ASSESSMENT AND EVALUATION OF STORM AND WASTEWATER COLLECTION SYSTEMS

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide
to Sustainable
Municipal
Infrastructure

Guide national pour
des infrastructures
municipales
durables

Canada

NRC · CNRC

Federation
of Canadian
Municipalities

Fédération
canadienne des
municipalités

Assessment and Evaluation of Storm and Wastewater Collection Systems
Issue No. 1.0
Publication Date: July 2004

ISBN 1–897094–72–8

TABLE OF CONTENTS

INTRODUCTION

INFRAGUIDE – INNOVATIONS AND BEST PRACTICES

Why Canada Needs InfraGuide

Canadian municipalities spend $12 billion to $15 billion annually on infrastructure, but it never seems to be enough. Existing infrastructure is ageing while demand grows for more and better roads, and improved water and sewer systems. Municipalities must provide these services to satisfy higher standards for safety, health, and environmental protection as well as population growth. The solution is to change the way we plan, design, and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

This is what the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices (InfraGuide)* seeks to accomplish.

In 2001, the federal government, through its Infrastructure Canada Program (IC) and the National Research Council (NRC), joined forces with the Federation of Canadian Municipalities (FCM) to create the National Guide to Sustainable Municipal Infrastructure (InfraGuide). InfraGuide is both a new, national network of people and a growing collection of published best practice documents for use by decision makers and technical personnel in the public and private sectors. Based on Canadian experience and research, the reports set out the best practices to support sustainable municipal infrastructure decisions and actions in six key areas: municipal roads and sidewalks, potable water, storm and wastewater, decision making and investment planning, environmental protocols, and transit. The best practices are available on-line and in hard copy.

A Knowledge Network of Excellence

InfraGuide’s creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers, and other experts, and a host of volunteers throughout the country. By gathering and synthesizing the best Canadian experience and knowledge, InfraGuide helps municipalities get the maximum return on every dollar they spend on infrastructure, while being mindful of the social and environmental implications of their decisions.

Volunteer technical committees and working groups — with the assistance of consultants and other stakeholders — are responsible for the research and publication of the best practices. This is a system of shared knowledge, shared responsibility, and shared benefits. We urge you to become a part of the InfraGuide Network of Excellence. Whether you are a municipal plant operator, a planner, or a municipal councillor, your input is critical to the quality of our work.

Please join us.

Contact InfraGuide toll-free at **1-866-330-3350** or visit our Web site at **<*www.infraguide.ca*>** for more information. We look forward to working with you.

ACKNOWLEDGEMENTS

The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure (InfraGuide)* is acknowledged and much appreciated.

This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review conducted by the Centre for Expertise and Research on Infrastructures in Urban Areas (CERIU). The following members of InfraGuide's Storm and Wastewater Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff, CERIU, and by Stantec Consulting Ltd.

John Hodgson, Chair	City of Edmonton, Alberta
André Aubin	City of Montréal, Quebec
Richard Bonin	City of Québec, Quebec
David Calam	City of Regina, Saskatchewan
Kulvinder Dhillon	Province of Nova Scotia, Halifax, Nova Scotia
Tom Field	Delcan Corporation, Vancouver, British Columbia
Wayne Green	City of Toronto, Ontario
Claude Ouimette	OMI Canada Inc., Fort Saskatchewan, Alberta
Peter Seto	National Water Research Institute, Environment Canada, Burlington, Ontario
Timothy Toole	Town of Midland, Ontario
Bilgin Buberoglu	Technical Advisor, NRC

In addition, the Storm and Wastewater Technical Committee would like to express its sincere appreciation to the following individuals for their participation in working groups.

Gerry Bauer	R.V. Anderson Associates Ltd, Ottawa, Ontario
John Hodgson	City of Edmonton, Alberta
Dave Krywiak	Stantec Consulting Limited, Edmonton, Alberta
Pierre Lamarre	City of Laval, Quebec
Brendan O'Connell	City of St. John's, Newfoundland and Labrador
Marek Pawlowski	M.J. Pawlowski and Associates, Richmond, British Columbia

The Committee would also like to thank the following individuals for their participation in peer review:

Ken Chua	City of Edmonton, Alberta
Chris Macey	UMA Group, Winnipeg, Manitoba
Paul Marsh	Delcan Corporation, Toronto, Ontario
Christoph Moch	UMA Group, Victoria, British Columbia
Gerry Taylor	City of Ottawa, Ontario
Todd S. Wyman	City of St.Albert, Alberta

This and other best practices could not have been developed without the leadership and guidance of InfraGuide's Governing Council, the Relationship Infrastructure Committee, and the Municipal Infrastructure Committee, whose members are as follows.

Governing Council:

Joe Augé	Government of the Northwest Territories, Yellowknife, Northwest Territories
Mike Badham	City of Regina, Saskatchewan
Sherif Barakat	National Research Council Canada, Ottawa, Ontario
Brock Carlton	Federation of Canadian Municipalities, Ottawa, Ontario
William G. Crowther	City of Toronto, Ontario
Jim D'Orazio	Greater Toronto Sewer and Watermain Contractors Association, Toronto, Ontario
Douglas P. Floyd	Delcan Corporation, Toronto, Ontario
Derm Flynn	Town of Gander, Newfoundland and Labrador
Ralph Haas	University of Waterloo, Ontario
John Hodgson	City of Edmonton, Alberta
Joan Lougheed	City of Burlington, Ontario
Saeed Mirza	McGill University, Montréal, Quebec
Umendra Mital	City of Surrey, British Columbia
René Morency	Régie des installations olympiques Montréal, Quebec
Lee Nauss, Councillor	Municipality of Lunenburg, Bridgewater, Nova Scotia
Vaughn Paul	First Nations (Alberta) Technical Services Advisory Group, Edmonton, Alberta
Ric Robertshaw	Public Works, Region of Peel, Brampton, Ontario
Dave Rudberg	City of Vancouver, British Columbia
Van Simonson	City of Saskatoon, Saskatchewan

Basil Stewart, Mayor	City of Summerside, Prince Edward Island
Serge Theriault	Government of New Brunswick, Fredericton, New Brunswick
Tony Varriano	Infrastructure Canada, Ottawa, Ontario
Alec Waters	Alberta Infrastructure Department, Edmonton, Alberta
Wally Wells	The Wells Infrastructure Group Inc. Toronto, Ontario

Municipal Infrastructure Committee:

Al Cepas	City of Edmonton, Alberta
Wayne Green	City of Toronto, Ontario
Haseen Khan	Government of Newfoundland and Labrador St. John’s, Newfoundland and Labrador
Ed S. Kovacs	City of Cambridge, Ontario
Saeed Mirza	McGill University, Montréal, Quebec
Umendra Mital	City of Surrey, British Columbia
Carl Yates	Halifax Regional Water Commission, Nova Scotia

Relationship Infrastructure Committee:

Geoff Greenough	City of Moncton, New Brunswick
Joan Lougheed,	City Councillor, Burlington, Ontario
Osama Moselhi	Concordia University, Montréal, Quebec
Anne-Marie Parent	Parent Latreille and Associates Montréal, Quebec
Konrad Siu	City of Edmonton, Alberta
Wally Wells	The Wells Infrastructure Group Inc. Toronto, Ontario

Founding Member:

Canadian Public Works Association (CPWA)

EXECUTIVE SUMMARY

In many Canadian municipalities, development of storm and wastewater collection system maintenance and renewal programs follows a reactive approach, responding to service disruption and odour complaints and, in some instances, even more dramatic system failures involving road collapses, damage to other utilities and flooding. This best practice presents a systematic and proactive approach for the assessment and evaluation of storm and wastewater collection systems, so maintenance and renewal programs can deal with system problems before they become failures.

The methodology to achieve this is presented as five distinct but interrelated tasks.

TASK 1 – INVENTORY

A detailed inventory of the storm and wastewater collection system attributes should be compiled. Guidelines for setting up, populating and maintaining inventory databases for municipal infrastructure are presented in *Best Practices for Utility-Based Data* (InfraGuide, 2003b). The attributes should include information on location, physical dimensions, related land use areas, operating conditions, and applicable operational data. Procedures should be established to ensure the inventory is continuously updated.

TASK 2 – INVESTIGATION

Key to the assessment and evaluation of storm and wastewater collection systems, is the availability of accurate, reliable, up-to-date information for the system operating conditions. Inspection programs need to be developed based on a preliminary assessment to obtain details on the physical and operating conditions of these systems, targeting critical sectors. Visual, geometric, mechanical, or geophysical methods can be used to carry out inspections.

TASK 3 – CONDITION ASSESSMENT

With the investigation findings in place, the pipes within the system can be assessed based on:

- structural integrity (physical condition);
- functional integrity (service condition); and
- hydraulic adequacy (capacity).

The assessment should provide a standardized condition rating, allowing a quantitative comparison between various sections of the system and a means of tracking the deterioration of each individual section over time. A number of available manuals and guidelines provide condition rating systems for sewer systems. Rating systems suitable for the municipality's needs should be selected and consistently used to ensure the long term value of the assessment results.

TASK 4 – PERFORMANCE EVALUATION

Following the condition assessment (structural, functional, hydraulic adequacy), a performance evaluation should be completed integrating all rating criteria for each individual pipe and evaluating them on a system-wide basis. Performance criteria can be developed relative to the level of service, taking into account health and safety, risk management, environmental and economic parameters. Performance evaluation allows the sewers to be rated and priorities for potential renewal plan locations and candidate technologies set for each location. The best practice, *Selection of Technologies for Sewer Rehabilitation and Replacement* (InfraGuide, 2003c) provides additional information.

TASK 5 – REHABILITATION /REPLACEMENT PLAN

With the system components in need of renewal identified and prioritized based on structural, functional, and hydraulic conditions, a long-term renewal (rehabilitation/replacement) plan should be developed. This plan must address socio-economic impacts, flood risk, growth needs, changing regulations and policies, as well as the technical requirements for renewal of a section of the system. Synergies with other linear infrastructure (e.g. roads, watermains) can be integrated at this stage (see best practice titled *Coordinating Infrastructure Works* [InfraGuide, 2003d]). On addition to sewer rehabilitation and replacement work, the recommended plan may include ongoing monitoring and inspection programs, as well as detailed assessments of infrastructure in critical sectors. Feedback to other decision makers should be provided through regular update reports on the asset value, system condition, emergency repair costs, and reinvestment levels in proactive renewal programs.

