Multi-discipline

An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks

This document is the second in a series of multidisciplinary best practices which has been developed with the combined efforts of various Technical Committees. For titles of other best practices in this and other series, please refer to *www.infraguide.ca.*

National Guide to Sustainable Municipal Infrastructure

NRC · CNRC Federation of Canadian Municipalities Canadä

An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks

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INTRODUCTION

InfraGuide – Innovations and Best Practices

Why Canada Needs InfraGuide

Canadian municipalities spend $12 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 responding both to higher standards of 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: 1) municipal roads and sidewalks 2) potable water 3) storm and wastewater 4) decision making and investment planning 5) environmental protocols and 6) 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.

The InfraGuide Best Practices Focus

Multidisciplinary best practices are relevant to two or more Infrastructure sectors. The current best practice combines Potable Water, Storm and Wastewater, and Roads and Sidewalks.

Potable Water

Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. Issues such as water accountability, water use and loss, deterioration and inspection of distribution systems, renewal planning and technologies for rehabilitation of potable water systems and water quality in the distribution systems are examined.

Storm and Wastewater

Ageing buried infrastructure, diminishing financial resources, stricter legislation for effluents, increasing public awareness of environmental impacts due to wastewater and contaminated stormwater are challenges that municipalities have to deal with. Storm and wastewater best practices deal with buried linear infrastructure as well as end of pipe treatment and management issues. Examples include ways to control and reduce inflow and infiltration; how to secure relevant and consistent data sets; how to inspect and assess condition and performance of collections systems; treatment plant optimization; and management of biosolids.

Municipal Roads and Sidewalks

Sound decision making and preventive maintenance are essential to managing municipal pavement infrastructure cost effectively. Municipal roads and sidewalks best practices address two priorities: front-end planning and decision making to identify and manage pavement infrastructures as a component of the infrastructure system; and a preventive approach to slow the deterioration of existing roadways. Example topics include timely preventative maintenance of municipal roads; construction and rehabilitation of utility boxes; and progressive improvement of asphalt and concrete pavement repair practices.

Decision Making and Investment Planning

Elected officials and senior municipal administrators need a framework for articulating the value of infrastructure planning and maintenance, while balancing social, environmental and economic factors. Decision-making and investment planning best practices transform complex and technical material into non-technical principles and guidelines for decision making, and facilitate the realization of adequate funding over the life cycle of the infrastructure. Examples include protocols for determining costs and benefits associated with desired levels of service; and strategic benchmarks, indicators or reference points for investment policy and planning decisions.

Environmental Protocols

Environmental protocols focus on the interaction of natural systems and their effects on human quality of life in relation to municipal infrastructure delivery. Environmental elements and systems include land (including flora), water, air (including noise and light) and soil. Example practices include how to factor in environmental considerations in establishing the desired level of municipal infrastructure service; and definition of local environmental conditions, challenges and opportunities with respect to municipal infrastructure.

Transit

Urbanization places pressure on an eroding, ageing infrastructure, and raises concerns about declining air and water quality. Transit systems contribute to reducing traffic gridlock and improving road safety. Transit best practices address the need to improve supply, influence demand and make operational improvements with the least environmental impact, while meeting social and business needs.

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EXECUTIVE SUMMARY

In many Canadian municipalities, the road renewal program has driven renewal planning for sewer and water systems. In some cases, a condition assessment and performance evaluation of the existing sewers and water mains were not completed and it was assumed that old sewers and water mains should be replaced when the roads were reconstructed. At the other extreme, some road work has been carried out without examining the condition of the piping below (putting the roadway investment at risk). However, in light of shrinking financial resources and the public's demand for a more transparent decision-making process, it is becoming more important for municipalities to plan the renewal of their road, sewer, and water systems using an integrated approach.

A systematic and proactive method should be used to ensure renewal programs are based on sound data and are adequately funded. A five-phase approach is proposed for assessment and evaluation of these systems.

Task 1 — Inventory
Municipalities should compile a detailed inventory of their road, sewer, and water systems following the guidelines presented in the *Best Practices for Utility-Based Data* (NGSMI, 2003e). The inventory for each system must be structured to permit cross-referencing among the systems. The inventories should also be linked to a geographic information system (GIS) to facilitate spatial analysis. The format and content of the inventories will vary among municipalities. However, each municipality should adopt a plan for data collection and storage that will eventually allow the municipality to manage its systems proactively and in an integrated manner.

Task 2 — Investigation
An inspection program should be developed for the road, sewer, and water systems to ensure the renewal programs are proactive in nature, based on sound data and are adequately funded. The frequency of inspection of each component depends on its expected condition and importance. The results of each inspection should be documented to allow comparisons with subsequent inspections so, over time, reasonable estimates of deterioration rates can be made. Critical components should be dealt with more proactively than non-critical components.

