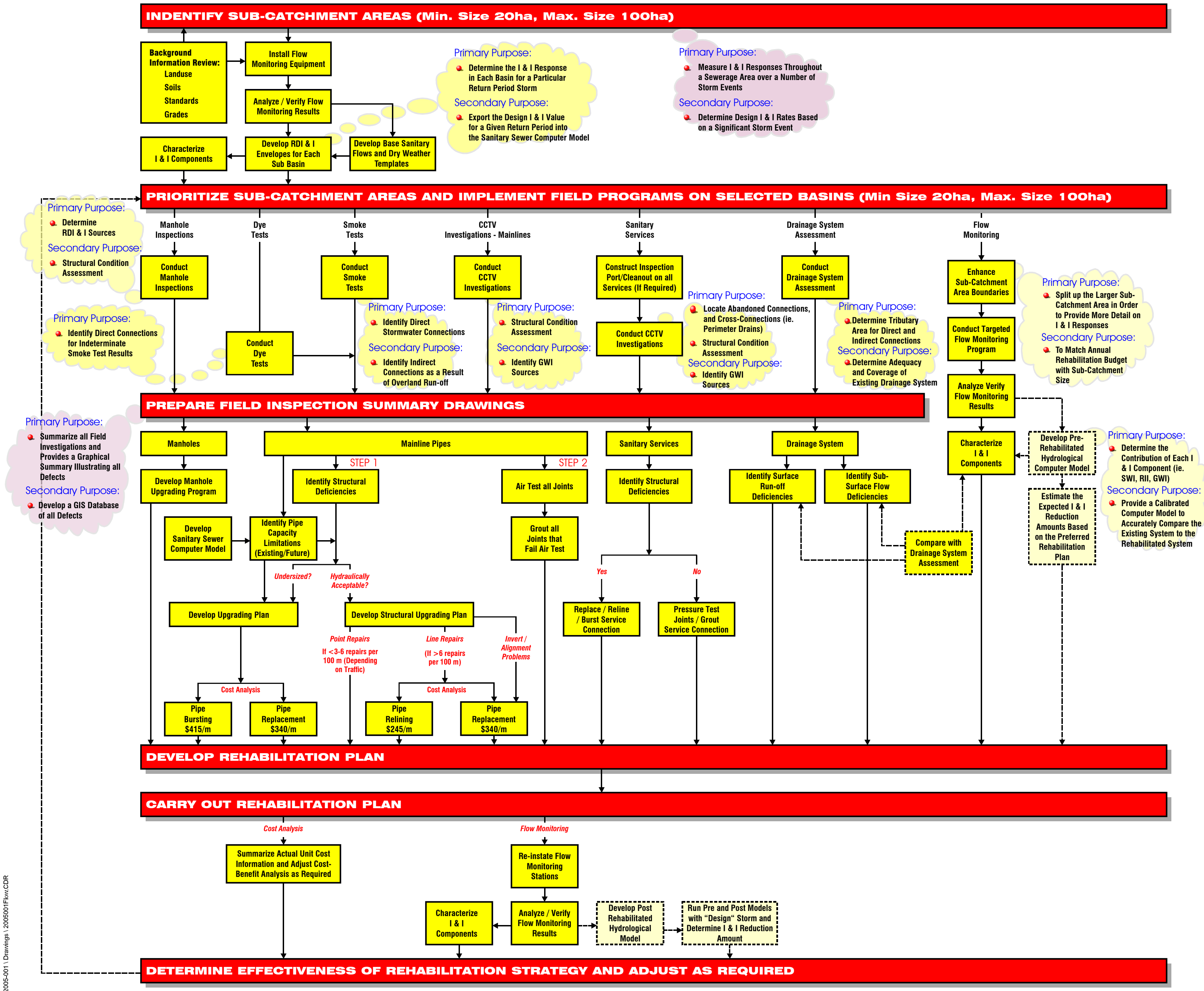

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Figure 2-2: Possible I&I Investigation and Reduction Strategy for Small to Medium Sized Sanitary Sewer Catchments

2.6 Asset Age, Construction, and I&I Relationships

2.6.1 The 2011 I&I and Catchment Age Relationship

I&I-Catchment Age Relationships can be derived from multiple I&I analyses. The calculated I&I total for each catchment can be plotted on the Y-axis of a graph. On the X-axis, the average age of the catchment (determined by a pipe length-weighted average using a GIS calculation) is plotted. With enough catchments plotted, a curve fit through the data can represent the average I&I response for all of the catchments considered within the dataset. The catchments could include just those from a specific municipality, or, where rainfall and soil conditions are similar there could be benefit in combining and comparing data from multiple municipalities as well.

The intent of the relationship is to show I&I response versus average pipe age relative to other catchments in the data set. There are several opportunities to use this type of analysis when planning and assessing the success of infrastructure rehabilitation efforts, as well as identifying potential candidates for such programs.

The relationship was first introduced in 2011 as part of the original I&IMP Template. Figure 2-3 illustrates I&I-Catchment Age Relationships analyzed in 2011 for 87 unique catchments within both Metro Vancouver and the Capital Regional District (CRD)

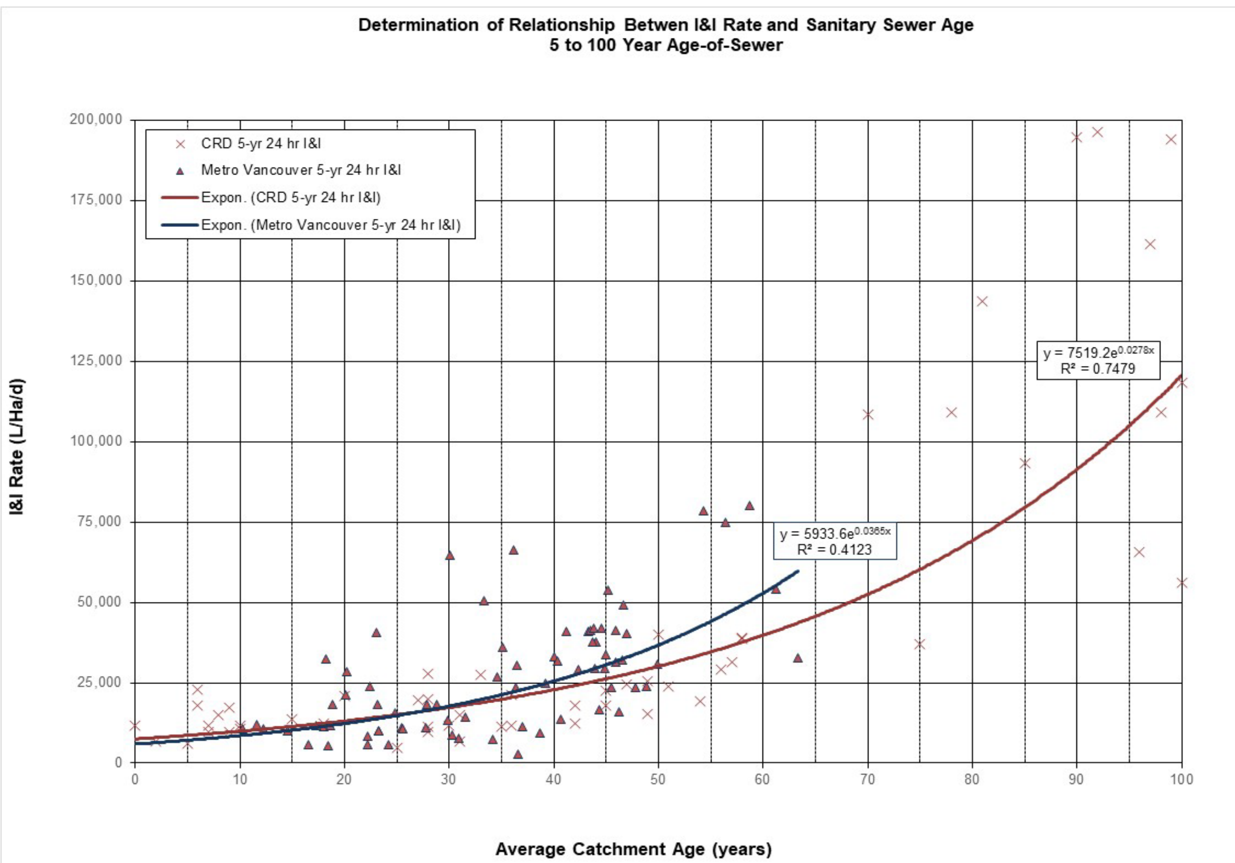

Figure 2-3: 2011 Analysis of Catchment Age versus 5-year/24 hour I&I Rate

Figure 2-4 shows an updated 2021 relationship using 163 unique catchments (sand/gravel catchments excluded due to their general lack of trench-water driving head).

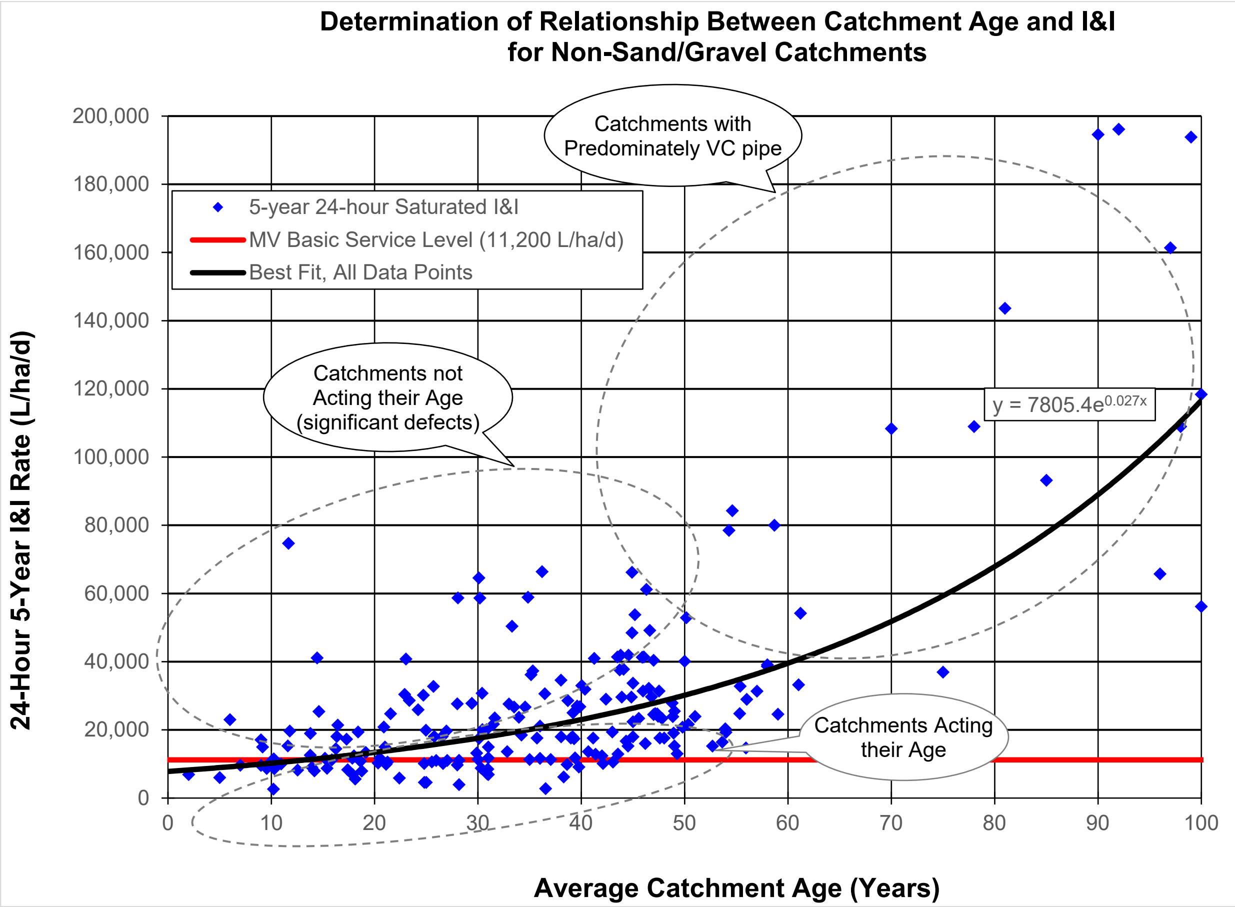

Figure 2-4: Updated 2021 I&I Versus Catchment Age Relationship

2.6.2 I&I – Age Relationships Based on Pipe Material and Construction Methods

PVC Pipe Materials

With improvements in pipe material and construction practices over the past several decades, a separate analysis was performed in 2021 to determine if newer catchments (with primarily PVC pipe) could provide an alternative relationship revealing performance near the 11,200 L/ha/d basic service level. Figure 2-5 shows the relationship based solely on catchments with greater than 95% PVC pipe on both private sewer laterals and mainline pipes. The relationship suggests that there is no real correlation with age and the 5-year, 24-hour I&I mean is less than Metro Vancouver's basic service allowance of 11,200 L/ha/day. It is possible that an age-relationship may form as the pipes age and more data is collected, but it is encouraging to see that with 32 years of data so far, the basic service level of 11,200 L/ha/d can be maintained.

It should be noted that a few catchments, even though they are 95% PVC, still exhibit elevated I&I rates for their age. This should be expected in some areas as even though the overall trend is flat, some catchments will have inadequate construction inspection and inferior construction practices (i.e., poor compaction leading to joint deflections, cross-connections, lack of comprehensive post-construction testing, etc.). Although only anecdotal evidence suggests that this is the case with the elevated catchments in Figure 2-5, rehabilitation programs in other younger catchments suggests this is likely the situation.

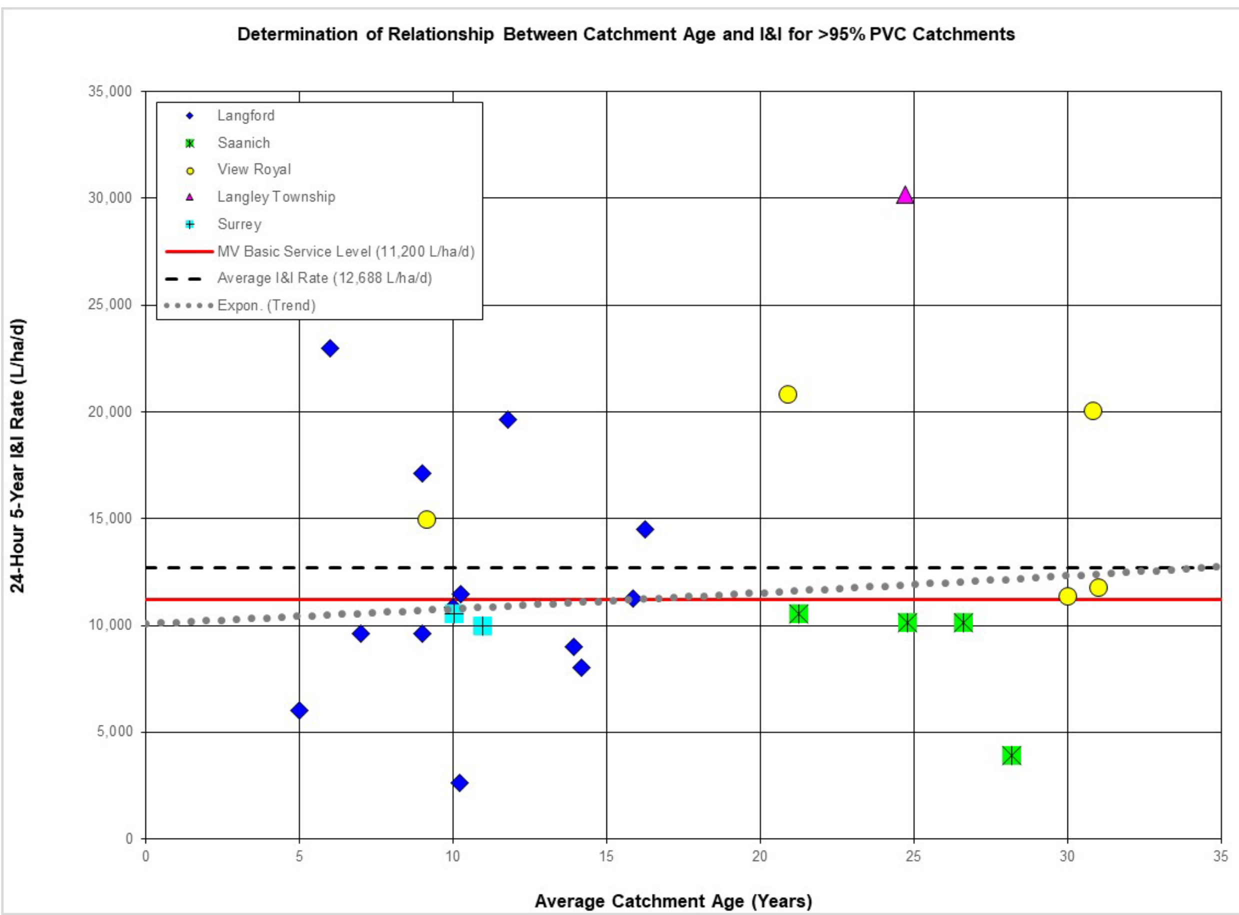

Figure 2-5: I&I Age Relationship with Only PVC Pipe (Public and Private)

It should also be noted that the starting I&I rate at year zero would not be the approximately 10,000 L/ha/d shown on Figure 2-5, but a significantly lower value, and more comparable to the allowable leakage specified for public and private property prior to commissioning. For more information on the differences between allowable leakage, unacceptable leakage, and excessive leakage, the reader is referred to Section 2 in *Reducing the Risk of Inflow and Infiltration (I/I) in New Sewer Construction*, November 2019, by Barbara Robinson (Norton Engineering Inc., Dan Sandink (ICLR), and David Lapp (Engineers Canada). The report is a foundational document for the development of a national I&I standard.

Relationship with Catchments Less than 40 Years Old

Figure 2-6 illustrates I&I-Catchment Age Relationships for PVC and younger AC material types less than 40 years in both Metro Vancouver and Greater Victoria. Unlike Figure 2-5 that only included catchments with greater than 95% PVC pipe on both mainlines and services, Figure 2-6 includes the larger data set where the average age of the mainland pipe is less than 40-years old. Figure 2-6 is likely more representative of typical conditions in existing areas and shows how there is a mild correlation with age.

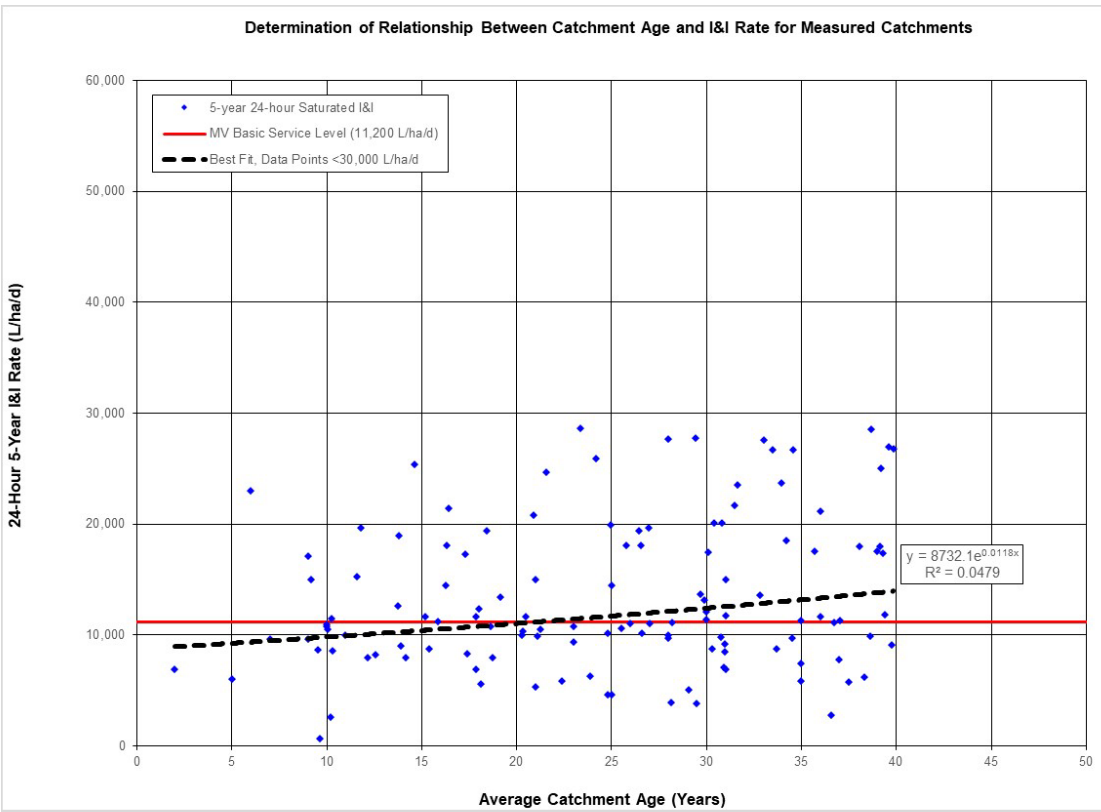

Figure 2-6: I&I Age Relationship For Catchments Less than 40 Years Old

Although the graphs are useful to identify trends with different types of pipes and corresponding construction methods, the primary purpose of these graphs is to show catchments that have excessive I&I response for their age, relative to other catchments in the data set. There are several opportunities to use this type of analysis when planning and assessing the success of infrastructure rehabilitation efforts, as well as identifying potential candidates for such programs.

The Figure 2-6 relationship will be used in Section 5 to help with the prioritization of I&I rehabilitation work.

2.7 Suggested I&I Rehabilitation Philosophy for the 2022 I&I Management Plan Update

Building on the recommendations identified in the original *Metro Vancouver 2011 I&I Management Plan Template*, Municipal I&I Programs can be structured as follows:

1. A City-wide program similar to a CCTV program based on asset management decisions whereby pipes are replaced based on age, material type, or condition (both public and private sewers);
2. A targeted I&I reduction program focusing on critical catchments where I&I is excessive; or
3. A hybrid program using a combination of the above.

There are benefits to each style of program above. This document suggests that No.3, a hybrid program of both city-wide programs and targeted catchment I&I reduction, may be the most effective at achieving the objectives laid out in the ILWRMP. Figure 2-7 summarizes a suggested approach.

Suggested Municipal I&I Rehabilitation Philosophy for 2022 Update

Private Laterals	Public Sewers and Maintenance Holes	Reporting
Adopt a structured private sewer renewal and/or bylaw infraction correction program with proper inspection systems and have it run on autopilot.	Simplify the rehabilitation programs so it is easy to understand what needs to be done in any given catchment and city-wide. Develop strategy to prioritize catchments and funding.	Simplify reporting but add checks so that results are repeatable.

Figure 2-7: Suggested I&I Rehabilitation Philosophy

2.8 Impact of Climate Change on Inflow and Infiltration

Most climate change projections indicate that future rainfall events will be more extreme in size and intensity resulting in the potential for greater I&I. This relationship can now be predicted for 24-hour durations. Since I&I response to rainfall is highly correlated, once this number is established, it is possible to predict the impact of climate change on current I&I rates (although somewhat more difficult for rainfall durations less than 24-hours).

However, it should be noted that although the above makes sense in theory, studies showing the cause and effect of increased rainfall intensities and volume are not highly developed at this time.

Rising sea levels could result in saltwater intrusion within pump stations, and inside low-lying sewer infrastructure. Changes in the seasonality and intensity of storm events could impact the buffering capacity of the ecosystem.

To support local governments undertaking this work, the Public Infrastructure Engineering Vulnerability Committee (PIEVC) has developed a protocol and procedure to guide a national engineering assessment of the vulnerability of Canadian public infrastructure to climate change. This work has been completed for Metro Vancouver in several of their sewerage areas and identifies a number of vulnerabilities that should be addressed in future.

For the purposes of this report, the modification of I&I rates due to future climate change has not been included at this time and is left to the professional to assess the applicability of any modifications.

3. Data Collection and Analysis Methods

The section reviews the procedures to collect sanitary sewer flow and rainfall data as well as the collection of field data. It also reviews the I&I analysis methods proposed in the management plan.

3.1 Flow and Rainfall Measurement

3.1.1 Documenting Flow Monitoring in the I&IMP

The I&IMP records a municipality's intended monitoring program and progress to date, and as such identifies:

- all discrete flow monitoring catchments in the municipality/region;
- history and results of previous monitoring; and
- time frame for monitoring all catchments, with known monitoring priorities stated.

The I&IMP should also contain an I&I versus catchment age graph, as outlined in detail later in this section, to present the current conditions of the catchments and show potential candidates for rehabilitation or repair.

Methods for designing and conducting a flow monitoring program, and subsequent analysis of the data, are described in detail in Appendix A. The following material is a summary of the key points from that material.

3.1.2 Flow Monitoring Catchment Selection

Selecting which catchments to monitor is a balancing act between the need for data and budget restrictions. Numerous factors are considered when designing a flow monitoring program, including:

- characterizing catchments by factors such as pipe age, material, soil conditions, and land use;
- selecting suitably sized areas for measurement;
- prioritizing monitoring programs based on expected areas of development and reported or modelled flooding risk; and
- looking for opportunities to share the data with other users that could benefit.

3.1.3 Flow Monitoring Site Selection

Sometimes what seems like a simple exercise on paper turns into something quite different once maintenance hole locations are inspected for potential monitoring sites. Select sites that have:

- easy access or reasonable traffic control requirements; and
- good hydraulic conditions allowing accurate measurement.

Be aware of possible pitfalls such as:

- undocumented sewer laterals at the maintenance hole causing turbulence;
- high gradient pipes where velocities exceed 3 m/s;
- pipes with significant sediment and no recent flushing program;
- drop maintenance holes; and
- maintenance holes that simply do not exist or are paved over.

It is important to check record drawings or accurate GIS databases to avoid surprises prior to installation and/or conduct site visits to view access, safety, and interior maintenance hole conditions. Further, it is recommended to check the operations and maintenance service call records to gain familiarity with other issues that have come up at sites.

3.1.4 Flow Monitoring Technology Selection

Technology to monitor sewer flows varies widely in cost, accuracy, and suitability for a given condition. Some of the more common types used include:

- area-velocity (AV) meters – relatively inexpensive to deploy but intrusive and with less accuracy than other systems;
- flumes and weirs – better accuracy but intrusive and can cause deposition or grease issues in some locations;
- radar velocity meters – non-intrusive with good accuracy but expensive; and
- acoustic doppler profilers – very good accuracy but intrusive and expensive.

3.1.5 Rainfall Monitoring

It is important to consider the following for establishing a rainfall station or use of a nearby rainfall station when conducting a sewer flow monitoring program:

- Location of rain gauging station: Preferably, the rain gauge is located within the sewer catchment being monitored. Failing that, the gauge should not be more than 3 km away. If the gauge is not in the catchment but less than 3 km away, a second gauge may be required to substantiate the rain that fell on the catchment;
- Rainfall can be derived from Ground-Adjusted Radar Rainfall (GARR) but the procedure can be time consuming and costly. GARR is typically used for very large catchments where deployment of rain stations is costly; and
- If the extent (area) of stormwater inflow (SWI) and flow from semi-combined cross-connections is being calculated, it is imperative that the rain gauge is located within the sewer catchment to provide sufficient accuracy in the estimate.

3.1.6 Field Work: Municipal/Regional Crews and Contractors

Many factors weigh into the decision to use municipal/regional staff, contractors, or a blend of both to implement the field portion of the flow monitoring program:

- Best results will come from continuously dedicated staff (a minimum of two are required to satisfy confined space entry requirements), who will benefit from and maintain their skills through ongoing practise and training;
- Significant investment is needed in flow monitoring and support equipment, including vehicles, confined space entry equipment, field computers and a variety of flow monitoring gear to meet onsite requirements;
- Costs of ongoing repair and replacement of equipment;
- Maintenance of safety programs and permits to satisfy WorkSafeBC requirements;
- Costs for training programs for confined space entry and flow monitoring concepts; and
- Occupational health and safety workplace requirements (e.g., medical vaccinations for those who work in and around the sewer sites).

The alternate to in-house staff is to hire a dedicated flow monitoring services contractor. Guidelines on hiring and using their services are provided in detail in Appendix B.

3.1.7 QA/QC Procedures

Quality control and assurance of the sewage flow data is essential but may be overlooked. Assumptions may be made by flow monitoring contractors that the engineers will be performing the review, and engineers may assume the same of the contractors. Responsibility for this important task must be clearly defined during the planning and hiring stages.

A set of QA/QC guidelines is provided in Appendix C for reviewing flow monitoring data. These guidelines are meant to help prevent of some of the most common problems that occur before they can have serious impact on the I&I analysis.

3.2 Other Data Sources

Further to that outlined in Section 3.1, there is a lot of additional information that helps establish a good understanding of a system, particularly regarding where I&I is likely to occur within the system. This is ultimately useful for developing an effective I&IMP. This section outlines information that can be used to enhance system understanding, and notes where the information is typically found.

3.2.1 Interviewing Operations and Maintenance Field Staff

- Field staff can provide insight and help to check/validate information gathered from desktop research. They can also assist with first hand knowledge of historical events and how the system preformed.

3.2.2 Collection System Age, Materials

- GIS.
- Tangible Capital Asset Register.
- Asset Management Plans.

3.2.3 Construction and Maintenance Quality

- Inspections.

3.2.4 Soil, Topography, and Groundwater Conditions

- Review of these conditions in the upstream sewer shed can be used to interpret results, noting:
    - poorly draining soils may concentrate infiltrating rainwater in utility trenches with granular backfill;
    - areas with steep slopes may experience movement that increases vulnerability to infiltration; and
    - high groundwater table or location within floodplain may result in higher I&I.

3.2.5 Land Use, Building Age and Density

- Older single-family neighbourhoods without storm sewerage or with shallow storm (semi-combined systems).
- Property consolidation resulting in abandoned laterals – proper abandonment/sealing.