1. GENERAL

1.1 INTRODUCTION

Municipal infrastructure is the backbone of the entire municipal enterprise, from community development to economic growth. To sustain a vibrant community, it is essential to have knowledge of the existing systems to operate, maintain, and expand these systems effectively. This is especially true today when both human and financial resources are limited.

The first step is to identify all available data, develop an inventory and determine the current status of the infrastructure. This provides municipal and utility managers with the information they need to manage, operate, and maintain their infrastructure proactively. It enables them to inform other decision makers of the importance of investing in these systems. It also provides the basis to determine the scope of the financial commitment required to develop a suitable rehabilitation/replacement plan. This document outlines the best practice for assessment and evaluation of gravity flow linear (piped) storm and wastewater collection systems. It does not address related infrastructure such as culverts, pump stations, forcemains and service laterals.

In 2001, a survey of common practices in over 150 Canadian municipalities explored the methods used for the inspection, assessment, and evaluation of storm and wastewater collection systems. The survey found that a relatively large gap exists between the most and least advanced assessment practices being used in wastewater management. The majority of the municipalities surveyed manage their system information, however, they do not perform any (or enough) activities necessary to determine the condition of their system.

Storm and wastewater collection systems are critical in supporting the public health, safety, environmental, and economic objectives of a community. These systems represent about half of a community’s investment in municipal infrastructure. Despite this importance, their robust (well-built sewers will provide decades of service), hidden (buried), and passive (operating with little or no customer interaction) natures often result in neglect. Systematic reinvestment in this infrastructure is a critical and cost effective approach to maintaining its functionality and to meet changing needs as a community grows and matures.

1.2 PURPOSE AND SCOPE

This best practice focuses on infrastructure management activities and tasks in the context of gravity flow linear (piped) storm and wastewater collection systems. Activities that can integrate this work with other municipal infrastructure (roads, water) are included in the best practice, *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* (InfraGuide, 2003a). This best practice is presented in the form of the five-step approach commonly used in infrastructure management: inventory, investigation, condition assessment, performance evaluation, and a rehabilitation/replacement plan.

1.3 HOW TO USE THIS DOCUMENT

Section 2 provides background to the need for, and benefits and risks of, implementing this best practice. Section 3 expands the five-step process presented in *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* (InfraGuide, 2003a), identifying elements specific to the assessment and evaluation of storm and wastewater collection systems. Section 4 presents some of the applications and limitations of this best practice. Section 5 describes measures that can be used to evaluate the effectiveness of this best practice. Four appendices are also included to provide additional insight and reference material to assist with the development of an infrastructure management plan for storm and wastewater collection systems.

1.4 GLOSSARY

Assessment — The process used to describe the condition and/or performance of a system component.

Collection System — The gravity flow linear piped system.

Critical pipe — Those pipes of the system where the risk of failure is least acceptable.

Critical sector — A sector where storm or wastewater sewers are either of strategic importance or present a high failure rate.

Evaluation — The process used (following completion of the assessment) to determine the remedial measures necessary to improve the condition and/or performance of a system component at the best value for the community.

Flexible Pipe — A pipe that will deflect at least two percent without structural distress.

Functional integrity —The ability of the pipe to convey flows on an operational basis. Defects are usually corrected by means of operational or maintenance activities.

Hydraulic adequacy — The capability of the pipe to convey existing and anticipated flows.

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 catchbasins, stormwaters, surface runoff, street wash waters or drainage.

Inspection — Brief or small-scale investigation.

Investigation — All activities related to collecting information on the system or any of its components, either planned in advance or carried out as needed (complaints, observations, inspections).

Link — A section of sewer between two adjacent nodes.

Maintenance — Activities of a local nature that occasionally or regularly are needed to ensure the asset performs its intended function.

Manholes — Components of a storm or wastewater collection system that allow access to buried pipes (also called access structures, access holes or maintenance holes).

Municipal manager — Any public or private sector staff working on behalf of a municipality or public utility at the technical or administrative level, either directly or in a consulting capacity (also called decision maker).

Node — A point at a manhole or junction of two or more sections of sewer.

Rehabilitation — Upgrading the condition or performance of an asset to extend its service life.

Rigid Pipe — A pipe that deflects less than two percent before cracking.

Renewal — Restoring or upgrading the condition or capacity of an asset by rehabilitation or replacement/reconstruction to satisfy the objectives for structural and functional integrity, and hydraulic adequacy.

Replacement — Replacing an asset that has reached the end of its service life.

Sector — Area, district, zone, or neighbourhood relating to any attribute that may help identify specific characteristics of a system (land use, soil conditions, pipe material, pipe age, method of construction, etc.).

Strategic link — A section of sewer with a high consequence of failure, such as trunk sewers, river crossings or sewers located within arterial road right of ways (also called critical pipe).

Structural integrity — The ability of the pipe to sustain its cross-section for the rest of its service life. Defects are usually corrected by a construction procedure that introduces new materials.

Trunk Sewer — Trunk sewers are typically used to intercept regular sewers, and receive and transport sewage to a few central places such as a treatment plant or a discharge point on a riverbank.

2. RATIONALE

2.1 BACKGROUND

The majority of storm and wastewater collection systems consist of pipes that collect storm or wastewater, and transport it from its point of entry to its destination (storm outfall, wastewater treatment facility) by gravity flow. A properly designed and constructed gravity wastewater collection system may be operated with minimal maintenance as flushing velocities should be experienced daily during peak flow periods. This often leads to an “out of sight, out of mind” situation. As a result, gravity systems can operate under less than ideal circumstances for extended periods before problems become evident. Structural integrity or hydraulic adequacy problems may not become apparent until some time after they occur, manifesting themselves through service disruptions, road collapse, or basement flooding.

Poor design and installation practices or difficult soil conditions can result in both structural integrity problems and hydraulic capacity problems. Structural problems may include cracked, broken, or collapsed pipe, possibly leading to road failure and basement flooding problems. Hydraulic problems may result from reduced capacity due to a lost cross-sectional area, reverse grades, or sags in the pipe. This may be caused by such things as a partial pipe collapse, root intrusions, debris buildup, or pipe settlement. Infiltration and inflow may also impact pipe capacity. All of these increase the potential for flooding problems.

2.2 BENEFITS

The assessment and evaluation of storm and wastewater collection systems is necessary to sustain the continuous operation of these systems in an effective manner. Proactive assessment and evaluation can be used to establish maintenance and renewal programs that maximize the useful service life of the system components.

There are many benefits that can be realized by understanding the operating conditions of storm and wastewater collection systems.

- Help safeguard public health.
- Reduce the potential for flooding of private and/or public property.
- Support economic development.
- Show due diligence.
- Facilitate asset management programs.
- Provide input to risk analysis.
- Maintain an inventory of system conditions.
- Improve or enhance maintenance and capital program planning.
- Provide input to design standards and construction specifications.

- Minimize the chances of a catastrophic failure.
- Identify urgent repair and rehabilitation/replacement needs.
- Maximize system life expectancy by correcting problems at the most cost-effective time.
- Facilitate risk management of critical pipes.
- Improve asset planning and prioritization of non-critical pipes.
- Take advantage of the lower costs of pro-active rehabilitation.
- Facilitate strategic planning and cost-effective inspection.

2.3 RISKS

The following list summarizes some of the potential risks with not following this best practice.

- Potential environmental costs may occur from wastewater overflows/flooding.
- Potential liability issues.
- More emergency repairs may be required, thereby impacting operating budgets.
- Opportunities to provide expected level of service with reduced capital investment will be missed.
- Renewal programs may miss sections in greatest need of upgrading.
- Renewal programs may be less cost-effective, since replacing a pipe in a state of failure is much more expensive than rehabilitation of a pipe in a state of distress.
- Operations and maintenance activities may not be focused on the most critical areas.

3. WORK DESCRIPTION

In order to maintain an acceptable level of service, municipalities must invest in and manage their assets wisely. To do this they need to know

- What they have.
- Where the assets are.
- What condition are they in.
- What is needed.

The inspection, assessment, and evaluation activities specific to storm and wastewater collection systems are described in the following tasks in a step-by-step fashion. Activities that can integrate this work with other municipal infrastructure are covered in *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* (InfraGuide, 2003a) and *Coordinating Infrastructure Works* (InfraGuide, 2003d).

Following these tasks provides a complete evaluation of the storm and wastewater collection system(s). The tasks describe all activities required assuming that no previous work exists. Depending on the available records, previous work, staff knowledge, and the objectives for the current evaluation, the five steps may be adjusted to meet the specific needs of each project.

3.1 TASK 1 – INVENTORY

This first task is to gather and classify all available information, and manage and store the resulting data, readily available in an easily retrievable manner. Refer to *Best Practice for Utility Based Data* (InfraGuide, 2003b) for a discussion on data management.

3.1.1 Data Collection and Storage

Cost-effective operation of storm and wastewater collection systems depends on a complete understanding of the operating conditions of each system. This requires a thorough knowledge of the system which, in turn, makes a complete inventory of system attributes necessary. This inventory can be established as a stand - alone database, or in conjunction with a Geographic Information System (GIS) or Computer Assisted Drawing (CAD) system. There are several systems available to assist with these activities (see Section 4.2). Setting up, populating, and maintaining inventory databases for municipal infrastructure is addressed in *Best Practices for Utility-Based Data* (InfraGuide, 2003b). Sources for the inventory data include:

- network inventory plans;
- as-built drawings;
- existing reports;

- inspection reports;
- operations and maintenance manuals and reports;
- operations and maintenance staff
- rehabilitation/replacement reports; and
- customer service records

Information from many sources (descriptive, operational, etc.) is necessary for analysis. Information provides the user with details on the underlying characteristics of the system and its components, the events and constraints the system will be required to face throughout its life cycle, and the changing service needs to which the system must respond. To be useful over the long term and ensure that actions are planned in an efficient and effective manner, data must be relevant and stored in an easily retrievable manner. It must also be diligently updated.

