

INFILTRATION/INFLOW CONTROL/REDUCTION FOR WASTEWATER COLLECTION SYSTEMS

A BEST PRACTICE BY THE NATIONAL GUIDE
TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide
to Sustainable
Municipal
Infrastructure



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Infiltration/Inflow Control/Reduction for Wastewater Collection Systems

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FOREWORD

In spite of recent increases in public infrastructure investments, municipal infrastructure is decaying faster than it is being renewed. Factors such as low funding, population growth, tighter health and environmental requirements, poor quality control leading to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, construction and operation practices have impacted on municipal infrastructure. At the same time, an increased burden on infrastructure due to significant growth in some sectors tends to quicken the ageing process while increasing the social and monetary cost of service disruptions due to maintenance, repairs or replacement.

With the intention of facing these challenges and opportunities, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) have joined forces to deliver the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. The Guide project, funded by the Infrastructure Canada program, NRC, and through in-kind contributions from public and private municipal infrastructure stakeholders, aims to provide a decision-making and investment planning tool as well as a compendium of technical best practices. It provides a road map to the best available knowledge and solutions for addressing infrastructure issues. It is also a focal point for the Canadian network of practitioners, researchers and municipal governments focused on infrastructure operations and maintenance.

The *National Guide to Sustainable Municipal Infrastructure* offers the opportunity to consolidate the vast body of existing knowledge and shape it into best practices that can be used by decision makers and technical personnel in the public and private sectors. It provides instruments to help municipalities identify needs, evaluate solutions, and plan long-term, sustainable strategies for improved infrastructure performance at the best available cost with the least environmental impact. The five initial target areas of the Guide are: potable water systems (production and distribution), storm and wastewater systems (collection, treatment, disposal), municipal roads and sidewalks, environmental protocols and decision making and investment planning.

Part A of the *National Guide to Sustainable Municipal Infrastructure* focuses on decision-making and investment planning issues related to municipal infrastructure. Part B is a compendium of technical best practices and is qualitatively distinct from Part A. Among the most significant of its distinctions is the group of practitioners for which it is intended. Part A, or the decision making and investment planning component of the Guide, is intended to support the practices and efforts of elected officials and senior administrative and management staff in municipalities throughout Canada.

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments and suggestions from various stakeholder groups, which shaped the enclosed document.

Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g. geographic location, municipality size, climatic condition).

For additional information or to provide comments and feedback, please visit the Guide at <www.infraguide.gc.ca> or contact the Guide team at infraguide@nrc.ca.

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EXECUTIVE SUMMARY

This best practice describes the implementation of an infiltration/inflow (I/I) control/reduction program with the focus on sanitary sewers. It is part of the National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices. This best practice, together with others, will provide a road map to the best available methods for addressing municipal infrastructure issues.

Uncontrolled infiltration/inflow in sanitary sewers can have very detrimental effects on social, economic and environmental aspects of urban areas. Excessive flows can severely limit the capacity of existing sewer systems to serve expanded populations. They also generate sewer backups, basement flooding and health risks, increase the operation and maintenance costs of the treatment and pumping facilities, and give rise to overflow of wastewater to streets or to watercourses.

An infiltration/inflow control/reduction program may be divided into five main stages.

- **Knowledge of the sewer system:** Gathering information on existing sewer system conditions.
- **Monitoring flows:** Monitoring wastewater flows during dry and wet weather conditions to establish if the system is subject to excessive flows and I/I.
- **Sewer assessment and analysis:** Inspecting, testing and flow monitoring sub-basins exhibiting excessive flows aimed at locating infiltration/inflow sources and providing information on the structural state of the sewer appurtenances.
- **System remediation plan development:** Establishing priorities for cost-effective solutions in rehabilitation, repair or replacement work based on the structural and hydraulic conditions of the system as well as additional factors, such as environmental impacts, social implications and treatment, operation and maintenance costs.
- **System remediation plan implementation:** Designing and constructing the rehabilitation and replacement projects followed by flow monitoring to ascertain the actual results of the remedial work.

The emphasis of this best practice has been placed on the elements necessary for the execution of such a program. The first stage includes information gathering related to the existing system, monitoring and assessment of sewer flows, monitoring of related parameters and assessment of the infiltration/inflow level.

Monitoring of the infiltration/inflow should be done in every municipality where there is a sanitary sewer system. Infiltration/inflow control/reduction should be implemented where potential problems have been identified or when significant I/I volumes are observed. These programs should be proactive, preventing rather than responding to problems, such as overflows and backups due to I/I. They must also be undertaken before any major sewer system or treatment plant expansions to ensure the selection of cost-effective solutions.

Experience has shown that, in many cases, I/I removal rates were substantially less than expected due to many reasons, particularly the migration of infiltration from rehabilitated areas to non-rehabilitated areas. Care must be exerted when forecasting rehabilitation results. Cost-effectiveness evaluation of rehabilitation methods should be done on an entire sub-basin rather than concentrating on a more conventional individual source approach. Private building connections can contribute a large part of I/I (as much as 70 percent or more) and must be considered carefully in an infiltration/inflow control/reduction program.

While this best practice emphasizes the technical side of infiltration/inflow control/reduction, other measures (such as source control and education) can also help to reduce and prevent future I/I problems. By-laws related to private connections should be reviewed to ensure proper inspection is made during construction. Public education programs should be maintained or introduced to inform the public of the need for the proper separation of sources of waters discharged into sewers and the consequences of diverting excess water to a sanitary sewer system.

Infrastructure and development standards and policies should be reviewed or developed to ensure new sewer systems are designed and built using materials and techniques that protect against future I/I problems. Design criteria should be reviewed so that new systems are designed with I/I flow allowances consistent with the revised standards and policies. Proper application of construction inspection procedures will play an important role in ensuring protection of the new systems against future I/I problems.

1. GENERAL

1.1 INTRODUCTION

The primary purpose of a sanitary sewer system is to collect and convey wastewater from the source to a wastewater treatment facility or to its point of discharge. Physical integrity of a sewer system may deteriorate with time due to such factors as physical defects, design flaws, illicit connections, root penetration, poorly adjusted manholes, corrosion due to biochemical reactions, soil conditions and aggressive ground waters. The result may be an increase in flows to be conveyed and treated through the entry of groundwater and rainwater into the sanitary sewer system. Increasing the hydraulic load on the sewer system can have numerous detrimental consequences: reduced available capacity of the system to convey and treat wastewater, increased operating costs, and the generation of sewer backups and overflows.