3.2.6 I&I Field Investigation Techniques

- Smoke/Vapour Testing.
- Dye Testing.
- Air Testing.
- Exfiltration/Hydrostatic Testing.
- Mainline CCTV Inspection.
- Abandoned Service CCTV Inspection.
- Private Lateral CCTV Inspection.
- Perimeter Drain Connection Identification Methods.

3.3 Analysis

3.3.1 I&I Analysis Methods

There are many I&I analysis methods and derivations in use throughout North America for analyzing flow monitoring data to produce I&I component summaries. Many of the methods were reviewed in the original I&I Sewer Condition Reporting Template, (KWL Earthtech 2001). The I&I Envelope Method was selected as the simplest and most applicable method for use in Metro Vancouver. It was developed by the East Bay Municipal Utility District (EBMUD) in San Francisco. In addition to its simplicity, the method was shown to be highly repeatable when comparing multiple years of data. Results since 2001 in both Metro Vancouver and Greater Vancouver have confirmed these earlier. All of the data and trends shown in Section 2 were developed using the I&I Envelope Method.

Traditional hydrologic computer modelling using I&I simulation modules (i.e., SWMM, Mike Urban, etc.) were also recommended, but it was recognized that significantly more effort would be required to complete an analysis. When the RTK Method was introduced to Metro Vancouver, less than a decade ago, it offered another I&I tool for I&I analysis and supplemented the existing tools.

The purpose of this section is to summarize the most common methods in use in Metro Vancouver and their differences, then explain the analysis procedures.

3.3.2 I&I Envelope Method

The I&I Envelope Method, adopted in the Metro Vancouver Sewer Condition Reporting Template, is a statistical method used to estimate peak I&I flows. In essence, the I&I Envelope Method involves plotting a linear regression of peak RDI&I flows, determined from flow monitoring data from many storm events, against measured rainfall depths from a local rain gauge. Subsequently, the best-fit line is shifted up to the event with the highest ratio of RDI&I to estimate the peak RDI&I flow for the flow monitoring catchment. The shift is made to reflect ‘saturated soil conditions’ as some of the rainfall events may have been recorded in drier soil conditions. The best-fit-line is then extrapolated to the design rainfall amount in order to determine the design RDI&I flow rate. Figure 3-1 illustrates an I&I envelope previously completed for the City of Burnaby.

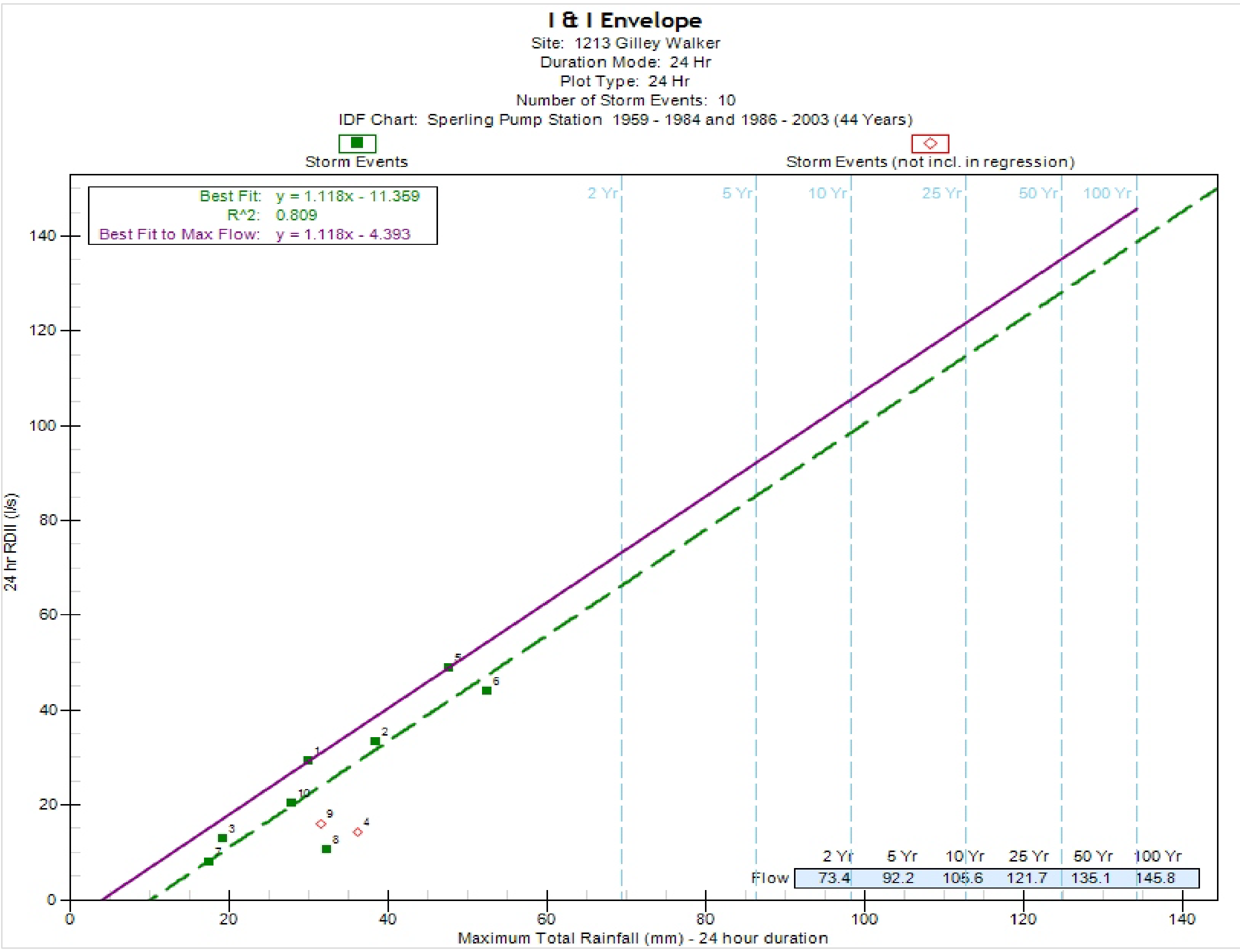

Figure 3-1: Example of an I&I Envelope

Refer to Appendix D for more details on the analysis steps to use the I&I Envelope method.

3.3.3 The RTK Method

The RTK Method is used to calibrate the I&I loading to an individual storm event or multiple events based on the flow monitoring data. The results can be used to determine a design I&I rate and/or imported into a computer model. By quantifying the R (amount of rainfall getting into sewer), T (time to peak), and K (ratio of time to peak to total time of I&I response) variables, the model would be able to mimic the storm event experienced in the system and identify any capacity deficiencies. This deterministic approach would provide accurate volumetric and flow rates based on the largest storm the system has experienced. In summary, RTK provides an accurate shape hydrograph and volume of flow for a measured storm event. A drawback of this methodology is that in most cases, temporary flow monitoring records do not capture a design storm event for calibration. Figure 3-2 provides a breakdown of the R, T, and K variables on a hydrograph and compares it against a uniform hydrograph. Typically, three RTK sets are used to simulate the three components of RDI&I (stormwater inflow, fast infiltration, and slow infiltration) to form one composite RDI&I hydrograph.

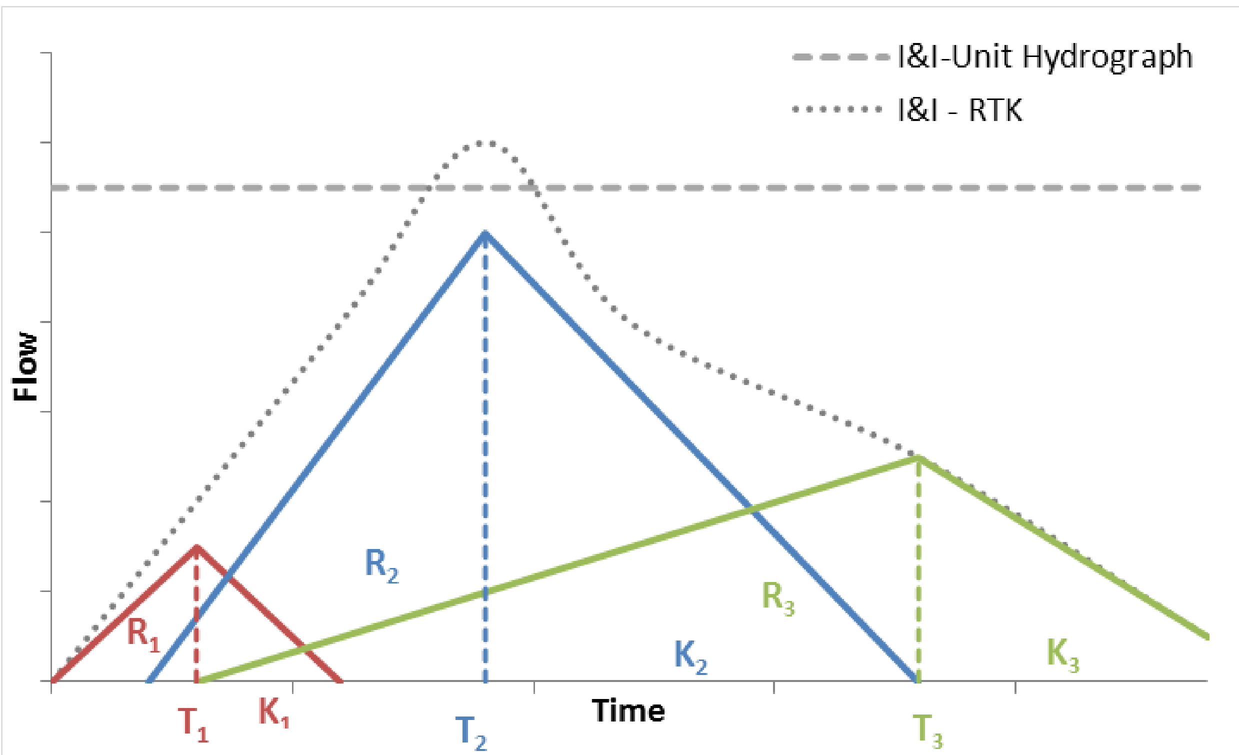

Figure 3-2: Breakdown of R, T, and K Variables Against Uniform Hydrograph

3.3.4 I&I Loading Methods

As both methodologies have their advantages (I&I Envelope Method has the ability to extrapolate design I&I rates for return periods not captured by flow monitoring, and the RTK Method has the ability to simulate previous storm events experienced by the system), the proposed methodologies for I&I loading are to run the model under two methods to analyze wet weather scenarios. Each method described has an analytical advantage with respect to the result it produces.

Peak-on-Peak Method

The I&I rate derived from the I&I Envelope is loaded using a unit hydrograph, which results a 'peak-on-peak' approach to estimating peak flows. This method provides a conservative approach in assessing the capacity of the collection system under peak wet weather flow conditions at all times. Figure 3-3 provides an example of a hydrograph using the 'peak-on-peak' method. This method produces the most conservative peak wet weather flow results.

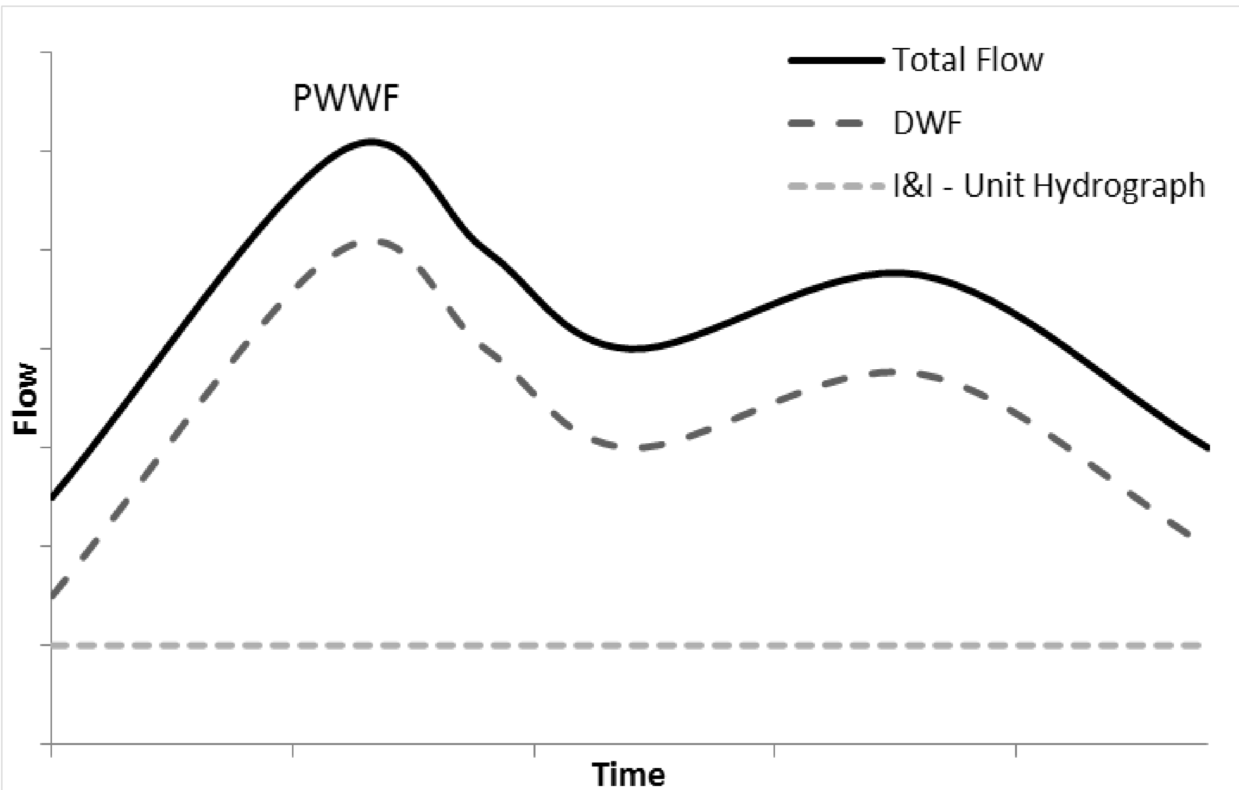

Figure 3-3: Wet Weather Hydrograph, 'Peak-on-Peak' Method

Synthetic RTK Method

The Synthetic RTK Method is a combination of using the I&I rate determined using the I&I Envelope and scaling the storm event previously experienced by the collection system to match the design storm event. By scaling peak flow rate to match the peak hour I&I flow rate and scaling the rest of the hydrograph to match the volume generated by the rainfall event, this methodology will provide a reasonable estimate of a design storm event which can be loaded into the model using the RTK method. Most commercial computer models can enable this approach.

Figure 3-4 provides an example of a hydrograph using the synthetic RTK Method. This method produces the most realistic flow volume for the given storm event.

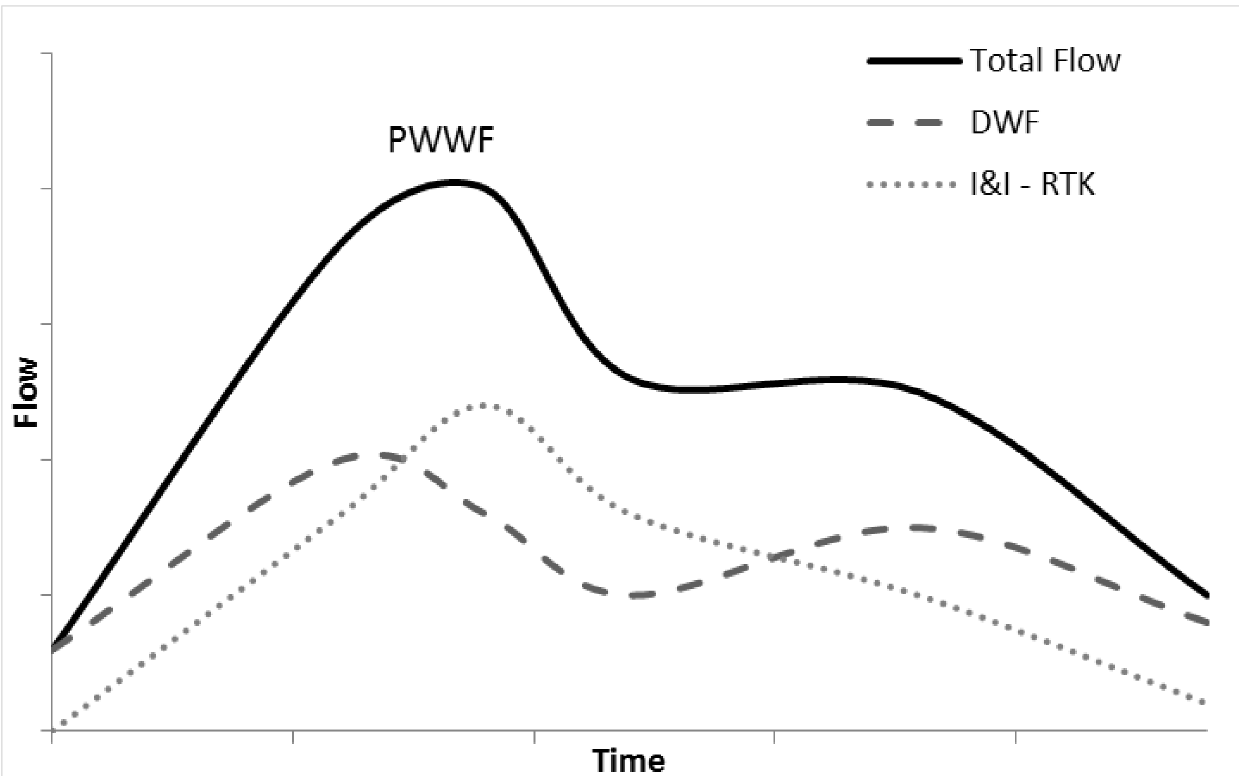

Figure 3-4: Wet Weather Hydrograph, Synthetic RTK Method

3.3.5 Hydrologic Modelling

A hydrologic computer model can be used to simulate the response of sewer catchments to rainfall. Once calibrated using flow monitoring data, the models can simulate historical antecedent moisture and rainfall patterns and run design wet-weather events. A 'design rainfall event' is usually selected to simulate the typical response of each of the basins.

Typically, hydrologic models are complex and require specialist knowledge and significant time to calibrate. Recently, the United States Environmental Protection Agency (USEPA) developed the public-domain Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox. The SSOAP toolbox uses the synthetic unit hydrograph (SUH) approach for predicting RDI&I. Specifically, this approach employs the RTK method to characterize the RDI&I response to a rainfall event. This methodology is currently the only means of characterizing I&I approved by the USEPA.

The free SSOAP software is a powerful means to determine the amount of inflow, fast infiltration, slow infiltration, and groundwater measured in a sanitary sewer as a percentage of rainfall.

3.3.6 RDI&I Hydrograph Analysis

Hydrologic analysis involves examining responses to various rainfall events, and in doing so, paying particular attention to the shape and magnitude of an RDI&I hydrograph, or the slope of an I&I envelope. Any one of the methods described above is capable of assisting in this analysis. I&I components are generally indicated on a hydrograph as follows:

- RII_{slow} – deep groundwater, delayed response to rainfall, attenuated peak occurs up to several hours after peak rainfall, observed as decay toward the end of an RDI&I event;
- RII_{fast} – shallow groundwater, fast response to rainfall, generally only fully developed during saturated conditions; and
- SWI – surface runoff, immediate response to rainfall, presence during dry antecedent conditions can be indicated using I&I envelope.

Rehabilitation methods generally associated with these components can be associated as suggested in Table 3-1.

Table 3-1: I&I Sources and Common Causes

I&I Source	Common Causes	Repair Work
SWI	• Defective maintenance hole cover • Storm-sanitary cross-connection	• Repair defective maintenance hole • Correct storm-sanitary cross connection
RII (fast)	• Defects at upper portion of maintenance hole • Defective service connections	• Plug abandoned service connections • Repair service lateral • Repair maintenance hole
GWI + RII (slow)	• Defects in sewer mainline (cracks, defective joints, etc.) • Defects at lower portion of maintenance hole • Defects at service lateral-mainline interface	• Repair sewer mainline • Repair maintenance hole

Hydrologic analysis alone is generally not sufficient to draw conclusions regarding specific sources of I&I but is most useful for identifying SWI. SWI sources may be identified by examining RDI&I responses to storms after long periods of dry weather, in particular, summertime convective storms greater than 10 to 15 mm in 24 hours. When plotted as an envelope, for example, this will form a ‘lower bound’ line and indicate the amount of SWI present.

If the rain gauge is located within the catchment, comparison between the volume of I&I with total rainfall volume during the dry-soil event will provide a rough approximation of cross-connected area.

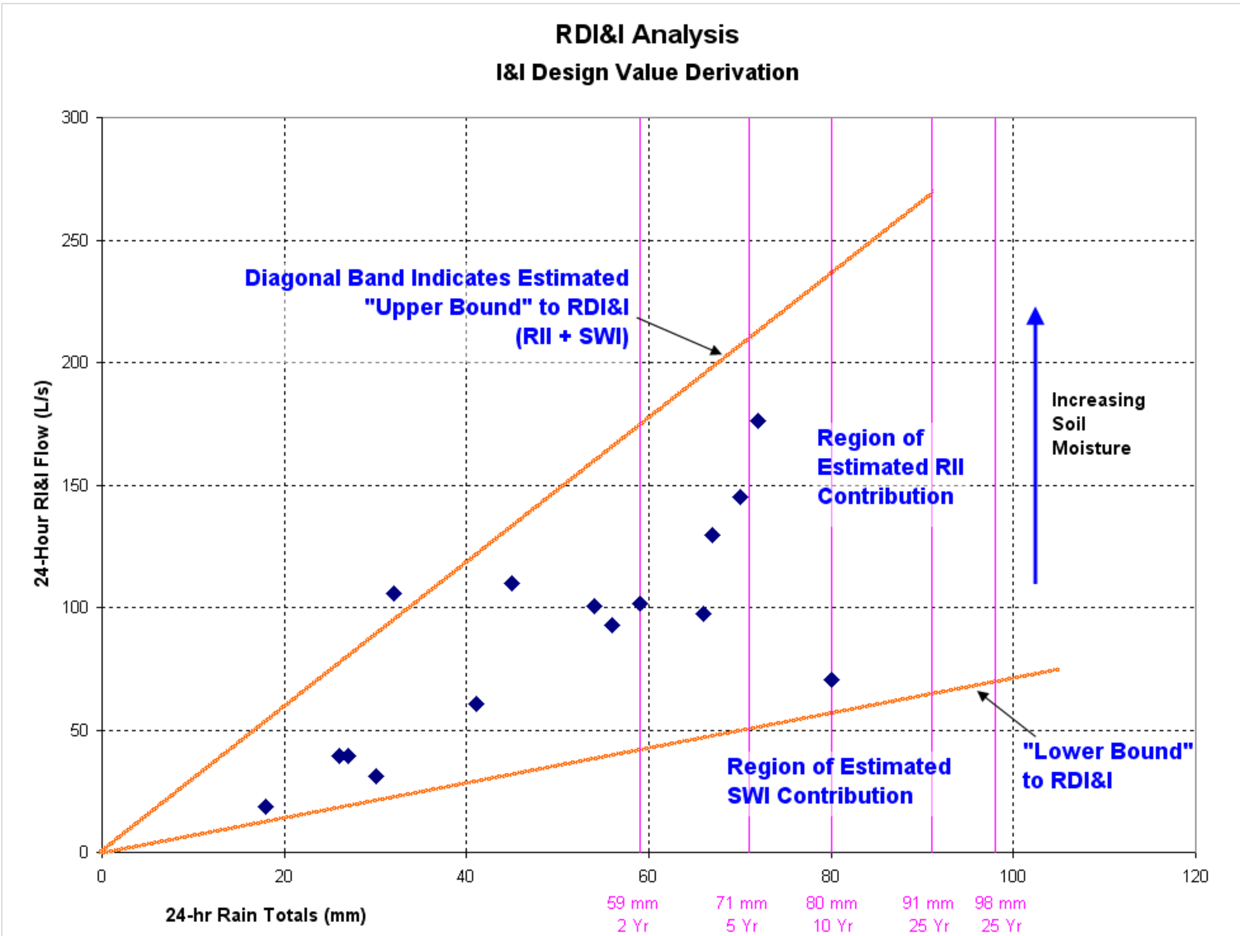

Figure 3-5: Example of Using an I&I Envelope to Identify the SWI Component

If I&I envelopes have been developed, the necessary data to conduct hydrologic analysis is already present. Reviewing storm drainage practices, soils mapping and any knowledge of ambient groundwater conditions is also helpful. Hydrologic analysis requires the time of someone with sufficient experience to review the RDI&I responses to rainfall events. Modelling and/or field investigations would generally be required to verify any assumptions derived from the hydrologic analysis.

4. I&I Management Programs

This section proposes programs and techniques for managing I&I on both private and public property. The section also presents cost information for rehabilitation methods.

4.1 Public and Private Systems

- Private Sewer Laterals: Adopt a structured private sewer renewal program with proper inspection systems. Ideally this is a program that can be integrated into standard operating procedures with minimal oversight. Section 4.2 proposes a shift to a renewal by bylaw adoption system.
- Public Sewers and Maintenance Holes: Simplify the approach to rehabilitation programs so it is easy to understand what needs to be done in a given catchment and city-wide.

4.2 Private Sewer Lateral Rehabilitation and Replacement

Private sewer laterals include the portions of the system not owned by the public utility. Most of the private sewer connections in Metro Vancouver are detached residential buildings and are relatively simple systems. Multiple-family residential, residential strata and non-residential buildings may involve more complex systems. Properties with sewers that collect multiple buildings may be considered similarly to public sewer systems with similar components.

4.2.1 Components

Private sewer laterals generally include the pipe connection from a building sewer to the property line. In newer areas, a cleanout or inspection chamber will typically be provided at the property line as a point of demarcation. Older systems may not have these features. Common components in most detached residential systems include:

- sewer pipe, which may be any number of materials and typically a minimum size of 100 mm;
- one or more cleanout(s), which may be located inside or outside the building; and
- an inspection chamber, typically located at the property line and has a larger diameter than the sewer pipe to allow for visual inspection.

The private sewer lateral should be considered as a system from an I&I perspective. The BC Plumbing Code allows foundation drainage to be connected to a building sewer, and other building drains may be incorrectly connected to the building sanitary sewer. Most sewer use bylaws prohibit such connections, but these may be present due to historic conditions or insufficient inspections.

4.2.2 Inspection and Testing

There are several methods for inspection and testing available, but all require permission from the property owner to conduct the following:

1. Visual – a CCTV camera can be inserted into a sewer lateral through a cleanout or launched from a robotic camera in the sewer mainline if geometry permits. The Lateral Assessment Certification Program (LACP) is a protocol developed by National Association of Sewer Service Companies (NASSCO) that is similar to the de facto PACP inspection standard but tailored for lateral sewers. More commonly a push camera operated by a non-certified inspector may be used to identify

problems in sewer laterals due to blockages or other issues. Use of visual methods to assess I&I issues in sewer laterals requires high quality video capture and standardized defect coding as LACP or PACP provides. Visual inspection is also combined with dye testing to verify sources of flow;

2. Smoke/Vapour Testing – vapour testing can identify leakage from infiltration under non-saturated soil conditions and sources of inflow where vapour escapes the system. This method can also indicate improperly vented plumbing systems if a vapour plume is not produced from the building vent stack;
3. Dye Testing – if there are known points of inflow or infiltration to be tested, dye can be used to determine whether the source flows into the sanitary building drain and verified visually using a camera inserted in the line or at an inspection chamber or maintenance hole downstream;
4. Air Testing – air testing may be limited in application in private portions of sewer laterals unless a testing bladder can be inserted at both ends of the lateral sewer. Systems used to test the mainline and service interfaces are discussed in Section 4.5. Air testing is considered a very effective means of identifying infiltration issues if the test can be performed, but the type of pipe material should be considered due to potential for damage from testing; and
5. Hydrostatic Testing – this method is more commonly used in new construction and involves filling the pipe with water between cleanouts and pressurizing to a specified elevation above the highest point in the lateral. Observable water loss should be minimal to none.

A certification program for lateral condition is not currently available. The following table lists the methods and criteria used by selected jurisdictions in North America with private lateral certification programs in place. As noted, the smoke and dye method is not used for certification, but is nonetheless useful in diagnosing problems.

Table 4-1: Examples of Private Sewer Lateral Testing and Certification Programs

Program	Trigger	Visual	Smoke/ Dye	Air Test	Hydrostatic Test
City of Santa Barbara (CA): (SLIP) [1]	• Overflow • New construction > 400 ft^2 or addition of 2 plumbing fixtures • City inspection identifies issue • For properties identified as Commercial, Industrial or Common Interest Development (≥ 3 dwelling units), required every 10 years by municipal code	Yes	N/A	N/A	N/A
East Bay Municipal Utility District (CA) [2]	• Property Sale • Building Permit > $100k • Change in Water Meter size • Voluntarily	N/A	N/A	Yes	Yes
City of Golden Valley (MN) [3]	• Property Sale • Occupancy Permit	Yes	N/A	N/A	N/A

References:
[1] Sewer Lateral Inspection Program (SLIP): https://www.santabarbaraca.gov/gov/depts/pw/resources/slip/default.asp
[2] Private Sewer Lateral (PSL) inspections: https://www.ebmud.com/wastewater/private-sewer-laterals/
[3] I&I Inspections Program: https://www.goldenvalleymn.gov/358/Inflow-Infiltration

4.2.3 Rehabilitation Methods

Property owners are typically responsible for rehabilitation and replacement of the private portion of the sewer lateral, which must be installed to BC Plumbing Code and any applicable municipal bylaw requirements. Potential options for rehabilitation could include:

- open cut replacement;
- CIPP lining;
- pipe bursting; and
- directional drilling (boring) (new).

Refer to Appendix E for detailed description of methods.

When a private lateral is rehabilitated or replaced, there is a critical opportunity to correct I&I-related deficiencies such as foundation drainage.

4.2.4 Private Sewer Management Programs

Metro Vancouver conducted extensive reviews of private sewer lateral programs in 2008 and 2012. [20] This included regulatory and incentive approaches.