3.1.2 DATA INVENTORY

The information that should be included in the data inventory may be subdivided as follows:

- system attributes (physical data);
- operational data (including rainfall data); and
- land use and environmental data.

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

A listing of the data items to be included in the system inventory are included as Appendix A.

System Attributes (Physical Data)

The physical attributes of the sewer system are necessary information for a comprehensive assessment or evaluation. Physical data provide a basis for preliminary screening to help identify what may potentially be involved in further stages.

Physical data can generally be found through engineering, public works, and municipal archives. Certain details may also be obtained from infrastructure maintenance staff. When data have not yet been compiled using a data management tool, it is very important to gather this information quickly to ensure it is not lost or destroyed.

Physical data related to each pipe (such as the invert of the pipe, elevation at manholes, type of backfill, water table elevation, topographical information, location and capacity of pumping stations, existing appurtenances, and direction of flow) all provide information useful for the assessment and evaluation of structural or functional conditions occurring in the system. For the identification of critical sectors, information such as road classification (above the sewer), traffic volume, ground conditions, depth of bury, zoning and anticipated socio-economic impacts of service disruptions are useful data.

Operational Data

Operational data include the structural (physical) condition, functional (service) condition, and hydraulic adequacy (capacity) of each section of pipe. Operational data include detected deficiencies and knowledge of municipal employees, complaints from the public, results from flow monitoring programs, infiltration/inflow (I/I) programs, winter table level and soil conditions, operations and maintenance activities, condition inspections, pump station operations, surcharge and flooding records, and recorded rainfall data. This structural, functional, and capacity information complements the basic data or attributes of the various system components.

Structural condition data include pipe repairs (number, types and locations) and other physical defects observed in the pipe.

Functional condition data include flooding or surcharge potential due to the presence of roots, pipe deposits, protruding laterals, or other conditions in the pipe that affect its operation. It is also important to include employee observations and user or public complaints, in the system database, on such things as sanitary sewer overflows, surcharge and odour complaints, and historic knowledge of drainage flows and patterns, as these are often an early indicator of existing or forthcoming problems.

Capacity data can be general observations related to the sizing of the system and includes such things as the results of ongoing or periodic flow monitoring programs, storm event surcharge height observations, I/I search results, and flooding records.

It is important to record the dates of all observed structural, functional, or capacity deficiencies. Any actions carried out in response to these complaints are additional sources of information about the actual conditions of the pipe and should also be included in the database. These data elements are necessary for systematic assessments searching for critical sectors in the system.

Land Use and Environmental Data

These quantitative and non-technical details related to individual pipe segments, as well as collection systems or parts thereof, provide the basis for the original design. This information is also required when assessing a system to determine whether the sewer is meeting its originally intended objectives and whether the design basis has changed in the interim. These include such things as land use, service area, and contributing population.

Environmental data are also important when completing collection system assessments. These could include the identification of unusual water quality characteristics and outfall locations relative to water intakes or sensitive habitat. Many of these factors are necessary when setting up a computer model to evaluate a system's hydraulic adequacy. They can also be of value when preparing a renewal plan.

3.2 TASK 2 – INVESTIGATION

Infrastructure management should include annual or ongoing inspection programs and opportunistic inspection procedures for maintenance or repair projects. Communities with large systems usually have ongoing programs that can achieve complete system inspection over several decades (see IRC, 2001). A comprehensive model for scheduling initial and subsequent inspections has been developed by Baur and Herz (2002). The steps in this task describe the development of an investigation program to collect these data from operational activities and regular or one-time investigations.

3.2.1 CRITICAL SECTORS

Every pipe in a collection system should be inspected regularly. The interval between inspections can be longer for sound and non-critical pipes. Critical pipes and pipes with known structural or hydraulic deficiencies should be inspected more frequently. Inspection frequencies should be determined by experienced competent practioners. Critical pipes (or strategic links) can be defined by criteria such as road classification (above the sewer), ground conditions, depth of bury, high repair cost potential and socio-economic impacts. They will include trunks, forcemains, and other pipes that would have a major impact on the system and the community should they fail for any reason. Critical sectors can also be identified if there is a strategically important land use or in conditions where a high failure rate is expected.

3.2.2 PRELIMINARY ASSESSMENT

Once the critical sectors and strategic links have been identified, and all relevant information compiled in a database, the next step is to proceed with the preliminary assessment. The preliminary assessment of a system needs to look at both its structural and functional adequacy. The preliminary assessment will identify additional information requirements, and the specific investigations necessary to obtain the missing information. Examples of additional programs that may be required include flow monitoring, I/I source identification, and conventional or stationary closed circuit television (CCTV) inspections (see Appendix B).

The preliminary assessment will assist managers in determining the best course of action. A risk assessment should be the first activity completed, taking into account various aspects, such as cost, safety, and performance. For example, what level of financial resources are needed to improve knowledge of the system for a long-term management plan? Are the costs and problems of doing nothing greater than the costs of taking action?

Investigations to obtain more detailed information fall into two categories: functional and structural. Functional investigations look at sustaining the hydraulic or environmental performance of the system, while structural investigations concern the physical condition of the system.

The decision to investigate further is based on technical, financial, and risk factors. Recently installed pipes that show no signs of deterioration will not need to be inspected as urgently as old pipes that have suffered several breaks over past years. Pipes located in critical sectors should be subjected to a functional investigation at closer intervals than similar pipes in non-critical areas. Pipes located in critical sectors defined by flooding, breaks, pipe material, and odour complaints may also require thorough investigation in the near term.

At the end of this step, municipal managers should have a detailed picture of the areas where assessment is needed most and what needs to be assessed at these locations. At this point, the scope, schedule and resources needed to move forward with the investigation will be known.

3.2.3 PREPARATION OF INSPECTION PROGRAM

Once it has been determined what additional information is required, a methodology for getting these data can be chosen. This usually means the use of a particular type of equipment or technology, such as flow monitors or CCTV inspections. This step aims at gathering more specific data on the condition of certain sectors of the network. This can be achieved using electronic or manual monitoring techniques or inspection methods carried out on an ongoing, intermittent or “as needed” basis.

There are a number of methods available to determine existing conditions in a section of pipe. Visual, geometric, mechanical, or geophysical methods can be used to carry out inspections, depending on the information to be gathered and the existing conditions in the pipe(s) to be inspected (Appendix B). Data requirements, system configuration, site conditions, and other factors will dictate which technology would be best to carry out the inspections efficiently. In some cases, it may be desirable to use more than one of these methods to obtain the desired information. The methods available locally may also be a determining factor. To date, most sewer inspections are conducted using CCTV technology. These inspections should also be conducted at the right time (season, time of day) to maximize the value of the information collected, and they must adhere to local and provincial safety regulations.

At this point, having identified the critical sectors and the techniques that should be used to get the needed information, it is possible to schedule the activities to optimize the mobilization of municipal and contractor resources, taking into account information needs and urgency. By extending the scheduling process to encompass several years, municipal managers can produce a well-structured, complete inspection program. This program should interact with the routine and non-routine inspection campaigns so the appropriate sections of the system are targeted at the right time.

3.2.4 INSPECTION

Once the investigation program is established and the assessment method(s) defined, it is time to proceed with the actual inspection. Depending on certain factors, such as the level of expertise and equipment required, these inspections may be carried out by in-house personnel or a specialized firm.

To ensure the results achieved by way of these inspections are consistent and comparable from one organization to the next, standards should be established for the equipment to be used. It is also recommended that all staff involved are required to have suitable training in inspection techniques and safety. Several specialized groups provide training programs. Moreover, certain documents designed to standardize observations noted during CCTV inspections are also readily available. In the case of other techniques or technologies for which few or no documents or reference groups are available, a formal, specialized training program should be encouraged to ensure the services provided by firms are of a high quality and facilitate the task of the municipal managers in understanding and interpreting the data.

Following investigation, it is important that the gathered data be presented in formats compatible with the existing management tools of the municipality or firm for which the inspections were carried out, and that the resulting data be suitably documented and stored in management systems.

3.2.5 DATA UPDATE

When the inspections are completed and the findings compiled, the data inventory must be updated. Data updates should occur, automatically, every time new information is gathered. It is important to input the inspection findings as a new entry, including the date of the inspection, and do not overwrite the previous information. This allows tracking of deterioration over time, which may lead to the development of deterioration curves. Preserving the knowledge of observations, maintenance activities, and rehabilitation work is critical to the successful long-term management of storm and wastewater collection systems.

3.3 TASK 3 – CONDITION ASSESSMENT

Condition assessment of storm and wastewater collection system piping should focus on three perspectives:

- structural integrity (physical condition);
- functional integrity (service condition); and
- hydraulic adequacy (capacity).

Establishing the condition of sewer pipes requires sound judgment and experience. Since it is virtually impossible to predict the precise moment a pipe will fail or collapse, categorization using different levels of deterioration (or risk) makes it possible to rate the condition of the system, and to provide a basis for rehabilitation or a baseline for further performance evaluation.

A number of sewer condition rating systems are available. The Water Research Centre (WRc), the Water Environment Federation/American Society of Civil Engineers (WEF/ASCE) and the National Research Council Canada have all published manuals and guidelines for the assessment and evaluation of sewer systems (see Section 4.2). These systems can be used “off the shelf” or can be customized and adapted to the specific needs of individual municipalities or utilities. These manuals and guidelines include:

- Manual of Sewer Condition Classification (WRc, 2001);
- Guidelines for Condition Assessment and Rehabilitation of Large Sewers (IRC, 2001);
- Manuel de standardisation des observations-inspections télévisées de conduites d’égout (CERIU, 1997);
- Existing Sewer Evaluation & Rehabilitation (ASCE, 1994); and
- Manhole Inspection and Rehabilitation, (ASCE, 1997).