The assessment of buried systems, such as potable water and sewer systems, presents special difficulties due to the fact that these infrastructures cannot be easily inspected visually. Furthermore, excessive flow events often happen during short periods (e.g., heavy rainfall events) or in parts of the year when access to the system can be more difficult (e.g., thawing periods, flooding).

To implement a comprehensive infiltration/inflow control/reduction program, knowledge of the sewer system components and of flow variations in the system are prerequisites before deciding on potentially necessary remedial works. This best practice provides guidance for developing such a control/reduction program.

1.2 SCOPE

This best practice is one of numerous best practices developed by the National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices. It is one of more than 50 aspects identified by the Guide's Storm and Wastewater Technical Committee relating to linear infrastructure, wastewater treatment, customer interaction and receiving water issues.

This best practice applies to the development of an infiltration/inflow control/reduction program for sanitary sewer systems. The emphasis has been placed on the elements necessary for the elaboration of such a program. These include:

- information related to existing systems (sewer maps, drainage maps, digital maps, overflows location, population served, industries connected, sewer inspection videos, etc.);
- monitoring and assessment of sewer flows;

- monitoring of related parameters (potable water consumption, groundwater levels, etc.); and
- assessment of the I/I level.

Complete development of an infiltration/inflow control/reduction program is beyond the scope of this best practice. The following subjects, important in an overall program, will be covered in less detail in this document or they may be the subject of future best practices:

- structural and hydraulic assessment;
- physical investigation of the pipes;
- rehabilitation methods and cost evaluations;
- by-laws, inspection and enforcement;
- review of design criteria;
- construction methods and material;
- construction inspection techniques;
- recommended practices for new sewers and laterals; and
- new standards and policies.

1.3 HEALTH AND SAFETY

Some activities described in this best practice can involve entering confined spaces (manholes, pumping station pits, etc.). Information on safety procedures is presented in Appendix A.

1.4 GLOSSARY OF TERMS¹

The main technical terms used in this document and their meaning are presented in this glossary.

The two main terms relevant to this best practice, inflow and infiltration, have been defined in various ways. Figure 1–1 below is used to present the meaning and definition of the main terms used in I/I analyses.

¹ Adapted in part from WEF and ASCE, 1994.

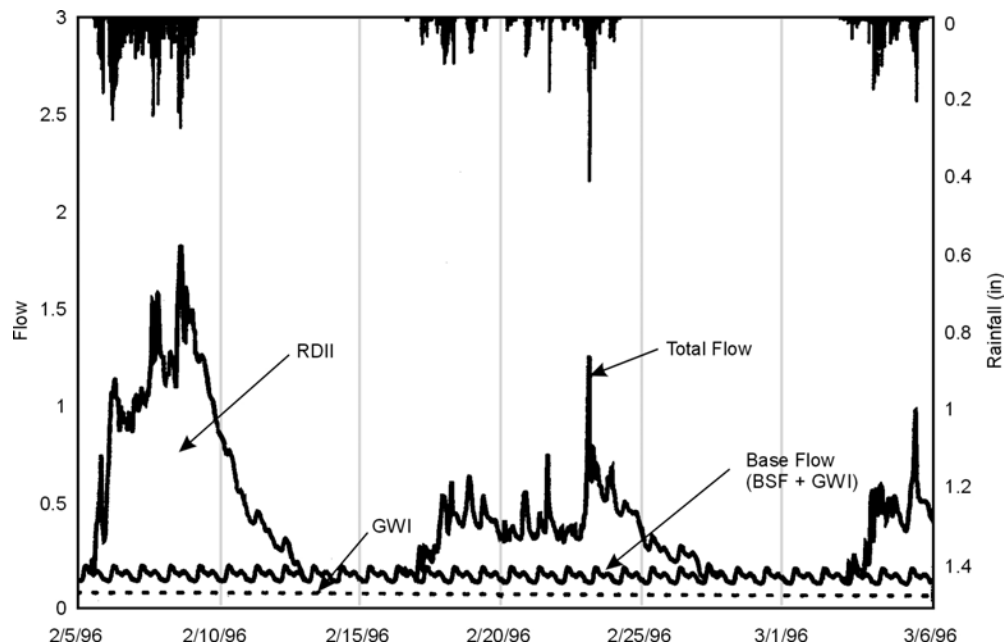


Figure 1-1: Typical wet weather wastewater hydrograph components (WEF, 1999b)

Base flow — Base sanitary flow plus groundwater infiltration.

Base sanitary flow (BSF) — Total sanitary flow from residences and all other connections.

Building sewer — A conduit that connects wastewater sources from a building to the public or street sewer. See also sewer lateral.

Combined sewer — A sewer intended to function simultaneously as a storm sewer and a sanitary sewer.

Dry weather flow (DWF) — Flow as measured in the sanitary sewer during a dry weather period.

Exfiltration — Leakage or discharge of flows from sewers into the ground through leaks in pipes, joints, manholes or other sewer system appurtenances.

Groundwater infiltration (GWI) — Flow deriving from groundwater flowing into the sewer cracks in the pipe, manholes, etc. This I/I component tends to be continuous and dependent on groundwater levels. GWI can experience seasonal changes as the groundwater table varies.

Groundwater table — Upper surface of the zone of saturation in permeable rock or soil.

Infiltration — The water entering a sewer system, including building sewers, from the ground through such means as defective pipes, pipe joints, connections or manhole walls.

Inflow — The water discharged to a sanitary sewer system, including service connections, from such sources as roof leaders, cellar, yard or area drains, foundation drains, drainage from springs and swampy areas, manhole covers, interconnections from storm sewers, combined sewers and catch basins, storm waters, surface runoff, street wash waters or drainage.

Invert — The lowest point of the internal cross section of a pipe or sewer.

Lateral — Any pipe connected to the main sewer.