Regulatory Approaches

- Municipal Bylaw – may require that private sewers be kept in good condition and specifies enforcement measures and fees. They are municipal sewer bylaws that forbid cross connections. Orders can/are issued requiring homeowner to correct and bring connection into compliance with the bylaw.
- Provincial Regulation – would be needed to create new powers for local governments to regulate sewer laterals, for instance at point of sale.
- Expropriate Laterals – would involve expropriating all sewer laterals and the municipality assuming responsibilities for maintenance and replacement. Would involve large expense and increase to utility fees.
- Insurance Program – typically focused on covering sewer backup costs and would not reduce I&I on a widespread basis.
- Lateral Condition Certification – would be implemented through bylaw structures and require that a sewer lateral condition certificate be obtained.

[20] Private Sewer Lateral Programs: A Study of Approaches and Legal Authority for Metro Vancouver Municipalities, 2008, The Sheltair Group and West Coast Environmental Law

Incentive Approaches

- Subsidies (Rebates and Loans) – similarly to other municipal rebate programs (e.g., low-volume water fixtures), property owners could be incentivized to maintain and replace sewer laterals by accessing rebates or loans from the municipality.
- Property Tax Exemption – property taxes or utility fees could be discounted for qualifying properties, likely requiring some form of certification.
- Provincial Tax Exemption – this could involve a reduction in property transfer taxes or other provincially-administered tax at the time of a property sale for qualifying properties, likely requiring some form of certification.

Some of the above measures have been considered for implementation in several Metro Vancouver municipalities. The City of Vancouver and City of Surrey, for example, have mandatory requirements in place for sewer lateral replacement based on building permits. Potential impediments to successful implementation of the above measures have included:

- lack of political support for point-of-sale trigger mechanism;
- provincially regulated issues such as building code may require changes to provincial acts and powers available to local governments; and
- organizational burden to administer any or all of the above measures.

It is recommended though that one of the following private lateral replacement measures is adopted as part of an I&I Management Plan:

Lateral Replacement – New Construction and Building Permit Trigger

As mentioned above, both the City of Surrey and the City of Vancouver have adopted this approach. The approach is based on a trigger based on a certain building permit dollar amount. A set of conditions and actions are required to ensure that the service is either operating within reasonable limits or it is replaced.

Figure 4-1 highlights the basic attributes of both bylaws.

Excerpts from the City of Vancouver Program

2.2 NEW PUBLIC SEWER CONNECTION FOR CONSTRUCTION - Subject to Section 2.9, a new public sewer connection is required whenever:

(a) **a new house** or building is constructed, or

(b) an existing house or building is renovated, and the estimated construction value is more than:

(i) **100% of the latest building assessment (from the BC Assessment Authority), or**

(ii) **$95,000, whichever is the greater,** and the work involves:

(iii) extensive excavation work,

(iv) enlargement of the plumbing system by adding two or more fixtures,

(v) an increase in the number of bedrooms, or

(vi) a resulting increased demand upon the existing sewer system after renovations are complete.

Excerpts from the City of Surrey Program

39. When there is an application to redevelop a parcel, the following shall apply to the service connection and the building sanitary sewer:

a) If the service connection or the building sanitary sewer is **less than 30 years old**, the owner must provide **a video inspection** from a pipe **assessment certification program (PACP)** certified contractor and recommendation for the City to review. The owner shall repair or replace the service connection or the building sanitary sewer, or both, if the City determines that: it contains defects or deficiencies, including excessive damage; is not in adequate condition for service; does not meet the City's Design and Construction Standards; or is made of materials other than PVC;

b) If the service connection or the building sanitary sewer **is 30 years old or older and is made of materials other than PVC, a replacement or new service connection or building sanitary sewer, or both, is required**;

c) If the service connection or the building sanitary sewer is **30 years old or older and is made of PVC**, the owner must provide **a video inspection from a PACP** certified contractor and recommendation for the City to review. The owner shall repair or replace the service connection or the building sanitary sewer or both, if the City determines that it: contains defects or deficiencies, including excessive damage; is not in adequate condition for service; or does not meet the City's Design and Construction Standards;

d) **Despite Sections 39(a), (b) and (c), all no-corrode, asbestos, cement, clay or otherwise non-standard material pipes of any age or condition shall be replaced with PVC** or an alternate pipe material approved by the City;

e) Despite Sections 39(g) and (h), renovations to an existing building on a parcel **where the combined building value is less than or equal to $120,000 are exempt from the requirements of this Section 39;**

Figure 4-1: Private Lateral Replacement Bylaws Based on Building Permit Triggers

Lateral Replacement – Certification Method

Based on the noted challenges in implementing a universally applicable sewer lateral certification and replacement program, the following practices are recommended:

1. Incentive-based method with certifications required, which would involve inspection and testing as described in Section 4.2.2;
2. Base utility rate for non-certified sewer laterals or expired certifications, which could be stepped up over time once a program is in place and property owners have been given time to comply;
3. Utility rate discount for certified sewer laterals. Provide automatic certification for PVC services less than 30-years old;
4. Premiums added to utility rate if City determines private lateral to be in bad condition due to side shot CCTV inspection or observation port inspection;
5. Enhanced premiums added to utility bill for combined connections provided a functional storm sewer is available. Rebates are offered for separation; and
6. Consider working with home insurance companies to provide additional incentives for certified laterals.

Determining an appropriate premium and discount structure would need to be done by each municipality.

4.2.5 Key Actions Needed

Several actions are required to implement the program described above:

1. Adopt a Lateral Replacement Bylaw: either the Building Permit Trigger Method or the Certification Method;
2. Determine what methods and resources will be used to inspect the new service;
3. For cities with significant VC laterals and partially separated connections, consider the Certification Method and/or other tools available to municipalities as laterals may be replaced on a timelier basis; and
4. Develop public-side stormwater servicing plans to address areas with partially separated private sewer-laterals.

4.3 Public Sewer Main Rehabilitation and Replacement

This section generally refers to gravity sewer pipes. Pressurized pipes are not considered an I&I source.

4.3.1 Components

Public sewers consist of the following components:

- Mainline Pipe – which may be segmented/jointed or continuous;
- Lateral Interface/Connection – where sewer laterals enter the main pipe, with a fitting, saddle, or break-in type connection; and
- Public Sewer Lateral – portion of the sewer lateral within the public right-of-way and maintained by the public utility.

4.3.2 Inspection, Testing, and Condition Assessment

Sewer mains are most often inspected for I&I condition using CCTV, and in some cases air testing, which is typically paired with pressure grouting.

The PACP is currently used by most utilities for CCTV. The specific version of PACP used for inspection will depend on the date of the most recent inspection. PACP is analogous to the previously used WRC Manual of Sewer Condition Classification and can be roughly though not equivalently converted unless the video footage is re-coded in the PACP system. PACP uses a structured visual observation and coding system to describe sewer condition. Coding Categories include the following:

- **Structural**: Cracks, Fractures, Breaks, Holes, Deformations, Joint offsets, Surface Damage;
- **Operations and Maintenance**: Attached Deposits, Settled Deposits, Roots, Infiltration, Obstacles, Vermin;
- **Construction Features**: Taps, Alignment Changes, Access Points, Intruding Sealing Materials; and
- **Miscellaneous**: Water Levels, Camera Underwater, Photographs, Material Changes, Shape Changes, Sags, Survey Abandoned.

Each observation in an inspection run is assigned a code, which may or may not be 'scored' using a five-point scale. A pipe inspection can then be evaluated in terms of the peak, total or 'quick' score. Appendix G describes the PACP method in detail. It is proposed that the PACP method be adopted as the method of scoring for the 2022 I&I Management Plan. Of interest, the Canadian Standards Association (CSA) had adopted the PACP as a new standard for condition assessment but has recently discontinued this standard.

Air testing may be completed using a robotic crawler to test pipe joints and service interfaces for airtightness. The air test is typically accompanied by grouting for locations that fail. Grouting can be an effective way to reduce infiltration if conducted on a widespread basis.

4.3.3 Rehabilitation Methods

- Point Repairs.
- Grouting.
- Partial Reconstruction – coincide with paving programs, replace, and seal top portion of maintenance hole.
- Lining.
- Pipe Bursting
- Full Replacement.

Refer to Appendix E for detailed description of methods.

4.4 Inflow Identification and Repair

4.4.1 Overview

Stormwater Inflow (SWI) occurs when there is a direct connection to the sanitary system from a surface or piped system that contains runoff from rainwater. Many times, these connections were deliberate and legal at the date they were installed, but sometimes they are a result of accidental cross-connections with a drainage water source. SWI sources are a concern as they are highly sensitive to rainfall intensity and can significantly burden a sanitary system's capacity. SWI is often confused with rainfall-induced infiltration (RII) as the response times to rainfall are similar, but the mechanisms for entry are different. RII is an indirect connection that must first flow through soil meaning that the soil is saturated and able to hydraulically pass water. It is this difference (dry soil conditions) that allows SWI to be isolated from RII and allows SWI to be identified.

Examples of Inflow sources include:

- catch basins,
- roof leaders,
- paved areas around potential spill areas such as gas stations,
- lawn basins, and
- overflows from storm sewers.

SWI connections are common when there is a deficiency in the drainage system such that a drainage service is unable to connect to the storm sewer system (i.e., due to an elevation difference or lack of formal drainage network). SWI connections are also common in areas with partially separated sewers where only one pipe leaves the property. In any case, SWI connections need to be identified and separated. If a properly functioning storm sewer is available at sufficient depth, the disconnection of SWI connections from the sanitary sewer represents one of the least expensive I&I reduction procedures available to a municipality.

4.4.2 Identification

Traditionally, SWI connections are identified through smoke and dye testing programs or through observations in service cleanouts or observation ports. Unfortunately, these programs sometime miss SWI connections when the smoke or dye becomes trapped and unable provide a positive result. More recently, side-launch CCTV cameras have been used to audit and trace all connections. These programs also have limitations and can be expensive to administer. The key to any program though, is to know the extent of the SWI connections in a basin before embarking on a field program. If field tester knows the surface area of the SWI sources in the basin, they can audit the SWI connections found such that the areas equate.

As discussed in Appendix A, measuring the extent of SWI contributing surface area can be accomplished through a summer and early fall flow monitoring programs when soil conditions are dry. Capturing small to medium sized rainfall events with an ongoing flow monitoring program allows the total tributary area of the SWI connections to be calculated if there is a rainfall gauge within the basin. There will be an initial abstraction of roughly 2 mm, but with a minimum of three events measured, an area can be calculated. This area will then determine the objective of the field programs. If the tributary area matches the area identified in the field investigation programs, the field programs are successful. If they do not match, additional effort and cost is required to overcome the various catchment conditions.

4.5 Maintenance Holes

4.5.1 Components

A maintenance hole is a vertical structure typically consisting of the following components (bottom to top):

- Base;
- Barrel;
- Lid OR Cone/Corbel;
- Riser;
- Frame; and
- Cover.

Maintenance holes have been constructed using a wide variety of materials and methods, with modern systems being primarily pre-cast reinforced concrete with segmental barrels. From an I&I perspective each of the components has different considerations for I&I and each interface between sections is a potential point of infiltration.

4.5.2 Inspection and Testing

Maintenance hole inspections have historically been conducted using visual assessment without entry to the maintenance hole. The Manhole (maintenance hole) Assessment Certification Program (MACP) method involves using a winch-mounted camera that is suspended over the maintenance hole opening and lowered into the maintenance hole, at which point a coded observation inspection method similar to PACP is applied.

I&I in maintenance holes can be assessed using visual methods to identify possible I&I from observations such as staining, encrustation or other structural issues, but this will not allow for quantitative assessments. Hydrostatic testing is feasible if the maintenance hole can be isolated but requires large amounts of water and bypass pumping and is best used in new construction. Low pressure air testing is possible but likely of limited value as a tight seal is very difficult to achieve.

The riser, frame and cover are often weak points due to poor construction quality and vulnerability to external loading that may damage or displace components. The cover is a source of inflow through the vent holes and maintenance holes located in low drainage areas or open ditches should be investigated for susceptibility to flooding by surface runoff. The riser and frame are often sources of shallow infiltration, especially if the structure has settled or the pavement around the frame is cracked. Maintenance hole covers that have an open grate design should be systematically replaced in sanitary sewer systems.

The deeper components (barrel, base) are mostly subject to infiltration, which will tend to occur at joints or interfaces between sections. Brick maintenance holes may be encountered in older areas and observations of mortar damage or displacement of bricks may indicate potential I&I problems.

Signs of surcharging are also indicative of overall I&I problems but are not necessarily attributable to maintenance holes themselves.

Inspections should therefore focus on these types of observations noting that it is difficult to observe I&I visually during peak wet weather flow conditions, and that inspections often occur during dry weather. MACP inspections will accurately describe structural and operational condition, and the video footage provides a superior basis for visual identification of other I&I indicators.

4.5.3 Rehabilitation Methods

Maintenance holes require specific treatments based on the observed I&I conditions. Maintenance holes by definition allow for entry, which opens up a wider range of rehabilitation options and products than pipes. These may include the following:

- Point Repairs;
- Grouting
- Partial Reconstruction – coincide with paving programs, replace and seal top portion of maintenance hole;
- Lining; and
- Full Replacement.

Many of the grouting and lining systems are manually applied from inside the maintenance hole, resulting in minimal disruption. A wide range of cementitious, polymeric or hybrid products are available which must be applied by qualified installers to achieve the desired quality.

4.6 New Assets

4.6.1 Design

Most municipalities in Metro Vancouver use MMCD or a modified version as the design standard for new sewer systems.

4.6.2 Inspection

New systems are typically inspected as per MMCD or modified design requirements. This includes CCTV inspection, mandrel testing (roundness) and may include air or hydrostatic testing.

New private laterals are inspected by building/plumbing inspectors and must meet current code requirements. Compliance with sewer use bylaws should be considered at this stage including prevention of foundation drainage connections.

4.7 I&I Rehabilitation Program Costs

This section describes the cost-incurring elements of an I&I rehabilitation program. The activities that generally comprise a program are the investigation, and the rehabilitation efforts on the mainline, the laterals, and the maintenance holes. Note that the PACP scores and grades referred to in this section are described in Appendix G, Table 1-1. The unit cost of each piece, which may be used in estimating the costs of a rehabilitation program, are summarized in Table 4-2.

4.7.1 Investigation

Flow Monitoring

Flow monitoring is the most important component of I&I management programs. Flow monitoring requirements are discussed extensively in earlier sections of this report.

Flow monitoring at a given location should occur for at least six months duration during the wet weather season, and if SWI is a concern, extend to nine to twelve months. This allows the SWI component to be observed in relative isolation during unsaturated soil conditions.

CCTV Program

- Complete CCTV inspections with certified PACP inspectors for all assets from maintenance hole to maintenance hole.
- Perform desktop review of CCTV inspection data using PACP asset and defect scoring systems.
- Prepare maps displaying CCTV findings (Structural and O&M Scores, Material, Inspection coverage, Defects, etc.).
- Develop rehabilitation and I&I reduction plan from reviewed data and maps.

Smoke Testing

Determine locations where storm sewers are connected to the sanitary system, pipe failures, and blockages.

Dye Testing

Can be used to confirm suspected cross connections by dosing dye into the suspected storm connection and monitoring the downstream sanitary system.

4.7.2 Mainline Rehabilitation

Excavated Point Repairs

Specifically targeting grade 5 defects that cannot be remedied with trenchless methods.

Trenchless Point Repairs

Short length CIPP used to target locations of heavy infiltration, effects such as infiltration runners/gushers, or to cap abandoned services.

Joint Air Test + Grouting

Crawler mounted grouting unit that uses inflatable bladders to air test joints. Joints that fail the air test will have pressurized grout injected until the joint passes the air test. This can be done to the entire basin or target locations with infiltration codes at joints.

CIPP Lining

Target assets with high total scores but without defects that would prevent lining. Targeting continuous or repeated defect codes such as cracks, fractures, infiltration, or attached encrustation.

Bursting

Target assets with high total scores that have defects that may prevent lining such as offset joints. Bursting also provides an opportunity to increase the asset diameter to allow for a higher capacity than the existing main.

Replacement

Where an asset's condition or capacity requires excavated replacement over trenchless rehabilitation.

4.7.3 Lateral Rehabilitation

CIPP Lining

Lining can be accomplished with the presence of an inspection chamber or other access point at the property line. Lateral liners with mainline wraps in conjunction with mainline CIPP provide a sealed system with no joints available for I&I.

Bursting

Provides an opportunity for upsizing service laterals or can be accomplished where lining is not feasible. Requires access pits at the mainline and the property line.

Service Interface Air Test + Grouting

A crawler with two mainline bladders and a lateral bladder that are inflated to perform an air test on the service connection of a service. All connections that fail the air test are grouted until the test is passed.

Service Grouting

Lateral grouting for the full length of the service from mainline to property to seal joints and prevent I&I.

4.7.4 Maintenance Hole Rehabilitation

Injection and Cementitious Grouting

Cementitious grouting repairs superficial interior damage to maintenance hole walls and helps prevent infiltration and root growth. Injection grouting provides a waterproof barrier to prevent infiltration of groundwater through the maintenance hole barrels.

Maintenance Hole Replacement

Full replacement provides a new maintenance hole built to modern standards with rubber gaskets at each barrel joint and fresh grout at all inlet and outlet locations, preventing infiltration.

4.7.5 Rehabilitation Cost Summary

The following costs are based on data compiled by contractors and public tenders over the last 10-years with prices escalated to 2021.

Table 4-2: Cost Summary

Component	Bare Costs (2021$)	Engineering (%)	Contingency (%)	Total Cost	Range (+/- %)	Unit(1)
Flow Monitoring	$15,000	incl.	20%	$18,000	+/- 20%	/6-months /catchment
CCTV	$8	incl.	20%	$10	+/- 20%	/m
Condition Assessment	$1.70	incl.	20%	$2	+/- 20%	/m
Rehabilitation Program Development	$4.20	Incl.	20%	$5	+/- 20%	/m
Smoke Testing	$4	incl.	20%	$4	+/- 20%	/m
Dye Testing	$3	incl.	20%	$4	+/- 20%	/m
Storm Sewer Improvement	$2,352	20%	40%	$3,800	-50%/+100%	/m
Point Repairs	$11,592	20%	40%	$18,500	-50%/+100%	/m
Pipe Grouting	$92	20%	40%	$150	-50%/+100%	/m
Pipe Replacement	$790	20%	40%	$1,300	-50%/+100%	/m
Pipe Relining	$571	20%	40%	$900	-50%/+100%	/m
Pipe Bursting	$958	20%	40%	$1,500	-50%/+100%	/m
Maintenance Hole Rehab	$3,528	20%	40%	$5,650	-50%/+100%	/each
Maintenance Hole Rehab(2)	$50	20%	40%	$80		/m
Maintenance Hole Replacement	$13,944	20%	40%	$22,300	-50%/+100%	/each
Maintenance Hole Replacement(2)	$198	20%	40%	$320	-50%/+100%	/m
Service Lateral Grouting	$3,528	20%	40%	$5,650	-50%/+100%	/each
Service Lateral Grouting(2)	$97	20%	40%	$160	-50%/+100%	/m
Service Lateral Relining	$9,240	20%	40%	$14,800	-50%/+100%	/each
Service Lateral Relining(2)	$255	20%	40%	$410	-50%/+100%	/m
Service Lateral Pipe Bursting	$9,240	20%	40%	$14,800	-50%/+100%	/each
Service Lateral Pipe Bursting(2)	$255	20%	40%	$410	-50%/+100%	/m

Notes: (1) /m denotes length of collection system mainline. (2) to convert from “/each” to “/m” (mainline), a conversion factor was used: there is roughly 70 m of mainline pipe per MH, and 36 m of mainline pipe per service lateral.

5. I&I Rehabilitation Plan: Prioritization, Costing, and Evaluation Programs

This section summarizes the items that comprise an I&I Rehabilitation Plan and also proposes new measures to focus I&I reduction efforts. In addition, the section provides guidance on developing cost estimates for budgeting.

5.1 Methods

The Previous 2011 I&I Management Plan

The 2011 I&I Management Plan Template recommended a Prescription or Goal Based rehabilitation program based on severity of I&I. The previous template also proposed the following Tier system for rehabilitation:

- Tier 1: Mainline and Interface Repairs;
- Tier 2: Public Lateral Repairs; and
- Tier 3: Private Lateral Repairs.

The 2022 update intends to refine this further by being more specific on the types of measures required based on the I&I rate measured and adopting city-wide measures that target specific actions. Tiers 1 and 2 are incorporated into a new 'Archetype' method of prioritization, and Tier 3 is replaced with full-scale implementation and enforcement of one of the proposed two sewer lateral renewal bylaws.

City-Wide Measures

The common components of city-wide measures in an I&I Management plan include the following:

1. Delineation of catchment areas for the entire municipal sewerage area. As noted in Appendix A, the size of the catchments should range from a minimum of 20 ha to a maximum of 300 ha (preferable range is 50 to 150 ha);
2. Flow monitoring to identify I&I rates in all catchments every 10 to 15 years:
    a. As discussed later in this section, the flow monitoring timeline and frequency depends on the catchment age and whether or not I&I is believed or known to be 'above' the I&I-age curve; and
    b. Catchments with older pipes or I&I rates suspected to be above the I&I-age curve should be prioritized for flow monitoring and I&I assessment within 10 years.
3. CCTV inspection of all linear sewer assets on a maximum 20-year cycle (more frequent for assets in poor condition with higher PACP scores);
4. Tracking of I&I rates using the I&I-Age relationship;
5. Characterization of I&I components through I&I Analysis Methods presented in Section 3 and/or field programs;
6. Identification and delineation of areas with partially connected (partially combined) private laterals. Areas with foundation drains connected to the sewer lateral and/or areas with a combined sewer/storm lateral, should be identified. A screening process to identify these types of areas was proposed in the report: *Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow*

and Infiltration Source, June 2016, Metro Vancouver. Targeted I&I rehabilitation programs should not be scheduled for these areas until a functional drainage system/storm sewer has been constructed;

7. Adoption of a Lateral Replacement Bylaw: either the Building Permit Trigger Method or the Certification Method. Determine what methods and resources will be used to inspect the new service. For cities with significant VC laterals and partially separated connections, consider the Certification Method and/or other tools available to municipalities as laterals may be replaced on a timelier basis; and
8. Implementation of Asset Management Programs that replace sewer pipe at the end of its service life. This could be defined in multiple ways within the program and could include specific pipe material with significant deterioration due to ground conditions (i.e., AC pipe), pipe types with ages requiring significant and costly on-going repairs (i.e., VC pipe), etc.

Targeted Catchment Measures

In addition to the City-Wide measures outlined above, some sewer catchments will continue to 'not act their age' and have disproportionate I&I responses relative to other catchments with similar pipe ages, materials, and construction methods. These catchments should be identified and prioritized for catchment rehabilitation programs. The programs are not intended to be full-basin rehabilitation programs whereby the asset life is reset to new, but rather programs that identify and target the defects in a catchment that allow the I&I response to be greater than its age.

The common components of targeted catchment measures in an I&I Rehabilitation plan include the following:

1. Using the I&I Envelope Method and I&I age relationship results developed in the City-wide Measures above, identify catchments that are outliers from the curve (i.e., 'not acting their age') for the 5-year, 24-hour I&I rate;
2. Using the 'Archetype Classification System' proposed in the next Section, identify the recommended I&I reduction programs to undertake and develop a cost estimate of catchment rehabilitation costs using the guidance in the Archetype Classification System;
3. Prioritize the importance of initiating rehabilitation works in the basin based on 5-year, 24-hour I&I rate, downstream pipe capacity deficiency, downstream SSO contribution, or exceedance of ADWF multiplier (i.e., greater than 2 to 4 x ADWF). Schedule basin into capital plan;
4. Develop and undertake a rehabilitation program based on the recommended procedures identified in this report; and
5. Conduct iterative follow-up flow monitoring (to determine program effectiveness and to evaluate next rehabilitation steps) and successive rehabilitation works until target is achieved.

It is important to highlight that targeted catchment measures **should not** be implemented on basins with partially separated service laterals where it has been proven that the drainage system is unable to service the building foundations. The contributions from these connections will reduce the effectiveness of any achievement made. Partially separated sewer catchments could require significant investments in storm sewerage/drainage improvements in order to be effective. These improvements should be made first.

It is also important to note that the rehabilitation of separated sewer laterals is proposed to be handled by one of the two Lateral Replacement Bylaws. Again, as recommended above, for cities with significant VC laterals or deteriorated AC laterals, the Certification Method should be considered for an earlier replacement program.

5.2 I&I Archetype Classification System

I&I Archetypes

It is proposed that the 2022 I&I Management Plan Template introduce a concept known as the I&I Archetype Classification System. This system was also adopted by the Capital Regional District (Greater Victoria) in 2012.

The archetype classification is designed to do the following:

1. Prioritizes which catchments should be investigated for I&I rehabilitation work; and
2. Provides high level budget and planning estimates in the absence of actual sewer investigation data and detailed rehabilitation plans.

The I&I Archetype System noted in this section guides the municipal process in a particular basin but is then superseded by actual rehabilitation plan developed by the municipality. Of interest, once a catchment has been fully rehabilitated (Archetype G and including the services), the catchment's average age is reset to zero and the process begins again. If only the public sewers are rehabilitated in Archetype G, then the catchment age can only be modified based on the public sewers. For Archetype D to F, the catchment age is not modified after rehabilitation as the goal is to return the I&I response back to 'acting its age'.

Seven categories of archetypes were developed. Figure 5-1 shows a typical graph used to determine what archetype a catchment is in based on the catchment's average sewer age (x-axis) and its 5-year 24 hour I&I rate (y-axis).

Average age is calculated by the following formula:

$$\text{Catchment Age} = \frac{(\text{sum of public sewer pipe age x length}) + (\text{sum of private lateral pipe age x length})}{\text{Sum of public sewer length + sum of private lateral length}}$$

The key to the I&I Archetype process is the 'I&I versus Age' relationship line developed in Section 2. This line is based on more than one hundred Greater Victoria and Lower Mainland sewer catchment areas and past rehabilitation efforts. It establishes if a catchment is 'acting it's age' or not. If a catchment plots on the line or below it, the catchment is acting its age and no significant I&I rehabilitation is recommended. If a catchment plots significantly above the line, it is not acting its age, and it is highly likely that I&I investigation efforts will be successful. Conducting substantial I&I rehabilitation on catchments plotting below the line will likely yield high $/L/s reduction costs based on experience from other municipalities. Further, if full basin rehabilitation is conducted prior to the end-of-life catchment age, the long-term funding of the utility asset management plan will be at risk.

Table 5-1 summarizes the characteristics of each archetype including a typical list of rehabilitation actions needed and a per meter budget number to complete the work. The rehabilitation percentage and costs referred to in Table 5-1 are based on actual catchments in the southwest BC and northwest Washington area where rehabilitation work was completed, and a cost estimate provided. The costs should also generally represent the unit costs in Table 4-2.

More detail on the actual data behind each archetype is provided in Appendix G. It should be noted that the costs for rehabilitation in Archetypes E, F, and G include items for the rehabilitation of sewer laterals (both the public and private side). As discussed in Section 4.2 above, the rehabilitation of service laterals has now shifted to renewal by bylaw adoption rather than targeted basin approaches. However, the costs for lateral renewal have still been incorporated in Appendix G and is up to the municipality to decide if they wish to include these costs in their budgeting process.

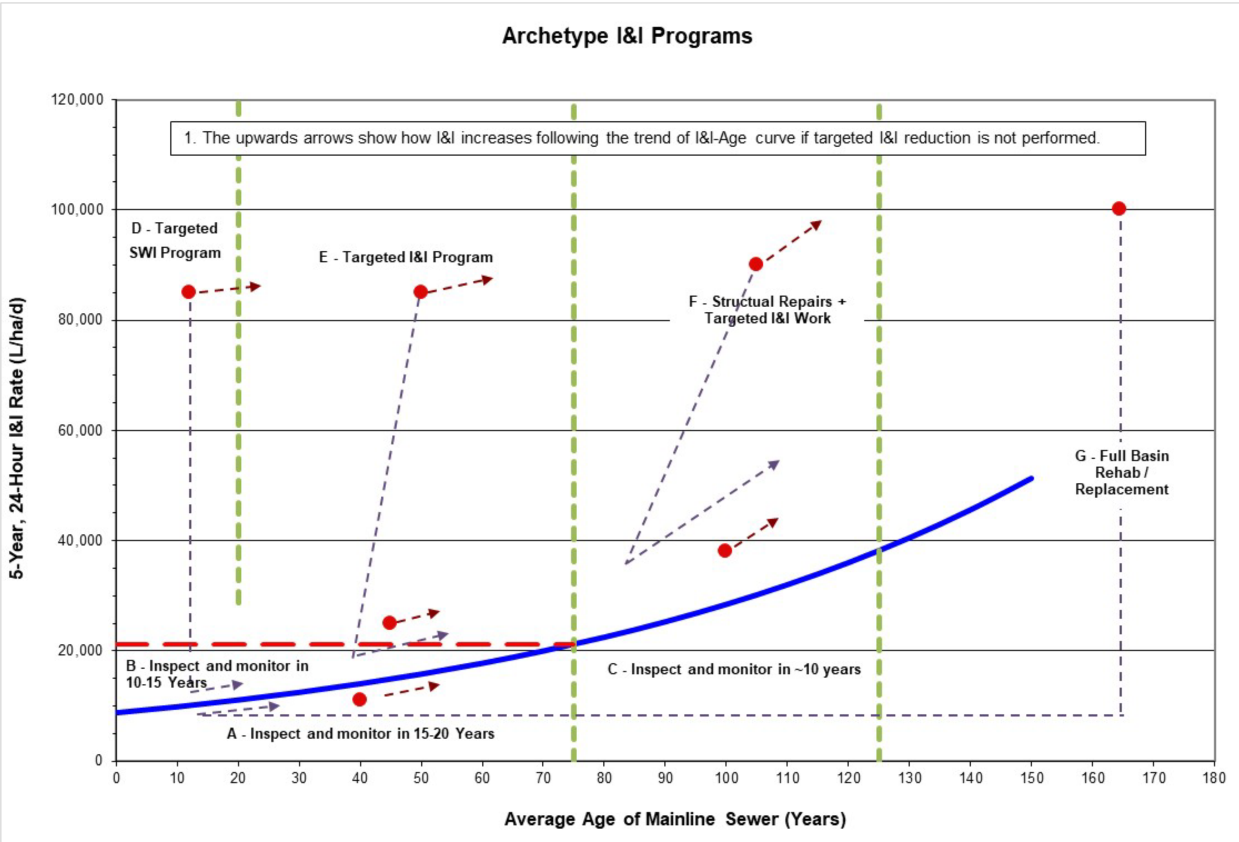

Figure 5-1: Graph Used to Classify Catchments into Archetypes

I&I Archetype Application

The implementation of the I&I Archetype Process can be described by the following steps:

1. Divide the municipality into sub-catchment areas;
2. Conduct Flow Monitoring and CCTV inspections in each catchment;
3. Use the I&I Envelope method to derive 5-year, 24-hour I&I rates from the flow monitoring data;
4. Calculate the average age of the catchment using the formula above;
5. Plot the catchment on Figure 5-2 to determine the recommended archetype;
6. Develop a budget estimate for the rehabilitation work using Appendix G; and
7. Develop a plan for a catchment.