Although most communities developing renewal programs have adopted a specific condition assessment system, some have adapted these guidelines. For example, the cities of Edmonton, Lethbridge and Nepean have all developed sewer condition rating systems.

3.3.1 STRUCTURAL INTEGRITY

Structural defects are compiled either through observations (see Task 1) or more advanced investigations (see Task 2). Structural defects usually require some type of rehabilitation, while functional defects require some form of maintenance.

Typical structural defects for different types of pipes (both rigid and flexible), brick sewers, and manholes are listed in Appendix C. In most of the manuals mentioned earlier, these defects are defined and coded along with their corresponding level of deterioration (slight, medium, large, or light, moderate, severe, etc.). Once defect coding is completed, each defect is assigned a weight depending on the severity and the degree of risk to the structural integrity of the pipe. These weights combined with the failure impact rating are converted to a physical condition rating for each pipe. This physical condition rating helps municipal managers prioritize future inspection, repair, or rehabilitation activities.

To provide an indication of the structure of a condition rating system, tables taken from the IRC NRC Guidelines indicating the structural defects along with the corresponding codes and weights for pipes and manholes are included in Appendix D. Similar manhole structural rating and I/I flow rating schedules are available in Chapter 5 of the ASCE (1997) *Manhole Inspection and Rehabilitation*.

3.3.2 FUNCTIONAL INTEGRITY

Functional integrity is related mainly to the service condition of the pipe. Functional defects generally focus on the cross-sectional area of the pipe, and include exposed gaskets, protruding services, roots or debris. These defects can be rectified by some form of maintenance activity. These activities usually cost less than rehabilitation activities. Although many of the structural defects may have an impact on the functionality of a pipe, some non-structural defects (i.e., blockages) will have a greater impact on a pipe’s hydraulic performance. Typical functional (service) defects are also listed in Appendix C.

3.3.3 HYDRAULIC ADEQUACY

The hydraulic condition of a storm or wastewater system can be assessed several ways. Two common methods are the theoretical loading factor (TLF) and the grade line factor (GLF).

- The theoretical loading factor is the ratio of peak flow to pipe capacity. This measure does not predict where flooding will occur. However, it does give an indication of undersized sewer sections. If a detailed analysis is completed, modelled peak flows should be used.
- The grade line factor makes use of the maximum hydraulic gradeline (HGL) reached during the event (historical or theoretical) relative to pipe crown, basement elevation and ground level. This information can be used to determine where restrictions in the system are most serious and surcharge elevations may reach basement or ground levels, indicating a high risk for flooding potential. Determining the HGL for GLF determination requires the use of a hydraulic model, as well as flow monitoring studies for model calibration and verification.

The use of both measures for hydraulic assessment is recommended, as system restrictions will be identified by the theoretical loading factor, while the severity of the restrictions can be determined from the grade line factor. Beyond targeting problem sectors, the HGL makes it possible to understand the hydraulic behaviour of the system and the factors contributing to the hydraulic deficiencies. Furthermore, the model can also be used in Task 4 to compare the existing level of service with the performance criteria stipulated in standards and regulations.

Building a Hydraulic Model

There are several public and private domain computer models available to simulate hydrologic and hydraulic conditions in storm and wastewater collection systems (see Section 4.2). A well-constructed hydraulic model can provide the user with an accurate depiction of the storm or wastewater collection system response to various design or historical operating conditions. These can include dry weather flows (DWF) and wet weather flows (WWF) for selected historical or synthetic design storm events. A hydraulic model allows the user to:

- understand the system operating constraints;
- establish the existing level of service;
- compare the current and required levels of performance for the system; and
- assess the impacts of proposed upgrades, rehabilitation or replacement work, and development proposals on system expansions.

System information required to construct a hydraulic model includes:

- pipe diameters;
- pipe lengths;
- pipe roughness coefficients;
- invert elevations;
- manhole rim elevations;
- catch basin characteristics;
- equipment characteristics (valves, pumping stations, etc.);
- retention facilities
- flow measurements;
- rainfall data;
- connectivity;
- catchment areas;
- percent impervious/pervious;
- type of soils;
- I/I components;
- ground slopes; and
- percolation rates.

Most models consider both the generation of the flows (wastewater and runoff) and the dynamic nature of pipe system hydraulics. These models provide the information necessary to determine TLF and GLF values. Simpler model formulations (e.g. Rational Method) provide more limited information. It is recommended that experienced professionals be used to apply an appropriate model for each municipality's situation.

Calibrating and Verifying the Model

Model calibration and verification is essential to provide confidence that the simulation results will provide an accurate representation of system response under various operating conditions. Calibration involves using monitored rainfall, flow, and water level data from one or more historical storms to establish parameters for the model. When the model output matches or looks similar to the measured data, the model is considered to be calibrated. Verification involves using data from several other historical storms to prove the established parameters are valid. Proper calibration and verification requires actual flow measurements at key system locations, combined sewer overflow (CSO) or sanitary sewer overflow (SSO) volumes and corresponding rainfall data. In addition, historical data, such as flooding locations or high water marks in manholes, can be used to further corroborate the calibration/verification process.

Calibration and verification activities can occur on a project basis or as an ongoing program. Once the model has been calibrated and verified to an acceptable level of confidence, it can be used to perform a hydraulic condition assessment of the whole network or provide a rating for each pipe section. The table in Appendix D provides an example of hydraulic condition ratings for various combinations of theoretical load factors (TLF), grade line factors (GLF), and upstream impacts.

3.4 TASK 4 – PERFORMANCE EVALUATION

Once the condition of the entire system, or the portion under investigation, has been established, a performance evaluation can be completed. The performance evaluation for storm and wastewater collection systems has been divided into two general parts:

- establishing the performance criteria; and
- conducting the performance evaluation

3.4.1 PERFORMANCE CRITERIA

The initial evaluation step is to derive the criteria that will be used to evaluate each system's performance. Following establishment of the evaluation criteria, satisfactory performance levels must be determined.

Laws or regulations from municipal, provincial, or federal authorities and industry standards already define and limit certain criteria, but municipalities can still choose to be more severe or add further criteria to meet their specific situation. It should be noted that some of these criteria may be socio-economic, environmental, or financial in nature rather than technical. Also, the definition and required performance level for each criterion may change depending on whether the evaluation is being carried out at a system or project level. In some instances, the criteria may only apply to one level. Regardless, all criteria should be chosen to reflect specific municipal objectives.

Many factors can go into defining the minimum acceptable level of service to be provided by a storm or wastewater collection system. These include health and safety and environmental issues, as well as economic and social impacts.

System failures can be broadly grouped into two categories. Flooding (basement or surface) or sewage overflows are the result of inadequate hydraulic capacity and/or functional integrity. Structural failures will usually also lead to sewer backup due to pipe collapse, causing flooding, and potentially damaging other utilities and resulting in road collapse. The results may include:

- threats to public health and safety;
- environmental pollution (soil, water, erosion);
- service interruption;
- traffic disruption and impacts on public transportation and emergency services;
- public inconvenience;
- claims of lost business; and
- damage to private or public property.

Many of these consequences are subjective and difficult to quantify. As such, they may be most easily handled by combining them into an “impact factor” that looks at the consequences of failure as an additional prioritization criterion.

Many larger municipalities will have in-house standards for level of service to be provided by their storm and wastewater collection systems. Smaller centres most often will follow provincial guidelines and regulations for the design of their systems. These should be the basis of establishing the performance criteria for system performance evaluation.

Possible Criteria

The technical literature reviewed suggests certain information that should be gathered and used to compare structural and functional performance requirements:

- structural condition rating and defect types;
- functional condition rating and defect types;
- condition of nearby utilities;
- maximum flow velocity of 3 m/s or less (excessive velocities can lead to premature deterioration of the invert);

- sewer main leaks limited in terms of recurrence and the number of sections; and
- appropriate and safe access available for maintenance activities.

Similarly, evaluating hydraulic adequacy could consider:

- flooding history in area affected by pipe;
- overflows in area affected by pipe;
- complaints about odours;
- functional condition rating and cause (e.g. roots, debris, protruding laterals, etc.);
- minimum velocities between 0.6 m/s and 0.75 m/s for sanitary sewers and 0.8 m/s and 0.9 m/s for storm and combined sewers (to avoid deposits in pipes and the corresponding risks of blockages leading to overflows);
- construction history and test results (e.g. new sanitary and storm sewer systems must meet water tightness standards); and
- the main purpose of every storm or wastewater collection system is the protection of public health and the environment. This objective should be at the forefront when selecting performance criteria.

If performance criteria are not available, the current system performance may be established using incident reports on pipe behaviour. Data concerning past incidents or any specific information about a section (e.g., recurrent maintenance problems or complaints) will make it possible to compare the actual situation with specific performance criteria.

Each selected criterion should be assigned an evaluation mechanism along with trigger values, which must be in line with the previous condition assessment stage. The trigger values are used to determine a course of action to be undertaken by the managing body, such as:

- conducting maintenance activities for all pipes which receive a poor service condition rating;
- repairing all pipes with a poor structural condition rating;
- repairing pipes with a fair structural condition rating if synergies exist between water main replacement and road surface renewal.

The main purpose of a trigger value is to let managers know when it is the right time to correct a problem or what the extent of a rehabilitation program is.

3.4.2 PERFORMANCE EVALUATION

All these performance criteria, or those selected and developed to meet specific local situations, represent the starting point in determining the expected performance of the system and must be fed into the monitoring, rehabilitation, and replacement plan described in Task 5.

Once the criteria and analysis mechanisms have been selected, it is possible to proceed with the performance evaluation. At this point, municipal managers are aware of the actual performance of their system (system level) as well as a fair portion, or the total, of the performances of the various sections (project level) in terms of condition assessment compared with performance evaluation. It is now possible to prepare an action plan aimed at preventing or correcting the performance problems at the local level.

Application of the performance criteria will provide a performance evaluation of the entire system, or the portion being investigated. This will identify pipes that meet all requirements and, more importantly, those that do not. The evaluation should provide an indication of the remedial measures necessary to address the deficient pipe. This may be pipe rehabilitation or replacement for structural concerns, pipe upsizing or relief installation for hydraulic concerns or, in many instances, a combination of both. By looking at various upgrading combinations, an optimum renewal plan can be developed.