Task 3 — Condition Assessment
Condition rating systems should be used to identify and prioritize the renewal requirements for road, sewer, and water systems. The number of performance indicators in a condition rating system will vary depending on the size of the municipality, the available data and the specific conditions within each system. The condition rating system should incorporate information on the need to increase the capacity of the road, sewer, and water systems as well as address non-standard components. Some discussion is provided on condition rating systems developed in-house as well as proprietary and non-proprietary systems.

Task 4 — Performance Evaluation
Once the condition of each component has been determined, a performance evaluation should be conducted to project the investment required over the next 10 to 20 years. Ideally, the performance level should be linked to the annual investment tracking both planned (proactive) and unplanned (reactive) to optimize the renewal program for each system.

Task 5 — Renewal Plan
Once it has been established that a system component should be rehabilitated or replaced, an economic analysis should be used to select the most cost-effective method of renewal and the timing for its renewal. An economic analysis typically compares the renewal alternatives in terms of their present worth. The renewal alternatives should also account for socio-economic impacts, risk, growth needs, changing regulations and policies, adjacent infrastructure condition as well as emerging technologies.

Applications and Limitations
All municipalities across Canada should implement an integrated approach to assessment and evaluation of road, sewer, and water systems. The practices must be tailored to each municipality to reflect the size, age, and condition of the systems. Municipalities may be challenged to complete an integrated system assessment and evaluation due to lack of data, tools, resources, and a standard approach. It is recommended that existing publications (related to products, technologies, specifications or best practices) from recognized organizations be referred to by municipalities when applying this best practice.

Evaluation
Several measures can be used to evaluate the effectiveness of the practices used in a municipality for renewal planning of road, sewer, and water systems, such as tracking unplanned (reactive) spending, monitoring the data collection program, conducting pilot studies and, periodically, updating the renewal plan.

1. General

1.1 Introduction

In the fall of 2001, the *National Guide to Sustainable Municipal Infrastructure* (InfraGuide) conducted a survey of municipalities, public utilities, and private companies across Canada to identify the best practices used to inspect, assess, and evaluate the structural condition and capacity of roads, sewers, and water mains.

This survey revealed a wide range of practices in use across Canada. It also revealed the need for a network level approach to infrastructure assessment and evaluation. Furthermore, it also became apparent the best practice for managing these networks should treat them as an integrated system to better coordinate the renewal programs. A coordinated renewal program would minimize disruption to the public and minimize costs to the municipality. It should also be noted that some communities have a formal coordinating group to plan out capital upgrades on streets such that restoration costs and social impacts on the community are minimized by consideration of one upgrade for all of the surface and underground systems. This group typically includes all municipal utility services and well as hydro, telecom, cable and gas entities.

This document outlines the best practice for assessing and evaluating municipal road, sewer, and water networks using an integrated approach.

1.2 Purpose and Scope

Many larger municipalities have separate departments[1] responsible for road, sewer, and water systems. Furthermore, in some large municipalities, there may be separate departments responsible for planning, design, construction, and maintenance of each system. In smaller municipalities, there may be only one or two persons responsible for managing the entire municipal infrastructure. These factors create a significant challenge for municipalities in managing their systems effectively in an integrated manner.

It should also be noted that the sewers and water mains on a given section of road typically have a longer life expectancy than the road itself. In addition, sewers and water mains typically have a different service life expectancy. This further increases the challenge of managing these systems in an integrated manner. Municipalities should recognize that decisions made at any stage in the life cycle of one group of assets could affect the other assets.

1.2.1 Purpose

The best practice for assessment and evaluation of each system is generally well documented. Unfortunately, there is limited information available on the integrated planning for renewal[2] of road, sewer, and water systems. Integration provides an opportunity to exploit potential economies of scale when more than one infrastructure element requires renewal. This can maximize economic and social benefits to the area served by the infrastructure. This document presents an integrated approach to assessment and evaluation of these three systems.

An integrated approach to renewal planning will help maintain a high level of service while minimizing life cycle costs, impacts on the environment, and disruption to the community. In simple terms, the goal of every municipality should be to spend the right amount of money, on the right things, at the right time. This is consistent with the InfraGuide's sustainable

An integrated approach to renewal planning will help maintain a high level of service while minimizing life cycle costs, impacts on the environment, and disruption to the community.

1. In some cases, a utility or private company may be responsible for one or more of the municipal systems.
2. For the purposes of this document, renewal includes both rehabilitation and replacement/reconstruction.

municipal infrastructure principles of full life cycle costs applied across social, economic and environmental dimensions in the pursuit of sustainable infrastructure to minimize overall intended and unintended costs both today and for future generations.

1.2.2 Scope

This best practice focuses on the integrated assessment and evaluation of the road, sewer, and water systems at a network level. More detailed investigation will be required to assess the condition and evaluate the needs at a project level. It should also be noted that this best practice focuses on the linear systems only and does not address structures, such as bridges, pumping stations, treatment plants, and reservoirs. Furthermore, this document primarily focuses on the process used to develop an integrated renewal plan. It does not specifically address operation and maintenance practices.