Rainfall-derived inflow/infiltration (RDII) — Extraneous flows, both inflow and infiltration, derived from rainfall. RDII is typically assumed to be comprised of the fast response component (inflow) and the slow response component (infiltration).

Roof leader — A drain pipe that conveys storm water from the roof of a structure to a sewer for removal from the property or for disposal onto the ground.

Sanitary sewer — A sewer receiving and carrying liquid and water-carried wastes, to which storm, surface, or groundwater are not intentionally admitted.

Sanitary sewer overflow (SSO) — An emergency discharge of untreated or partially treated wastewater from a sanitary sewer system.

Sewer lateral — The conduit that connects building wastewater sources to the public or street sewer, including lines serving homes, public buildings, commercial establishments and industrial facilities.

Storm sewer — A sewer that carries stormwater and surface run-off water, excluding wastewater.

Surcharge — Flow condition when the sewer flow exceeds the hydraulic capacity of the sewer line.

Wet weather flow (WWF) — Flow observed during rainy and snow melt periods and affected by rainfall-derived infiltration/inflow.

2. RATIONALE

2.1 MOTIVATION TO PERFORM INFILTRATION/INFLOW CONTROL/REDUCTION

Excessive I/I in sanitary sewers can hydraulically overload sewer lines and wastewater treatment plants, and result in surcharging, basement flooding, sewer bypasses and reduced treatment efficiency. As noted in the *US EPA Handbook on Sewer System Infrastructure Analysis and Rehabilitation* (US EPA, 1991), infiltration and inflow are the major deterrents to the successful performance of a wastewater conveyance or treatment system.

Planning for sewer systems and treatment plants normally includes flow allowances for growth and expansion. However, as these systems deteriorate, the opportunities envisaged by these allowances for growth and expansion are reduced substantially by the presence of extraneous flows due to I/I. The need for upgrading sewer systems or expansion of treatment plant capacity involves a heavy economic burden. The implementation of a successful infiltration/inflow control/reduction program has a positive economic impact by increasing and/or maintaining the existing infrastructure life expectancy and capacity.

Control of I/I can have positive effects on urban development and must be considered when planning for required conveyance and treatment facilities. Controlling and reducing extraneous flows in sewers can enable an increase in population served without upgrading the conveyance (pipes, pumping stations) or the treatment facilities. Neglecting to take action in reducing such flows may limit the capacity of existing facilities to serve properly the planned populations and areas, or increase operational costs.

The social and environmental impacts of excessive infiltration and inflow are substantial. The urban environment and the quality of the water resources are adversely affected by the surcharges and overflows induced by the excessive flows. Basement backups and surcharging on streets and private properties have serious economic and social costs, and present serious health hazards. Sewer system faults causing infiltration may, depending on the groundwater table level, generate exfiltration of wastewater when the groundwater table drops. This could result in contamination of the groundwater.

Regulatory agencies are setting tighter criteria on discharge quality parameters and on overflow frequencies. Excessive I/I flows can have adverse effects on treatment efficiencies including bypassing secondary or tertiary treatment, thus causing effluent pollution discharge events. Rainfall-derived infiltration/inflow (RDII) can cause more frequent sanitary sewer overflows and prevent compliance with the permitted overflow frequencies.

Excessive infiltration/inflow can be the source of structural damages to sewer system components (pipes, manholes, etc.) by washing out surrounding soils. These problems tend to grow with time, and deferring action can result in serious disorders, such as pipe collapses. Voids created in the soil may also cause serious damage to neighbouring infrastructures (e.g. watermains, road base, phone, gas).

3. WORK DESCRIPTION

3.1 INFILTRATION/INFLOW CONTROL/REDUCTION PROGRAM

Implementation of an infiltration/inflow control/reduction program is a multi-step process, as shown in Figure 3–1. The steps can be grouped in five major stages:

- knowledge of the sewer system;
- I/I monitoring;
- sewer system analysis;
- system remediation plan development; and
- system remediation plan implementation.

Acquiring knowledge of the system includes gathering information on the physical aspects of the sewer system (pipes, manholes, laterals, etc.), as well as related data that can be used in assessing the sewer system (flow records, sewer operation and maintenance records, population history, groundwater data, meteorological data).

The goal of monitoring I/I is to determine if the system or parts of the system exhibit excessive I/I flows and if further analysis is required through monitoring and assessing wastewater flows and related parameters.

The next stage is sewer system analysis, which involves assessment of infiltration/inflow sources through field activities, such as visual inspection, CCTV inspection and smoke tests. At this stage, the goal is to identify the parts of the system needing rehabilitation/replacement.

The development of the system remediation plan involves considering rehabilitation or replacement options for parts of the system, based on the structural and hydraulic conditions of the sewer system and future capacity needs. Identifying and setting priorities for cost-effective solutions must be undertaken for the direct rehabilitation/replacement, taking into account additional factors, such as the condition of neighbouring infrastructures, social implications, and operation and maintenance costs. The plan should also include non-technical measures to reduce I/I, such as public education programs on sump pump or downspout connections and encourage disconnection programs.

Implementation of the system remediation plan entails designing and constructing the rehabilitation and replacement projects, monitoring the results and reviewing the plan as needed.

Figure 3–1 presents a decision schematic to assist system operators and planners in developing and I/I control/reduction program. Following the approach laid out in the schematic should enable operators and those responsible for planning the system to implement a program specifically tailored for the community being served. It provides specific triggers for action, such as extraneous flows causing bypasses at the treatment plant. As a minimum level of activity, it requires ongoing monitoring and assessment of dry and wet weather flows and the continuous updating of basic sewer plans due to the addition of new infrastructure or new field information.