For some catchments, particularly in younger sewerage areas, the course of action may be as simple as conducting some routine maintenance on a concern raised by the CCTV inspection. In older catchments, where the average age has not reached the end-of-life threshold (determined by an asset management plan), additional structural and targeted I&I programs will likely be required.

Table 5-1: Archetype Overview

Archetype	*Phase 1: Data Collection*	*Phase 2: Investigation Work (per cent of collection main lineal metres)*	*Phase 3: Rehabilitation Work (per cent of collection main lineal metres)*	*Estimated Component Costs (2021) ($/m)**
A	Flow Monitoring and Analysis (ongoing)	CCTV (100%) Condition Assessment and Rating (15-20 years)	Point Repairs (0.1%)	$31/m *Plus $18k for flow monitoring + I&I analysis*
B	Flow Monitoring and Analysis (ongoing)	CCTV (100%) Condition Assessment and Rating (10-15 years)	Point Repairs (0.1%)	$31/m *Plus $18k for flow monitoring + I&I analysis*
C	Flow Monitoring and Analysis (ongoing)	CCTV (100%) Condition Assessment and Rating (~ 10 years)	Point Repairs (0.1%)	$31/m *Plus $18k for flow monitoring + I&I analysis*
D	Flow Monitoring and Analysis (ongoing)	CCTV and Condition Assessment (100%) Program Development Smoke Testing Dye Testing (20%)	Point Repairs: 0.1% Maintenance Hole Rehab: 2%	$30-50/m *Plus $36k for full-year flow monitoring + I&I analysis*
E	Flow Monitoring and Analysis (ongoing)	CCTV and Condition Assessment (100%) Program Development Smoke Testing: 100% Dye Testing: 20%	Point Repairs: 0.1% Maintenance Hole Rehab: 2% Pipe Grouting: 94% Pipe Relining: 5% Pipe Replacement: 1% Lateral Relining: 40% Lateral Pipe Bursting: 20% Lateral Grouting: 40%	$275-1,100/m *Plus $36k for full-year flow monitoring + I&I analysis*
F	Flow Monitoring and Analysis (ongoing)	CCTV and Condition Assessment (100%) Program Development Smoke Testing: 100% Dye Testing: 20%	Pipe Relining: 20% Pipe Bursting: 5% Pipe Grouting: 74% Maintenance Hole Rehab: 10% Maintenance Hole Replacement: 5% Point Repairs: 0.5% Pipe Replacement: 1% Lateral Relining: 40% Lateral Pipe Bursting: 20% Lateral Grouting: 40% Storm Sewer Improvements: 5%	$500-2,000/m *Plus $36k for full-year flow monitoring + I&I analysis*
G	Flow Monitoring and Analysis (ongoing)	CCTV: 100% Condition Assessment	Pipe Replacement: 10% Pipe Relining: 60% Pipe Bursting: 30% Maintenance Hole Rehab: 90% Maintenance Hole Replacement: 10% Lateral Relining: 50% Lateral Pipe Bursting: 50% Storm Sewer Improvements: 30%	$1,400-5,600/m

*Note: Cost per metre applied on the entire catchment length (mains only) to estimate total budget needs.

5.3 Implementation

This report has been reviewed by the Regional Engineering Advisory Committee's (REAC) Liquid Waste Sub-committee and comments have been incorporated.

Member municipalities should consider incorporating their I&IMP into sewer system asset management planning to account for future budgetary requirements. The following specific issues may arise:

1. Integrating I&I reduction measures into asset management planning may require a shift from prioritizing rehabilitation works based on pipe condition to a more catchment-focused approach. I&I reduction measures may be less effective if applied in a 'patchwork' manner across a system as opposed to intensively in specific catchments where I&I issues are noted; and
2. Member municipalities are encouraged to review proposed I&IMPs with Metro Vancouver to align I&I reduction activities with regional priorities for reducing SSOs. Areas experiencing significant growth may benefit from capacity gains.

I&I reduction benefits are more likely to be realized over the long term versus immediately. Biennial reports should include a profile of I&I reduction activities using the I&I Archetype Process as well as follow up efforts to show results.

5.4 Template Renewal

The proposed I&IMP Template is a newer approach that has not been used widely in Metro Vancouver. Member municipalities using the template may have feedback or experiences that will lead to future improvements. This should be reviewed during biennial LWMP reporting, periodically through the REAC Liquid Waste Sub-committee and prior to the next LWMP update.

6. Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

For Costing Information

2022-12-02

Permit to Practice #1000696

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Appendix A

Flow Monitoring Program Development

Appendix A – Flow Monitoring Program Development

1. Introduction

The task of laying out a successful flow monitoring program and analyzing the results is complex. The following sections provide guidance on the process, regardless of whether the planning and execution of a flow monitoring program is done entirely in-house, entirely by qualified contractors and consultants, or by a mixture of both.

1.1 Catchment Selection

Assume that the goal is to determine discrete I&I values for catchments within your municipal boundaries.

1. Consider delineating your sanitary collection system into individual catchments. The size of the catchments should range from a minimum of 20 ha to a maximum of 300 ha (preferable range is 50 to 150). Try to group areas of similar pipe material, age, and underlying soil type. If there are areas of partially separated service laterals, try to group those areas together as well. Once these boundaries have been set, it is advisable to keep them intact for the future (i.e., keep consistent catchment area boundaries).
2. Establish a rough budget for the flow monitoring program. As an approximation, use $2,200/site/month for a full-service flow monitoring contractor to supply data for a site. Consider a 6-month period, from mid-September to mid-March, as the period for a winter flow monitoring season. If you suspect there are a significant number of direct inflow connections, consider expanding the monitoring period to collect data during dry soil conditions (mid-June through September). Allow a budget of $4,000/site for data quality assurance and production of the I&I Envelope.
3. Based on your budget, determine the approximate number of sites that can be implemented over the winter season. Your budget may be insufficient for monitoring all of your desired catchments in a given season, but it is useful to have an idea of the number of sites that your organization can afford per year.
4. As a way of addressing budget issues, consider monitoring some catchments as indicators of conditions in larger areas. For example, if you are faced with a need to monitor four neighbouring catchments (all of which have similar pipe age, material, and soil conditions), consider monitoring just one or two initially as indicators of likely conditions in the others. This is only an approximation and experience and when budget permits, the other catchments should be monitored.
5. Decide on the base mapping to be used for catchment delineation. Access to a GIS database will produce the best results. A suggested mapping scheme is:
    a. use an aerial photo with muted colours as the background image, to help you identify land use and large, unsewered areas such as regional parks;
    b. colour pipes by type (AC, PVC, etc.) in order to help distinguish areas with similar pipe material. Alternately or as well, try colouring pipes by their age;
    c. show maintenance holes to assist with selecting potential flow monitoring sites;
    d. overlay subtly coloured contour lines to establish areas with steep grades from those in low lying or flat areas; and
    e. If available, prepare a separate map, replacing the aerial photo with soil type to distinguish between fast and slow draining areas.

6. With base mapping in hand, the goal is to establish catchments with similar pipe materials, age, slopes, and soil types. Delineating catchments with these similar characteristics will increase the odds of finding 'smoking gun' catchments. Choosing catchments with broadly mixed characteristics will likely just produce 'average' I&I results.
7. To a lesser extent, consider land use when delineating catchments. Catchments that mix residential with significant industrial, commercial, or institutional sources can make identifying some components of the I&I difficult, as the dry weather components of the flow are often not as repeatable or predictable as residential areas.
8. Consider catchment size carefully. A good limit for the lower size is 20 to 30 hectares. While achievable, catchments much smaller than this tends to produce too little flow to measure a dry weather signal and have higher solids content. This can result in failure to flush debris from the flow monitoring equipment where rigorous maintenance on equipment is required. Monitoring of a catchment smaller than this may also require special equipment and techniques and should only be used as necessary in specialized pilot projects.
9. On the opposite end of the spectrum, try to keep catchment size under 300 hectares. While there is no hard upper limit to the size of a catchment that can be monitored, eventually the results collected from an excessively large catchment become of little practical value aside from reporting a 'total' I&I value (i.e., totals for each municipality). Factors such as travel times, attenuation, difference in rainfall distribution, and non-uniform pipe characteristics will yield little information to guide targeted repair and replacement programs.
10. Be aware of diversion pipes (both intentionally installed and undocumented), which can 'move' water from one catchment to another during wet weather events. In such cases it is necessary to monitor the diversion flow as well as the main outlet flow for a catchment. These monitors must be operated concurrently in order for the results to be conclusive. If you discover a diversion in a catchment which has already been monitored, you should consider re-monitoring the outlet along with the diversion simultaneously for true results to be obtained.
11. When drawing catchment boundaries, do not include large unsewered areas (such as regional parks, industrial areas such as gravel pits or large material storage yards), rail yards, etc. (especially when those areas are on the outside edge of the catchment). These areas do not contribute to I&I and will artificially reduce the stated I&I when expressed as an area-weighted value.
12. It is generally acceptable to leave in smaller neighbourhood parks and school yards in a catchment. A rule of thumb is that when a catchment is viewed as a whole on the map, it should not include visually obvious non-contributing areas.
13. Use other information such as planned upcoming developments, known replacement programs, current pipe condition, and need for computer model calibration data to assist in prioritizing areas to monitor. Could others use the data for model calibration? Will flow estimates for bypass pumping be required during a replacement program? Alternate funding sources may be identified to assist in monitoring costs, which would also allow for the flow monitoring data to serve additional needs beyond I&I measurement.

1.2 Technology Selection

When the process of delineating catchments is complete, begin to identify potential maintenance hole for monitoring. A brief understanding of the usual measurement technologies is helpful for this and can be broadly broken into four categories for temporary monitoring programs.

1. Area-velocity meters – these units are intrusive (a sensor is placed in the flow, usually at the bottom of the pipe). Different sensors measure the depth and velocity of the sewage, and the meter then calculates the flow rate using the principle of continuity (cross sectional area of water multiplied by velocity equals flow rate).

   Uses: Generally, works best in shallow grade pipes with uniform flow. Overall, the most economical.

   Disadvantages:

   - Will not work on steep sites with low depth and high velocity.
   - Should be avoided in pipes above 600 mm in diameter as velocity tends to under-report or overcompensate.
   - Depth sensor may drift overtime.
   - Requires extensive field maintenance, as they are subject to debris fouling.

2. Weir/flume – specially shaped weirs and flume inserts are available for temporary deployment, having proven fairly reliable at remaining clear of debris. The sensor used is often a downward facing ultrasonic to measure the water level behind the weir. Examples of these types of stations exist in the Lower Mainland that have been running continuously for years with little maintenance.

   Uses:

   - Weirs generally work best at steeper slopes (has been used successfully at grades up to 15%). Shallow slopes are better suited for flumes.
   - Tends to require less maintenance but with slightly more upfront cost.
   - Can collect flow data from two or more inlets simultaneously.
   - Weirs in particular have good low flow resolution.

   Disadvantages:

   - Backwater pool can cause gravel and grease buildup on shallower grade sites.
   - Requires more extensive installation at each site.
   - Not well suited for sites that surcharge.
   - Reduces flow capacity of the pipe.
   - Weirs are not suitable for larger diameter pipes such as interceptors where head loss across the weir would be unacceptably high.

3. Non-Contact Area Velocity Meter – non-invasive sensors hang in the maintenance hole barrel and shine down on to the water surface to measure level and surface velocity, from which flow is computed.

   Uses:

   - Little maintenance is required as the sensor is above water and not susceptible to fouling.
   - Most pipe grades where ease of maintenance is desired.
   - Can handle larger diameter pipes.

   Disadvantages:

   - Average velocity measurement is inferred from surface velocity. Requires calibration with manual site profiling measurements if high accuracy is required.
   - Limited functionality in surcharge conditions without additional add-on components.
   - Relatively expensive when compared to Options 1 and 2.

4. Acoustic Doppler Profiling Meter – invasive sensor that sits at the bottom of the pipe, similar to an area-velocity meter. High power sensor and acoustic binning allow the unit to handle large diameter pipes and flow asymmetry.

   Uses:

   - Large diameter (up to 6 m), and/or significant flow asymmetry.
   - Recommended for permanent flow monitoring sites.

   Disadvantages:

   - Relatively expensive compared to Options 1 and 2.
   - Difficult to install.
   - Highly recommend installing permanent power for permanent operations.

Choice of equipment is dictated by site conditions, available budget, and equipment availability (either rental or purchase). Ultimately, an experienced flow monitoring specialist should approve the technology selection for each site, based on their experience and professional judgement.

1.3 Site Selection

With catchments delineated, begin to select maintenance holes for each site. Consider the following:

1. Regardless of which technology is used, all flow monitoring sites benefit from a straight through maintenance hole with no contributing laterals or other disturbances. Always opt for this configuration if available;
2. Avoid maintenance holes with significant bends. It is possible to monitor sharp bends, if necessary, by using weirs or monitoring inside the upstream pipe;
3. Avoid maintenance holes with contributing laterals. It is possible to monitor in these maintenance holes, if necessary, by using weirs to either include or exclude flow from the lateral;
4. Consider traffic control issues for installation, maintenance, and removal of the equipment. When possible, choose a maintenance hole that would not require traffic control for access;
5. In many areas within Metro Vancouver, the municipal collection system flows down a steep grade into the Metro Vancouver sewer, which is often laid at a flat grade. Many of the Metro Vancouver sewers were designed to surcharge, so choose sites that are high enough up the hill to stay out of the surcharge zone of the Metro Vancouver sewer. Look for any evidence of surcharge when doing the field check of each site (toilet paper and other debris hanging from the rungs is a common sign of a maintenance hole that surcharges and should be avoided);
6. Never rely purely on the desktop site selection exercise. Always have a field inspection of each maintenance hole done prior to final selection to ensure that any unforeseen circumstances are avoided prior to site installation. Sites that are particularly dirty or greasy should be power washed and flushed prior to site installation;
7. In many areas locating the maintenance hole can be problematic. Some maintenance holes have been covered over by repaving, while others may be lost in a right of way overgrown with blackberry bushes. In other locations, the maintenance hole may simply never have been built even if it is shown on a GIS system; and
8. Be wary of bolted maintenance hole lids. On some systems (especially Metro Vancouver's), bolted lids are often a sign of a system that surcharges. Other lids may be bolted to eliminate odour complaints, or to prevent metal theft.

1.4 Personnel Selection: Contractor or In-house

Within Metro-Vancouver, there are municipalities that contract out their flow monitoring needs and others that use in-house staff. There are pros and cons to each, and in some cases a mixture of both may be useful. This decision is an individual choice for each municipality based on policy, staffing levels, and available budget. Consider the following when deciding to develop an internal flow monitoring services team:

1. Installing and maintaining sanitary flow monitoring sites is a two-person job. During many phases of installation and removal, confined space entry procedures must be followed mandating two staff members. Additional crew may be needed if traffic control requirements for the site dictate;
2. Minimum equipment consisting of a vehicle, confined space entry tripod, blower with generator or invertor for ventilation, harness, traffic signage, fitted mask, and gas detector with pump is required for confined space entry. In addition, each member of the crew should have undergone a confined space entry/supervisor course and be currently certified as such. Gas detector maintenance must be undertaken, and bump tests done daily;
3. Owning and maintaining sewage flow monitoring equipment is an ongoing cost that escalates as time goes on. It is not unusual for sensors to need calibration after every season, typically an ongoing cost that is best handled by shipping the equipment back to the factory for recertification. Loss or damage of equipment due to theft, sewer surcharge, and incoming debris is a common occurrence;
4. Specific staff should be dedicated to the task, otherwise poor-quality data will likely the outcome. Ongoing maintenance including battery changes, calibration checks, site documentation, and inspection/cleaning must be undertaken ritually. If this work is being done in-house, timely data QA/QC must also be done by in-house staff to avoid collecting an entire season of poor-quality data;
5. Many techniques including onsite calibration checks are best done by well-practised staff, both to ensure accuracy and repeatability of the data. Senior staff should oversee junior staff until satisfied that the knowledge gained through years of experience is passed on;
6. All staff that work around sewers should have Hepatitis A and B vaccinations and refer to WorkSafe BC for a list of additional health and safety precautions;
7. A laptop, preferably field fitted, is required to program and retrieve data from the flow meters. Even flow monitoring units that use wireless services to send their data to a central server still need initial programming that requires a laptop;
8. Train your staff to recognize and step back from a site or situation that is beyond their abilities, either due to safety concerns or lack of appropriate monitoring equipment. In these cases, it may make more sense to hire a dedicated flow monitoring contractor, to take advantage of their experience and specialized equipment;
9. A current safety plan must be prepared and kept onsite with staff at all times. The safety plan outlines the procedure to be performed, the conditions under which the crew can operate and those under which they must cease operations. A site permit must be filled out ahead of each installation during a tailgate meeting, and the completed documentation kept for auditing purposes; and
10. If bypass pumping is not conducted during installation, WorkSafe BC Section 9.22 Requirements for Municipal Manhole (Maintenance Hole) Confined Space Entry must be met for all confined space entries.

1.5 Contractor Qualifications

If the decision is made to hire a contractor to perform the flow monitoring services, consider the following:

1. Even if the project is small enough to sole-source, prepare a specification so that the contractor clearly understands the scope of the work. Important points to cover in the specification include:
    a. table of the site locations, with alternates if the sites have not yet been inspected for suitability. Clarify if the contractor is permitted to select an alternate site with final approval from the program manager;
    b. indication of which technology is suitable and pre-approved for installation;
    c. period of monitoring;
    d. format, method, and frequency of data delivery;
    e. required reports;
    f. quality control expectations;
    g. traffic management costs (if applicable); and
    h. payment terms relative to percentage of good data.
2. Appendix B is provided which contains sample specifications for a typical temporary flow monitoring program;
3. If tendering the work, ensure an understanding of what each contractor is providing in order to ensure comparable pricing. Some contractors focus on raw data delivery with little or no data manipulation, while others employ dedicated engineers or technologists to ‘scrub’ the raw data into a final product. If the latter is the case, always ensure that the unfiltered raw data is also delivered alongside the final data, along with clear explanations of what was done to the final dataset;
4. Request and check a recent list of references;
5. Verify your insurance requirements against the contractor’s coverage well before the start of the monitoring season. Pay special attention to coverage for accidental and sudden environmental releases, and also to total amounts for comprehensive. Most contractors can obtain extra insurance as needed but this process takes time and additional funds;
6. Verify the contractor is trained and approved to conduct confined space entries and WorkSafe BC Section 9.22 Requirements for Municipal Manhole (Maintenance Hole) Confined Space Entry is met; and
7. Review the data in a timely manner, not just for payment purposes but to ensure that problems that occur are rectified early in the monitoring season. Utilize techniques from the next section to assist in your data review.

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Appendix B

Flow Monitoring Program Development

Appendix B – Flow Monitoring Specification

Part 1 Sample Flow Monitoring Specification

1.1 Scope of Work

.1 The City is undertaking sanitary sewer flow monitoring as part of its sewer assessment and performance program.

.2 The Work to be performed is described as:

a. installation and operation of temporary flow monitoring sites (and associated reporting of sanitary flow) at seven maintenance holes for a period of five-months during the winter of 2010/2011.

b. traffic control per site, as required.

.3 The sites are located within the City, and most are categorized as steep slope, high velocity sites (slopes from 3-15%, with full-pipe velocities from 2-5 m/s). Some sites require monitoring of the combined flow from two laterals. These sites are listed in the table in Section 1.6. The Tenderer shall visit each of the pre-selected sites prior to submitting their Tender to familiarize themselves with the existing conditions, dimensions, and limitations.

.4 Pricing is required for the complete set of installations as described above as shown in the Schedule of Prices.

1.2 Schedule

.1 The target date for having the seven temporary winter stations operational is November 1, 2010. The five-month operating period would then be from November 1, 2010 until March 31, 2011.

1.3 Basis for a Contractual Relationship

.1 This document is a ‘performance specification’. Within it, the City has defined what it requires as deliverables. The Contractor has the flexibility and discretion to determine how the Contract deliverables can be most effectively provided within the spirit of the guidelines presented herein.

.2 The deliverables within this quote include but is not limited to the supply, installation, calibration, and operating of equipment (including data quality assurance) to collect reliable flow data for the operational duration.

1.4 Description of Contract Tasks

.1 The ‘performance specification’ as presented is comprehensive and detailed in describing the contract deliverables. The key points are summarized below to provide an overview of the program requirements:

a. Commissioning of Stations: supply, installation, and calibration of approved equipment to measure sewer flow for the operational period.

b. Station Operation: maintenance and operation of flow monitors for the operational period.

c. Flow Data Reporting: monthly reports in approved format of quality-assured data in graphical (hydrograph) and electronic form to the Engineer (both raw and corrected data to be provided, as well as documentation of calibration procedures).

.2 The Contractor is encouraged to develop innovative and cost-effective ways of providing the deliverables. Approval of methods and equipment by the Engineer is required prior to proceeding with any proposed work.

1.5 Selection of Monitoring Sites

.1 The Contractor is advised that most sites that will be encountered are steep slope, high velocity conditions (slopes from 2-15%, full-pipe velocities from 2-5 m/s). Some sites require monitoring the combined flow from two laterals. Traditional AV meters are not expected to work in most of the encountered sites. As a result, a limited number of approved technologies will be accepted, as detailed in Section 2.

.2 The City has identified the required monitoring sites based on field investigations and the City's information needs. Use of alternate maintenance hole locations for pre-selected sites, or selection of new sites, must be approved in writing by the City.

1.6 Existing Field Conditions

.1 Station numbers, maintenance hole numbers, and pipe diameters are listed in the following table:

Station Name	Mh #	Location Description	Slope	Pipe	Status
Station Name # 1	SM008903	Lane east of Street A south of Street B	5.0%	200 mm	Repeat
Station Name # 2	SM007151	Street C at Street D	6.0%	200 mm	New
Station Name # 3	SM009565	Street E. south of Street F.	4.0%	200 mm	New
Station Name # 4	SM006333	Avenure A, north of Street G.	9.0%	250 mm	Repeat
Station Name # 5	SM001504	Steet H at Street I	15.0%	375 mm	Repeat
Station Name # 6	SM007682	Street J, N of Highway A	12.0%	300 mm	Repeat
Station Name # 7	SM003001	Street K at Street L	7.0%	200 mm	Repeat
Additional Site information required to select equipment shall be collected by the Contractor during a Site visit prior to submitting their quote. Site visit will be requested by the Contractor to the District before the closing date if the Contractor deems necessary. There is no scheduled Site visit at this time.					

1.7 Wet Weather Event Response Time

.1 The Contractor will meet the performance specification for site visits during high flow events, local representation is required. Refer to clause 3.3.

Part 2 Products

2.1 Flow Measurement Methodologies

.1 Due to the hydraulic conditions in many of the proposed sites, the Contractor may only use and install approved methodology and equipment for monitoring steep-slope, high velocity sewer flow. This is limited to weirs with elevated weir crests designed to dissipate the excessive velocity head, and to velocity-area meters that are capable of correctly measuring depth under high-velocity conditions. In either case, the Tenderer must demonstrate that they have successfully used the proposed equipment in previous multi-site, steep-slope, high-velocity conditions. The Contractor is required to submit laboratory documentation that the proposed equipment and methodologies are capable of operating under the anticipated range of conditions.

.2 Pre-Approved equipment is described in Section 2.7.

2.2 Electronic File Formats

.1 Data shall be submitted in monthly comma-separated ASCII files. Tab-separated ASCII files will not be accepted.

.2 File names shall indicate STATION NAME AND MAINTENANCE HOLE NUMBER, month, and year of data contained within. Files shall contain homogeneous month-long data records, starting at the first day of each month at 00:00:00 and ending on the last day of each month at 23:55:00. File names shall indicate the station identification and the month and year of data contained in each file and shall be of consistent format from month to month.

.3 Files shall be provided via email to johnsmith@abc.ca

2.3 Time and Date

.1 All times and dates shall be reported in Pacific Standard Time (PST), synchronised to coordinated universal time.

2.4 Data Recording Frequency

.1 All data shall be recorded at an interval of 5 minutes.

2.5 Data Reporting Frequency

.1 All data shall be reported in electronic files at a frequency of 5 minutes, on even 5-minute increments (i.e., 00:05, 00:10, 00:15 etc.).

2.6 Sewer Flow Reports

.1 Monthly reports shall be provided within two weeks of the end of each month.

.2 Each monthly report shall contain the following information:

a. Site sketch and installation data sheet.

b. Monthly Data files for each site.

c. Documentation of quality assurance procedures, which may include but is not limited to scatter plots (for VA meters), manual flow profiling reports, offset tracking narratives, and site maintenance records.

d. Electronic files as specified containing both raw and corrected data, including correction information and flagging of all suspect data.

e. Confined space entry reports.

2.7 Approved Equipment

.1 Equipment pre-approved is outlined below. Any other equipment proposed is subject to the approval of the Engineer. Approval will not be unreasonably withheld; however, the Engineer must be satisfied that the proposed equipment suits the needs of the City. The Contractor assumes responsibility for the appropriate operation of all equipment.

.2 Weirs pre-approved for use in flow monitoring include designs from the following manufacturers:

a. Southwestern Flowtech and Environmental (SFE).

.3 V-A meter (‘flow meter’) equipment pre-approved for use in flow monitoring includes equipment from the following manufacturers:

a. Detectronic.

b. Hach Flo-Dar.

c. Raven-Eye.

d. ISCO.

e. ADS Triton+ FlowShark CS4 and CS5 sensors.

.4 The Contractor is reminded that these instruments typically have limitations in terms of velocity and depth ranges that must be considered prior to installation. Pre-approval does not warrant that these instruments are necessarily applicable for the sites to be monitored under this Contract.

.5 Equipment pre-approved for manual flow profiling includes:

a. Marsh-McBirney Model 2000.

b. Hach FH950.

c. Sontek FlowTracker.

.6 Equipment pre-approved as ultrasonic level monitors include:

a. ADS Echo.

b. Telog RU35 with Massa ultrasonic module.

Part 3 Execution

3.1 Equipment Installation Approval

.1 Design drawings shall be provided for approval by the City prior to installation of any non-temporary equipment.

.2 Provide information on confined space entry training of installation personnel.

.3 Provide safety plan, including details of confined space entry plan.

.4 Submit Equipment Installation Plan including items 3.1.1, 3.1.2 and 3.1.3.

3.2 Flow Site Calibration

.1 All instruments used shall be calibrated by manual flow (velocity) profiling throughout the full range of flows recorded at each station. Documentation of profiling exercises shall be provided in the monthly reports.

.2 The ‘full range of flows’ is defined as the range of recorded depths of flow from dry weather nighttime low flow conditions up to a minimum of 80 per cent of the highest depth peak wet-weather event flow recorded.

3.3 Site Visits

.1 The sites shall be visited at a frequency appropriate to ensure proper equipment operation to meet the Data Capture specified and for manual flow profiling during wet-weather events to confirm equipment calibration over the range of flows defined.

3.4 Data Capture

.1 The Contractor is required to obtain a data capture of at least 95 per cent of readings over each one-month period. This is calculated as the number of 5-minute recordings reported out of the total number of 5-minute intervals between the start and end of the billing month.

.2 Of the data captured, at least 95 per cent of readings must accurately represent sewer flow after quality assurance and approved correction if required.

.3 The overall capture of approved and usable data is therefore 90 per cent (95 per cent * 95 per cent = 90 per cent).

3.5 Quality Assurance

.1 Data shall be examined by the Contractor and corrected as necessary to provide an accurate representation of sewage flow for all readings. Both the raw and corrected data shall be provided in electronic and hydrograph (for sewer flow) or hyetograph (for rainfall) formats. Documentation of corrections made and reasons for corrections shall be provided in the reports.

.2 The data reported shall be of high calibre and should not require extensive examination or correction by the Engineer. However sufficient data shall be reported to allow the Engineer to fully audit all corrections made by the Contractor.

Part 4 Requirements

4.1 Delivery Costs

.1 The Contractor must include in their submitted prices, all transportation and delivery costs to the Sites for all tools, equipment and materials required to perform the Work and/or to be installed.

.2 Work completed under this Contract will be paid for at the lump sum prices and unit prices set out in Schedule A – Schedule of Pricing.

.3 No claim by the Contractor for extra payment on grounds that Work performed or materials supplied in accordance with the Drawings and/or specifications could not be properly charged to items listed in the Schedule of Pricing will be considered by the District, or prorated costs of a general nature that do not pertain to any one item among all items.

4.2 Mobilization And Demobilization

.1 This item shall include all costs for mobilization and demobilization associated with the Contractor's equipment, Site facilities, and services.

.2 Payment for mobilization and demobilization will be made at the lump sum price shown in Schedule A – Schedule of Pricing. Fifty per cent (50%) of the lump sum price will be paid on the first progress payment certificate due after the Contractor has established the operation and facilities specified. The remaining 50% will be paid upon completion of the Contract and removal of equipment and cleanup of the Work areas to the satisfaction of the Contract Administrator.