1.3 How to Use This Document

Section 2 outlines potential benefits and risks of implementing this best practice. Section 3 presents a five-step process for assessment and evaluation that is applicable to all types of municipal infrastructure. Section 4 presents some of the applications and limitations of this best practice. Finally, Section 5 describes measures that can be used to evaluate the effectiveness of this best practice in a municipality.

Readers should be aware that InfraGuide has published two other best practices that are relevant to integrated renewal planning of road, sewer, and water systems. These are briefly described as follows.

- **Coordinating Infrastructure Works** outlines the best practice for coordinating infrastructure works. Five service delivery areas are addressed: coordination practices, corridor upgrades, restrictive practices, approval processes/better communication, and technical considerations.
- **Planning and Defining Municipal Infrastructure Needs** outlines the best practice for planning and defining municipal infrastructure needs using five methods: strategic planning, information management, building public support and acceptance, exploring new and innovative methods for continuous improvement, and prioritization models.

1.4 Glossary

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

Critical Component — Those components of the system where failure is not an acceptable risk.

Evaluation — The process used (after the assessment is completed) to determine the remedial measures necessary to improve the condition and/or performance of a system component at the least cost to the community.

Full Cost Accounting — A system that includes all costs (including capital investment, financing, renewal and rehabilitation, decommissioning, and operational) across social, economic and environmental dimensions.

Life cycle cost — Costs over the full life cycle of an asset, from construction, through operation, maintenance and rehabilitation, to replacement/reconstruction.

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

Renewal — Restoring the condition of an asset by rehabilitation or replacement/reconstruction.

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

2. Rationale

2.1 Background

Best practices for assessing and evaluating road, sewer, and water systems are generally well documented. The Transportation Association of Canada (TAC) has published the *Pavement Design and Management Guide* that presents information on the best practices for programming and optimizing pavement investments, in-service evaluation, structural design, construction, and maintenance. InfraGuide has published *Timely Preventive Maintenance for Municipal Roads — A Primer and Priority Planning and Budgeting Process for Pavement Maintenance and Rehabilitation.*

For sewer systems, many municipalities across Canada have adopted the sewer condition rating system developed by the Water Research Centre (WRc) in the United Kingdom. In addition, the Water Environment Federation (WEF) and the American Society of Civil Engineers (ASCE) have published a manual of practice entitled *Existing Sewer Evaluation and Rehabilitation.*

For water systems, InfraGuide has published *Developing a Water Distribution System Renewal Plan.* The American Water Works Association (AWWA) and the American Water Works Research Foundation (AwwaRF) have also published several technical reports on water distribution system renewal.

A formal process for assessment and evaluation of these systems will identify the short-term renewal requirements. Over time, it should be possible to monitor the deterioration rate for the system components to facilitate longer-term planning. An integrated approach to assessment and evaluation of the road, sewer, and water systems will further enhance renewal planning.

2.1.1 Common Practices

The condition of municipal roads is more readily apparent than the condition of buried sewer and water systems. As a result, pavement management systems are generally better developed than management systems for sewer and water systems. Furthermore, the service life of roads is generally shorter than that for the sewer and water systems. Consequently, in many municipalities, the road renewal program has driven the renewal planning for the sewer and water systems.

Municipalities have not always made sound engineering decisions regarding the timing for renewal of sewers and water mains. This shortcoming stems from the fact that condition of the sewers and water mains is difficult to ascertain since they are buried. As a result, in some cases, sewers and water mains have been replaced when the road was reconstructed even though the existing sewers and water mains were still in good condition. This conservative approach has been adopted by some municipalities to avoid the potential embarrassment of having to excavate the road shortly after it was reconstructed to repair a sewer or water main. These municipalities also argue that replacing the underground services when the road is reconstructed will achieve cost savings and minimize disruption to local traffic and residents.

Over time, it should be possible to monitor the deterioration rate for the system components to facilitate longer-term planning.

In other cases, municipalities did not replace deteriorated sewers and water mains when a road was reconstructed. Such a decision may lead to unnecessary costs and disruption when the underground services had to be repaired or replaced while the road was still in good condition. Municipalities should conduct a detailed assessment of the sewers and water mains to determine the optimum timing for their renewal.

In light of shrinking financial resources and the public's demand for a more transparent decision-making process, it is becoming more important for municipalities to plan the renewal of their road, sewer, and water systems using an integrated approach.

2.1.2 Collateral Impacts

One system may impact the other systems in various ways.