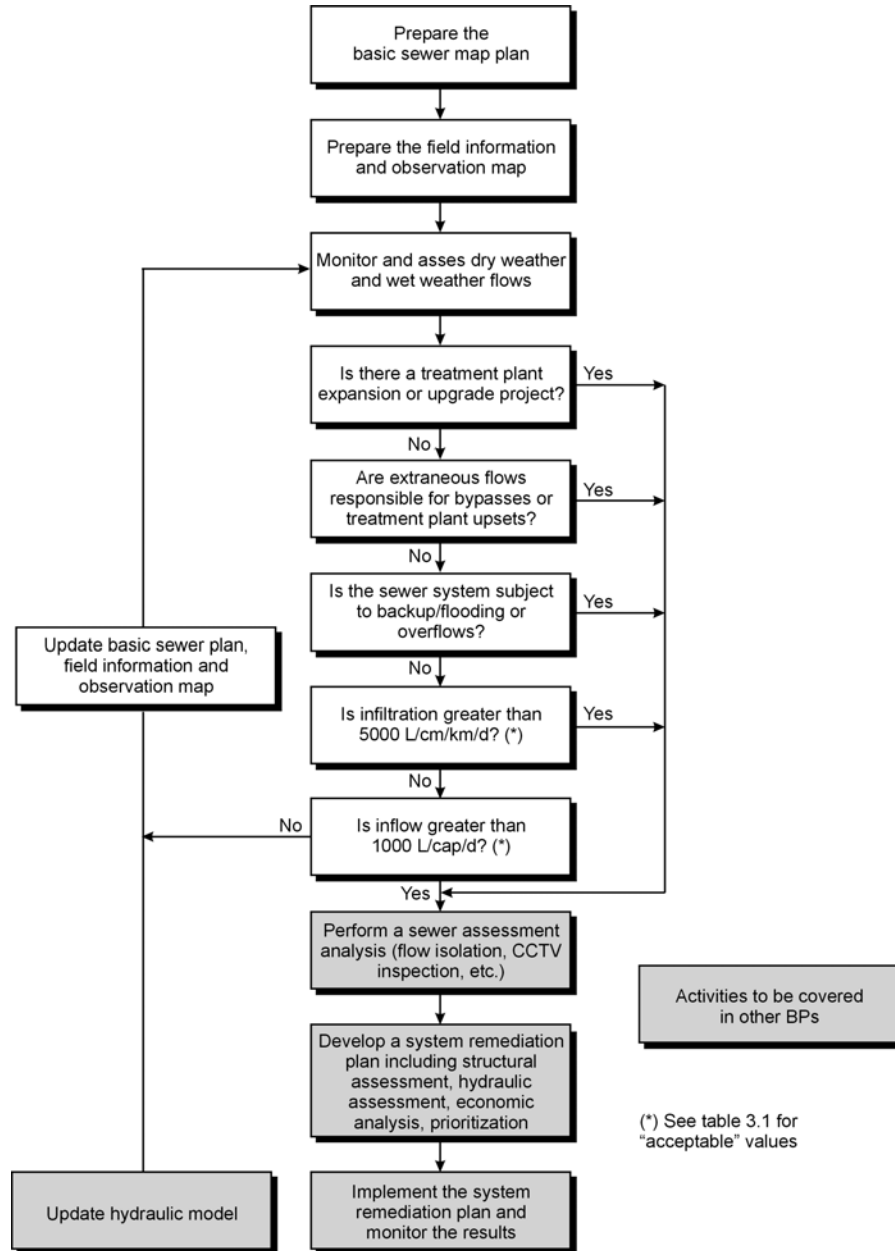


Figure 3–1: Infiltration/inflow control/reduction program activities flowchart

3.2 THE STAGES

3.2.1 KNOWLEDGE OF THE SEWER SYSTEM

Before undertaking I/I monitoring, proper knowledge of the sewer system, related to operational conditions and other basic data, is required. This information includes physical aspects of the sewer system (pipe layout, characteristics, etc.), the served areas (population, industrial discharges, connected flat roofs, etc.), as well as operational data (emergency pumping sites, abnormal flows, etc.).

Information related to municipal systems is more and more commonly recorded in a geographical information system (GIS). Such systems store information in both graphical layers and in a database allowing for the combination and extraction of data for further analysis. If such a system is not available, the information can be registered on CAD-based systems or paper drawings.

Basic information on the sewer system must be available on a base sewer map. This map should be at a scale of 1:2500 to 1:5000 and provide the following information:

- street names;
- floodplain delineation for specific flood events (e.g., for 20/100/500 years);
- important water users (industries, large businesses, schools, etc.);
- pumping stations and regulator device locations;
- storage facilities;
- wastewater treatment plant location;
- sanitary sewer, combined sewer, storm sewer layout;
- diameter, length and slopes of sewer pipes;
- manhole inverts;
- outfall, overflow to receiving body and/or storm sewer location; and
- stream and large drainage ditch locations.

A field information and observation map, based on the sewer map, overlays information pertinent to I/I and includes the following (through symbols):

- infiltration observations in manholes and pipes;

- potential inflow sources (flat roofs, roof leaders entering the soil, garage entrance sloping toward the house, manhole covers, weeping tiles, etc.);
- presence of sediments in manholes, traces of surcharge in manholes;
- high level of water flow during wet weather;
- emergency pumping sites;
- abnormal dry weather flows (high or low);
- location of overflow and basement flooding events;
- manholes in low lying areas; and
- CCTV inspection results.

Based on the above information, the sewer system can be subdivided into major sub-basins. Flows will be monitored on the basis of sub-basins. The limits of the sub-basins should take into account the availability of a downstream monitoring point, the use of a permanent structure for flow monitoring (pumping station, treatment plant, flow meter, etc.) and the location of overflow points. Ideally, the area of the sub-basins should not exceed 500 hectares to allow for proper flow monitoring and assessment. The sub-basin limits must be included on the base sewer map. Each manhole must also be numbered on the base sewer map. A manhole numbering system based on sub-basin identification facilitates referencing in future activities.

3.2.2 MONITORING I/I

Wastewater flow monitoring is required to assess the I/I portion of the sewer flow. I/I flows can be highly variable depending on such factors as the seasonal groundwater table elevation, snow pack, water levels in adjacent watercourses and antecedent moisture conditions. Continuous flow monitoring is a very useful tool to reveal these variations in flows (daily, seasonal, etc.). If continuous readings are not available, other means, such as temporary flow measuring points, pumping station operating time and total wastewater treated volumes, can also be used. Overflow event monitoring is also required to provide for proper inflow assessment.

In larger systems, real-time continuous flow measurements are often available at the wastewater treatment plant as well as at other permanent measuring points in the sewer system (e.g., inter-municipal connections, connections to an interceptor, etc.).