4.3 Flow Monitoring Site Installation

.1 This item shall include all costs for locating, delivering to sites, and installing flow monitoring Sites as proposed by the Contractor and accepted by the Contract Administrator. This item shall also include the cost for removal of all equipment, Site restoration and traffic control as required by the District's Traffic Department during the installation.

4.4 Flow Monitoring Equipment Supply

.1 This item shall include all costs for supplying the flow monitoring equipment for each Site. Payment will be made at the lump sum price quoted in Schedule A – Schedule of Pricing and will be made in equal monthly installments over the duration of the Contract.

4.5 Data Reporting and Maintenance

.1 This item shall include all costs, for each station, for collecting, analyzing, and reporting data as required in the specifications. This item shall also include all flow profiling and station maintenance as required and submitting documentation as evidence that these checks have been completed.

4.6 Traffic Control (Provisional Item)

.1 This item shall include all costs, for each station, for providing traffic control for the duration of the project, as required at each location. Where traffic control is not required to operate a specific Site, this payment item will not apply.

4.7 Submittals

.1 Where required in this document, the Contractor shall submit all required information at least five (5) days prior to starting the proposed Work.

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Appendix C

Flow Monitoring Data QA/QC Procedures

Appendix C – Flow Monitoring Data QA/QC Procedures

1. QA/QC Procedures

The purpose of this section is to provide guidance and procedures for reviewing sewer flow monitoring data. Reviewing this type of data is both an art and a science; with regular review and practise it is possible to identify numerous issues with the data early on. Doing so avoids collection of data that would otherwise require complex repair or, worse, be unusable.

Scatter Plots

A traditional method of reviewing flow monitoring data is to plot two variables (level vs. velocity, or level vs. flow) and establish a baseline for normal operation. Then, for example, if the site were to experience a sudden change such as backwatering or sensor shifting, the data would plot off of the 'normal' curve.

In the example in Figure C-1, plotting level vs. flow yields a repeatable scatterplot relationship. A curve fit (such as a polynomial fit) can then be applied to a portion of 'good' data to determine the normal hydraulic relationship for this location. By plotting data to be reviewed against the curve fit, variation from the 'norm' is usually identifiable which can then trigger further investigation to identify the cause.

The scatter plot approach is of limited use for weirs and flumes as plotting the level vs. flow curve will yield the level vs. flow relationship for the weir or curve. However, were the relationship to accidently change partway through a season due to human error or a meter fault, the change would be obvious. See Figure C-2 for an example.

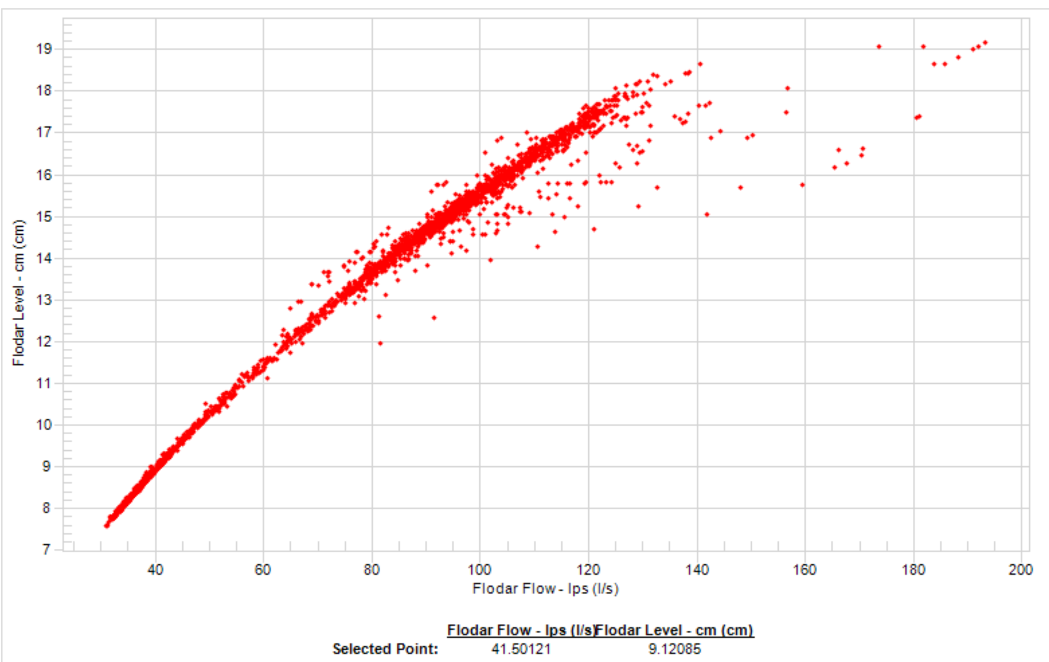

Figure C-1: Example Scatter Plot of Level and Velocity Data

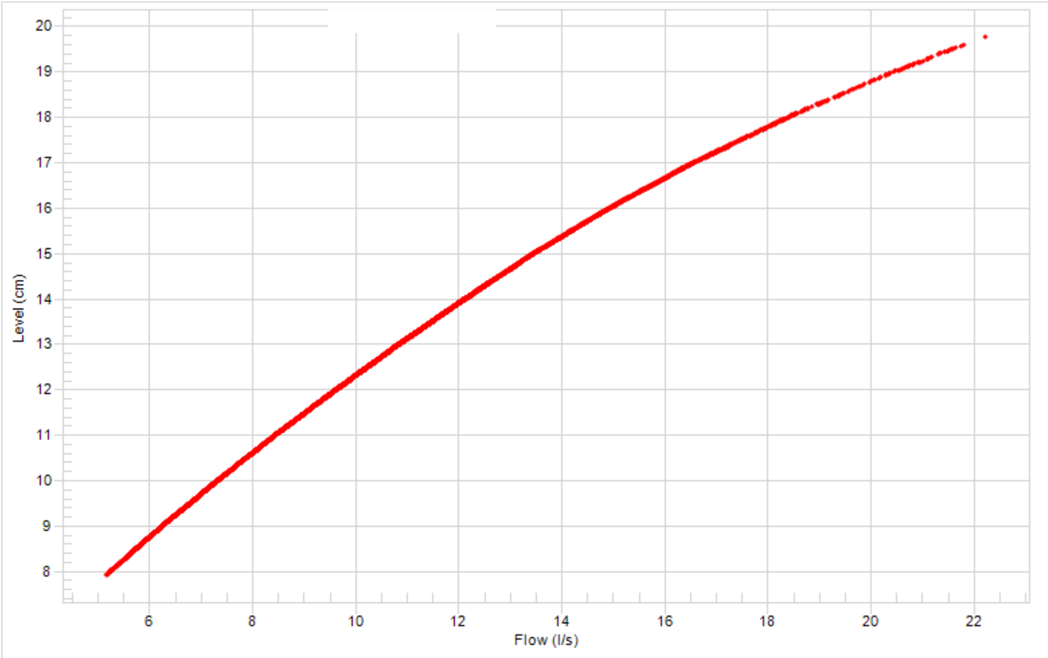

Figure C-2: Example Scatter Plot of a Weir or Flume

Time Series Review

With practise and enough examples, reviewing the data plotted directly as time series (i.e., flow vs. time) is a convenient and quick way to identify issues. The method looks for repeatability in the data. If for example, on a weekly basis, one week of non-validated data is plotted along with the preceding three weeks of validated data, a reference point from which to view the new data is provided. Looking for inconsistencies in magnitude, baseline, etc. routinely will help identify issues and provide possible insight on the issues experienced by the flow monitor or the sewer itself.

The following sections outline some of the common issues that often appear in sanitary flow monitoring data.

Sudden Upward Baseline Shift

A sudden upward baseline shift almost always indicates a weir or flume has become obstructed by an object. Common items like blocks of wood and other types of debris may be stuck onto the flow monitor, affecting the sensor readings. Clearing of the object (either by maintenance staff or self-clearing from higher flows) would restore the sensor back to its original readings. This should be identifiable in the data as shown in Figure C-3.

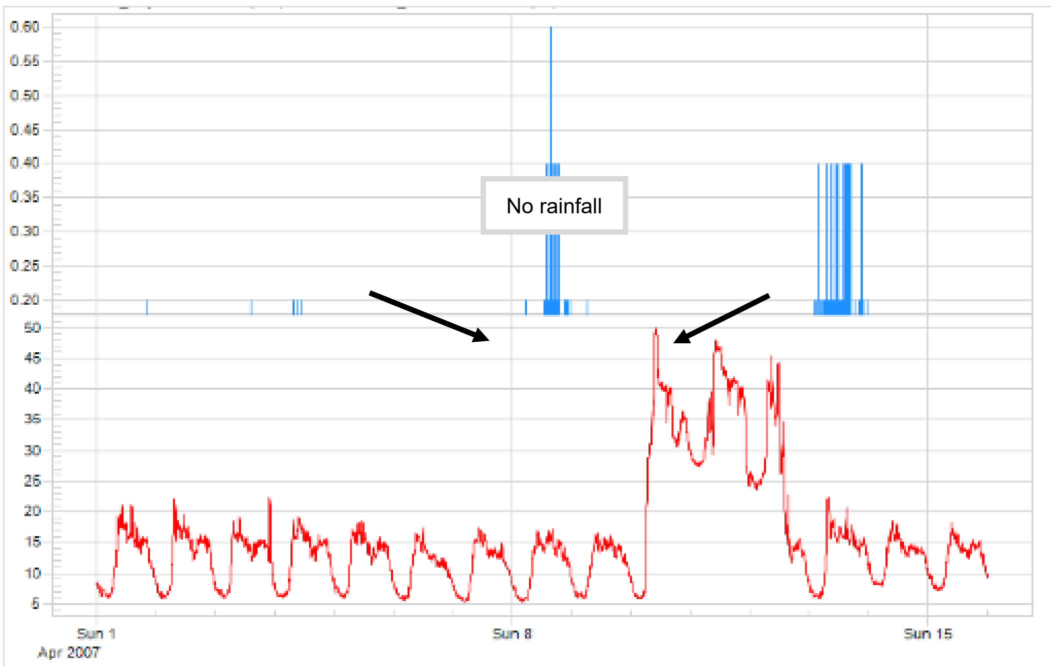

Figure C-3: Sudden Rapid Rise/Fall w/o Rainfall Indicates Likely Blockage and Removal

Benching Interference – Sensor Misalignment

A sudden flattening of the baseline at night during minimal flow periods indicates that an ultrasonic sensor may have been moved out of its installation alignment. If the sensor is not pointing directly downwards onto the sewage level, it may be registering the maintenance hole benching elevation instead as shown in Figure C-4.

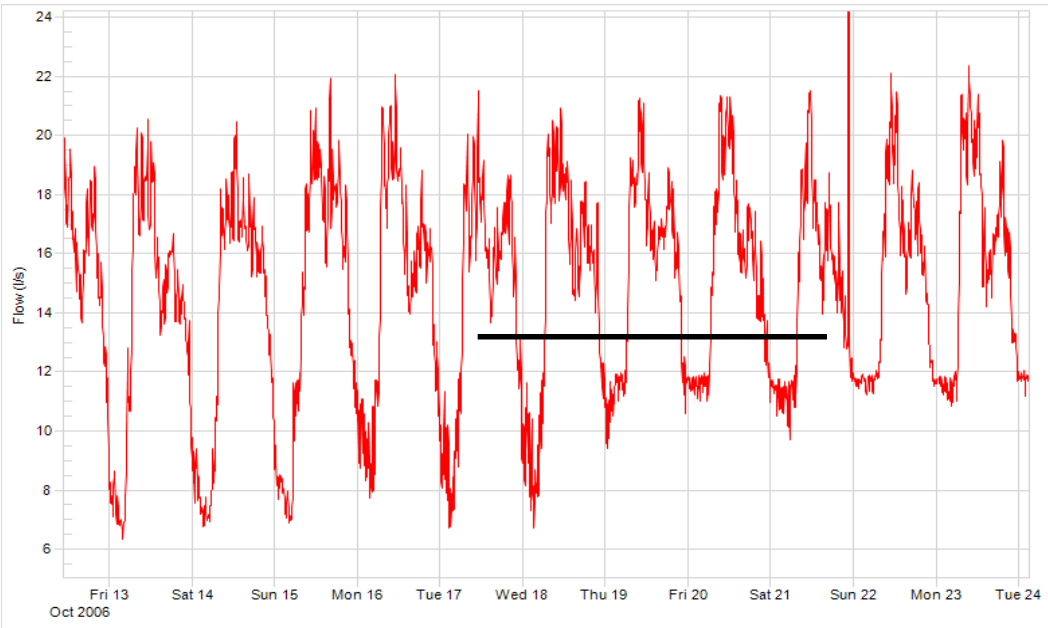

Figure C-4: Sensor Echo Off of Benching from Misaligned Sensor

Gradual Upward Shift

Gradual upward shift is almost always caused by gradual debris build-up, which can include gravel, grease, rags, etc. The upward shift is easily identified by plotting the flow along with the rainfall signal. Baseline shifting due to Inflow & Infiltration (I&I) visually correlates very well with rainfall and its typically varied seasonally. A slow steady increase in the baseline with no identifiable rainfall pattern will usually indicate debris build-up. It is very important that this problem be addressed quickly, as it is difficult to reconstruct the data that has been impacted by a changing debris level.

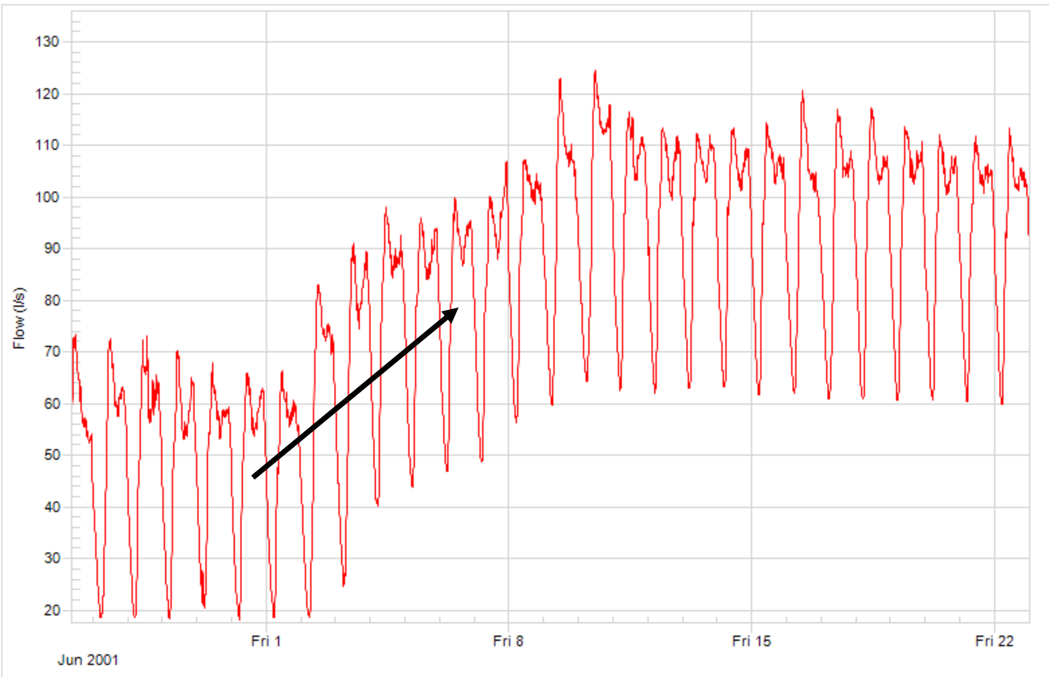

Figure C-5: Gradual Baseline Increase Caused by Debris Build-Up

Magnitude of Baseline Flow

The minimum flows that occur in the middle of the night are usually assumed to be about 85% groundwater, with only about 15% being sewage when the main land use upstream of the flow monitoring station is residential. Even with commercial and institutional uses, these are often focussed on serving people who are asleep at night. As a result, looking for a consistent minimum base flow each night is often an indicator of the flow data is repeatable and consistent with field calibrations. Specifically, a large base flow relative to the magnitude of the daily flow variation can indicate a problem with sensor drift.

One exception is sites that serve mostly industrial uses, which can operate during night shifts and can have fluctuating usages. Therefore, the baseline magnitude is not necessarily an indicator of sensor issues. The latter half of the previous Figure C-6 is a good example of where the baseflow remains consistent during dry weather flow periods and only elevates during a rainfall event but restores subsequently after the rainfall event.

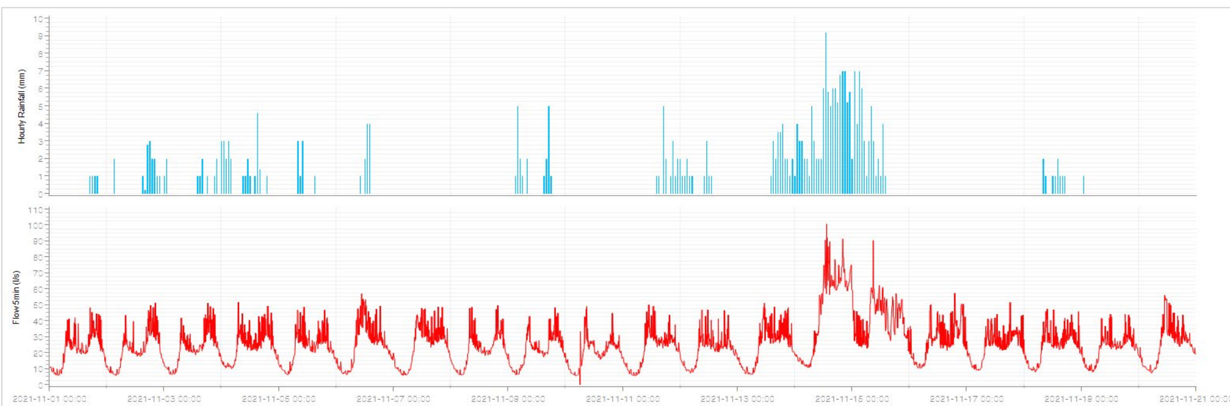

Figure C-6: Issue with Different Diurnal Pattern Magnitude after Meter Repair

Magnitude of Diurnal Variation

Similarly, there is a ‘normal’ range of daily fluctuations in typical land-use applications. When the magnitude of these diurnal variations is too large or too small, or when it suddenly changes, it may be indicative of problems with the data (sensor drift or sensor misalignment). The data difference may also be explained by a new diversion installed within the catchment area. Figure C-7 demonstrates a sudden change in flow signal due to sensor issue but was subsequently restored.

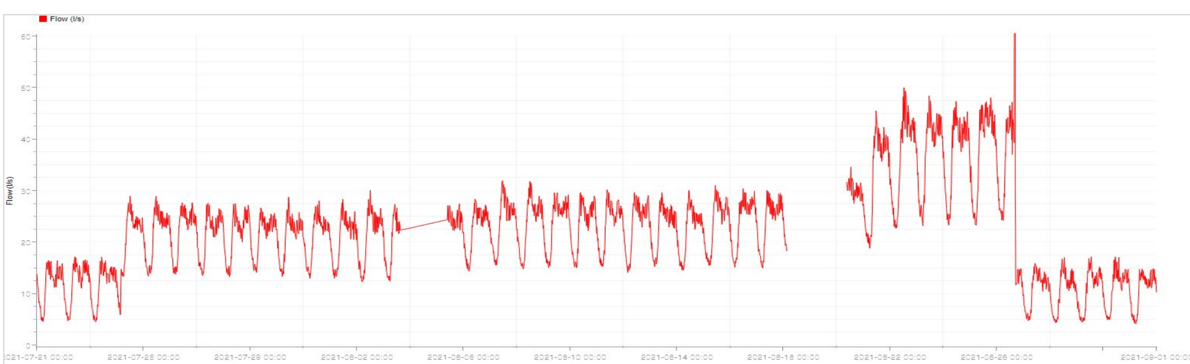

Figure C-7: Issue with Different Diurnal Pattern Magnitude after Meter Repair

Year-Long Groundwater Trend

On sites where longer data collection is being conducted, a year's worth of data is worth reviewing to see how the minimum baseline flow (which is mostly groundwater) has varied over the course of the year. The minimum should occur in August and September. After the first rains in October and November, it is typical to see that the baseline has risen to what could be called the 'winter' value. This will often be noticeably elevated above the 'summer' value. From generally April onwards the value will often decrease back down to the minimum 'summer' value as groundwater levels decrease. Some sites may not show a noticeable change throughout the year, which depends on the ground conditions within the catchment. What is important to look for is a trend in the wrong direction (i.e., summer baseflows higher than winter). See the following figure for an example of a properly working station (the spurious zero readings in August were caused by a temporary meter failure).

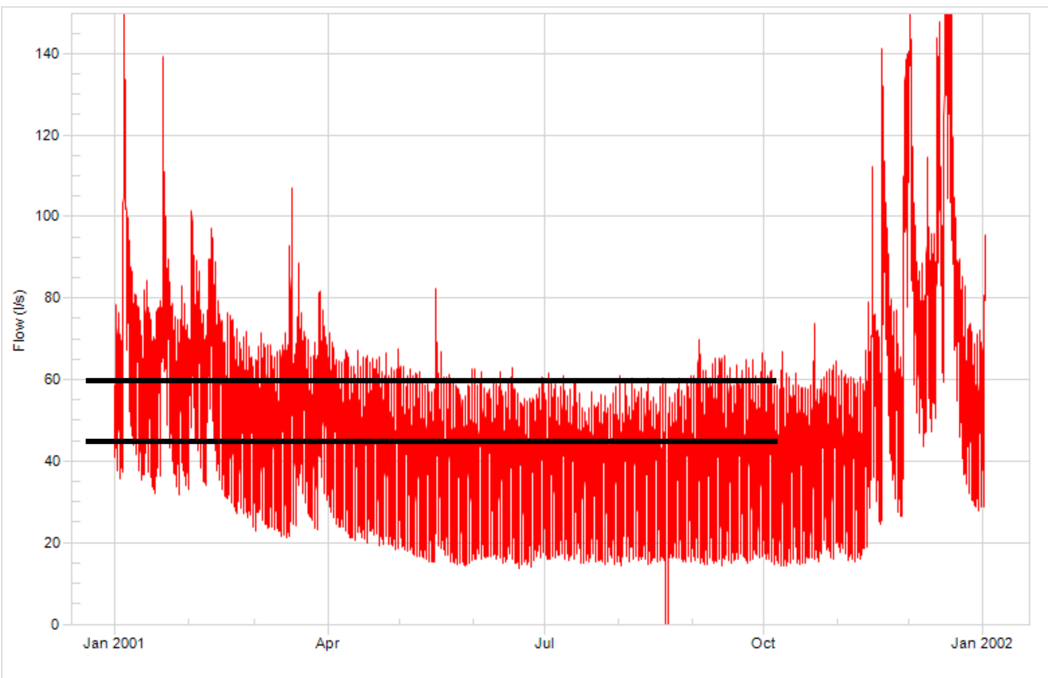

Figure C-8: Typical Summer and Winter Change in Baseflows

Backwatering at Station

On sites where backwatering conditions may be experienced due to downstream capacity issues, it can be seen from the flow meter where there is sudden rise in level while there is a drop in the velocity signal during a rainfall event (the opposite of what is expected from a standard velocity vs level scatterplot). As can be seen from Figure C-9, the level abruptly increased while the velocity signal dropped from its normal range. This indicates the station was experiencing backwatering and clear itself subsequent to the storm event.

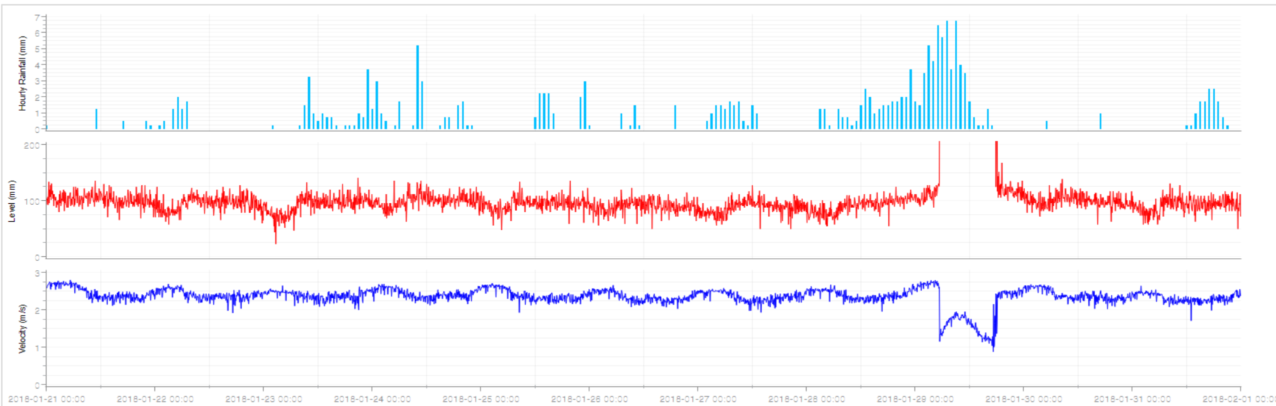

Figure C-9: Sample of Backwatering Hydrograph

Rainfall: Visual Comparison of Multiple Gauges

By far the most common type of rain gauge failure is debris plugging. This is usually easily identified by comparing a given time period against other rain gauges near the area, as shown in the following figure. When preparing such a figure, make sure that the axis scaling is set to the same value for each station, and stack the stations on top of each other for easiest visualization.

Another common indication of a plugged rain gauge is a slow, continual single rain tip repeated at regular intervals, when other gauges clearly show a more dramatic response. This is caused by a very slow leakage of the plugged funnel, as shown in Figure C-10.

Figure C-10: Rainfall Signals from Multiple Stations Showing Plugged Gauge

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Appendix D

I&I Envelope Methodology

Appendix D – I&I Envelope Methodology

This section explains the procedures to apply the I&I Envelope Methodology. It assumes that the dataset is quality controlled and corrected. In order to use the methodology, flow and rainfall data should both be at 5-minute intervals. The rainfall gauge should be the closest gauge that represents the rainfall for the sewer flow monitoring catchment.

1. Purpose

The purpose of the I&I Envelope Method is to use a collection of recorded storm events to create a correlation between the amount of rain that falls in a catchment and the amount of I&I that shows up at the flow monitoring site. Knowing the return period of the rainfall, combined with the assumption that rainfall return period correlates to I&I return, allows the correlation to be used to produce estimates for return period based I&I. This allows catchments that were monitored in different seasons with different storm events to be compared on an 'apples to apples' basis.

1.1 Step 1: Prepare Data for Storm Selection

To begin, prepare monthly graphs of flow with rainfall for the site to be analyzed. Keep the same y-axis scale for each graph and lay them out end to end to see the entire season. In addition, if monthly rainfall summary tables exist lay these out as well. See the following figures for a monthly example of a graph and rainfall table.