Once all the renewal requirements have been established, an unrestrained cost estimate needs to be developed. This cost estimate will reflect the total cost to bring all deficient sewers up to an acceptable level, and is a necessary element when preparing the rehabilitation/replacement plan in Task 5.

Another part of the performance evaluation task is to prioritize the remedial works identified. This will identify the highest priority projects based on their current structural and hydraulic condition. As there may be several sections with similar ratings, the “impact factor” may be applied at this point. As noted previously, this is a subjective analysis that looks at the impact of failure (hydraulic or structural), giving higher priority to sections with greater impact of failure (i.e. the critical pipes).

3.5 TASK 5 – REHABILITATION/REPLACEMENT PLAN

After establishing the performance criteria for the system at the network and project levels, municipal managers are ready to make decisions on the timing and extent of remedial work and develop a rehabilitation and replacement plan. For other than relatively new systems, it is highly likely that most municipalities will not have the budget to complete all the necessary remedial works within a short time frame, necessitating a multi-year, long-range plan. (Note that the condition of sewers in the later years of a long range plan will likely have continued to deteriorate prior to their renewal.) An effective rehabilitation/replacement plan should result in the maintenance of (or improved) hydraulic capacity and fewer:

- complaints (odour, flooding);
- unplanned user interruptions (number of breaks);
- operations and maintenance activities;
- infiltration/inflow episodes (or their elimination);
- flood damage costs; and
- combined sewer overflows (or their elimination).

3.5.1 SETTING PRIORITIES

The first step in this task aims to set priorities based on certain driving factors and the various aspects discussed in the previous phases (municipality's objectives, laws and regulations, cost, functionality, etc.). To help managers achieve this, a decision-support system may be used. Many types of systems are commercially available; some deal with only one type of system, while others offer different modules to integrate information from several systems.

For each priority deficiency, it will be necessary to recommend an appropriate action to minimize the impacts on:

- durability of the system and protection of the integrity of nearby structures;
- economic factors, including direct and indirect costs; and
- impacts on users and residents (especially in terms of nuisance, level of service, or lost access).

These are discussed further in the best practice, *Selection of Technologies for Sewer Rehabilitation and Replacement* (InfraGuide, 2003c).

This step may also involve integration with other infrastructure programs. Integration aspects are covered in the best practices, *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks* (InfraGuide, 2003a) and *Coordinating Infrastructure Works* (InfraGuide, 2003d). If some of the required information is missing or is making prioritization difficult or impossible, then managers should request further specific checks or inspections to gather the missing data.

3.5.2 REMEDIAL OPTIONS

In the second step, municipal managers should consider the various remedial options. To decide on the proper course of action or rehabilitation method, managers will need to consider various factors, such as availability, cost, suitability, social impacts, and service disruptions resulting from the particular technology or method. It is important to note that the options chosen in this step may modify some of the priorities determined in the first step. For example, if the outcome of the first step is to prioritize eight sewer pipe sections to be rehabilitated with a relining technology, and step two identifies another section of lesser priority, which also needs the same type of rehabilitation, it may be decided, in the interests of cost effectiveness, to upgrade all sections simultaneously.

Rehabilitation or replacement solutions for a particular section of pipe are available when facing a single structural deficiency. Broader solutions exist when facing a functional deficiency that occurs more often during wet weather conditions in a sewer system. The following storm and wastewater management best management practices may help:

- storage or temporary detention of excess runoff;
- flow diversion using pipes in adjacent streets that may have excess capacity;
- sewer separation in an undersized combined sewer area;
- rooftop downspout disconnection and redirection on pervious areas; and
- inflow and infiltration (I/I) control through disconnection of foundation drains connected to sanitary sewers and draining the infiltration flow to the pervious area;
- inlet control and use of the natural capacity of the streets (major system) to convey flow during high-intensity events, with proper allocation for excess water to either be stored before re-entering the minor system, or discharged to a natural watercourse.

3.5.3 COST EFFECTIVENESS ANALYSIS

The third step allows for the identification of the most cost-effective solutions with regard to each problem and need, along with the available rehabilitation options. Cost-effective solutions may be identified for one or several pipe sections (projects) at a time. In certain instances, cost-effective solutions may force the manager to change some of the priorities set initially. In other words, the first three steps may need to be repeated several times to determine the best overall solution.

When completing the cost effectiveness analysis, the assessor needs to be aware that it may be more economical to continue performing maintenance activities for some defects, rather than renewal. Also, in many instances, rehabilitation of a pipe earlier in its deterioration cycle may cost less than rehabilitation carried out near the end of the deterioration cycle. For example, the City of Winnipeg has found that their planned rehabilitation costs at a condition rating of “5” are approximately three times the cost of planned rehabilitation for a condition rating of “3”.

3.5.4 ACTION PLAN

The fourth step leads to the development of short-, medium-, and long-term action plans. Considering the scope and costs of the operations to be carried out, and the budgetary and resource constraints, a remedial plan is recommended, accompanied by a timetable that considers the risks associated with taking no action whatsoever.

This program may include the following activities.

Recurring monitoring and inspection activities. These activities are useful in planning future on-site work (CCTV inspections, cleaning, lining, rehabilitation, or replacement) or developing maintenance and operational practices.

Flagged areas or sections. During the assessment and evaluation phases, certain areas of concern (hot spots) may be identified or flagged for further inspection in the short term. Future investigations (as planned in the program) will aim to complete the level of knowledge for pipe in other or non-critical sectors.

Sections that need replacement or rehabilitation. Short-term recommendations presented in the plan should be implemented within two years of inspection. Several studies and projects have shown that the more a system is damaged or experiences breaks or deficiencies, the more rapidly it will deteriorate. If a pipe has deteriorated significantly, the ability to implement certain rehabilitation technologies may also be encumbered.

At the program level, an annual investment in proactive repairs should be several times the expenditure on emergency repairs. This will ensure that reinvestment is sustained and will increase the effectiveness of emergency response.

3.5.5 INFRASTRUCTURE REPORT

The fifth and final step involves the production of an infrastructure report. The state of urban infrastructure and the corresponding "infrastructure deficit" has to be evaluated, documented, and reported periodically to the appropriate regulators, elected officials, or utility owners. At this stage, it is important that the document contains the significant findings arrived at using this best practice. Information on asset value, condition of the systems, emergency repair costs, reinvestment levels for rehabilitation, and long-term program needs will provide a good status report on the state of the storm and wastewater systems, and should be coordinated with other municipal infrastructure to provide an overall picture for the municipality (see *Coordinating Infrastructure Works* [InfraGuide, 2003d]).

3.6 RESEARCH NEEDS

To date, research on the deterioration of buried gravity flow sewer systems has been limited. An understanding of how sewers deteriorate over time is essential for the development of deterioration curves, which will aid with predicting investment needs to maximize the useful life of a sewer. This will also assist with understanding the costs of rehabilitating a sewer early on the deterioration curve versus, the more costly investment to rehabilitate/replace a sewer that is further along the curve.

To develop these deterioration curves requires extensive data on all types and sizes of sewers in all kinds of environments. This data should be collected across the country to provide as wide a representation as possible. To be truly representative, this understanding should be at the national level.

4. APPLICATIONS AND LIMITATIONS

4.1 APPLICATIONS

This best practice is applicable to storm and wastewater collection systems across Canada. Its application requires at least the essential information (data and inventory) concerning the system. This information needs to be properly classified, understood, and evaluated. It is important for organizations with few or no assessment activities to start implementing this best practice as soon as possible and to follow the steps as closely as their resources will allow.

- Organizations that carry out some type of assessment activities and find themselves carrying out some of the steps of this best practice should strive to continue these activities and slowly restructure them to comply with those outlined in the best practice.
- Organizations that own small and relatively young and trouble-free systems are encouraged to start the process as well. This will enable them to carry out various assessment activities, infrastructure maintenance and rehabilitation work more cost-effectively.
- Organizations whose financial and technical resources are more constrained and whose ability to dedicate resources to this task are limited are advised to seek the necessary support and resources from other organizations to undertake the various steps involved in the best practice.

Potential impacts with following this best practice include the following.

- Additional resources may be required to inspect, assess, and evaluate the storm and wastewater collection systems.
- Capital expenditure could be higher in the short term if renewal programs have been underfunded in the past.
- Capital expenditures will be more cost-effective as proactive renewal costs substantially less than emergency repair.

Since this best practice is an ongoing process:

- It is important to maintain the proper level of activities; this will ensure that the dynamics and results are acceptable.
- Condition rating systems should be established and used consistently over the long term to allow the tracking of system condition.
- Since storm and wastewater systems change over time, the process in this best practice can be adjusted as needed.
- Many of the actions performed throughout the process (especially gathering and updating data) should become habitual for municipal employees.

Investigation cycles are not fixed in time and will depend on the condition, size, age, type of materials, and environment (soil type, water table, etc.) of the storm and wastewater system. Critical sectors or hot spots may require immediate and repeated investigations. Proactive renewal is almost always more cost-effective and less disruptive than emergency repair.

4.2 LIMITATIONS

This best practice has focused on main line storm and wastewater sewers designed and constructed for gravity flow conditions. Other related infrastructure, such as pump stations, forcemains, culverts and service laterals, could be considered using the same general process, but would require adjustments to consider the specific investigation and evaluation methods applicable.

Experience has shown that storm and wastewater systems do not deteriorate in a predictable fashion. The assessment and evaluation of a portion of a collection system provides a point-in-time reference for the structural, functional, and hydraulic adequacy of that system. By implementing an ongoing assessment program and maintaining a system data inventory, including both current and historical conditions, municipalities will be able to proactively maintain their systems at the least life cycle cost.

There are several systems available in the public domain and from private sector organizations to assist in the application of this best practice. There are efficiency and knowledge sharing advantages to national standardization of such procedures and tools. However, there are also disadvantages as standardization does not always promote innovation or the application of the best tool for a given circumstance.