In smaller systems, continuous flow measurements are often recorded at the entrance to the wastewater treatment plant. When permanent continuous records

are not available, other techniques can be considered although they will not provide the same degree of information on flow variations. Such techniques include temporary continuous flow monitoring, pump running times and daily total volumes.

Temporary continuous flow monitoring at key manholes can be done through the use of combined area velocity-flow meters. Monitoring periods can last from one week if dry weather conditions are required up to several weeks or months if specific wet weather data are being gathered. These flow meters can be relocated at different key manholes during a flow measurement campaign.

Pumping station monitoring is another means of providing wastewater flow information. Use of an event recorder logging on-off cycles of pumps will provide continuous flow data while meters recording the running time of pumps can be read to record hourly or daily flows. Calibration of each pump can be done using wet well drawdown and return (WEF, 1994). Care must be exerted when calibrating two or more pumps feeding simultaneously the same discharge pipe. In this case, all the different pump operating combinations must be calibrated, and separate timers are required to record operating times.

Instantaneous flow measurement is often provided at the entrance of wastewater treatment plants. Continuous-level controllers, in conjunction with open channel flumes, provide instantaneous flows and total volumes. Consideration should be given, in this case, to the addition of data logging equipment that will provide continuous flow recordings.

Other instantaneous flow measurement methods include temporary weirs, manual depth measurement with velocity estimation, dye-dilution methods, timed volume and velocity-measuring equipment. Care must be used when using weirs not to induce backflows.

Overflows and emergency pumping from the system must also be monitored in parallel to flow monitoring. Level recorders in combination with overflow weirs can provide overflow volume or hydrographs. Event recorders can provide overflow time duration between readings. Finally, event indicators can be used to indicate if there was an overflow. Styrofoam blocks, located at overflow levels, can detect the occurrence of an overflow between two visits. These blocks, attached to a string, are removed from their support by high water levels in the sewer.

To evaluate I/I, wastewater flow must be subtracted from total flow. Water supply records can be used to estimate the amount of domestic wastewater that is normally returned to the sewer system. In general, around 70 percent of the water consumed is returned to the wastewater system in summer. This figure increases to about 90 percent in the winter months. Care must be exerted when the water

distribution system serves homes equipped with on-site treatment systems or where private well users can discharge water into the sanitary sewer system.

Groundwater table monitoring is an important consideration in I/I due to the fact that infiltration phenomenon is groundwater related. If no existing data on the groundwater table are available, installation of groundwater gauges should be considered (US EPA, 1991). Data from groundwater table monitoring may provide explanations for high seasonal variations in I/I. Furthermore, some of the inspections required in subsequent stages, such as CCTV, should be conducted under high groundwater conditions.

Daily precipitation data are normally available from the weather stations network of Environment Canada and provide sufficient information to be used in I/I analysis. Consideration should be given to installing recording rain gauges in areas subject to thunderstorms. Municipalities in areas covered by Environment Canada weather radar should use the superior resolution of this technology to augment rain gauge data when conducting a post-event analysis.

Infiltration flow can be computed in many ways depending on the type of data available. When continuous flow data are available, infiltration flow is determined as the lowest point in the flow curve during dry weather periods. It normally occurs during night hours (2 to 6 AM). Base sanitary flow is the combination of wastewater generated from domestic, commercial and industrial sources. Groundwater inflow (GWI) can be estimated as either 15% of the calculated daily average flow or 85% of the minimum flow monitored between 2 and 6 AM). The combination of infiltration and base sanitary flow results in a repetitive characteristic curve over weekdays and weekend days (although the hourly flow patterns on weekdays and weekends are different). Inflow is what remains when base sanitary flow and infiltration are subtracted from total measured flows during rainfall events (see Figure 3–2).