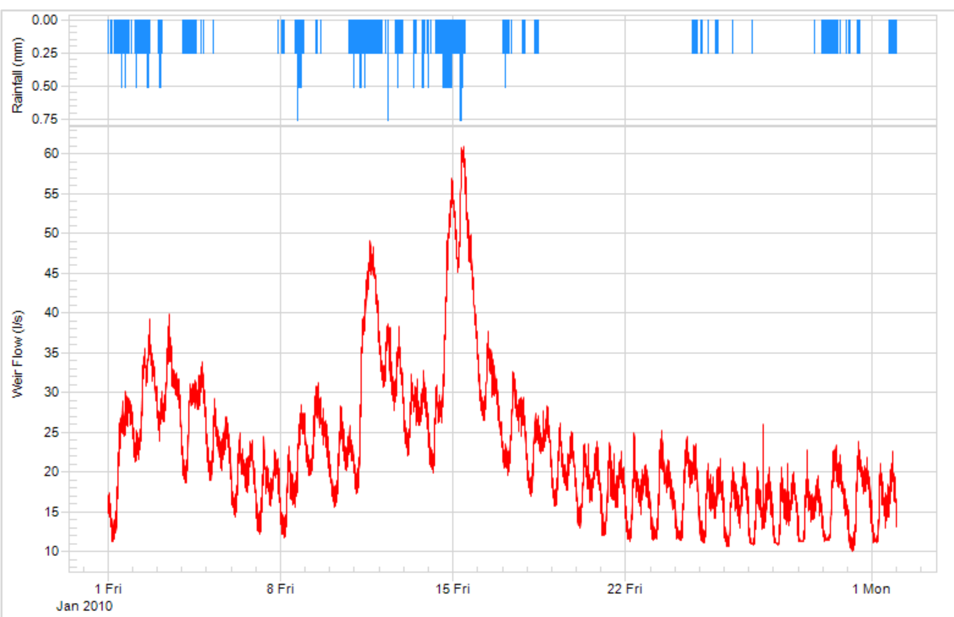

Figure D-1: Typical Monthly Data Plot showing Flow and Rainfall

Hourly Rainfall Totals (mm)

Day #	0 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	21 to 22	22 to 23	23 to 24	Total
1	0.8	.	0.3	0.3	.	0.3	1.3	.	1.0	1.8	1.5	1.5	1.3	2.3	1.5	1.0	2.0	3.0	0.5	0.8	0.8	.	0.5	.	**22.4**
2	.	.	0.3	3.0	1.0	0.8	0.5	0.3	0.8	0.8	1.5	1.0	0.3	0.8	2.0	2.5	0.3	.	.	.	.	.	.	.	**15.7**
3	0.8	1.0	3.6	2.5	0.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**8.4**
4	0.3	0.3	0.5	0.8	0.8	1.0	1.3	1.3	1.3	1.8	1.0	0.5	0.5	0.5	.	.	.	.	0.3	.	0.3	.	.	.	**12.2**
5	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.3**
6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	.	.	**0.3**
8	.	1.3	0.8	1.0	.	.	.	.	.	.	.	.	.	0.5	1.0	0.5	4.1	3.3	2.0	3.3	1.8	1.5	0.8	0.3	**22.1**
9	.	.	.	.	.	.	.	.	.	.	0.3	0.5	.	.	.	0.3	.	.	.	.	.	.	.	.	**1.0**
10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	0.3	0.5	2.3	1.5	2.5	**7.4**
11	1.0	1.8	1.8	1.8	2.5	3.8	3.6	2.5	1.8	2.3	2.8	2.0	2.3	2.8	2.3	1.3	.	1.3	0.3	0.3	0.3	0.5	0.8	0.5	**40.1**
12	0.8	0.8	0.5	0.3	.	.	0.3	.	2.0	0.3	.	.	.	.	.	.	0.3	2.3	2.0	0.5	0.3	.	0.5	.	**10.7**
13	.	.	.	.	.	.	.	.	.	1.5	2.0	0.8	0.3	.	.	.	.	0.5	2.0	0.3	0.5	.	0.3	1.5	**9.7**
14	0.3	0.3	0.3	.	.	.	0.3	.	0.3	0.8	1.3	1.0	1.3	2.5	3.6	3.8	3.8	3.6	2.8	3.0	3.0	3.6	4.3	2.0	**41.7**
15	2.5	1.5	0.8	0.3	0.8	1.3	1.8	6.4	3.8	2.8	2.0	0.3	.	.	.	.	.	.	.	.	.	.	.	.	**24.1**
16	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
17	0.8	1.0	1.8	1.8	0.5	.	0.5	.	.	0.3	.	.	.	.	.	.	.	.	.	.	0.8	1.5	0.5	.	**9.4**
18	.	.	.	.	.	.	.	0.3	1.0	1.8	1.0	.	.	.	.	.	.	.	.	.	.	.	.	.	**4.1**
19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
23	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
24	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	1.0	.	0.5	0.8	0.3	.	.	**2.8**
25	.	0.5	0.5	.	.	.	.	0.3	.	.	.	.	.	.	.	.	0.5	0.5	.	.	.	.	.	.	**2.3**
26	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.3**
27	.	.	0.3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.3**
28	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**0.0**
29	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0.3	.	.	.	.	.	.	.	0.3	**0.5**
30	0.3	0.8	0.5	0.5	0.5	0.5	0.5	0.3	1.3	0.5	0.5	0.3	0.5	0.5	0.3	.	.	0.3	.	.	.	.	0.3	.	**8.1**
31	.	0.3	0.3	.	.	.	.	.	.	0.3	0.5	1.0	0.3	.	.	.	.	.	.	.	.	.	.	.	**2.5**
Monthly Total (mm)																									**246.1**

Rainfall Maxima (mm)

Duration (for period ending at time):

Day #	5 Min		10 Min		15 Min		30 Min		1 Hour		2 Hour		6 Hour		12 Hour		24 Hour	
	mm	time	mm	time	mm	time	mm	time	mm	time	mm	time	mm	time	mm	time	mm	time
1	0.5	13:45	1.0	17:20	1.3	13:55	2.0	14:05	3.3	17:25	5.3	17:30	11.4	17:50	18.5	17:50	26.2	+05:50
2	0.5	03:20	0.8	03:25	1.0	03:30	2.0	03:45	3.6	15:30	4.6	15:30	8.4	+04:10	13.7	00:00	26.2	05:50
3	0.5	02:25	0.8	02:25	1.0	02:25	2.0	02:40	3.8	03:05	6.4	03:40	8.4	04:10	10.7	+11:30	21.3	03:15
4	0.3	00:45	0.5	09:10	0.5	03:30	1.0	09:20	2.0	10:00	3.3	10:00	8.1	10:35	11.4	13:40	12.2	20:50
5	0.3	06:50	0.3	06:50	0.3	06:50	0.3	06:50	0.3	06:50	0.3	06:50	0.5	00:00	1.3	00:00	12.2	00:00
6																	0.3	00:00
7	0.3	21:25	0.3	21:25	0.3	21:25	0.3	21:25	0.3	21:25	1.3	+01:55	3.0	+03:55	3.3	+03:55	22.1	+23:10
8	0.8	16:40	1.0	16:40	1.5	16:40	2.5	16:50	4.3	17:05	7.4	17:55	16.0	21:55	19.1	23:10	22.1	23:10
9	0.3	10:45	0.3	10:45	0.3	10:45	0.5	11:55	0.5	11:40	1.0	00:00	9.7	00:00	19.1	00:00	22.1	00:00
10	0.5	23:25	0.8	23:25	1.0	23:25	1.8	23:30	2.5	22:10	4.6	23:25	12.7	+05:55	28.4	+11:00	45.2	+18:25
11	0.5	05:05	0.8	05:05	1.3	05:45	2.0	05:40	3.8	05:50	7.4	06:50	16.8	10:05	30.7	15:10	45.2	18:25
12	0.8	08:30	1.5	08:35	1.8	08:35	2.0	08:40	2.8	18:10	4.3	18:50	5.6	22:20	12.2	00:00	40.1	00:00
13	0.5	10:05	1.0	18:40	1.0	18:40	1.5	18:50	2.5	10:40	3.8	11:05	5.1	23:40	7.9	20:50	42.2	+23:10
14	0.5	14:10	1.0	22:25	1.3	15:40	2.3	22:05	4.6	22:50	8.1	23:05	20.8	20:05	38.6	+00:50	62.2	+10:20
15	0.8	07:25	1.5	07:30	2.3	07:35	4.3	07:45	6.9	08:00	10.4	09:00	18.8	00:00	38.6	00:50	62.2	10:20
16							0.3	+00:25	0.8	+00:45	1.8	+01:50	5.8	+04:45	6.6	+09:00	23.9	00:00
17	0.5	02:55	0.8	02:55	1.0	03:00	1.3	03:10	2.3	03:45	3.6	03:45	6.1	06:20	6.6	09:00	9.4	22:30
18	0.3	07:10	0.5	09:45	0.8	09:50	1.3	09:55	2.0	10:05	3.3	10:10	4.1	10:40	4.1	10:10	9.4	00:00
19																	4.1	00:00
20																		
21																		
22																		
23																	2.8	+21:15
24	0.3	16:45	0.5	17:35	0.5	17:35	0.8	17:35	1.0	17:35	1.3	17:45	2.8	21:15	3.8	+02:45	4.3	+16:05
25	0.3	01:30	0.3	01:30	0.3	01:30	0.5	01:45	0.8	02:15	1.0	02:45	1.5	00:00	3.8	02:45	4.3	16:05
26	0.3	08:25	0.3	08:25	0.3	08:25	0.3	08:25	0.3	08:25	0.3	08:25	0.3	08:25	1.0	00:00	2.3	00:00
27	0.3	02:45	0.3	02:45	0.3	02:45	0.3	02:45	0.3	02:45	0.3	02:45	0.3	02:45	0.3	02:45	0.5	02:45
28																	0.5	+23:10
29	0.3	15:50	0.3	15:50	0.3	15:50	0.3	15:50	0.3	15:50	1.0	+01:55	3.0	+05:45	6.4	+10:50	8.4	+22:55
30	0.3	00:45	0.5	08:35	0.5	01:55	0.8	08:35	1.3	08:35	1.8	09:20	3.8	09:45	6.9	12:30	8.4	22:55
31	0.3	01:15	0.5	11:15	0.5	11:00	1.0	11:15	1.3	11:15	1.8	12:05	2.0	12:05	2.5	12:05	8.1	00:00
	0.8 max		**1.5 max**		**2.3 max**		**4.3 max**		**6.9 max**		**10.4 max**		**20.8 max**		**38.6 max**		**62.2 max**	

Figure D-2: Monthly Rainfall Summary Table

For sites in Metro-Vancouver, ideally you should have six months of data covering the span October to March. In any case work with the data that you have.

1.2 Step 2: Choose Storm Events

Using the graphs (and rainfall tables if available), begin to make a list of storm events. Here are some guidelines for selecting storm events:

1. Start with the largest events, identifying them by both their visual response on the graphs as well as by rainfall totals on your rainfall tables. Identifying storms that stand out using their 6-, 12-, and 24-hour totals is a good starting point; and
2. Give first priority to storms that have one clearly defined peak, and which clearly return to pre-storm baseflow conditions after the rain event. Storms with multiple peaks or that do not return to baseflow conditions before the next storm are more difficult to analyze.

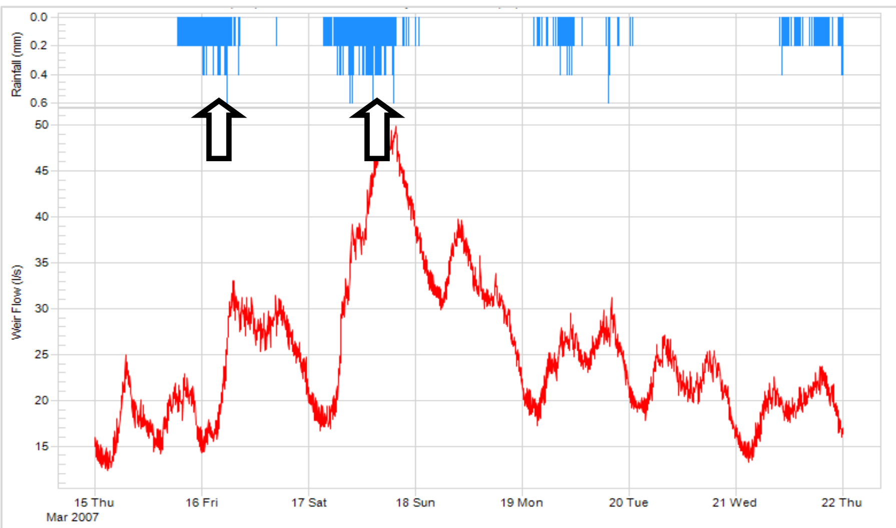

Figure D-3: Example of Two Rainfall Events, not Separated Sufficiently

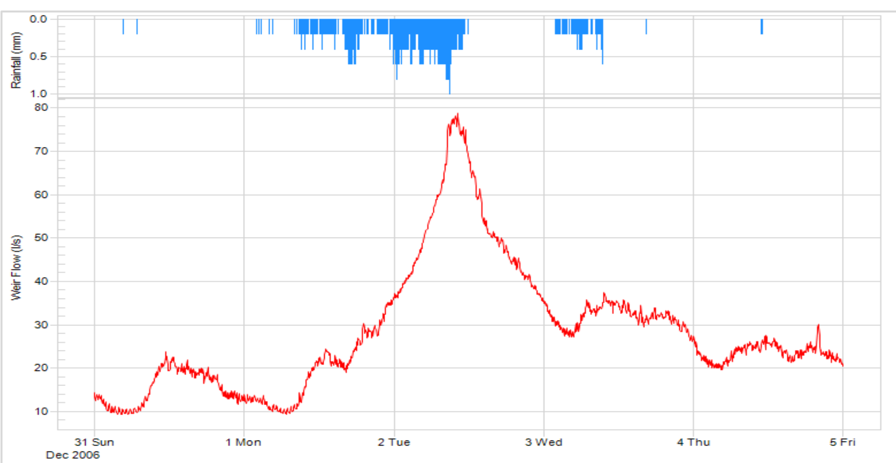

Figure D-4: Example of Storm Event with only One Major Peak

Starting from the largest storm in the record, work towards the smaller events until you have at least 10 events or have run out of useful storms in your record.

1.3 Step 3: Develop Dry Weather Patterns

A dry weather pattern is required for each storm. A good dry weather pattern will have the following characteristics:

1. Distinguishes between Saturday, Sunday, and weekdays, as each of these can have distinctly different patterns;
2. Will have a consistent minimum nightly flow that shows good agreement with the flow signal in the days leading up to the actual storm event. This ensures that the pattern is adequately estimating both the sanitary and groundwater components; and
3. The subtraction of the dry weather pattern from the total flow signal prior to the storm will thus generally yield zero.

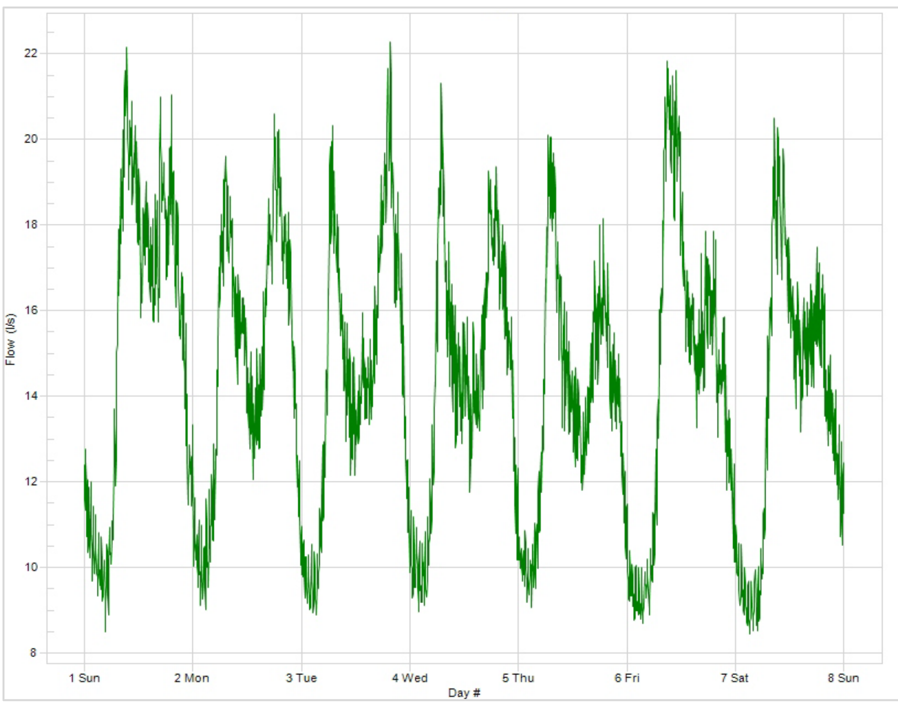

Figure D-5: Typical Dry Weather Flow (DWF) Pattern

Often, it is not possible to obtain suitable DWF patterns for each storm, due to a variety of reasons:

1. There may not be a suitable dry weather period that matches the minimum nightly flows leading into the storm event (i.e., the groundwater conditions do not match). In this case, it is acceptable to take an otherwise matching pattern and shift it by the required amount of GWI either up or down. However, this can only be done if the baseflow conditions prior to the storm event are constant. For example, if the DWF pattern does not match because the effects of a previous storm event are still present, this is not a suitable approach; and
2. An otherwise suitable pattern may have one or two damaged days of data. In this case, replacement with another day of data is acceptable, as long as the minimum nightly flows match and days are replaced with equivalent days (Saturday replaced with another Saturday, Sunday with Sunday, etc.).

1.4 Step 4: Prepare an Estimate of Groundwater Infiltration (GWI)

Groundwater can be extracted as a constant value from the DWF patterns prepared in Step 3. The easiest way to do this is to assume that a constant percentage of the minimum flow that occurs each night is GWI.

Many flow monitoring exercises in Metro-Vancouver and the Capital Regional District have been done over the previous 15 years. Comparisons of measured flow during dry periods with a standard sewage design parameter of 250 L/capita/day often yields a remainder for GWI that can be estimated as 85% of the minimum nightly flow. Smaller catchments tend towards 85%, while larger catchments and regional points tend towards 70%. This is an approximation which works well enough for catchments that are predominantly residential in nature.

Catchments with large industrial, commercial, and institutional loadings can contain processes which run even at night. In this case, there are several potential actions that can be taken:

1. Observe the flow on weekends and over holiday periods. Often, the processes will shut down during these times which can be identified in the flow monitoring data. Use the flows during these times to estimate GWI using the percent minimum nightly flow approach;
2. Compare estimated GWI from neighbouring catchments (on an area-weighted basis) that share similar pipe age and condition characteristics. If there is no reason to expect that GWI in the target catchment should be higher than neighbouring catchments, then ICI processes may be to blame; and
3. If neither of these options work, state in your analysis that the catchment in question contains ICI processes which may be affecting the accuracy of the GWI estimate.

To estimate groundwater using this method:

1. Read the seven minimum nightly flows from each night in your DWF pattern (you may need to apply an hourly boxcar average to your data first if it is excessively noisy); and
2. Average them, then multiply the result by 85% (or as low as 70% for large catchments with significant travel times or storage from upstream pump stations).

1.5 Step 5: Subtract the DWF Pattern from the Flow Signal

The DWF patterns that were previously developed contain both the sanitary component as well as the groundwater infiltration. When the DWF pattern is subtracted from the total flow signal, what remains is the rainfall dependent I&I (RDI&I). For each storm event, the ideal scenario is to have the RDI&I at effectively zero prior to the rainfall.

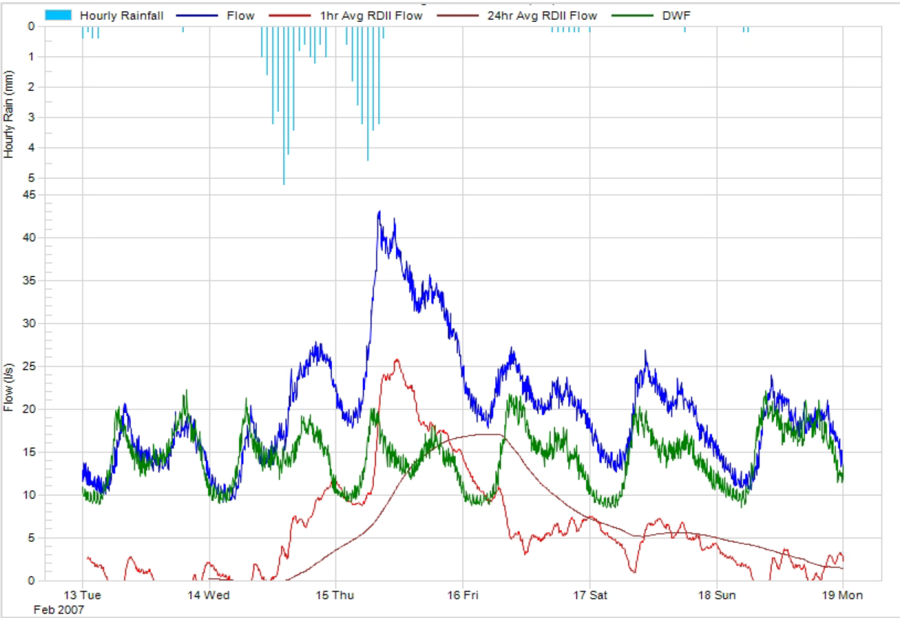

Figure D-6: Example of Storm and DWF Pattern with Good Pre-Storm Agreement

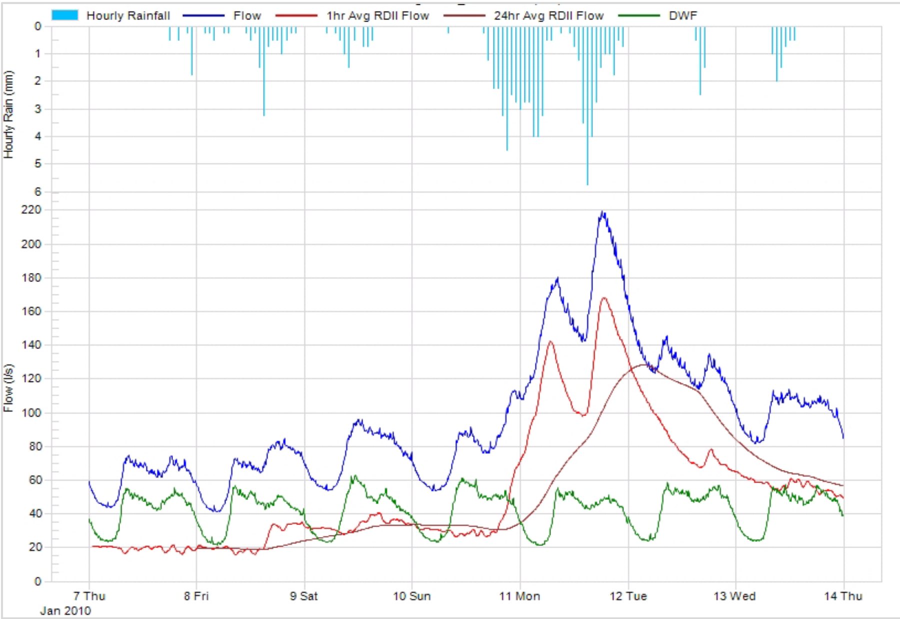

Figure D-7: Example of Storm and DWF Pattern Offset by Constant Value

If the DWF pattern is visibly offset by a constant value, this is an indication that the groundwater conditions were not the same for the DWF pattern and the storm event.

A simple subtraction of the DWF pattern from the total flow signal for each event will yield the instantaneous RDI&I for each storm event. When working with fine resolution data (5-minute timestamps), the RDI&I signal will often be quite noisy. Typically, a rolling 15 minute or hourly boxcar average can be applied to the raw RDI&I signal to remove spikes and make the true RDI&I signal easier to see.

RDI&I, when averaged over 15 minutes or hourly, is most often used for facilities design where an estimate of the true peak RDI&I is desired.

For reporting between catchments and also between Municipalities, the use of a 24-hour boxcar average is preferred. This averaging period removes practically all effects of system operation and catchment size, allowing for more consistent assessment of I&I values between catchments.

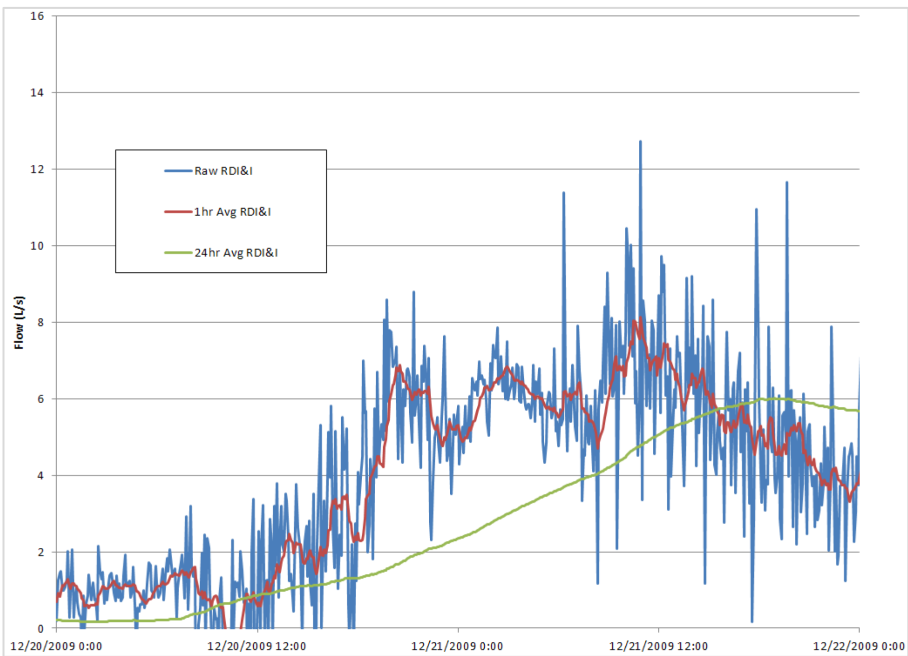

Figure D-8: Examples of Raw, 1-Hour, 24-Hour Average RDI&I Signals

1.6 Step 6: Determine Peak and 24-Hour RDI&I Values for Each Storm

For each storm event, read off the maximum 1-hour (or 15-minute) and 24-hour RDI&I values for each storm event and note these for use in the next steps. Pay close to attention to ensure that:

- the peak that you are reading correlates with the rainfall event, and is not unrelated to the storm of interest (this can be an issue when attempting to use very small storms with small RDI&I response); and
- the peak of the RDI&I event is over and is declining. This can be an issue when using 24-hour averaging if your graph does not extend far enough to see the 24-hour average RDI&I clearly reducing.

1.7 Step 7: Calculate Maximum Rainfall Totals at Various Durations

For each storm event, calculate the maximum amount of rainfall that occurred over the following durations: 1-hour, 2-hour, 6-hour, 12-hour, and 24-hour. These are common durations that rainfall intensity-duration-frequency (IDF) data is available for. Always work with a boxcar total on fine resolution (5 minutes), when locating each maximum total.

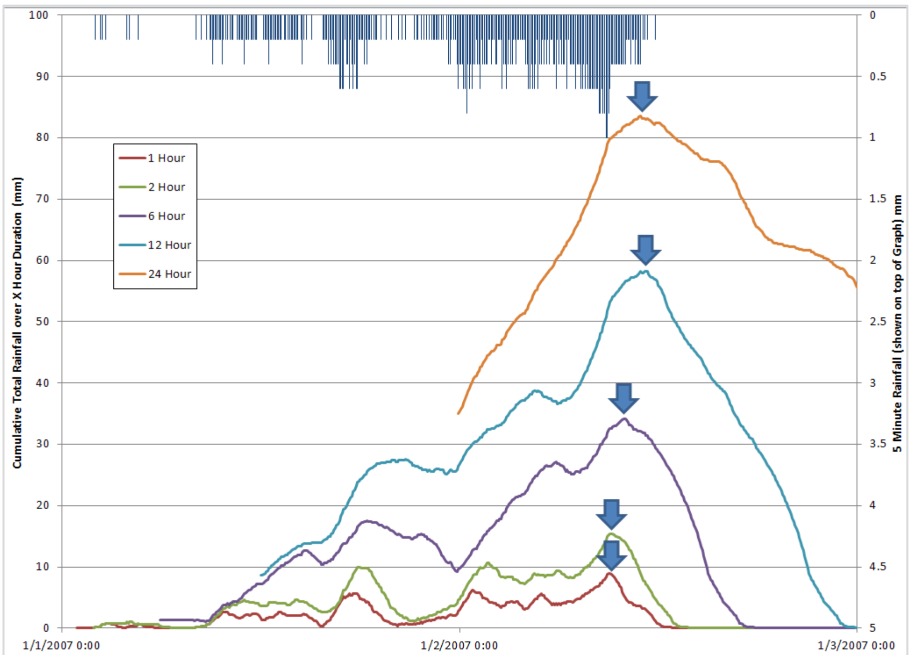

Figure D-9: Calculating Maximum Rainfall over Various Durations

1.8 Step 8: Plot Each Storm RDI&I Value with Rainfall

In this part of the analysis, each storm peak RDI&I value (derived from Step 6) is plotted as a point on the Y-axis of a graph, with the X-axis value being maximum total rainfall for that storm event (derived from Step 7). Work only with either the 24-hour RDI&I values or peak RDI&I values at any one time.

Overlay the return period lines for the rainfall gauge you wish to use in the analysis. Use 2, 5-, 10-, 25-, and 100-year return periods and these are normally available for any given rain gauge.

Assume for this example that we are working with the peak RDI&I values. The question arises: which rainfall duration to use for the X-axis of the graph? To answer this, a sensitivity analysis is performed to determine which rainfall duration produces the best correlation with RDI&I. To do this, plot the peak RDI&I values in turn against the 1, 2-, 6-, 12-, and 24-hour rainfall totals. Fit a linear trend line through the data and note the coefficient of determination (R2). Keep in mind the following:

- Smaller catchments, or catchments with larger inflow components will tend to correlate better with shorter rainfall durations; and
- Larger catchments, or catchments with less inflow and more infiltration will correlate better with longer rainfall durations.

Select the graph that produces the best correlation with the highest R2 value.