In this best practice, there are three areas where this issue exists:

- Asset Management Data Systems – there are several public domain systems (e.g. MIDS and MIMS) and private sector systems (e.g. Hansen) available.
- Condition Assessment Systems – several systems to quantify condition assessment have been identified in Task 3. There is also an initiative underway in Canada for standardizing these methods promoted by NAAPI (North American Association of Pipe Inspectors).
- Hydraulic Models – there are several models presently in use in Canada (e.g. SWMM, MOUSE, WALRUS, RUNSTEADY).

Infraguide has not taken a position of endorsement for any of these systems. However, Infraguide does support continued debate on the merits of standardization for users and service providers as they apply these best practices.

5. EVALUATION

The following points describe several measures that can be used to evaluate the effectiveness of the practices outlined in Section 3.

- Track both planned and unplanned maintenance and repairs on an annual basis to confirm that the evaluation is resulting in effective rehabilitation/replacement plans. Tracking should show that the planned rehabilitation/replacement works are more cost-effective than the unplanned, emergency response situations.
- Track all repair and rehabilitation/replacement costs on an annual basis and compare with the asset value for the infrastructure. Reinvestment rates are becoming a benchmark for infrastructure management programs.
- Track system deterioration over time and compare with design life expectancy to confirm benefits of a proactive approach to maintenance and renewal activities.

In addition, a review of the assessment and evaluation criteria and procedures should be completed every five to ten years to determine if updates are required to reflect advances in inspection techniques and renewal technologies, and changing environmental and social concerns.

APPENDIX A: DATA INVENTORY

Each component (link or node) of a storm or wastewater collection system must be assigned a unique identifier. All data pertaining to that component can then be easily retrieved for assessment and evaluation purposes. This also allows, for computerized databases, the ability to produce summary tables for one or more system attributes.

Storm and wastewater collection system data are broken down into three categories: the system attributes or the physical data associated with each link (section of sewer) or node (manhole, junction), operational data, and land use/environmental data. A listing of the data elements that should be included for each category is presented below. These elements are the same for computerized databases for large systems, or for paper records for smaller systems.

SYSTEM ATTRIBUTES (PHYSICAL DATA)

Essential

- Reference to plan/profile drawing
- Location/address (upstream and downstream co-ordinates)
- Road classification above the sewer
- Length
- Slope
- Pipe diameter
- Pipe material
- Shape of pipe
- Age of pipe (date of installation)
- Function (interceptors, collectors, culverts, etc.)
- Invert of pipe at upstream and downstream manholes
- Level of ground at upstream and downstream manholes
- Ground conditions
- Type of effluent (sanitary, storm, combined)
- Operation (gravity, forcemain, vacuum, open channel, outfall)
- Appurtenances:
  - air release chambers
  - catch basins
  - drain chambers
  - gates (check valves, flap gates, sluice gates)
  - inspection chambers (clean outs)
  - laterals (service connections)
  - manholes (maintenance holes)

  - pumping stations
  - retention reservoirs (ponds, storage tanks)
  - valve chambers.

Useful

- Type of backfill
- water table elevation
- topographical information
- capacity of pumping stations
- regulators, weirs, direction of flow
- depth of cover.

OPERATIONAL DATA

- Inventory of complaints (system malfunctions) from residents and municipal employees
  - flooding (basement, surface, blockage, sewer surcharge, dry weather overflows, sanitary sewer overflows, etc.)
  - bad odours
  - system deterioration (H2S attack, missing rungs in manholes, etc.)
- inventory of pipe breaks
- all data pertaining to actual flows (flow monitoring results), Manning roughness coefficients
- rainfall data (historical and design storms)
- all information pertaining to initial design conditions or requirements
- deposits in the pipe
- information pertaining to past municipal works (I/I search results, flow temperature readings, pipe replacement, high pressure flushing, bucket rodding, root cutting, reaming of protruding laterals, CCTV inspections, analysis of flushed effluent, results from smoke and dye testing).

LAND USE AND ENVIRONMENTAL DATA

- Nature of effluent (agricultural, residential, commercial, industrial)
- contaminated zones
- system planning data:
  - population (present and future development)
  - service area /catchment area
  - zoning (residential, commercial, industrial, agricultural)
  - special regulations with regard to construction in residential, agricultural, industrial, and commercial sectors

- other critical decision-making factors (e.g., the presence of essential services, hospitals, schools)
- demographics
- hydrologic surface characteristics (hydrology, type of soil, surface flow parameters, percolation rates, imperviousness).
- drainage patterns
- historic and planned detention areas

APPENDIX B: INSPECTION AND ASSESSMENT TECHNIQUES

GEOPHYSICAL TECHNIQUES

These techniques use sophisticated equipment that emit electric currents or electromagnetic waves which, once gathered and analysed, will provide information on soil characteristics for the areas where the infrastructures are buried (backfill and bedding) or for the location of the pipe itself and on the surrounding soil. These techniques are necessary when the conditions for the soil surrounding the pipe are suspected of damaging pipe integrity. Among these techniques you can find; sonar/camera, infrared thermography, ground penetrating radar, etc.

Ground-penetrating radar

In this technique, a ground-penetrating radar sends short microwave pulses. These pulses are reflected at interfaces between media of different properties (i.e. defects). These returned pulses are monitored by a receiver. The location of defects can be estimated from the round-trip travel time of the pulse (Makar 1999[1] and Hunaidi et al.[2] 2000 and Pla-Ruki and Eberhard 1995).[3] Ground-penetrating radar systems usually provide plots of signal magnitudes as a function of time of arrival of the echo (B-Scan). A drawback to B-Scan is that it is difficult to interpret (Makar 1999). Another limitation of this technique is that it does not work effectively on pipes buried in clay soil (Hunaidi and Giamou 1998).[4]

Sonar systems

Sonar is a practical alternative to CCTV. It is used for overloaded sewers or undrained watermains. Usually the excess water hampers visual techniques, but with sonar it is a positive factor. In fact, it is a vital medium for the acoustic method. The results from the sonar are displayed on a graphic screen on the surface. Different objects are shown as different colours and can be easily identified.

---

[1] Makar, J.M. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, June 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

[2] Hunaidi, O. et al. "Detecting leaks in plastic pipes," *Journal of the American Water Works Association - 21st Century Treatment and Distribution,* 92, (2), pp. 82-94, February 01, 2000 (NRCC-42813) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42813.pdf

[3] Pla-Rucki, G. and Eberhard, M. (1995). "Imaging of Reinforced Concrete: State-of-The-Art Review." *Journal of Infrastructure Systems*, ASCE, 1 (2), 134-141.

[4] Hunaidi, O. and Giamou, P. "Ground-penetrating radar for detection of leaks in buried plastic water distribution pipes," Seventh International Conference on Ground Penetrating Radar (GPR'98) (Lawrence, Kansas, 5/27/98), pp. 783-786, 1998 (NRCC-42068) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42068.pdf

INFRARED THERMOGRAPHY

In this technique, infrared cameras are used. These cameras measure the infrared radiation that is naturally emitted by a body. Thermal images are produced by converting the infrared radiation emitted by a body into electrical signals, which are further processed to create maps of surface temperature. This technique could be used to detect cracks and dilaminations (Weil 1989[5] and Hunaidi et al. 2000).[6] The technique suffers from difficulty in image interpretation. This is due to the fact that the surface temperature is dependent on the environmental and surface conditions. Surface moisture and roughness are all parameters that must be considered in interpreting infrared images. These limitations could be avoided if infrared technique is used in combination with microwave techniques such as ground-penetrating radar. It was suggested that this technique could be implemented as a screening process to other techniques (Hunaidi et al. 2000).[6]

Sewer scanner and evaluation technique

The SSET system consists of optical scanners and gyroscope. The optical scanners provide information about the structure condition of a pipe (i.e. surface defects), while the gyroscope provides information about the shape of a pipe (i.e. deformation). It should be noted that the system unwraps the circumference of the scanned images and stores all collected images in a digital format. The system is relatively slow compared to the conventional CCTV system (Wirahadikusumah et al., 1998[7], Gokhale et al., 1998, [8] and 2000).[9]

VISUAL TECHNIQUES

These techniques are used to identify deficiencies or problems, through an on-site visit of the infrastructure by either maintenance workers or an specialised firm. During this inspection, selective measures using the appropriate devices may be taken or monitoring equipment may be installed for ongoing observations. When the structures or pipes are inaccessible (diameters under 900 mm), other types of equipment, like cameras, may be used. Some of these techniques are CCTV inspection, visual inspection, telephoto camera inspection, inventory of sewer overflows, etc.

---

[5] Weil, G., 1998. “Detecting the Defects”, *Civil Engineering*, ASCE, 59(9), 72-77.

[6] Hunaidi, O., Chu, W., Wang, A. and Guan, W. , 2000. “Leak Detection for Plastic Water Distribution Pipes**”,** ***Journal AWWA***, 92(2), 82-94.

[6] Hunaidi, O., Chu, W., Wang, A. and Guan, W. , 2000. “Leak Detection for Plastic Water Distribution Pipes**”,** ***Journal AWWA***, 92(2), 82-94.

[7] Wirahadikusumah, R., et. al. “Assessment technologies for sewer system rehabilitation”, *Automation in Construction*, vol. 7, pp. 259-270, 1998.

[8] Gokhale, S., Abraham, D. and Iseley, T., 1998. “Intelligent Systems Evaluation Technologies—An Analysis of Three Promising Options”. *Proceedings of the North American No Dig 98*, New Mexico, 254-256.

[9] Gokhale, S., Hastak, M. and Huang, R., 2000. “Automated Assessment Technologies for Renewal of Underground Pipeline Infrastructure”, *Proceedings of the 17th International Conference on Robotics and Automation in Construction*, Taipei, Taiwan, 433-438.

Visual inspection

For man-entry systems (i.e. large diameter pipe with low flow), visual inspection can be achieved by physically entering the system. Proper equipment for safety must be used in connection with a code of practice and comprehensive staff training. Simple visual inspection of piping can be obtained from the surface by lifting the access hole cover and using a mirror with the aid of sunlight or artificial light. These latter inspections are limited in their extent but are quick, cost little and are often used for access hole, catch-basin and catch-basin lead inspections. They can also be used operationally to ensure that the critical pipes in the system are functioning properly.