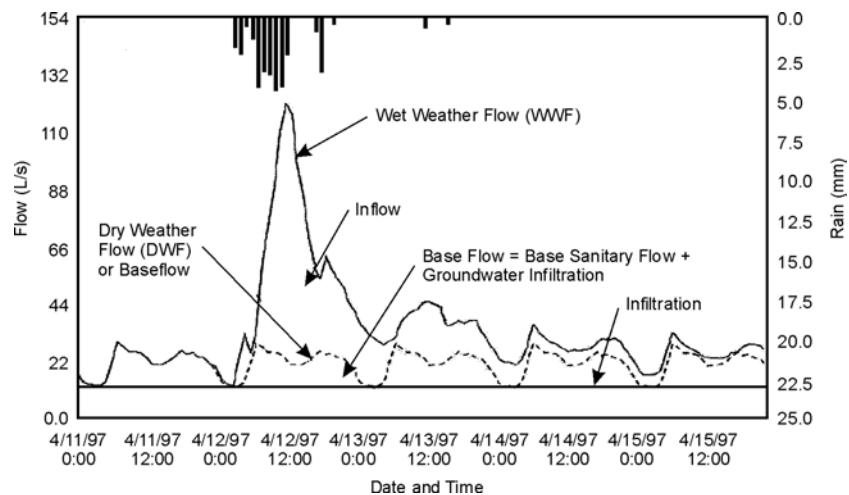


Figure 3–2: Hydrograph components of continuous flow monitoring

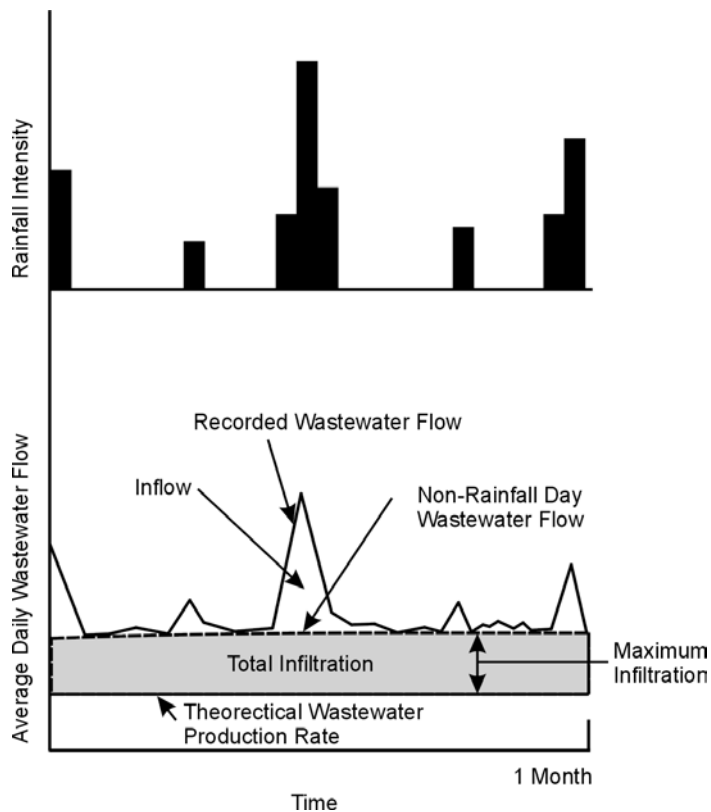


Figure 3-3: Infiltration/inflow based on average daily wastewater flow (USEPA, 1991)

When only daily flows are available, infiltration and inflow are estimated in the following manner (see Figure 3-3).

- Select several months of daily flows and plot them as a function of time.
- Establish the estimated wastewater production rate based on water supply records and draw the line on the plot for this flow.
- Draw a line through the lower limit of the recorded flows. The distance between this line and the wastewater production rate provides an estimate of the infiltration.
- The area left above the infiltration line is an estimate of the inflow.

Establishing acceptable I/I levels is not an easy task since construction methods, soil conditions and treatment processes vary widely throughout the country. However, some values have been used in grant programs, design manuals, etc. These figures are normally expressed in terms of population or contributing sewer network in the following units:

- litre/centimetre of diameter/kilometre of length/day (l/cm/km/d);

- litre/metre of length/day (l/m/d);
- litre/capita/day (l/cap/d); and
- litre/hectare/day (l/ha/d).

Examples of “acceptable” levels of infiltration/inflow for existing systems recommended by agencies from Canada and the United States are given in Table 3–1 as guidelines. These levels are generally based on the criteria used by municipalities in their evaluation for rehabilitation projects and newer sewers built with watertight connections must meet stricter standards for infiltration limits. The application of by-laws and inspections of all installations should limit the contribution of I/I from new connections.

Table 3–1: Guideline Levels of “Acceptable” Infiltration/Inflow for Existing Systems

Parameter Value	Source
11 200 l/ha/d as a result of a storm with less than a five year return period (infiltration + inflow design allowance)	Greater Vancouver Regional District, Liquid Waste Management Plan, February 2001
12 000 l/ha/d or 3 000 l/cm/km/d (average infiltration in existing systems)	Ministère de l’Environnement du Québec, Directive 004, 1989
450 l/cap/day (domestic + non excessive I/I) 1000 l/cap/d (storm flow)	US EPA, Handbook Sewer System Infrastructure Analysis and Rehabilitation, October 1991
5000 l/cm/km/d or 150 l/m/d (further investigations were required when infiltration exceeds one or both parameters)	Ministère de l’Environnement du Québec, Guide technique sur la réalisation des études préliminaires, October 1988

Rough cost comparisons between conveyance and treatment and elimination of I/I through corrective actions can be made before developing a system remediation plan.

Samples of I/I design allowances for new sewers from a number of municipalities in Canada are given in Appendix C.

3.2.3 ASSESS THE SEWER SYSTEM

The next stage is to determine the sources of infiltration/inflow, quantify the amount of infiltration/inflow and provide the elements required in establishing infiltration/inflow removal works. Results of this analysis should be sufficiently specific to describe the corrective action and the amount removed for each major source, sewer segment and sub-basin.

The most commonly used techniques in a sewer assessment analysis are presented in Table 3–2 (US EPA, 1991).

Table 3–2: Commonly Used Techniques in Sewer Assessment Analysis

Method	Application
Smoke testing	Most common routine source detection method to identify RDII sources. Source detection after previous lining or replacement.
Rainfall simulation (dye flooding and tracing)	Used after smoke testing to confirm suspected storm drainage connections and other RDII connections.
Building plumbing inspection	As needed after smoke testing to confirm suspected inflow sources, such as roof leaders and foundation drains.
Manhole inspection	Primary source detection to evaluate I/I sources and structural condition. Inspection performed along with other investigation procedures.
Flow isolation	Follow-up source detection after sealing; used to verify migration, identify I/I. Used where flow monitoring indicates high infiltration in large areas. Used where smoke testing indicates major infiltration sources.
TV inspection	Primary internal inspection technique, degree of inspection as determined by I/I analysis. Routine inspection for pipes rehabilitated by sealing, if interim detection does not reveal I/I sources. Used after grouting and sealing techniques. Used to verify smoke testing, flow isolation or when temporary flow monitoring indicates excessive I/I.
Lateral testing	Used when smoke testing indicates major defects. Used where building inspection indicates major defects.

3.2.4 DEVELOP A SYSTEM REMEDIATION PLAN

The objective of the system remediation plan is to establish priorities in rehabilitation, repair or replacement works. Identification of cost-effective solutions requires assessment of two other aspects of the sewer system: the structure and hydraulic performance.

The structural assessment is required to establish the degree of physical deterioration of the sewer and to determine the proper rehabilitation or replacement technique.

Hydraulic assessment involves investigating the hydraulic performance of the sewer system. This investigation, normally based on computerized hydraulic modelling of the system, establishes whether parts of the existing sewer system

fail to meet the required hydraulic performance. The assessment also serves to identify the required degree of I/I reduction or remedial work required to meet this performance level. This assessment must also include future expansion needs for the sewer system, if applicable. Several hydrograph generation methods have been developed to predict rainfall derived infiltration and inflow (RDII). These methods range from constant rate (e.g., litre per hectare per centimetre of rainfall) to components of commercial hydraulic software (e.g. XPSWMM, Hydra, Mouse, Hydroworks, etc.). Selection of a method to use should be based on the accuracy of the data rather than on the accuracy of the method, no method being more precise or accurate than the data it is based upon (WEF, 1999a).

Following the results of the sewer system analysis and the structural and hydraulic assessments, cost-effective solutions can be identified. These should be based on an assessment of rehabilitation and replacement costs, expected longevity and performance, environmental impacts, social implications, plant performance and operation and maintenance costs.