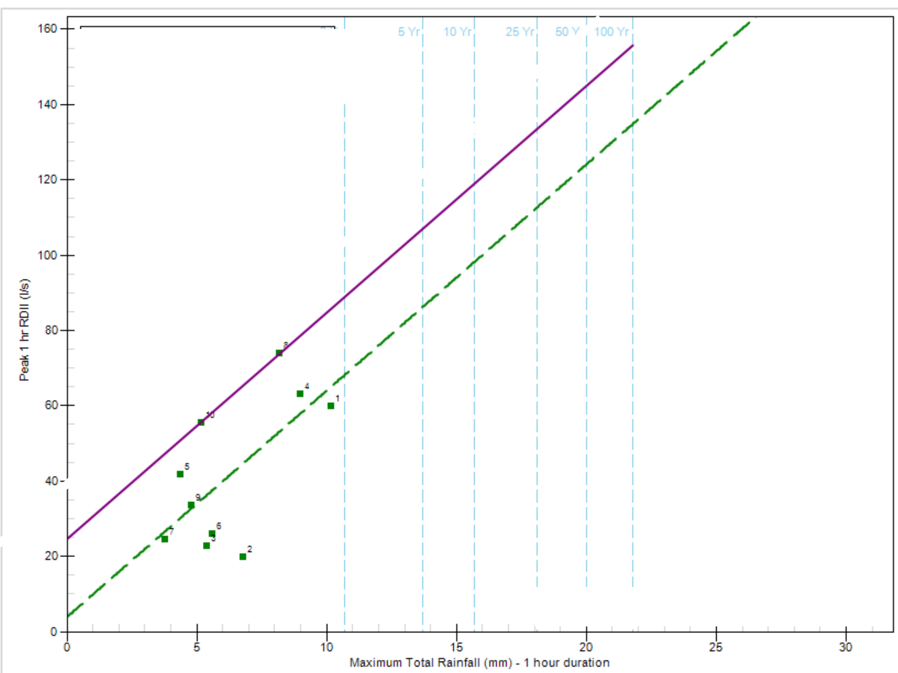

Figure D-10: I&I Envelope with Poor Correlation (1 Hour Rainfall Duration)

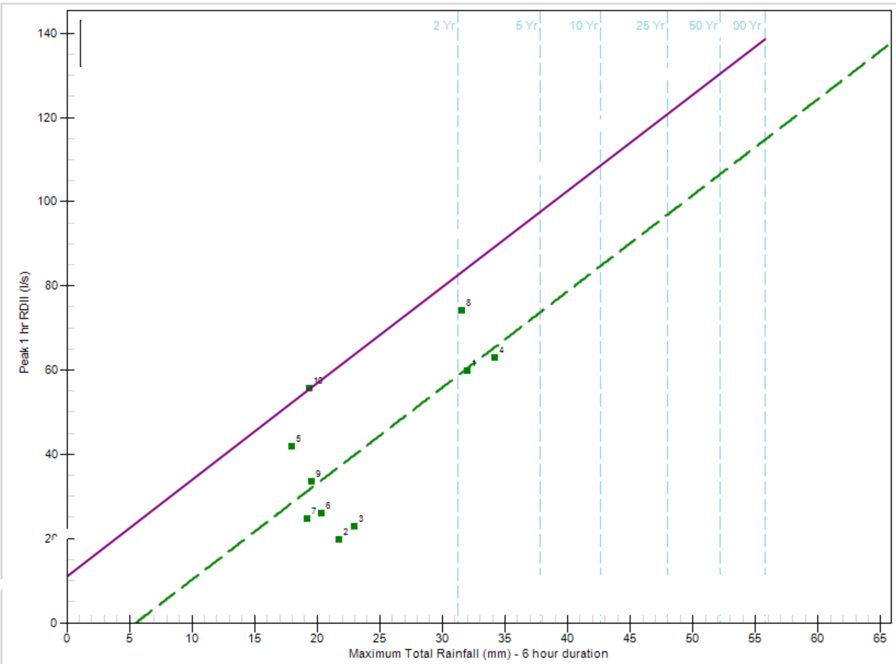

Figure D-11: I&I Envelope with Poor Correlation (6 Hour Rainfall Duration)

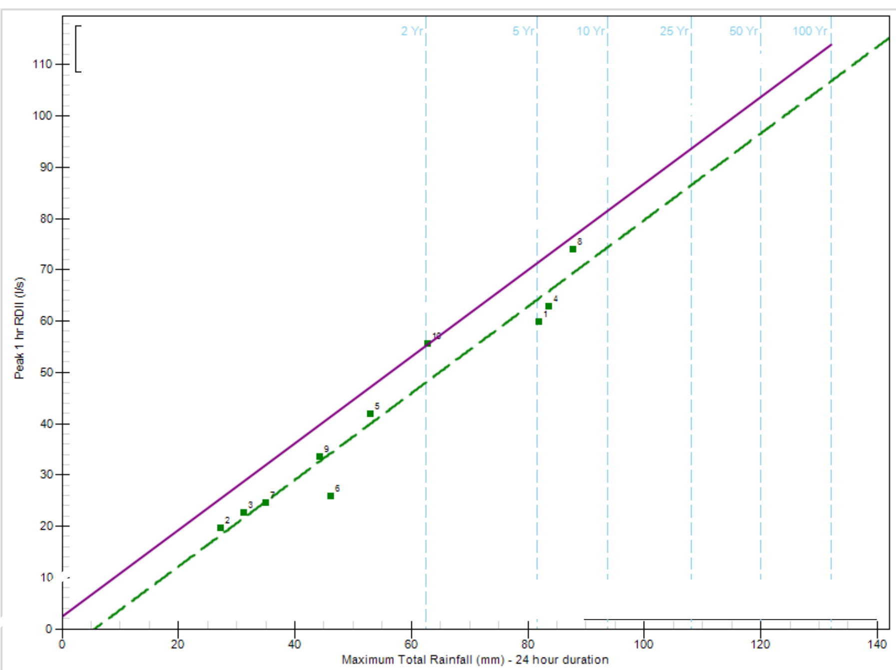

Figure D-12: I&I Envelope with Good Correlation (24 Hour Rainfall Duration)

1.9 Step 9: Critically Review any Outlying Storm Points

Attempt to increase the overall R^2 value by critically looking at each storm that does not appear to be a good fit with the other points. There are numerous reasons why this could occur, here are some examples:

Low Response from First Storm Event

This is most often caused by the first significant storm event of the season. If the groundwater table is still at summer lows, the storm will not yield the same amount of RDI&I as if it had occurred in the winter when the groundwater table is elevated.

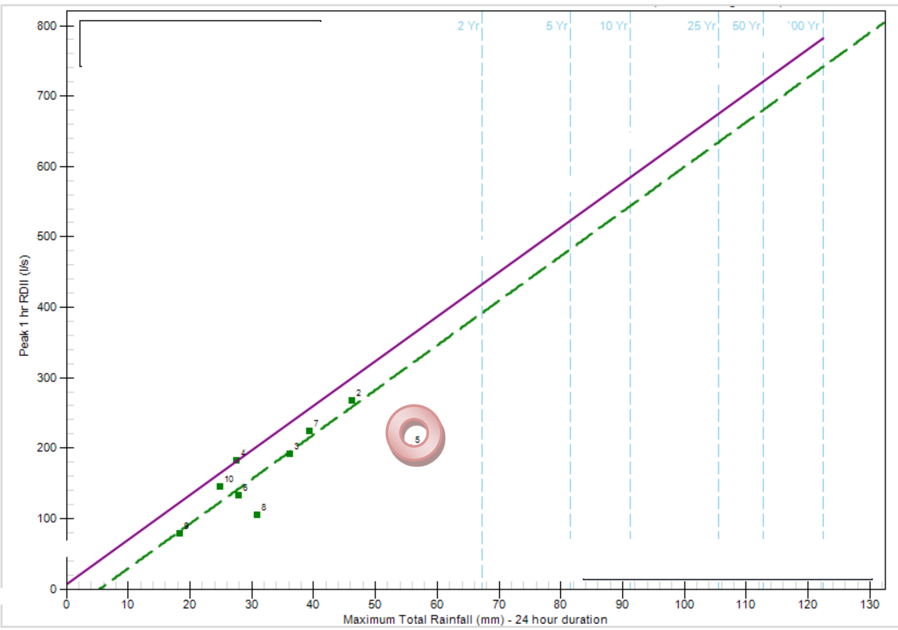

Figure D-13: Storm with Low RDI&I Response due to Low Groundwater Table

High Response from a Storm Event caused by Low DWF Pattern

If a storm seems abnormally high relative to the other events, it may be caused by a low DWF pattern which is not correctly estimating the amount of GWI. The result is that the RDI&I for that event will be overestimated.

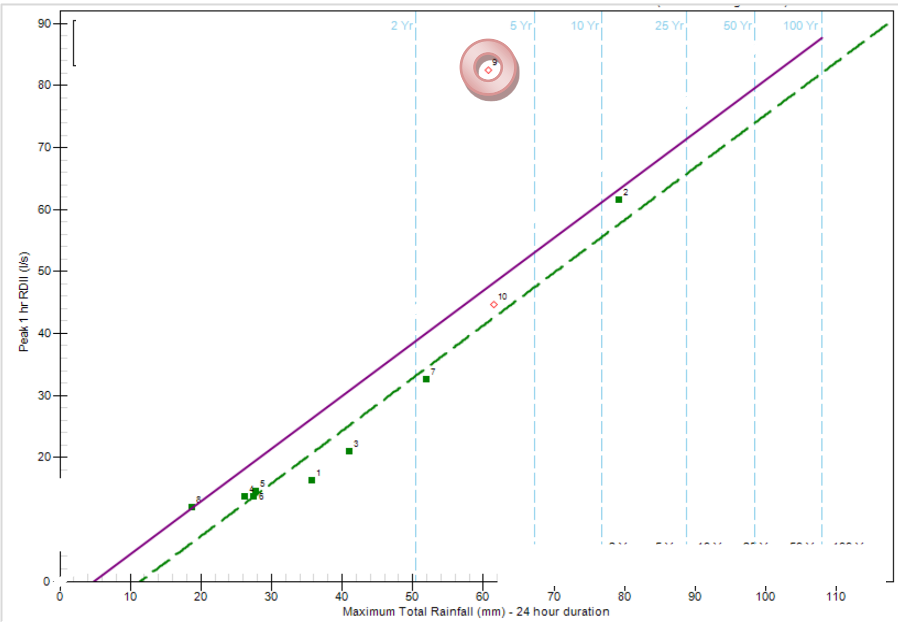

Figure D-14: Storm with High RDI&I Response due to Low DWF Pattern

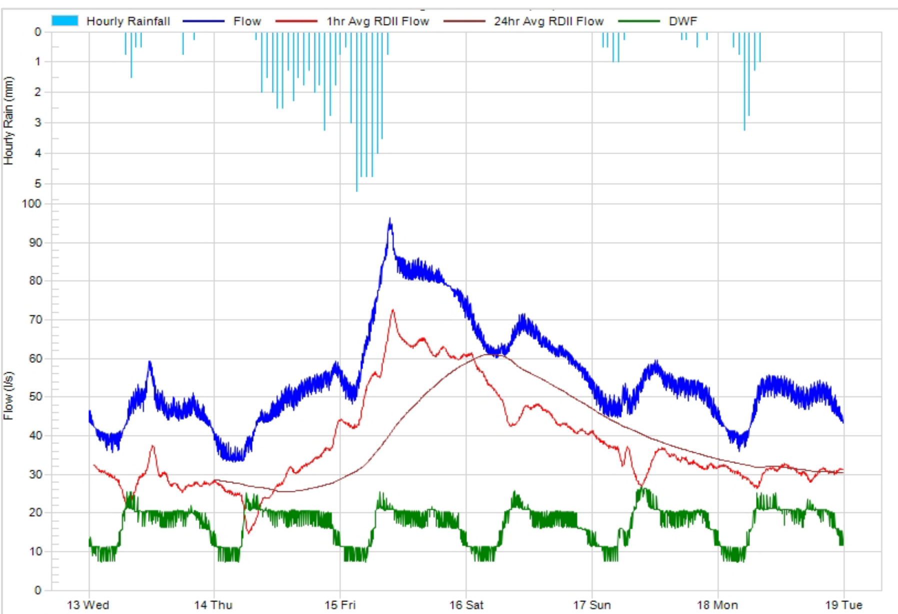

Figure D-15: Low DWF Pattern Resulting in Overestimate of RDI&I

High Response from a Storm Preceded by Another Storm

Another common source of a ‘high’ storm point on the I&I Envelope is when the storm of interest is preceded by another event, and the flow has not returned to baseflow conditions before the storm of interest occurs. The result is that the RDI&I for the second event will be estimated as being too high. In this case, it is recommended that only the first event be used.

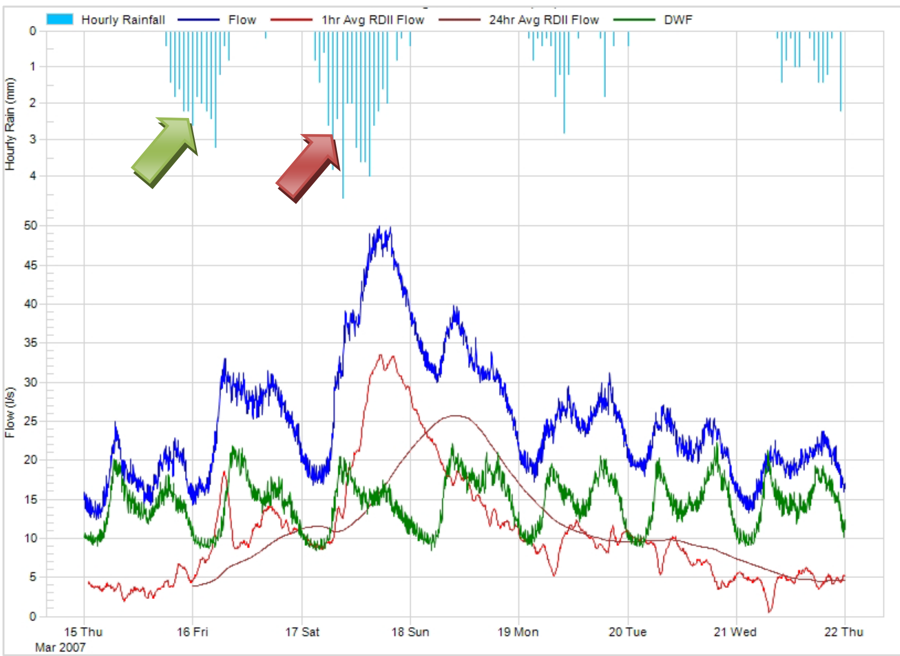

Figure D-16: Two Storms that are Too Close to Each Other, Only Use the First

Poor or No Correlation Possible

If it proves impossible to produce a useful correlation regardless of which rainfall duration is chosen, then the cause is typically either:

- the catchment is too small, or the RDI&I rates too small, to standout above the background noise of the flow monitoring data; and
- if there is a consistently measurable response in RDI&I but it does not appear to trend upward noticeably with rainfall, the catchment may have a hydrologic or hydraulic restriction that prevents the RDI&I from leaving the catchment beyond a limiting rate.

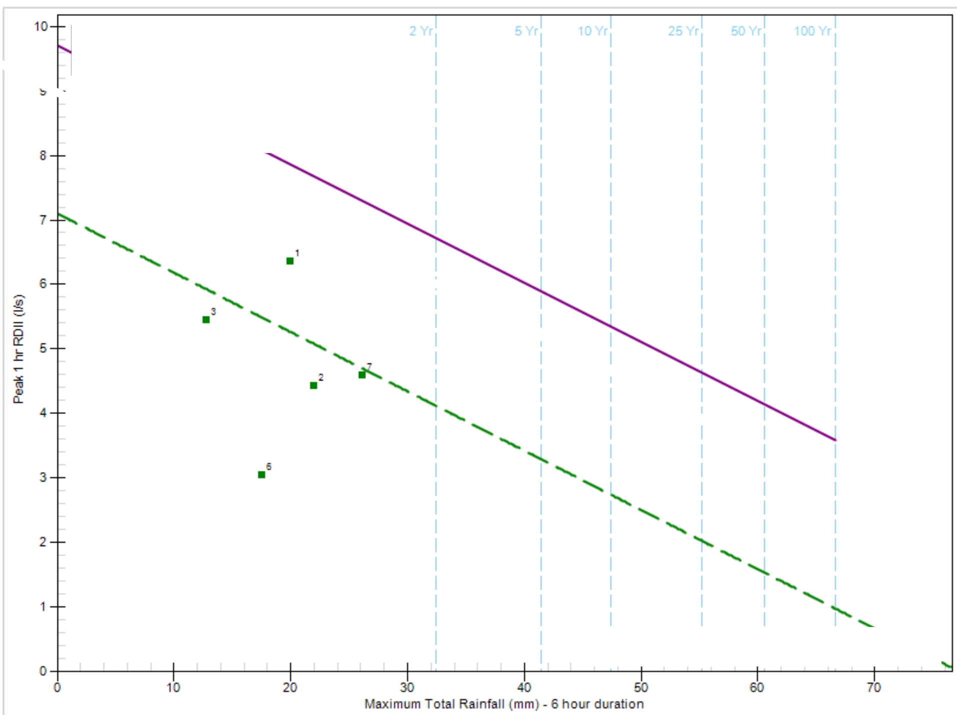

Figure D-17: No Correlation Possible, Regardless of Rainfall Duration Chosen

1.10 Step 10: Intersect the Trend Line with Rainfall Return Periods

After critical review and adjustments as necessary, the trend line may then be intersected with the various rainfall return periods, and values for the RDI&I read off the Y-axis.

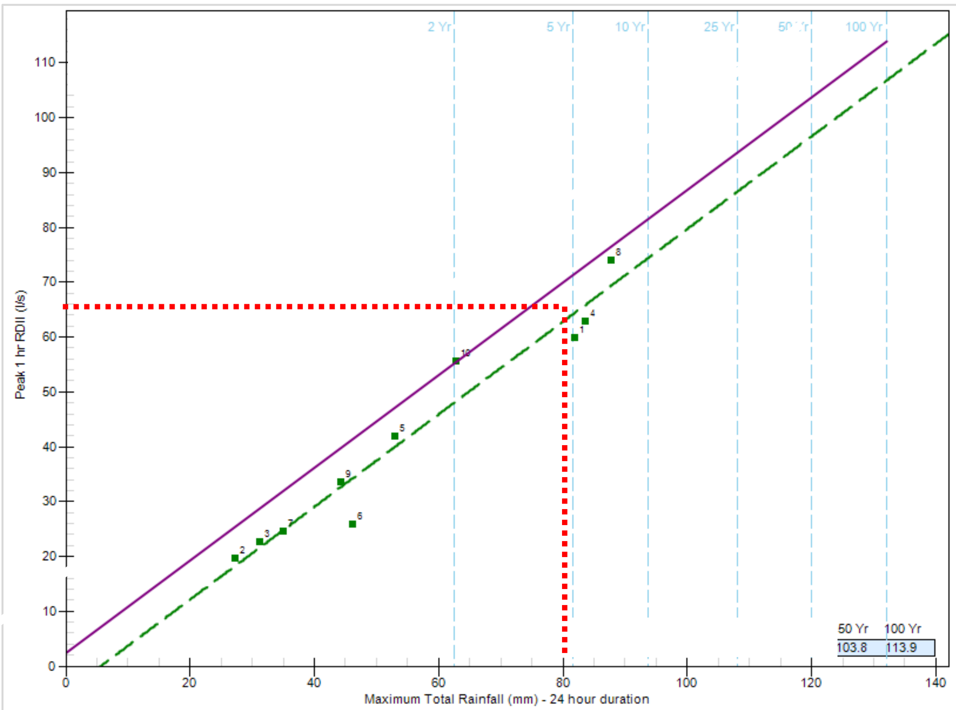

Figure D-18: Reading the 5-Year, Peak 1-Hour RDI&I (Based on 24-Hour Rainfall)

In the above example, the intersection of the best fit curve with the 5-year rainfall return period yields a 5-Year, peak 1-hour (based on 24-Hour rainfall) RDI&I value of 65 L/s.

1.11 Step 11: Repeat Steps 8-10 for 24-Hour RDI&I

The procedure is the same when looking for a correlation between rainfall and the 24-Hour average RDI&I. By convention, the 24-hour rainfall duration is chosen by default, rather than searching different durations for the best correlation.

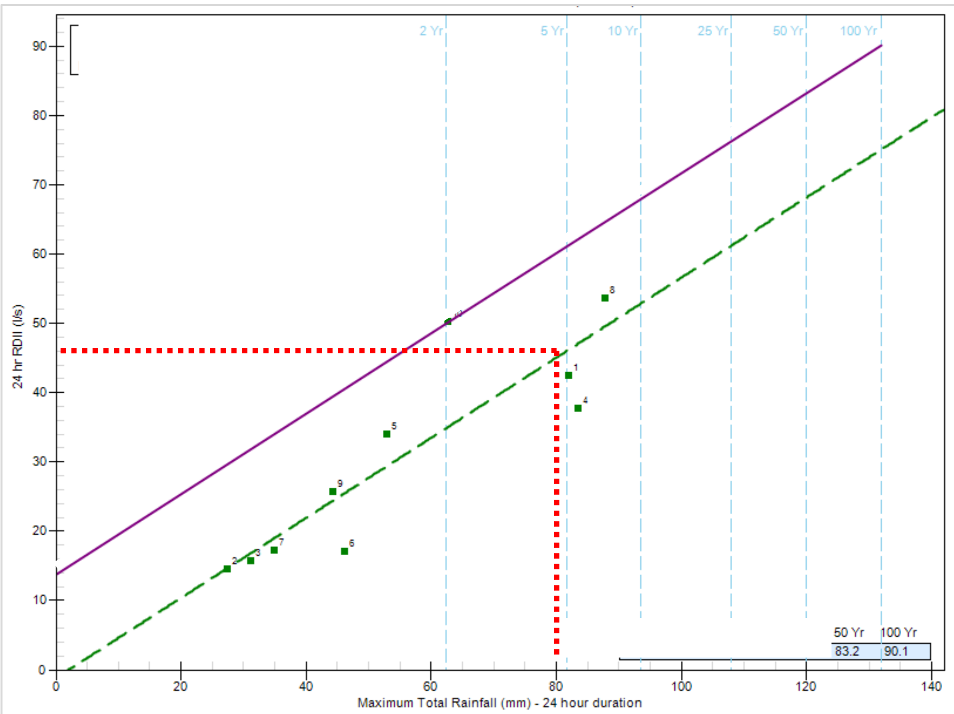

Figure D-19: Reading the 5-Year, 24-Hour Average RDI&I (Based on 24-Hour Rainfall)

In the above example, the intersection of the best fit curve with the 5-year rainfall return period yields a 5-Year, 24-hour average (based on 24-Hour rainfall) RDI&I value of 45 L/s.

1.12 Step 12: Add GWI to RDI&I to Calculate Total I&I

Total I&I = GWI + RDI&I

Add the GWI calculated from Step 4 to the RDI&I value obtained from Step 11 (for Peak I&I) or Step 12 (for 24-Hour Average I&I) to yield the total I&I.

1.13 Step 13: Normalize by Catchment Area

Expressing I&I in flow units (such as L/s) is useful for tasks such as sizing facilities. However, to compare the relative severity of I&I between catchments, and also to gauge how severe the I&I is relative to defined measures, it is useful to normalize I&I using one of two systems:

1. Area based: dividing the flow by the size of the catchment in hectares thus converting flow from L/s into L/ha/day; and
2. Pipe based: dividing the flow by the total sum of (length x diameter) of the pipes in the catchment, converting flow L/s to L/km-mm/day.

Both methods have the effect of allowing relative comparisons. The catchment area method has been used mostly in Metro Vancouver and the Capital Regional District, due to the relative ease of calculating catchment area. Due to the length of pipes on private property, the pipe-based method is harder to calculate accurately without good knowledge of the amount of private laterals in the catchment.

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Appendix E

Description of Rehabilitation Techniques

Appendix E – Description of Rehabilitation Techniques

1. Rehabilitation Technologies – Pipes (Sewer Mains)

Cured-In-Place Pipe

Cured-in-place pipe (CIPP) is a rehabilitation technology where a fabric liner saturated with a liquid resin is placed inside the existing sewer main, inflated, and then cured. The technology is used to provide a lining inside a host pipe to prevent infiltration through defects in the pipe, or it may be used to form a structurally sound new pipe. The process may be used on an entire segment of sewer main between maintenance holes, or in specific locations of a sewer main as a spot repair.

The resin type, fabric type, installation method, cure method, and design conditions vary. Resin types are typically epoxy, vinylester, or polyurethane. Fabric types are typically polyester felt or fibreglass. The liner is pulled (usually with a cable) or inverted in the host pipe. Cure method is usually by steam, hot water, ultraviolet light, or ambient air. CIPP can be used for spot repairs or maintenance hole to maintenance hole runs.

Pipe Bursting

Pipe bursting is used to replace an entire segment of sewer main between maintenance holes. The process involves replacing an existing pipe by pulling in a new high-density polyethylene (HDPE) pipe and simultaneously bursting the old pipe into fragments with a steel-bursting head. The broken pipe fragments remain in place in the surrounding soil.

Pipe bursting installation techniques are static, pneumatic, or hydraulic. In static pipe bursting, the bursting head is attached to a pulling device (usually a chain, cable, or threaded rods) and is pulled by force of the pulling device. In pneumatic pipe bursting, the bursting head may be attached to a pulling device or not but receives most of the force from a pneumatic device in the bursting head. In hydraulic pipe bursting, the bursting head has an expansion device that compresses surrounding soil by means of hydraulic jacking prior to the pull.

Pipe Reaming

Pipe reaming is used to replace an entire segment of sewer main between maintenance holes. The process involves a directional drill used with a rotating head to grind the existing pipe into small pieces while pulling in a new pipe of the same or larger diameter.

Chemical Grouting

Chemical grouting of sewer mains is a process where acrylamide grout is pressure-injected into a crack, joint, or lateral connection in a sewer main. A remotely operated grout packer delivers the grout to the selected location. The grout packer is similar to a pipe plug that uses air to inflate bladders at each end of the plug. The grout is then injected under pressure into the annular space between the plug and the sewer main, and then migrates into the cracks and open joints. The flexible and non-cohesive grout remaining on the pipe wall when the grout packer is removed is pulled out, leaving grout in the joint spaces of the pipe.

Sliplining

Sliplining is typically used to line an entire length of sewer main between maintenance holes, although it can be used in shorter portions of the sewer main. Sliplining involves pulling or pushing a smaller diameter pipe or liner into place inside an existing pipe. The sliplined pipe material is typically HDPE or fibreglass, although some other materials may be used. The pipe is typically grouted at the ends or over the length of the pipe.

Spiral Wound Pipe

Spiral wound pipe is a type of pipe used to slipline an existing pipe. This pipe is formed by spirally winding a continuous strip of some material into a pipe by means of a machine placed in the excavation or maintenance hole. Strips can be made of polyvinyl chloride (PVC), HDPE, or steel. The strips are typically 2 to 6 inches wide and have a locking mechanism such that the strips 'lock' into adjacent portions of the strip. Spiral wound pipe comes in two types: 1) those which are 'wound' to the diameter required for sliplining, and 2) those which are 'wound' in a smaller diameter, then twisted to expand the pipe to the host pipe diameter after the wound pipe is in place. There may also be steel wire or rebar placed in the strips to add structural support.

Deformed/Reformed HDPE

Deformed/reformed HDPE is a method for installing a new HDPE pipe or liner inside an existing sewer main. The HDPE pipe is pulled through a die to fold the pipe into a smaller diameter. The pipe is secured with breakaway plastic straps in the deformed position. The pipe is pulled into the sewer main and reformed either by plugging and pressurizing the main or by running a rounding device through the line to break the straps and allow it to form within the existing pipe.

Swage Lining

Swage lining is a method for installing a new HDPE pipe inside an existing sewer main. The HDPE pipe is pulled through a die or set of rollers to neck-down the pipe to a smaller diameter. This method relies on the property of polymeric materials to retain a memory of their original shape. The smaller diameter pipe is then pulled into the host pipe and pressurized to allow it to revert to the original diameter.

Fold and Formed PVC

Fold and formed PVC is a method for installing a new PVC pipe inside the entire segment of sewer main between maintenance holes. The PVC pipe is heated and then folded into a smaller diameter at the factory. Then, after it is pulled into the sewer main, the PVC pipe is heated and pressurized to unfold and form to the shape of the host pipe. The PVC pipe is then cooled to form a rigid pipe inside the host pipe. This process relies on the property of PVC that allows it to be rigid at normal temperatures and flexible at higher temperatures.

2. Rehabilitation Technologies – Maintenance Holes

Reset Frame and Raise to Grade

Resetting the frame is a method intended to adjust a frame that has moved horizontally and/or to raise the cover above grade to prevent inflow, mostly in non-paved areas (for example, when a cover is located in a slight depression where ponding of water occurs). The installation involves minimal excavation – only enough to allow replacement of damaged concrete levelling rings and addition of new rings to bring the top of the frame above grade.

New concrete levelling rings are used to repair the chimney section where existing brick or concrete chimneys have worn out. The levelling rings may be sealed with non-shrink cement grout, a rubber gasket, or butyl rubber mastic. Likewise, the frame may be sealed to the chimney by the use of a rubber gasket or butyl rubber mastic.

HDPE plastic levelling rings are also available that are meant to replace concrete levelling rings with a more watertight seal. The levelling rings are not solid HDPE; rather, they are hollow with support ribs.

Interior Coatings

Cementitious coatings are applied with a trowel, sprayed on, or poured, and are used to seal cracks on all or portions of the interior of the entire maintenance hole. These coatings typically contain a mix of cement and chopped fibres. The coatings may be sprayed directly on the wall, over a wire mesh, or poured into an HDPE form with rebar. The coatings often contain calcium aluminate as an additive, which provides additional corrosion resistance for the concrete.

Epoxy coatings are applied as a spray and are used to coat the interior of the entire maintenance hole to form a water/vapor barrier. These coatings are two-part epoxy, typically 100- per cent solids by volume. They require abrasive blasting or high-pressure water cleaning for surface preparation.

Polyurethane coatings are also applied as a spray and are used to coat all or portions of the interior of the entire maintenance hole to form a water/vapor barrier. These coatings are made of urethane resin. They require abrasive blasting or high-pressure water cleaning for surface preparation.

Exterior Coatings

Exterior coatings are used on all or portions of the barrel, cone, and chimney sections of

maintenance holes. These coatings are unique in that they require less bonding than interior coatings, due to the fact that the backfilled soil holds them in place and any groundwater presses the coating onto the maintenance hole. These coatings come in different types: spray-on cementitious, epoxy, or polyurethane; shrink-wrap plastic; and/or adhesive rubber tapes. These coatings require excavation around the maintenance hole.

Maintenance Hole Liners

PVC maintenance hole liners are used to line all or portions of the interior surface of the maintenance hole. They are made of sheets of PVC and are mechanically or adhesively connected to the maintenance hole. Mechanical connection is either by 1) locking protruding shapes of PVC that are embedded into grout applied to the interior of the maintenance hole, or 2) attachment to the maintenance hole by stainless steel anchors with a PVC cap welded over the top of the anchor. Adhesive connection is by a polymer applied to the concrete maintenance hole, which is then bonded to the PVC with an activator.

Pre-formed fibreglass or HDPE maintenance hole liners are rigid shapes fabricated at a plant to match the interior size of the maintenance hole. They are used to line the interior surface of the maintenance hole in the base, barrel, cone, and sometimes in the chimney sections. The liner is installed by excavating and removing the maintenance hole cone section. Then the liner is inserted, and the cone section replaced. For installations in portions of the maintenance hole, the edges of the liners are grouted to form a seal with the maintenance hole surface.

Fibreglass maintenance hole liners are used to line all or portions of the interior surface of the maintenance hole. The liners consist of a fabric liner saturated with a liquid resin. The liner is placed inside the maintenance hole, inflated, and then cured. The fabric typically consists of layers of woven fibreglass bonded to a non-porous membrane, the resin is epoxy, and the curing method is steam.

Chimney Barriers

Chimney barriers are made of a rigid medium-density polyethylene riser with a thick base that sits on top of the cone section of the maintenance hole. The concrete maintenance hole rings are then stacked on the thick base on the outside of the riser. The riser becomes a barrier to I&I entering the chimney section.

Another chimney barrier is a levelling ring boot. They are made of a circular heavy-ribbed rubber that is held in place with expanding interior stainless steel rings. The boots are installed by simply opening the cover, so no excavation is required. The boots need to be fitted around any ladder rungs located in the chimney or the ladder rungs may be removed.