Closed circuit television (CCTV)

Closed circuit television (CCTV) is used for a variety of reasons. One of the major uses is the inspection of sewer lines and watermains. The camera is placed in the pipeline and is either winched through, or it is self-propelled. The picture, which is available in both colour and black and white, is displayed on a monitor. The user is visually able to determine whether cleaning is needed, where repairs are needed, and location of services for reconnection following repairs. CCTV is also used to monitor work being done by remotely controlled robots. If too much water is present in the pipeline, it may have to be drained, in the case of watermains, or an alternative method used.

Recent developments have led to lateral inspection systems. They are able to enter the service connection from the main using remote control.

Stationary CCTV camera (Telephoto lens camera)

Stationary CCTV cameras are mounted at manhole. They utilize their zooming capabilities to search for defects (Aqua Data 2001).[10] They are limited with respect to what they can see. Defects that are close to the manhole will be detected, but the farther away the defect is, the harder it is to identify and evaluate. Defects beyond the range of the camera would be missed entirely. It was suggested that this technique could be used as a part of a screening process to determine which sewer sections should be thoroughly examined by the mobile CCTV system (Makar 1999).[11]

The decision to use either type of cameras (i.e. mobile and stationary) is a function of four major factors. These factors are economical, location of defect with respect to the camera, type of defect and type of pipe (Makar 1999).[12] It was documented that stationary cameras could be utilised effectively in brick pipes to detect structural defects, such as cracks, that are located within 40 meters range from the camera. If those structural defects are located beyond this particular

---

[10] Aqua Data (2001). Wastewater Collection System Diagnosis and Analysis using the Aqua Zoom Tele-objective Camera. Available online via http://www.aquadata.com.

[11] Makar, J.M. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, June 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

[12] Ibid.

range, then mobile cameras were found to be more effective (Makar 1999).[13] Although no range for effective utilisation of stationary CCTV cameras was documented in the literature for the case of concrete and clay pipes, the authors believe that it should be similar to brick pipes. In the case of non-structural defects, the decision to use mobile or stationary cameras is a function of economical factors (Makar 1999).[14]

MECHANICAL TECHNIQUES

These techniques are used to find the residual structural resistance of a pipe or to determine the condition of the mechanical elements of the existing appurtenances. The majority of these techniques involve: the use of hydraulic or manual tools to create or measure pressure on the pipe walls (e.g. hammer), or the use of portable equipment that can be inserted into the pipe to collect data. Among these techniques you can find; exfiltration tests, leak detection, flow measurements, etc.

MICRODEFLECTIONS

This method gives information on the overall condition of the wall of the sewer pipe, rather than identifying specific defects. In this technique, the pipe is subjected to a pressure that cusses slight deformation to its wall. It should be noted that this pressure is applied from inside the pipe being inspected. Measuring this deformation versus the applied pressure gives indication about the soundness of the pipe wall (Makar 1999).[15] A major limitation of this technique is to determine the safe load that should be applied without damaging the pipe. It should be noted that although this technique was originally developed to inspect brick pipes, it could be applied to clay and concrete pipes. It should also be noted that this technique can not be applied to plastic pipes such as PVC.

NATURAL FREQUENCY OF VIBRATION

As in the case of microdeflections, this method gives also information on the overall condition of the wall of the sewer pipe, rather than identifying specific defects. As the name implies, the pipe is vibrated and its natural frequency is measured. The measured natural frequency (i.e. signature) is compared to a standard signature of a good section of the pipe. Deviation from this standard signature suggests a problem that may exist in the pipe wall or the bedding condition (Rens et al. 1997[16] and Makar 1999).[17] It should be noted that in this

---

[13] Ibid.

[14] Makar, J.M. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, June 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

[15] Ibid.

[16] Rens, K. and Greimann, L. (1997). " Ultrasound Approach for Nondestructive Testing of Civil Infrastructure." *Journal of Performance of Constructed Facilities*, ASCE, 11(3), 97-104.

[17] Makar, J.M. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), juin, pp. 69-78, juin 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

method difficulties are usually encountered to differentiate between defects in the pipe wall and those in its bedding (Makar 1999).[18]

IMPACT ECHO AND SPECTRAL ANALYSIS OF SURFACE WAVES (SASW)

In these techniques a source of controlled impacts, such as a falling weight or a large pneumatic hammer and one or more geophones that are mounted on the wall of the pipeline are used. Low frequency surface waves are produced when the wall of the pipe is struck by the weight. These waves are then detected by the geophones and the soundness of the pipe wall is determined accordingly (Makar 1999).[19] The major difference between impact echo and SASW machines is that SASW technique allows for more information to be gathered about the surrounding soil. It should be noted that both techniques give information on the overall structural condition of the sewer line, rather than identifying specific defects. It should also be noted that these techniques require thorough cleaning of pipes before use and could be applied only to large diameter pipes that a human being can easily access. Further, the use of the impact echo method does not lead to conclusive diagnostics of defects that may exist in the pipe wall and the bedding of the pipe, but the SAWS method does (Makar 1999).[19]

Leak detection

Leak detection is a very important part of the inspection of a pipeline. The ability to locate and repair leaks without excavating saves valuable time and money. The methods used are:

1) Flow monitoring weirs

2) Smoke/gas testing

3) Sonic leak detectors

FLOW MONITORING WEIRS

Weirs have been used to monitor flow rates for quite some time. Conventional methods of collecting and analysing data are expensive and time consuming. However, the development of new techniques has led to more efficient and inexpensive methods of flow monitoring.

This system can be used to monitor entire systems or sections of a system, depending on the requirements. It can be used to measure flows over a period of hours, days, or even months. The main part of the system is the weir. It is designed and calibrated to enable flows to be measured using the upstream water level.

Depending on the system, a micro-computer can be placed in the manhole to record the water level at predetermined intervals. The information from the microcomputer can then be used to determine the flow rates. The location of

---

[18] Ibid.

[19] Makar, J.M. “Diagnostic techniques for sewer systems,” *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, June 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

leaks can then be determined by discrepancies in the flow rates between two points.

Weirs can be used in pipes from 200 to 1500 mm and at virtually any water levels.

SMOKE/GAS TESTING

Smoke testing is used to determine the presence of broken pipes, improperly sealed laterals, illegal lateral drains, and cross connections between different systems. Smoke canisters are released in the sewer system. The smoke filters out through the ground via defects in the pipe. These non-toxic and non-staining smoke devices quickly determine deficiencies.

A tracer gas procedure using helium has also shown a high level of success for determining leaks. The system is dewatered and pressurised with helium. Because helium is lighter than air, it rises easily through the soil to the surface. An instrument that is extremely sensitive to helium is then used to locate the seepage.

GEOMETRIC TECHNIQUES

These techniques are used to determine any changes in diameter or profile in sections of the system. Certain techniques use instruments that, once inserted and slid along the inner walls of a pipe, can detect variations in shape. Other radar- or laser-based techniques can verify any deflection or reduction in sections of the pipe. Among these techniques you can find; laser/optic photographic profile, radar sweep, etc.

Light line

It is basically an attachment to the CCTV camera that assists in detecting deformations in sewer pipes. The system projects a line of light around the circumference of pipe to assess its shape (Makar 1999).[20] It should be noted that this technique was found superior compared to the conventional CCTV cameras in detecting deformations (Makar 1999).[21]

Laser scanners

In this system, laser beams are projected around the circumference of the sewer being examined. The way in which the laser beams are reflected off the surface of pipe is evaluated to determine the pipe's geometry and presence of defects. A smooth surface reflects the maximum amount of laser light while cracked areas reflect reduced amount (Makar 1999).[22]

---

[20] Makar, J.M. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, June 01, 1999 (NRCC-42828) http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf

[21] Ibid.

[22] Ibid.

APPENDIX C: DEFECTS

STRUCTURAL DEFECTS

The following are major structural defects for different types of pipes as taken from the IRC Guidelines (2001):

Table C–1: IRC Guidelines for major structural defects for types of pipes

Defect Type	Applicable to		
	Rigid Pipe	**Plastic Pipe**	**Metal Pipe**
Fracture	X	X	X
Crack	X	X	
Deformation	X	X	X
Collapse	X	X	X
Broken pipe	X	X	X
Joint displacement	X	X	X
Joint opening			
Surface damage			
Local buckling		X	X
Corrosion			X
Spalling	X		
Wear	X	X	X
Sag	X	X	X

The following are structural defects for brick sewers as taken from the WRc Manual (2001):

- mortar missing
- displaced bricks
- missing bricks
- dropped invert (sag).

The following are major structural defects for manholes as taken from the IRC Guidelines (2001):

- fractures (vertical)
- fractures (horizontal)

- broken area
- crack (vertical)
- crack (horizontal)
- deformation
- collapse
- surface damage
- frame damage
- cover damage
- ground surface settlement.

SERVICE DEFECTS

The following are service defects as taken from the WRc Manual (2001):

- roots
- infiltration
- encrustation
- debris
- obstruction
- water level
- protruding services.

APPENDIX D: CONDITION RATINGS

The following are examples of defects and condition rating systems developed by the IRC (2001) and the City of Edmonton (1996).