In some cases, it is appropriate to carry out a pilot rehabilitation project prior to embarking on a full scale I/I reduction program. Results of selected pilot studies/projects should be applied to the system as a whole to establish cost effectiveness.

Rehabilitation or replacement of pipe often becomes a significant part of a system remediation plan. A list of potential rehabilitation alternatives can be found in another *National Guide to Sustainable Municipal Infrastructure* best practice entitled *Selection of Technologies for Sewer Rehabilitation and Replacement*.

3.2.5 IMPLEMENT THE SYSTEM REMEDIATION PLAN

The last stage is the implementation of the system remediation plan. This involves design and construction of rehabilitation and replacement projects that have been evaluated on a cost/benefit basis. Once works are completed, infiltration and inflow reduction and the structural condition of the sewer system must be monitored to ensure the predictions for flow reduction and the effectiveness of the selected solutions are met.

Sewer maps and records should be updated and the remediation plan reviewed on an ongoing basis as events occur and circumstances change that affect future projects. A computer hydraulic model, if used in the analysis, should be updated regularly and maintained as an ongoing planning tool. To calibrate a computer hydraulic model, a sewer flow monitoring program, complete with rainfall data analysis, should be carried out.

4. APPLICATIONS AND LIMITATIONS

4.1 APPLICATIONS

Monitoring programs to determine the magnitude of infiltration/inflow should be carried out in every municipality where there is a wastewater system. The smaller municipalities may conduct a comprehensive review periodically (every 5 to 10 years) while larger municipalities may have a continuous systematic program.

Infiltration/inflow tends to increase as the sewer system ages. Maintaining permanent and revisiting temporary measuring points in time can help detect trends in these flow increases.

Activity planning must consider temporal variations in the conditions of related parameters. For instance, CCTV inspections should be done under high groundwater table conditions to ensure that infiltration sources can be observed.

I/I control/reduction should be implemented where potential problems have been identified or when the trigger events and levels provided in Figure 3–1 of this document are noted. Triggers must be evaluated on a regular basis to reflect life cycle for the infrastructure. These programs should be proactive, designed to prevent rather than respond to such problems as overflows and backups due to I/I. Such a program must also be undertaken before beginning major sewer system or treatment plant expansions to ensure cost-effective solutions are selected.

4.2 RISKS AND LIMITATIONS

Experience has shown that, in many cases, I/I removal rates were substantially less than expected due several reasons. One of the reasons most frequently met in practice and noted in the literature is the migration of infiltration from rehabilitated areas to non-rehabilitated areas. In many instances, rehabilitation works on the main sewer increased the water-tightness of the pipe and resulted in higher groundwater levels. Learning from this experience, care must be taken when forecasting rehabilitation results; the cost-effectiveness evaluation of rehabilitation methods should be done on an entire sub-basin rather than concentrating on a more conventional individual source approach

Another important lesson over the years is the fact that private building laterals can contribute a large part of I/I. During a thorough review of I/I in 1992 and 1993, the City of Edmonton determined that about 70 percent of I/I flows were attributed to on-lot sources (Hodgson et al., 1995). Inspection and rehabilitation of these parts not only generates technical problems in assessing structural condition and I/I flow quantity, it also creates legal difficulties inherent in rehabilitation or other works on private property.

Care must be taken in cases where rehabilitation or replacement works substantially modify the groundwater table. Lowering the groundwater table can cause, in some instances, settlement. Dewatering soils that were previously under the groundwater table creates an overburden. This can lead to consolidation or settlement of compressible soils. Conversely, groundwater infiltration into some sewers may have the effect of lowering the groundwater table. Rehabilitation or replacement of those sewers can lead to watertight systems and an increase in the groundwater levels. Detrimental effects can be flooding of low-lying areas or damage to roads caused by freezing of groundwater in the road base. In such cases, effective drainage systems should be in place to limit the groundwater rise in areas where there may be detrimental consequences.

5. OTHER CONSIDERATIONS

The text of this best practice focussed on technical aspects of existing sewer systems. Other non-technical measures or new sewer criteria should also be considered to prevent future I/I problems.

By-laws related to system connections should be reviewed to ensure proper inspection is made during construction, and the means are available for evaluating existing services and correcting defective connections.

Public education programs should be maintained or introduced to inform the population about the proper separation of sources of waters discharged into sewers and the consequences of diverting excess water to a sanitary sewer system.

Infrastructure and development standards and policies should be reviewed or developed to ensure that new sewer systems are designed and built using materials and techniques that protect against future I/I problems. Design criteria should be reviewed so that new systems are designed with I/I allowances consistent with the materials and construction techniques used. During installation, consistent inspection and verification practices should be instituted and proper operational procedures should be followed after commissioning.

APPENDIX A — HEALTH AND SAFETY¹

Sewers are dangerous, confined-space work areas. They contain harmful gases, bacteria and other micro-organisms, and have insufficient oxygen supply, high humidity, odor and slippery working conditions. Furthermore, flows in many large sewers are difficult to divert and encumber work and inspection.

Health and safety is paramount and must not be compromised when working in sewers. A safety plan is required for all person-entry activities inside a sewer system. Safety procedures must be developed and followed by all involved personnel. Before any inspection and work begins, safety procedures must be in place, and trained personnel responsible for site safety must be identified. Fatalities can occur if appropriate safety procedures are not followed. If multiple parties are present at the site, tasks of each party has to be clearly defined and rules to be followed are to be set.