- Water main leaks and breaks can undermine adjacent sewers and the road structure leading to premature failure of these systems.
- Sewer deterioration can undermine adjacent water mains and the road structure leading to premature failure of these systems.
- Inadequate compaction around valve boxes, valve chambers, maintenance holes, and catch basins can result in premature failure of the road at these locations.
- Vibrations generated during road resurfacing/reconstruction and excavations can break deteriorated water mains.
- If the road profile is raised significantly during reconstruction, earth loads on the sewers and water mains are increased, potentially exceeding design loading and increasing the risk of collapse.
- If the road profile is lowered during reconstruction, the sewers and water mains are more susceptible to freezing, and live loads may also exceed design loading for the buried infrastructure.
- Road salt can accelerate the corrosion of metallic pipes and fittings as well as steel reinforcement in concrete pipes.
- Stray electrical currents can accelerate electrolytic corrosion of metallic water mains, force mains and appurtenances.
- Some trenchless technologies for sewer and water main construction could damage roads if the technology is not well suited for a particular application or if it is not correctly applied.
- Improperly sized or maintained storm drainage could result in flooding and the resulting detrimental impact on roads.
- Differential frost heave can occur if the trench backfill is a different material than the road sub-grade.
- Excavation within a roadway for construction/repair of a sewer or water main can lead to premature failure of the road if the backfill is not adequately compacted or the pavement is not properly restored.
- Different pavement structures can significantly impact future rehabilitation costs of buried infrastructure.

2.2 Benefits

There are several benefits in an integrated approach to assessing and evaluating road, sewer, and water systems in a municipality.

- The approach minimizes life cycle costs, impacts on the environment, and disruptions to local traffic and residents.
- Infrastructure management is more proactive, and a high level of service can be maintained.
- Coordination among municipal departments is improved with increased opportunities for cross-training of municipal staff, and easier staff transfers or changes.
- Ensures that municipal services with split jurisdictions are identified and considered.
- Road, sewer, and water system work can be coordinated with growth-related needs.
- Full cost accounting is improved.
- Integration provides a consistent repeatable approach to infrastructure management. Long-range planning is also improved in terms of technical, financial, and risk management.
- Decision making takes into account both intended and unintended costs to the public and communities.

2.3 Risks

The potential risks of an integrated approach include the following.

- Additional resources will be required to conduct an integrated assessment and evaluation of the systems.
- Renewal costs could be high in the short term if the renewal programs were underfunded in the past. Municipalities may not fully appreciate that an integrated renewal plan should help minimize life cycle costs.
- There could be a lack of support for an integrated renewal plan from stakeholders (e.g., operators, politicians, and the public) in those systems that have not experienced significant problems.
- Cost-sharing formulas that disadvantage one or more infrastructure elements could reduce support for an integration program (i.e., to be effective, financial benefits and costs should be determined in an open, transparent manner).
- Staff support may be lost if there is an expectation that the condition rating systems and other analytical tools can generate an optimum plan without input from the municipal staff.
- Assumptions made on infrastructure condition could be wrong. Deterioration and condition data for some infrastructure components is currently insufficient or unavailable.

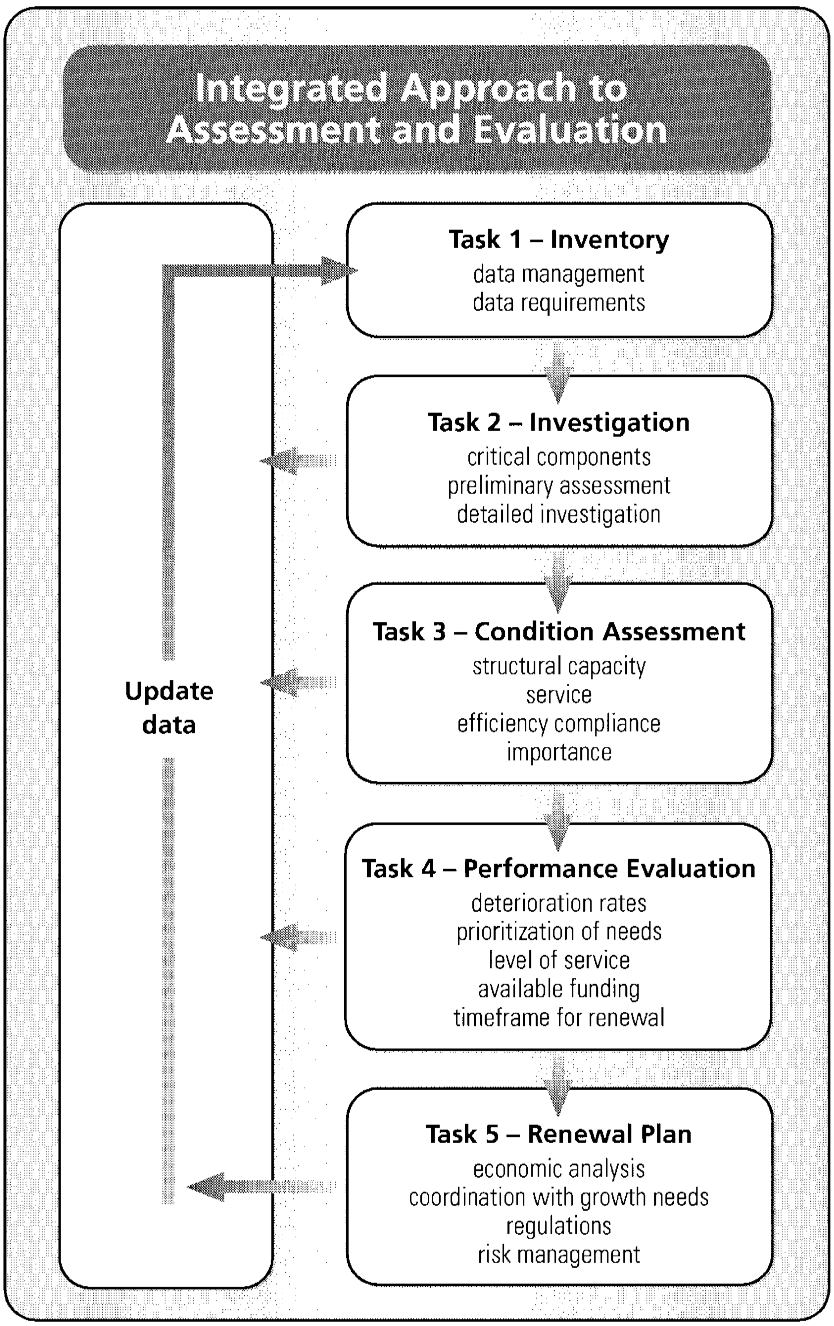
Integration provides a consistent repeatable approach to infrastructure management. Long-range planning is also improved in terms of technical, financial, and risk management. Additional resources will be required to conduct an integrated assessment and evaluation of the systems.