Table D–1: Structural defects, codes and weights for pipes

Defect Type	Code	Unit of Measure	Weight
Fracture longitudinal (FL)			
- light (< 10 mm wide)	FLL	metre	5
- moderate (10 mm - 25 mm wide, or 2 - 4 fractures)	FLM	metre	10
- severe (> 25 mm wide, 5 or more fractures)	FLS	metre	15
Fracture circumferential (FC)			
- light (< 10 mm wide)	FCL	metre	5
- moderate (10 mm - 25 mm, or 2 - 4 fractures)	FCM	metre	10
- severe (> 25 mm wide, 5 or more fractures)	FCS	metre	15
Fracture diagonal (FD)			
- light (< 10 mm wide)	FDL	metre	5
- moderate (10 mm - 25 mm wide, or 2 - 4 fractures)	FDM	metre	10
- severe (> 25 mm wide, 5 or more fractures)	FDS	metre	15
Fractures multiple (FM)	FM	metre	20
Crack longitudinal (CL)			
- light (up to 3 cracks, no leakage)	CLL	metre	3
- moderate (> 3 cracks, leakage)	CLM	metre	5
Crack circumferential (CC)			
- light (up to 3 cracks, no leakage)	CCL	metre	3
- moderate (> 3 cracks, leakage)	CCM	metre	5
Crack diagonal (CD)			
- light (up to 3 cracks, no leakage)	CDL	metre	3
- moderate (> 3 cracks, leakage)	CDM	metre	5
Cracks severe (CS)			
- severe (multiple cracks, leakage)	CS	metre	10
Deformation (D)			
- light (< 5% change in diameter)	DL	metre	5
- moderate (5% to 10% change in diameter)	DM	metre	10
- severe (> 11% to 25% change in diameter)	DS	metre	15
Collapsed (X)			
Pipe section lost its integrity or deformation is more than 25% in diameter change	X	each	20

Defect Type	Code	Unit of Measure	Weight
Broken pipe (B)			
(> 100 mm diameter or > 100 mm x 100 mm area or equivalent)	B	each	15
Joint displacement (JD)			
- light (< ¼ pipe wall thickness)	JDL	each	3
- moderate (¼ - ½ pipe wall thickness)	JDM	each	10
- severe (> ½ pipe wall thickness)	JDS	each	15
Joint opening (JO)			
- light (< 10 mm, gasket in place)	JOL	each	3
- moderate (10 mm - 50 mm, gasket off, leakage)	JOM	each	10
- severe (> 50 mm, soil visible, leakage)	JOS	each	15
Surface damage (H)			
- light (< 5 mm wall thickness lost, slight spalling or wear, pitting on metal pipe)	HL	metre	3
- moderate (5 mm - 10 mm wall thickness lost, exposed reinforcement or aggregates, extended corrosion in metal pipe)	HM	metre	10
- severe (> 10 mm pipe wall thickness lost, corroded reinforcement, corroded through metal pipe)	HS	metre	15
Sag (S)			
- light (< 50 mm)	SL	metre	4
- moderate (50 mm - 100 mm)	SM	metre	10
- severe (> 100 mm)	SS	metre	15

Table D–2: Structural defects, Codes and Weights for Access Holes

Access Hole Defect Type	Code	Unit of Measure	Weight
Fracture vertical (FV)			
- light (< 3 fractures)	FVL	metre	5
- moderate (3 - 5 fractures)	FVM	metre	15
- severe (> 5 fractures)	FS	metre	20
Fracture horizontal (FH)			
- light (< 10 mm wide)	FHL	metre	5
- moderate (10 mm - 25 mm)	FHM	metre	15
- severe (> 25 mm)	FHS	metre	20
Broken area (B)			
(a hole > 100 mm diameter, or 100 mm x 100 mm area or equivalent)	B	each	20
Crack vertical (CV)			
- light (no leakage)	CVL	metre	3
- moderate (leakage)	CVM	metre	8
- severe (multiple cracks, leakage)	CS	metre	12
Crack horizontal (CH)			
- light (no leakage)	CHL	metre	3
- moderate (with leakage)	CHM	metre	8
- severe (multiple cracks, leakage)	CHS	metre	12
Deformation (D)			
- light (< 7% ID)	DL	each	8
- moderate (7% to 25%)	DM	each	12
- severe (> 25%)	DS	each	18
Collapsed (X)	X	each	20
Surface damage (H)			
- light (< 5 mm wall thickness lost, delaminated lining)	HL	each	3
- moderate (5 mm - 10 mm wall thickness loss, exposed reinforcement or aggregates)	HM	each	12
- severe (> 10 mm wall thickness loss, corroded reinforcement)	HS	each	18
Frame damage (AD)			
- light (slight corrosion, anchors rusted)	ADL		4
- moderate (heavy corrosion, loose anchorage)	ADM		12
- severe (broken or displaced)	ADS		18
Cover damage (CD)			
- light (slight corrosion, poor fit)	CDL		8
- moderate (heavy corrosion, cracked)	CDM	each	16
- severe (broken)	CDS	each	20
Ground surface settlement (GS)			
- light (minor pavement surface cracking)	GSL		5
- moderate (major cracking in pavement, large bumps)	GSM		10
- severe (spalled pavement, holes)	GSS		18

Source: IRC (2001).

Total score, mean score, and peak score are reported for each access hole to access hole section. Table D–3 shows the peak score for condition ratings for structural defects, where 0 is the least severe and 5 is the most severe condition.

Table D–3: Peak Score for Condition Ratings for Structural Defects

Peak Score Range	Structural Condition Rating
0	0
1 – 4	1
5 – 9	2
10 – 14	3
15 – 19	4
20	5

Source: IRC (2001).

The IRC guidelines do not provide similar tables for total and mean scores. For comparison purposes, the structural condition rating table used by the City of Edmonton is shown below. The worst score is used when assigning the condition rating for the pipe.

Table D–4: Structural Condition Rating

Total Structural Score	Mean Structural Score	Peak Structural Score	Structural Condition Rating
less than 100	less than 0.5	less than 1.0	1
100 – 149	0.5 – 0.99	1.0 – 2.0	2
150 – 199	1.0 – 1.49	2.1 – 3.0	3
200 – 249	1.5 – 2.49	3.1 – 5.0	4
250 and greater	2.5 and greater	5.0 and greater	5

Source: City of Edmonton (1996)

HYDRAULIC CONDITION RATINGS

The following table provides hydraulic condition ratings for various combinations of theoretical load factors (TLF), grade line factors (GLF), and upstream impacts.

Table D–5: Hydraulic Condition Ratings

TLF	Upstream Impact	Hydraulic Condition Rating
Less than 1.0	No impact on upstream GLF.	1.0
1.0 – 2.5	Upstream GLFs are generally between 1 and 2. Pipe link contributes to GLF.	2.0
1.0 – 2.5	Upstream GLFs are generally between 2 and 3. Pipe link contributes to GLF.	3.0
2.5 and greater	Upstream GLFs are generally between 3 and 4. Pipe link contributes to GLF. Potential exists for basement flooding.	4.0
2.5 and greater	Upstream GLFs are generally between 4 and 5. Pipe link contributes to severe GLF. Potential exists for basement flooding.	5.0

Source: City of Edmonton (1996).

REFERENCES

Aqua Data, 2001. *Wastewater Collection System Diagnosis and Analysis using the Aqua Zoom Tele-objective Camera*. Pincourt, Quebec. Available online via <http://www.aquadata.com>.

ASCE (American Society of Civil Engineers), 1994. *Existing Sewer Evaluation & Rehabilitation.* Engineering Practice No. 62, USA.

———, 1997. *Manhole Inspection & Rehabilitation.* Engineering Practice No. 92, USA.

Baur, R. and Herz, R., 2002. *Selective inspection planning with aging forecast for sewer type,* Water Science and Technology, Vol 46, No. 6-7, London, UK.

CERIU (Centre d'expertise et de recherche en infrastructures urbaines), 1997. *Manuel de standardisation des observations – inspections télévisées de conduites d'égout*, Montréal, Québec.

Edmonton, City of., 1996. *Standard Sewer Condition Rating System Report,* Edmonton, Alberta.

Hunaidi, O. et al., 2000. "Detecting leaks in plastic pipes," *Journal of the American Water Works Association – 21st Century Treatment and Distribution,* 92, (2), pp. 82-94, February 01, (NRCC-42813), Ottawa, Ontario. <http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42813.pdf>.

IRC (Institute for Research in Construction), National Research Council Canada, 2001. *Guidelines for Condition Assessment and Rehabilitation of Large Sewers,* Ottawa, Ontario.

Makar, J.M., 1999. "Diagnostic techniques for sewer systems," *Journal of Infrastructure Systems,* ASCE, 5, (2), June, pp. 69-78, (NRCC-42828), Ottawa, Ontario.
<http://irc.nrc-cnrc.gc.ca/fulltext/nrcc42828/nrcc42828.pdf >

Moselhi, O., Shehab-Eldeen, T., 2002. *Inspection of underground sewer and water systems*, Montreal : Concordia University, 36 p.

NAAPI (North American Association of Pipeline Inspectors), 2003. *NAAPI Manual of Sewer Condition Classification*, CATT/NAAPI, Department of Civil Engineering, University of Waterloo, Waterloo, Ontario.

National Association of Sewer Service Companies (NASSCO), 1996*. Manual of practices: Wastewater Collection Systems*, Maitland, FL : NASSCO, 2nd Ed., 225 p. August.

National Guide to Sustainable Municipal Infrastructure (InfraGuide), 2003a. *An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks*, Ottawa, Ontario.

———, (InfraGuide), 2003b. *Best Practices for Utility-Based Data*, Ottawa, Ontario.

———, (InfraGuide), 2003c. *Selection of Technologies for Sewer Rehabilitation and Replacement*, Ottawa, Ontario.

———, (InfraGuide), 2003d. *Coordinating Infrastructure Works*, Ottawa, Ontario.

Pla-Rucki, G. and M. Eberhard, 1995. “Imaging of Reinforced Concrete:State-of-the-Art Review.” Journal of Infrastructure Systems. ASCE, 1(2): 134-141.

Stein, D., 2001. *Rehabilitation and Maintenance of Drains and Sewers*, Ernst & Sohn 2001, Berlin.

TTBC (Trenchless Technology British Columbia), 2002. “ Maintenance & Repair”, *Trenchless Technology – A Canadian Prospective Guide,* February. Web site: http://www.trenchless-technology.org/repair.html

Weil, G., 1998. “Detecting the Defects”, *Civil Engineering*, ASCE, 59(9), 72-77.

Wirahadikusumah, R., et. al., 1998. “Assessment technologies for sewer system rehabilitation”, *Automation in Construction*, Vol. 7, pp. 259–270.

WRc (Water Research Centre), 2001. *Manual of Sewer Condition Classification,* Fourth Edition, UK.