Although a national health and safety regulation does not exist in Canada, many provinces and municipalities have established their own regulations and procedures for confined space entry. Any municipality operating a sewer system should establish suitable procedures in consultation with provincial authorities and other municipalities. For additional information, refer to the following documents:

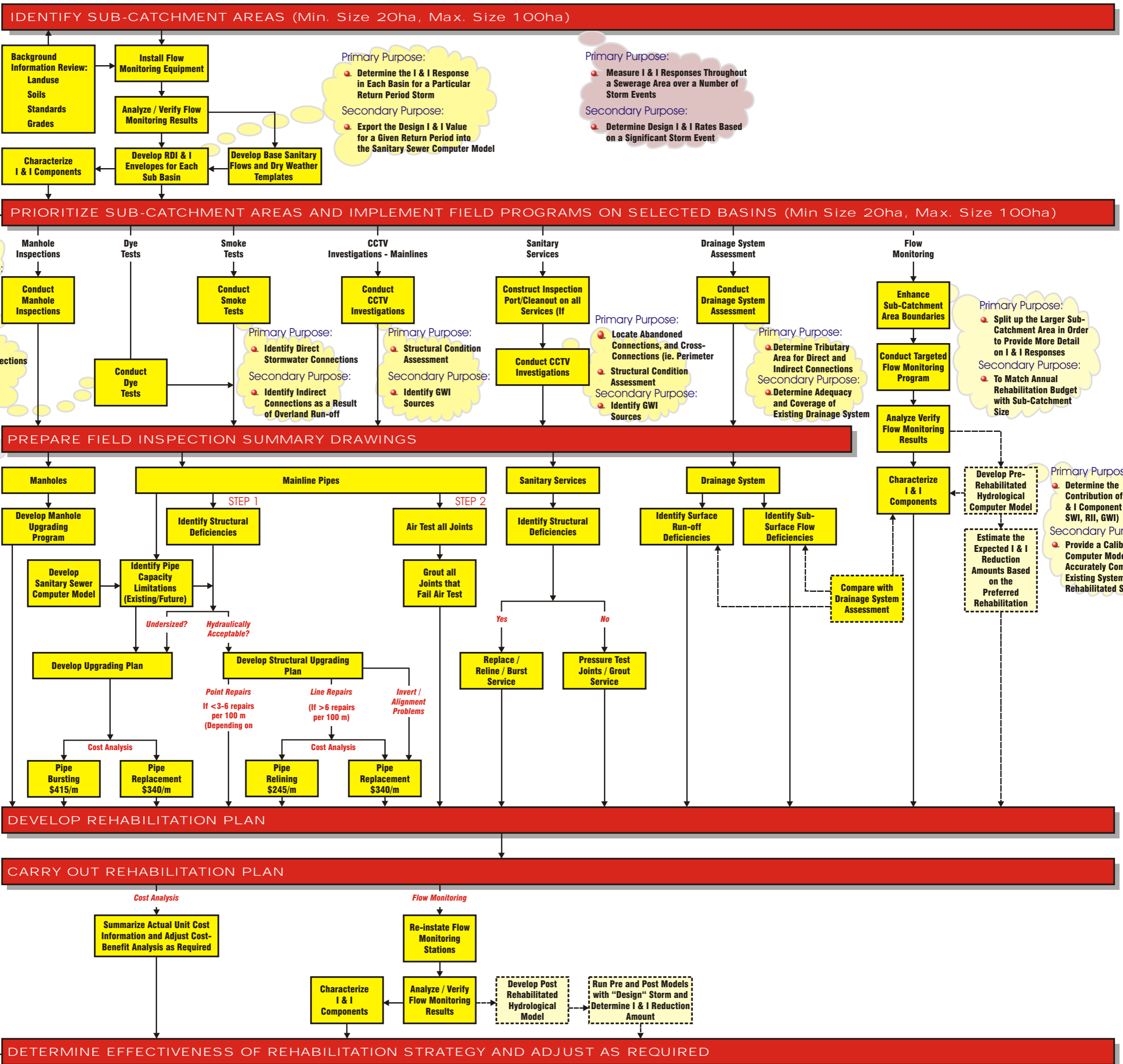
- Ontario Regulation 213/91: The Occupational Health and Safety Act;
- City of Toronto: Confined Space Entry and Exit, 1989;
- Victoria Capital Regional District: *Section 3 – Work Procedure (WP) 13: Confined Space Entry Procedure*, CRD ENG Policy/Procedures Manual, 1998;
- Region of Hamilton-Wentworth: Confined Space Entry Procedure, 1998;
- Greater Vancouver Regional District: Confined Space Guidelines, 1999; Confined Space Entry Guidelines for Sewer Entry, 1994; Personal Protective Equipment Policy Statement, 1993;
- City of Regina, Confined Space Entry Program, 1997; and
- Human Resources Development Canada Web site: <http://info.load-otea.hrdc-drhc.gc.ca/~oshweb/confinen.shtml>.

Minimum requirements for confined space entry are:

- proper training of above-ground and below-ground personnel participating in the inspection and works in sewers;
- detailed contingency plans for work and rescue;
- assessment of potential hazards before access point entry;
- availability of appropriate protective clothing and equipment (harness, life-line, breathing apparatus, and hoisting and conveying equipment);
- availability of appropriate tools and equipment that are in good working order;
- availability of emergency equipment (first aid kit and fire extinguisher);
- air quality testing and monitoring prior to and during person-entry;
- maintenance of adequate ventilation and lighting during person entry;
- effective communication between above-ground and below-ground personnel;
- safe control of surface traffic; and
- record keeping (e.g. entry permits, emergency plans, person in charge, etc.).

Any person entering a sewer must be aware of regulations and trained in health and safety requirements for confined space entry.

Contacts must be made with local health resources for preventive measures and vaccines (e.g., hepatitis, etc.).



Possible I & I Investigation and Reduction Strategy for Small to Medium Sized Sanitary Sewer Catchments

APPENDIX C – DESIGN ALLOWANCE FOR I/I IN NEW SEWERS

Municipality	Design Allowance (l/ha/d)	Municipality	Design Allowance (l/ha/d)
Atlantic -1	11 230	Atlantic - 5	12 096
Atlantic - 2	217	Atlantic - 6	11 000
Atlantic - 3	217	Atlantic - 7	28 034
Atlantic - 4	22 500		
British Columbia - 1	9 348		
Ontario - 1	33 696	Ontario - 4	19 008
Ontario - 2	17 280	Ontario - 5	8 600
Ontario - 3	34 560	Ontario - 6	15 552
Prairie - 1	24 192	Prairie - 3	17 820
Prairie - 2	24 192	Prairie - 4	18 000
Quebec - 1	843	Quebec - 4	3 343
Quebec - 2	5 600	Quebec - 5	3 343
Quebec - 3	5 600		

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