3. Work Description

Figure 3–1:
Integrated approach to assessment and evaluation

A systematic and proactive method should be used to plan the renewal of municipal road, sewer, and water systems in an integrated manner. Figure 3–1 illustrates a pragmatic approach for assessing and evaluating these systems. Although the inventory, investigation, condition assessment, and performance evaluation can be completed independently for the road, sewer, and water systems, significant efficiency can be achieved if the renewal alternatives are evaluated taking into consideration coordination of works over the life cycle of each element.

Figure 3–1: Integrated approach to assessment and evaluation



These phases are not necessarily distinct and do not always have to be conducted sequentially. For example, a detailed investigation of roads may not be done until after the condition assessment and performance evaluation has been completed. In other cases, the inventory is compiled along with the inspection.

It should also be noted that critical components should be dealt with separately from the non-critical components throughout all phases of the process. All components of infrastructure should be examined at a frequency that is shorter than half of its expected life. Critical components should receive a more thorough inspection and condition assessment on an increased frequency. Similarly, critical components should be treated with a higher priority in the evaluation and renewal planning phases.

3.1 Task 1 — Inventory

3.1.1 Data Management

This phase includes the compilation of an inventory of the road, sewer, and water systems. The inventory should include the physical attributes of each component as well as significant other features such as meteorological and environmental data. InfraGuide has published a document entitled *Best Practices for Utility-Based Data* that presents a foundation and guide for identifying, storing, and managing sewer and water system data. This best practice can be adapted for roads and other utilities.

The Best Practices for Utility-Based Data recommends the use of a documented data model/data structure, data collection standards, standard data units, and standard location referencing. It makes suggestions for collecting and maintaining data, properly storing data, and effectively managing that data. The best practice also recommends maintaining meta data.[3]

The data management plan should be updated periodically to reflect changing needs, new technologies, and new opportunities. In some cases, pilot tests can be completed to confirm the feasibility and costs of some data collection and management technologies.

In light of the significant amount of data required to conduct a detailed assessment and evaluation of road, sewer, and water systems, municipalities should compile the inventories in relational databases. Ideally, the databases should be linked to a geographic information system (GIS) to facilitate spatial analysis of the systems. In addition, these inventories should be coordinated with other applications, such as maintenance management systems, to share the inventory.

3.1.2 Data Requirements

Best Practices for Utility-Based Data identified several key data groups for sewer and water systems, including system attributes, operations and maintenance, performance, and meteorological, environmental, customer, and financial data.

The format and content of the databases will vary among municipalities depending on such factors as the size of the municipality, the available funding, the severity of the problems or apparent inefficiencies, and the capabilities of the municipal staff. In some cases, it may take several years for a municipality to compile a comprehensive inventory of its systems. However, each municipality should adopt a plan for data collection and management that will eventually allow the municipality to manage its systems proactively in a cost-effective manner.

3. Meta data describe the source and accuracy of the inventory data as well as information on when data were entered and by whom, and how the data were acquired, etc.

3.1.3 Integration of Data

The database for each system must be structured so the information tables can be cross-referenced with each other as well as with the databases for the other systems. Typically, the roads are divided into segments bounded by intersections. The sewers and water mains should be linked to the road segments to facilitate an integrated assessment and evaluation.

When all the data for the roads, sewers, and water mains have been entered into a map environment (preferably on GIS), it is possible to use spatial analysis to pull all the data together. This methodology eliminates the need to tie each facility into the exact same reference points.

3.2 Task 2 — Investigation

3.2.1 Critical Components

The inventory can provide much needed information to help identify critical infrastructure. Consideration can be given to size, age, infrastructure function, inspection history, maintenance history, operator observations and other important factors in a systematic way to establish integrated inspection and assessment programs.