Maintenance Hole Covers

Gasketed maintenance hole covers are steel covers with an inset gasket either in the frame or placed between the frame and cover. They are intended to prevent inflow from around the maintenance hole cover.

Solid covers without holes are available, as are plugs for the lifting holes.

Maintenance hole pans are available that fit under the maintenance hole cover and are intended to prevent inflow through holes in the maintenance hole cover. The pans are either HDPE or stainless steel.

Maintenance Hole Replacement

New maintenance holes are typically installed with rubber gaskets between barrel sections. Cement patching grout is typically used on all joints between base, barrel, cone, chimney, and frame sections.

Fibreglass maintenance holes are used to replace the base, barrel, cone, and in some cases the chimney portions of existing maintenance holes. The maintenance holes are typically prefabricated to ship to the site in one unit. The fibreglass maintenance holes require excavation and full installation, as is required for new concrete maintenance holes.

HDPE maintenance holes are used to replace the base, barrel, cone, and in some cases the chimney

portions of existing maintenance holes. The maintenance holes are typically prefabricated to ship to the site in one unit. The HDPE maintenance holes require excavation and full installation, as is required for new concrete maintenance holes.

3. Rehabilitation Technologies – From Sewer Main to Private Property Line

Cured-In-Place Pipe

CIPP installation and products for laterals and side sewers are similar to and in some cases the same as for sewer mains. A fabric liner saturated with a liquid resin is placed inside the existing pipe, inflated, and then cured. CIPP may be used to form a structurally sound new pipe or reduce infiltration. The method may be used on all or portions of the lateral or side sewer. A cleanout or excavation is required at some location on the lateral or side sewer to allow access for insertion of the liner.

Pipe Bursting

Pipe bursting is used to replace all or a portion of the lateral and side sewer between the house and sewer main. The process involves replacing an existing pipe by pulling in a new HDPE pipe and simultaneously bursting the old pipe into fragments with a steel bursting head. The broken pipe fragments remain in place in the surrounding soil. A cleanout is usually placed where the pipe-burst lateral connects to existing pipe, either at the house or at the property line. Pipe bursting of laterals is usually done using the static method because of the lower force required to burst smaller diameter laterals.

Chemical Grouting

Chemical grouting of laterals and side sewers is a process where acrylamide grout is pressure-injected into a joint or lateral connection point of a lateral or side sewer. The grout is delivered remotely to the location by a mechanism that has two sealing devices; the grout is injected into the entire space between the two. The flexible and non-cohesive grout is pulled out of the pipe in the area between the sealing devices, leaving grout in the joint spaces of the pipe. Where used to seal the connection between the sewer main and lateral, three devices are used, two in the main and one in the lateral.

Service Connection Liners (SCLs)

An SCL is a cured-in-place liner used to seal the service connection where the service lateral meets the sewer main. The SCL, installed by remote device, typically consists of a fibreglass fabric and polyester resin. A portion of the liner seals around the opening of the lateral in the sewer main, and a portion (usually 2 to 6 inches in length) is located in the lateral. The SCL is held in place either by an epoxy that forms a bond at the interface between sewer main and lateral, or by mechanical friction between the SCL and the lateral.

Service Connection and Lateral Liners (SCLLs)

An SCLL is a cured-in-place liner used to seal the service connection between the sewer main and lateral and some portion of the lateral and/or side sewer. The SCLL, installed by remote device, typically consists of a felt fabric and polyester resin. A short portion of liner is placed in the sewer main around the full diameter, and a second portion is located a defined distance up the lateral and/or side sewer. The two pieces are attached. Some products can be used for lining more than 80 feet up the lateral. Tees and fittings can sometimes be lined through; however, they are usually excavated to allow for reconnection.

4. Rehabilitation Technologies – Private Lateral [1]

Open Cut Replacement

The open cut method is most suitable for much damaged pipes that are shallow and in open areas with obstacles. Open cut allows installation of a new pipe of any diameter and material, and furthermore, the layout or depth of the lateral can be changed. Mature landscaping and driveways, retaining walls, etc., reduce the suitability of this method. The method causes disturbance to the homeowner's property causing public relations difficulties and restoration of landscaping and road payment can be expensive.

Sliplining

Sliplining is a method in which a slipliner pipe (typically an HDPE pipe for laterals) is pushed into the existing lateral pipe. The advantage of this method is that no special equipment or chemicals are needed, however, the disadvantages generally outweigh the advantages: the pipe diameter is unacceptably reduced, the method is time-consuming, and it is not cost competitive with other rehab methods.

Cured-in-Place (CIP) Relining

CIP relining method is a method in which a resin-saturated tube is inserted into the pipe and the resin subsequently cured creating a 'pipe within pipe'. The main components of a CIP relining system area a fabric tube and a resin, and often a plastic protective coating. Main advantages are the method stops infiltration through defects in the lateral pipe (cracks, offset joints, etc.); restores or enhances the structure integrity; not limited by soil conditions, groundwater level and active leaks; suitable for repair of deeper laterals; long-term repair (50 years design life), etc. Limitations are: The method does not allow upsizing of the pipe; not suitable for laterals with severe offset pipe joints; not suitable for severely corroded laterals with a mineral buildup; cannot remove sags or any protrusions in the pipe; roots could be a future problem; chemicals used are hazardous.

Pipe Bursting

Pipe bursting is a method in which a cone-shaped tool (bursting head) is forced through an existing pipe fracturing the pipe into small pieces. The replacement pipe is usually an HDPE pipe. Advantages are new lateral pipe is installed and can be upsized by one pipe size; excavation is much less than with open-cut replacement; applicable in all pipe types; works in most different soil conditions; roots should not be a future issue; short disruption of service to homeowners; no chemicals are used, etc. Limitations are excavation and associated surface restoration; difficult in hard clays; difficult in pipes repaired with metal clamps in the past; not suitable for pipes with many sharp bends. With more than three sharp bends in the pipe, CIP relining is usually better suited; significant sags cannot be removed; risk of damaging nearby objects and surface objects when bursting at shallow depths.

[1] WERF 02-CTS-5, Methods for Cost-effective Rehabilitation of Private Lateral Sewers, 2006

Chemical Grouting

Chemical grouting creates a sealing collar of material around the pipe by injecting a self-setting grout into an opening in a pipe wall, which is followed by the grout passing through the pipe wall into the surrounding soil and bonding of the grout with the soil. Advantages are: No excavation is generally required; performs pipe testing and repairs only where the repair is needed; eliminates infiltration; fast so disturbance to homeowners is minimal; inexpensive, etc. Limitations: no structural repair is possible; no pipe diameter upsizing; sometimes cannot be completed (the section can't be pressurized); the grout may dry out and crack under some groundwater conditions; chemicals used are hazardous if spilled or splashed on the skin or in the eyes (no hazard remains once the material cures), etc.

Flood Grouting

Flood grouting seals maintenance holes, mainlines and laterals simultaneously in one setup utilizing an exfiltration sealing process. Two proprietary chemical solutions are consecutively applied to 'flood' an isolated section of sewer, where they exfiltrate through defects in pipes and maintenance holes into the soil and chemically react with each other. The cured grout in the soil is a watertight sandstone-like silicate. Advantages are no excavation is generally required; eliminates infiltration in an entire section, i.e., both in mainlines and all connecting laterals at the same time; no limit in applicability with respect to the pipe material, shape or size, or depth; applicable in pipes with many sharp bends; disturbance to homeowners is minimal; the chemicals used are environmentally friendly. Limitations are no structural repair is possible; no pipe diameter upsizing; sometimes cannot be completed; chemicals used are hazardous if spilled or splashed on the skin or in the eyes (no hazard remains once the material cures), etc.

Slug Grouting

Slug grouting seals a mainline and the laterals connected to it in one setup utilizing an exfiltration sealing process. However, the grout does not flood the entire section but only a limited volume, which travels from the downstream maintenance hole towards the upstream maintenance hole and through each connecting lateral along the way. Advantages: the only time excavation is required is if a cleanout needs to be installed; eliminates infiltration both in mainlines and all connecting laterals at the same time; no limit in applicability with respect to pipe material or depth; little limit in applicability with respect to cavernous soils; disturbance to homeowners is minimal; no chemical are used; cost competitive. Limitations are no structural repair provided and no pipe diameter upsizing; this is a new method that needs to be tested and proved in practice.

Robotic Repair

Robotic repairs renovate lateral-to-mainline connections by applying a resin (or mortar) to the damaged piece of pipe, which cures into a material compatible with the host pipe and which becomes an integral part of the pipe. Advantages are no excavation is required; provides structural repair; eliminates infiltration; very suitable for repair of break-in protruding laterals; eliminates root problems; relatively easy to use in field applications; cost is reasonable; fast and disturbance to homeowners is minimal. Limitations are repairing only the lateral-to-mainline connection and a relatively short distance into the lateral; chemicals used are hazardous if spilled or splashed on the skin or in the eyes (no hazard remains once the material cures).

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Appendix F

Sewer Condition Reporting Standard Template

Appendix F – Sewer Condition Reporting Standard Template

1. Overview of Liquid Waste Management Plan Commitment

Every two years, the following sewer condition information will be summarized and forwarded by municipalities to Metro Vancouver for inclusion in a biennial Liquid Waste Management Plan (LWMP) progress report:

1. Sewer system mapping that indicates the overall extent of the current cycle of the sanitary sewer system evaluation program and the condition of the sewerage infrastructure;
2. The extent of new sewer construction and sewer repair and replacement work over the past two years; and
3. A summary of sewerage system expenditures for sewer system evaluation work, and repair and replacement work.

This section outlines the sewer condition reporting standard template for the biennial reports.

2. Biennial Report Contents

Based on the LWMP commitment and the related issues brought forth by Metro Vancouver's project Task Group members, it has been determined that the reporting template should be effective and simple to adopt. The template should recognize that municipalities have differing local conditions that affect their work plans and decisions to comply with the required commitments.

To meet the above commitment efficiently and cost-effectively, the biennial LWMP progress report will, as a minimum, need to contain the following two linked components:

1. Summary Table – A comprehensive Summary Table of all investigation and rehabilitation work carried out during the preceding two-years. These include:
    a. a summary inventory of the sanitary and combined sewer infrastructure, as applicable;
    b. a summary of the sewer investigation work such as smoke testing, dye testing, air testing, CCTV and visual inspection, and rainfall/sewer flow monitoring;
    c. a summary of newly constructed and rehabilitated sewer system components; and
    d. a summary of expenditures incurred on the above investigation and construction work.
2. Sewer System Maps – Sewer system maps that indicate the locations of the above work, by type. The level and number of maps should be kept to an optimum number to graphically show the information in the Table.

Using the above format, the template table and mapping have been developed, and are presented later in this report. To produce such a report, each municipality must plan and implement a comprehensive sewer system evaluation program. Some key program aspects, which are central for providing consistent input-data to the reporting template, are briefly discussed in the next section.

3. Reporting Data Development

The data requirements to populate the biennial report must be developed from field investigation-based information. In general, these field data collection investigation work includes sewer flow and rainfall monitoring; visual and CCTV inspections; smoke, dye, and air testing; developing a systematic database; and evaluating the data and rating/ranking the system components. The following section discusses the key data categories and data assessment methodology, which are pertinent to achieve a consistent reporting protocol among the member municipalities.

3.1 Sewer Condition Rating and Ranking Methodology

A key requirement of C19 commitment is to apply a consistent approach to Sewer System Evaluations Surveys (SSES) by each of the member municipalities. This is particularly applicable to the grading, rating, and ranking of the structural condition of sewers and maintenance holes from a perspective of their potential to add wet weather-induced inflow and infiltration (I&I) to the sewers.

Sewer Rating System

For consistency, the internal structural condition rating of sewers could be organized using a stepped ranking system, where sewer sections are graded from best to worst, on a 1 to 5 grading scale. The NASSCO Pipe Assessment Certification Program (PACP) has been chosen as the condition assessment methodology. The system is summarized below to show how the grading and categorizing could be made simple but effective for consistent application.

Table F-1: Sewer Rating System

Structural Condition Grade	Pipe Condition	Typical Structural Defect Description
1	Pipe is at the beginning of life in new or near new condition	No observable structural defects.
2	Pipe has progressed from near new condition and failure is unlikely in the distant future.	Circumferential, spiral or hinge cracks. Moderate joint defects, i.e., joint offset (medium) or joint separation (medium), and surface roughness increased.
3	Pipe is at the middle of life and is unlikely to fail in foreseeable future	Circumferential, longitudinal, or spiral fractures. Multiple cracking or hinge cracking. More severe joint defects, i.e., joint offset (large) or joint separation (large). Surface aggregate defects i.e., missing, visible or projecting.
4	Pipe is near end of life and will fail in foreseeable future	Broken pipe with soil visible or void visible. Multiple fractures or cracks. Surface chemical attack or reinforcement visible. Spalling large. Holes with soil or void visible.
5	Pipe has failed or will fail in immediate future	Already collapsed. Hinge fractures. Holes greater than one clock position.

The above 1 to 5 grading could be computed from any set of CCTV observation codes, which represent the structural defects in sewers. The CSA PLUS 4012-10, *Technical Guide: Visual Inspection of Sewer Pipe* contains a comprehensive methodology for describing, rating, and grading sewer pipes. The technical guide is based on *NASSCO Pipeline Assessment Certification Program (PACP) Manual* 2010 as well as materials from the Water Research Council (WRC).

In the PACP grading system, based on field observations from CCTV inspections, each type of Structural and Operations and Maintenance (O&M) defect is assigned a unique code to which a predetermined condition is associated. The types of structural defects that have scores assigned to them are as shown in the following table.

Table F-2: PACP Structural Defect Coding System

Defect Code	Various Descriptions	Structural Grade
Crack	Circumferential Longitudinal Spiral Multiple Hinge	1 2 2 3 2-4
Fractures	Circumferential Longitudinal Spiral Multiple Hinge	2 3 3 4 3-4
Breaks	Broken Soil Visible Void Visible	4 5 5
Holes	Hole Soil Visible Void Visible	4-5 5 5
Deformed	Rigid Flexible Bulging Inverse Curvature Flexible Elliptical	4-5 4-5 5 3
Collapse	Collapse	5
Joint	Offset Separated Angular	3-4 3-4 3-4
Surface Damage	Roughness Increase Aggregate Reinforcement Missing Wall Surface Spalling Corrosion	1 2-4 4-5 5 1-2 3
Lining Feature	Various Defects	3
Weld Failure	Circumferential Longitudinal Spiral Multiple	2 2 2 3
Point Repair	Defective	4
Brickwork	Displaced Missing Dropped Invert Missing Mortar	3 4 5 2-3

Each CCTV inspected sewer will be assigned a variety of scores based on the PACP grading system including the overall score, pipe rating index and a PACP quick rating. In each of these ratings, higher scores indicate poorer conditions for both structural and O&M ratings.

Overall Pipe Rating – All structural defects along the length of the asset are summed together to create a total score for both Structural Defects and O&M Defects. This total score should be viewed with caution, since a high Overall Pipe Rating score may indicate a high number of low severity defects, a low number of high severity defects or a balance of high and low defect grades.

Pipe Rating Index – Indicates the overall defect severity within the line segment. The index is calculated by dividing the overall pipe rating by the total number of graded defects. The Pipe Rating Indexes are calculated separately for structural and O&M. It should be noted that as this index represents an average of the segment grade scores, id does not indicate whether there are many or few defects with high or low condition grade numbers.

PACP Quick Rating – This is a shorthand way of expressing the number of occurrences for the two highest severity grades present in the pipe. The quick rating is a four-character score compiled as follows:

- **First Character:** Highest severity grade occurring along the pipe length.
- **Second Character:** Total number of occurrences of that highest severity grade. If the total number exceeds 9, then alphabetic characters are used as follows: 10 to 14 = A, 15 to 19 = B and 20 to 24 = C, etc.
- **Third Character:** Second highest severity grade occurring along the pipe length.
- **Fourth Character:** Total number of occurrences of the second highest grade occurrences, using the same alphabetic characters as described in the second character.

It is recommended that each municipality adopt a rating methodology that conforms to the above rating and grading scheme to achieve consistency in the process used to develop the related work plans.

Maintenance Hole Rating System

The rating and ranking of maintenance holes depend on two primary considerations:

1. The internal structural condition of the maintenance hole from the cover at the top to the base and bottom, in a manner similar to a ‘vertical’ sewer. This includes the cone/neck/ riser rings, the barrel, the base/bottom and all the joints; and
2. The external placement and elevation of the maintenance hole top and cover in relation to the surrounding surface area contour pattern and the overland stormwater flow path and pattern. The maintenance hole top and cover could be the lowest surface point. In such a situation, stormwater will pond over the maintenance hole and induce high direct inflows into the sanitary system.

Thus, each maintenance hole needs to be rated and ranked for the above two primary assessment conditions. For simplicity, effectiveness, and consistency, a 1 to 5 grade scale, similar to the sewer rating scale, is proposed for rating maintenance hole conditions. The following table provides the framework for categorizing the related field data for each maintenance hole.

The NASSCO Manhole (Maintenance Hole) Assessment Certification Program (MACP) method has been widely used by Member Municipalities to date but would be recommended as a standard protocol for maintenance hole condition assessments. This method does require a specialized camera and will have a higher inspection cost than visual assessment from the surface. Table F-3 describes a generalized five-point scale that is based on MACP.

Table F-3: Maintenance Hole Rating System

Internal Condition Grade	Implication	Typical Defect Description
1	Acceptable structural condition. No infiltration	No observable structural defects. No observable signs of infiltration.
2	Minimal risk of maintenance hole failure. Minor signs of infiltration.	Minor cracks, chips, spalling. Signs of minor staining, but no visible infiltration.
3	Structural failure unlikely in near future, but further deterioration likely. Signs of infiltration	Fractures, medium spalling, defective pipe/MH joints. Some staining, mineral buildup, and seeping infiltration. Possible infiltration through maintenance hole cover.
4	Structural failure likely in the near future. Severe signs of infiltration	Broken maintenance hole wall, channel, or riser assembly, multiple fractures, medium wear. Moderate staining, mineral buildup and running infiltration. Infiltration through maintenance hole cover.
5	Structural failure or failure imminent. High infiltration rate	Failure in maintenance hole wall, channel, or riser assembly, multiple fractures with deformation, large wear. Heavy staining, mineral buildup and gushing infiltration. Surface ponding and infiltration through maintenance hole cover.

Sewer Investigations and Costing Work

The biennial report also needs data related to sewer investigation and rehabilitation work as well as the related direct costs incurred in carrying out that work. These items are briefly discussed below.

Smoke and Dye Testing and Reporting

Generally, smoke testing of sewers and service laterals is carried out area-wide, and dye testing is used as a follow-up test on specific sewers/service laterals, to further confirm or further investigate the results of smoke testing. These tests would indicate the approximate locations of existing cross connections between the storm and the sanitary systems, in a given area. In case of sewers, the reported defects should include each occurrence of smoke detected through catch-basins, open-ended sewers, and sewer pipe defects. In the case of service laterals, the deficiencies would include those rainwater leaders, swimming pool drains, lawn basins, clean out caps and drain tiles through which smoke is detected during the testing.

Therefore, the findings from such investigation work should be reported as part of the biennial report. For consistency in reporting, it is recommended that for each sewer section (i.e., between two adjacent maintenance holes), multiple defects equaling the number of locations where smoke is detected along the length be reported. In case of service laterals, all detected defects could be included as one defect, so that each service is counted as either defective (one or more defects) or non-defective (no defect is detected).

Air Testing of Sewer Joints

Air testing of sewer joints is carried out to test whether a joint could hold a pressure higher than the atmospheric pressure, indicating that a joint is not defective. Each joint could then be classified as defective/non-defective based on the results of this pressure test. The total number of joints tested and the percentage that failed are the key data that need to be in the report.

Sanitary Sewer Overflows

Sanitary Sewer Overflows (SSOs) should include sewer flow discharges to the streets, environment, storm sewer system, and inside buildings, and should exclude sewer surcharging with no overflows. Sewer overflows due to blockages should be excluded. Planned overflows due to insufficient capacity are included because the they would result in some form of action (system upsizing, storage, or flow reduction). Municipal SSOs should be included even if the overflow was caused by a capacity restriction is in the GVRD system.

Program Costs for Reporting

The core objective is to include only those program costs that are directly attributable to the development and implementation of the sewer improvement program(s) and that comply with the commitments under the LWMP, as discussed in this report.

The following is a set of broad guidelines for developing the related costs:

1. The reported costs should be consistent with the scope of work required to meet the LWMP-related commitments and conform to the actual costs as per the municipality’s annual budgeting and costing reports;
2. These cost will, therefore, exclude all costs of normal operations, maintenance, and administration activity in the municipality;
3. If normal internal resources such as staff, equipment and material are used for specific work under this program, the related costs could be included using equivalent hourly rates and unit costs;
4. All direct costs would include the following:
    a. consultant fees for professional services to develop the program, and provide design and construction services;
    b. contractor fees for field investigation work such as CCTV testing, smoke/dye/air testing, etc.;
    c. flow monitoring costs and rainfall monitoring costs, including the costs of the associated equipment and/or rentals. These costs could be pro-rated if used jointly with storm system related work;
    d. capital improvement costs for sewer rehabilitation work, excluding concurrent costs for other work along the same reaches, such as full-width roadway/sub-base restoration, storm sewer replacement, etc.; and
    e. municipal GST rebates and other directly related costs for investigations and rehabilitation.
5. The costs could be rounded up to the nearest hundred when reporting.

This rating and ranking approach for the sewer infrastructure components, together with pre- and post-improvement sewer flow/rainfall monitoring data, provides a performance-based reporting protocol for the GVRD and its members to work toward achieving their I&I-related LWMP commitments.

4. Recommended Template and Pilot Area Results

The document titled 2001 *Draft Sewer Condition Reporting Standard Template Items*, was reviewed as part of this project. It is concluded that the list of infrastructure components and the associated parameters/characteristics included therein cover most of the relevant reporting parameters, at a suitable level of detail, to track the sewer infrastructure changes over time in each municipality.

4.1 Recommended Template

Using the reporting methodology presented above, a reporting template has been developed. It is in table form and is described in the presented on the next three pages. It is also attached as Appendix C. The reporting template entries should be rounded off to the nearest whole number. The associated mapping template and a pilot area sample biennial report are presented in the next section and Appendix D.

It is recommended that the GVRD and the member municipalities adopt this as the initial template, to be modified/amended in the future based on the results of their collective experience.

4.2 Recommended Implementation

The following implementation approach integrates the investigation, rehabilitation, and reporting work. The approach comprises six steps, as outlined below:

1. Apply the PACP condition grading scheme to assign a Structural and O&M condition grades (from 1 to 5) to each of the CCTV-tested sewers;
2. Assess maintenance holes based on the findings of field investigations, and grade them from 1 to 5;
3. Combine the assessment results with the municipality's GIS data to show results graphically;
4. Identify areas that show high ranking (3 to 5 on the condition grading scale of 1 to 5 for the sewers and for the maintenance holes), and recommend appropriate rehabilitation options and a priority plan;
5. Implement the recommended rehabilitation program on a priority system based on the likelihood of a structural failure and basin priority from flow monitoring results from a City-wide program; and
6. Report progress on a biennially, using the reporting methodology presented in this report.

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Appendix G

Archetype I&I Program Templates and Costs

Appendix G: Archetype I&I Program Templates and Costs

The purpose of this Appendix is to present the I&I Archetype Templates and Costs for the proposed I&I Management Program.

Archetype A
Inspect in 15-20 Years

Description

- Less than 75 years old
- Below the I&I-Age Curve
- Likely in well-drained soils
- Built to municipal bylaw standards
- PVC and AC sewers and laterals

Actions

- CCTV 100% of catchment in 15-20 years
- Flow Monitoring every 10-15 years

I&I Reduction Impact

- No direct impact on I&I rates
- Enables future planning for I&I management

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Point Repairs	0.1	18,500
Average Cost (Approx.)		**$31/m**
Range (+/- 20%)		**$25-37/m**
+ Flow Monitoring and Analysis		$18,000/Catchment

Timeline

Archetype B – Inspect in 10-15 Years

Description

- Less than 75 years old
- Above the I&I-Age Curve and below Threshold line
- Built to municipal bylaw standards
- PVC and AC sewers and laterals

Actions

- CCTV 100% of catchment in 10-15 years
- Flow Monitoring every 10-15 years

I&I Reduction Impact

- No direct impact on I&I rates
- Precedes I&I reduction activity

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Point Repairs	0.1	18,500
Average Cost (Approx.)		**$31/m**
Range (+/- 20%)		**$25-37/m**
+ Flow Monitoring and Analysis		$18,000/Catchment

Timeline

Archetype C – Inspect in ~ 10 Years

Description

- More than 75 years old
- Below the I&I-Age Curve
- Collection system performing exceptionally well
- VC sewers and laterals

Actions

- CCTV 100% of catchment in ~ 10 years
- Flow Monitoring every 10-15 years

I&I Reduction Impact

- Limited impact on I&I rates

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Point Repairs	0.1	18,500
Average Cost (Approx.)		**$31/m**
Range (+/- 20%)		**$25-37/m**
+ Flow Monitoring and Analysis		$18,000/Catchment

Timeline

Archetype D – Targeted SWI Reduction

Description

- Less than 20 years old
- Above the Threshold line
- Any system, suspected stormwater cross-connections

Actions

- CCTV 100% of catchment (if not already done)
- Smoke & dye testing
- Identify and eliminate cross-connections
- Use a summertime flow monitoring program to identify extent and tributary area of cross-connections
- Separate combined maintenance holes
- Investigate storm drainage system

I&I Reduction Impact

- If cross-connections present, should have large impact
- Stormwater components removed from sanitary
- ‘Back to the Line’

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Program Development	100	3
Smoke Testing	100	4
Dye Testing	20	4
Point Repairs	0.1	18,500
Maintenance Hole Rehab	2	80
Average Cost (Approx.)		**$40/m**
Range (+/- 20%)		**$30-50/m**
+ Flow Monitoring and Analysis (all year - summer and winter)		$36,000/Catchment

Timeline

Archetype E – Targeted I&I Reduction

Description

- Less than 75 years old
- Above the I&I-Age Curve and the Threshold line
- Any system
- May have previous rehab completed on public side
- May have SWI issues

Actions

- CCTV 100% of catchment (if not already done)
- Use a summertime flow monitoring program to identify extent and tributary area of cross-connections
- Smoke & dye testing
- Identify and eliminate cross-connections
- Lateral rehabilitation (if proceeding ahead of bylaw)
- Mainline grouting & minor rehabilitation

I&I Reduction Impact

- Typically averages 40% for appropriately-planned programs
- May get up to 60% in areas with high I&I rates
- 'Back to the Line'

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Program Development	100	5
Smoke Testing	100	4
Dye Testing	20	4
Point Repairs	0.1	18,500
Pipe Grouting	94	150
Maintenance Hole Rehab.	2	80
Pipe Relining	5	900
Pipe Replacement	1	1,300
Lateral Relining	40	410
Lateral Pipe Bursting	20	410
Lateral Grouting	40	160
Average Cost (Approx.)		**$550/m**
Range (-50% / +100%)		**$275-1,100 /m**
+ Flow Monitoring and Analysis (all year – summer and winter)		$36,000/Catchment

Timeline

2022 → 2025 → 2030 → 2035 → 2040

Archetype F – Targeted I&I Reduction and Structural Repairs

Description

- Greater than 75 years old, less than 150 years old
- Above the I&I-Age Curve
- Primarily VC and AC systems

Actions

- CCTV 100% of catchment (if not already done)
- Smoke & dye testing
- Identify and eliminate cross-connections
- Use a summertime flow monitoring program to identify extent and tributary area of cross-connections
- Storm sewer improvements
- Lateral rehabilitation & replacement (if proceeding ahead of bylaw)
- Maintenance hole rehabilitation & replacement
- Mainline rehabilitation & replacement

I&I Reduction Impact

- 'Back to the Line'
- Reduce effective age of catchment

Timeline

2022 → 2025 → 2030 → 2035 → 2040

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Program Development	100	5
Smoke Testing	100	4
Dye Testing	20	4
Pipe Relining	20	900
Pipe Bursting	5	1,500
Pipe Grouting	74	150
Maintenance Hole Rehab	10	80
Maintenance Hole Replacement	5	320
Point Repairs	0.5	18,500
Pipe Replacement	1	1,300
Lateral Relining	40	410
Lateral Pipe Bursting	20	410
Lateral Grouting	40	160
Storm Sewer Improvements	5	3,800
Average Cost (Approx.)		**$1,000/m**
Range (-50% / +100%)		**$500-2,000/m**
+ Flow Monitoring and Analysis (all year – summer and winter)		$36,000/Catchment

Archetype G – Full Basin Rehabilitation

Description

- Greater than 100 years old
- Full basin rehabilitation should be completed at the end of the catchment's service life (as determined in the Asset Management Plan)
- Plotting point could be anywhere on I&I curve, but likely high I&I rate due to catchment age
- Likely over 90% VC pipe

Actions

- Lateral rehabilitation & replacement (if proceeding ahead of bylaw)
- Maintenance Hole rehabilitation & replacement
- Mainline rehabilitation & replacement
- Storm sewer improvements

Note: Although estimates have been provided for targeted rehabilitation costs based on programs undertaken, it is preferrable that basins in this category are fully replaced.

I&I Reduction Impact

- Complete renewal of catchment brings the age to zero relative to percentage of rehabilitation completed

Costs

Work Component	% of Catchment	Component Cost ($/m)
CCTV	100	10
Condition Assessment	100	2
Program Development	100	5
Pipe Replacement	10	1,300
Pipe Relining	60	900
Pipe Bursting	30	1500
Maintenance Hole Rehab	90	80
Maintenance Hole Replacement	10	320
Lateral Relining	50	410
Lateral Pipe Bursting	50	410
Storm Sewer Improvement	30	3,800
Total Cost (Approx.)		**$2,800/m**
Range (-50% / +100%)		**$1,400-5,600/m**

Timeline

2022 → 2025 → 2030 → 2035 → 2040