Arterial roads are more critical than collector and local roads since arterial roads have higher traffic volumes. Similarly, water transmission mains are more critical than water distribution mains, and trunk sewers are more critical than collector and local sewers. The importance of each component should be indicated in the inventory. Several factors can be used to identify critical components, such as traffic volumes on roads, diameter of sewers and water mains, potential costs of failure (in terms of repair costs and damages to property and the environment), and impacts of service disruption on customers.

The primary objective of a renewal plan for non-critical roads, sewers, and water mains is to minimize the life cycle costs recognizing that occasional repairs are tolerable. On the other hand, the primary objective of a renewal plan for critical roads, sewers, and water mains is to minimize failures. As a result, renewal planning for critical components must be more proactive than that for non-critical components.

Furthermore, the renewal planning for the sewers and water mains located under critical roads should be proactive recognizing that sewer collapses and water main breaks should be minimized under critical roads.

It should be noted that critical infrastructure service life should be a prime consideration in the planning and design stages for new infrastructure. This concept is important in the planning of replacement cycles.

3.2.2 Roads

The *Pavement Design and Management Guide* (TAC, 1997) outlines several methods for investigating and assessing the structural capacity, condition, roughness, and safety of roads. The following paragraphs summarize methods used to quantify the condition and performance of roads. More detailed information is provided in the *Pavement Design and Management Guide.*

Structural Capacity
The structural capacity of a pavement is typically determined using field tests, such as the Benkelman Beam, the Dynaflect®, and the Falling Weight Deflectometer. These tests measure pavement deflections under a load.

Condition
Visual surveys are commonly used to measure pavement distress. Pavement condition surveys should include the type of distress as well as its extent, severity, and location. Surface defects, permanent deformation and distortion, cracking, and patching are the most common types of distress.

The primary objective of a renewal plan for non-critical roads, sewers, and water mains is to minimize the life cycle costs recognizing that occasional repairs are tolerable.

An inspection program should be developed for the road, sewer, and water systems to ensure renewal programs are based on sound data and are adequately funded.

Roughness
Pavement roughness is a primary indicator of serviceability. The Riding Comfort Index (RCI) is commonly used in Canada as a measure of serviceability. The International Roughness Index (IRI) has recently been gaining industry acceptance as well. A panel would drive along a road, and their opinions on the roadway would form the RCI. In recent years, several mechanical tools have been developed to measure pavement roughness.

Safety
Pavement safety can be quantified in terms of skid resistance, ruts, light reflectivity of the pavement surface, and lane demarcation. There are several methods used to measure skid resistance. Visual inspections are commonly used to assess ruts, light reflectivity, and lane demarcation.

3.2.3 Sewers

Deterioration of sewers is manifested as:

- structural defects (e.g., cracks, fracture, sags, deformation, open joints, displaced joints);
- service defects (e.g., protruding laterals, tree roots, silt, grease, encrustation, obstructions);
- system surcharges and sewer backups; and
- a high groundwater infiltration rate in sanitary sewer systems.

Closed-circuit television (CCTV) is commonly used to inspect sewers. Many Canadian municipalities have adopted the scoring system developed by the Water Research Centre (WRc, 1986) to quantify the structural condition and functional adequacy of sewers.

The National Research Council has published a guideline (NRC, 2000) for condition assessment and rehabilitation of sewers that are larger than 900 mm in diameter. This guideline also describes several other inspection techniques for large sewers (e.g., sonar, stationary camera, visual). *(http://irc.nrc-cnrc.gc.ca/catalogue/uir.html)*

Some municipalities use flow monitoring and computer modelling to quantify groundwater infiltration in sanitary sewer systems and to determine if there is spare capacity. InfraGuide has published a best practice, *Infiltration/Inflow Control/Reduction for Wastewater Collection Systems* (NGSMI, 2003h). It describes the techniques commonly used to assess the structural condition and hydraulic capacity of sewer systems.

3.2.4 Water Mains

Deterioration of water mains is evident with one or more of the following manifestations:

- frequent breaks;
- reduced hydraulic capacity;
- a high leakage rate; and
- impaired water quality.

Water main break records and hydraulic roughness tests are commonly used to quantify the condition of water mains. InfraGuide has published *Deterioration and Inspection of Water Distribution Systems — Best Practice* (2003g). It uses a two-phase approach. The first phase involves a preliminary assessment of the water distribution system using data that should be collected by every municipality on a routine basis (e.g., water main break records, customer complaints, water quality). The second phase involves a more detailed investigation of specific problems based on findings of the preliminary assessment.

3.2.5 Inspection Program

An inspection program should be developed for the road, sewer, and water systems to ensure renewal programs are based on sound data and are adequately funded. The frequency of inspection for each system component depends on its expected condition and importance. The results of each inspection should be documented to allow comparisons with subsequent inspections so, over time, reasonable estimates of deterioration rates can be made.

3.3 Task 3 — Condition Assessment

3.3.1 Condition Rating Systems

Condition rating systems should be used to identify and prioritize the renewal requirements for roads, sewers, and water mains. Several performance indicators can be used to assess their structural condition and functional adequacy. The following tabulation summarizes the general categories of performance indicators:

Roads	Sewers	Water Mains
Structural/ bearing capacity Condition/distress	Structural defects	Structural/ break rates
Volume/capacity ratio	Hydraulic capacity	Hydraulic capacity
Roughness/ rideability	Infiltration	Leakage
Safety	Service defects	Water quality
Importance	Importance	Importance

The number of indicators to be included in a condition rating system will vary among municipalities depending on the size of the municipality, the data available, and the specific conditions for each system.

Condition rating systems typically include a point scoring system for each performance indicator. Weighting factors can be applied to each performance indicator to generate a total score for each component. The total scores for the components on a street segment can then be added (with appropriate weighting factors) to generate an overall score for each street segment.

The total scores for each system can be ranked so the components in the poorest condition are easily identified. Similarly, the overall scores for the street segments can be ranked. A sensitivity analysis should be conducted to assess the relative significance of each performance indicator. Ideally, the condition rating systems should be linked to a GIS to more easily assess any spatial trends in the ratings for each system.

3.3.2 Capacity Analysis

Traffic studies should be conducted periodically to identify the need to upgrade the roads in a municipality to accommodate projected traffic volumes.

Hydraulic analyses should be conducted for sewer and water systems to provide input to the development of a renewal plan. In some cases, it may be necessary to expedite the renewal of sanitary and combined sewers experiencing high rates of infiltration to reduce the risk of basement flooding and overflows.

Similarly, it may be necessary to rehabilitate an unlined water main that is heavily tuberculated in order to supply adequate water pressures and fire flows. In some cases, it may be necessary to replace a water main with a larger diameter pipe if it does not have adequate capacity, even if it was rehabilitated.

Master plans based on community plans which outline future growth should be prepared and updated periodically to identify the need for improvements to the road, sewer, and water systems to service projected development/redevelopment. For complex larger systems, computer models of the system are helpful in the preparation of the master plans. Ideally, the computer models for each system should be linked to the inventory to facilitate periodic updates of the models and the assignment of capacity ratings.

Condition rating systems should be used to identify and prioritize the renewal requirements for roads, sewers, and water mains.

3.3.3 Compliance with Current Service Level Requirements

An existing sewer or water main may not meet current service level requirements. In these cases, it is not practical to rehabilitate the pipe, and replacement is necessary. The timing for replacement of non-standard components will depend on available funding and whether the non-standard component poses a major risk to the municipality. Ideally, non-standard sewers and water mains should be considered for replacement when the road is reconstructed to minimize costs, and disruption to local traffic and residents.

A comprehensive renewal plan should also consider risk management issues as well as the possibility of implementing more stringent regulations.

3.3.4 Technology tools

Condition rating systems may be classified as proprietary, non-proprietary, or those developed in-house.

Systems Developed In-House
These systems are designed to make use of existing data and reflect the specific needs of a municipality. In-house systems are best suited for assessment of systems when only a few parameters are considered. These systems are usually limited in terms of the sophistication of the rating system, the graphical user interface, and the data standards. It is difficult to compare the condition ratings generated using an in-house system with the ratings generated using other systems. Nevertheless, in-house systems are often used as a stepping stone toward more sophisticated systems if such is required.

Proprietary Systems
Several proprietary systems are available for rating the condition of roads, sewers, and water mains. The sophistication and cost of these systems varies over a wide range. Some can be customized to better reflect the needs of a municipality. Municipalities should carefully review their current and future information technology (IT) needs before selecting a proprietary system. In some cases, the condition rating system is an add-on module to a maintenance management system. The selection of a proprietary system should be based on a review of cost for software and upgrades, as well as other factors such as technical support, vendor's track record, and cost for customization.

Non-Proprietary Systems
Several agencies and organizations have developed condition rating systems that reflect the experience of many experts. Some provincial transportation departments have developed condition rating systems for roads, and the American Public Works Association (APWA) has developed a system (known as Paver) that has become a standard condition rating system for roads. Similarly, the Water Research Centre (WRc) in the United Kingdom and the U.S. Environmental Protection Agency (EPA) have developed condition rating systems for sewers. Currently, there is no Canadian standard for condition rating of water mains.

3.4 Task 4 — Performance Evaluation

Once the condition of the road, sewer, and water systems has been quantified, a performance evaluation should be conducted for each system to project the investment required over the next 10 to 20 years.

The cost to renew the system components that are in poor condition (i.e., those that exceed a threshold) can be estimated. Consequently, the time frame for renewal of these components depends on the funding available each year. Several scenarios can be considered to evaluate the trade-offs between the level of service (i.e., the condition rating), the annual investment, and the time frame for renewal of the components that are in poor condition.

Renewal plans that are developed using this network-level evaluation should be checked using a top-down approach to ensure the investment will be sufficient to sustain the systems over the long term. The long-term average annual renewal cost for a system can be estimated using the top-down approach by dividing the total replacement cost for a system by its estimated life expectancy.

If sufficient information were available to estimate the deterioration rate for each system component, then it would be possible to refine the projected renewal needs. In any event, the performance evaluation should be updated periodically to reflect current conditions.

More sophisticated performance appraisal systems include an assessment of the probability of the individual component reaching its intended service life.

3.5 Task 5 — Rehabilitation/ Replacement Plan

Once it has been established that a system component should be rehabilitated or replaced, an economic analysis should be used to select the most cost-effective method of renewal. An economic analysis typically compares the renewal alternatives in terms of their present worth.[4]

The following list describes some examples where an economic analysis should be used.

- Is it more cost effective to replace a water main rather than continue to repair it?
- Is it more cost effective to replace a sewer rather than complete several spot repairs?
- Is it more cost effective to rehabilitate a sewer or water main (to extend its service life) rather than replace it now?
- Is it more cost effective to overlay a road to extend its service life rather than reconstruct it now?
- Is it more cost effective to replace a sewer or water main in conjunction with a planned road reconstruction or defer the replacement of the sewer or water main as long as possible?

An economic analysis should account for intended and unintended socio-economic impacts (e.g., disruption to traffic, business activity and residents). Several sources, including the USDOT (1997) and the AwwaRF (2002) identify a method for quantifying socio-economic impacts.

InfraGuide has published two documents that summarize the best practice for selecting technologies for rehabilitation and replacement of sewers and water mains (NGSMI, 2003a,b). Similarly, the *Pavement Design and Management Guide* (TAC, 1997) outlines an approach for optimizing investment in roads.

The long-term average annual renewal cost for a system can be estimated using the top-down approach by dividing the total replacement cost for a system by its estimated life expectancy.

4. Present worth analysis is a technique used to compare alternative schemes that have different costs over a certain planning period. The present worth represents the current investment that would have to be made at a specific discount (or interest) rate to pay for the initial and future cost of the works.

The selection of the preferred renewal strategy for a component should not be based strictly on the economic analysis. The renewal plan should also account for other factors, such as risk, growth needs, environmental impacts and changing regulations and policies, as well as emerging technologies.

To maximize social and economic benefits, infrastructure needs should be examined to identify areas where integrated renewal activities could be concentrated:

- geographic areas with significant renewal needs could result in neighbourhood renewal programs; and
- links requiring renewal work for several infrastructure elements could result in corridor upgrades.

Ideally, municipalities should use an integrated decision support system to facilitate the renewal planning of road, sewer, and water systems. Currently, there are only a few proprietary systems available in Canada.

4. Applications and Limitations

4.1 Applications

All municipalities across Canada should implement an integrated approach to assessment and evaluation of municipal road, sewer, and water systems. The practices must be tailored to each municipality to reflect the size and age (i.e., condition) of the systems.

An integrated approach is particularly important for those municipalities that have a significant backlog of renewal work to be completed. Furthermore, an integrated renewal plan is critical for those municipalities expecting a decline in population and revenue base. For those municipalities that are not experiencing significant problems, an integrated renewal plan should identify opportunities for improving the management of their systems.

All municipalities should recognize that integrated planning of the renewal needs for road, sewer, and water systems is an ongoing process of continuous improvement and not simply a one-time event. It might take several years to compile detailed inventories and inspections of the infrastructure. However, during this period, systems will likely be expanded, some elements will be replaced, and the other elements will have deteriorated.

The renewal plans should be updated every year or so to reflect current information. Over time, as more information becomes available, the renewal plans will become more refined and better integrated.

Municipalities should develop a plan for integrated assessment and evaluation of their infrastructure. This plan should identify both short- and long-term goals. The short-term plan should recognize the realities of the municipality's current resources whereas the long-term plan should strive for a fully integrated renewal plan.

4.2 Limitations

Municipalities may be challenged to complete an integrated assessment and evaluation of their road, sewer, and water systems due to the lack of data, tools, resources, and a standard approach. Ongoing education of all stakeholders is necessary to develop and maintain an integrated renewal plan. Municipalities should strive to maintain an adequate complement of qualified and highly motivated staff to manage their systems.

All municipalities should recognize that integrated planning of the renewal needs for road, sewer, and water systems is an ongoing process of continuous improvement and not simply a one-time event.

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 spending and disruptions to confirm that the integrated approach is effective. Tracking should provide evidence that there are sufficient resources to manage unplanned work and that planned renewal activities are more cost effective. It is commonly accepted that preventive maintenance of municipal infrastructure is generally more cost effective than reactive maintenance.
- Develop a plan to compile the inventory and conduct the investigations. This plan should outline a schedule and budget for completion of these activities. Review these activities periodically to ensure compliance with the plan.
- Conduct pilot studies to confirm the approach to the data collection and inspection activities as well as to assess the effectiveness of the renewal technologies.
- Update the performance evaluation and renewal plan every five to ten years to reflect the current conditions as well as account for the effectiveness of the various renewal technologies.
- Track and compare the planned versus actual life cycles of the various infrastructure elements. This provides useful data, which either validates the assumptions made or provides more accurate information for input into an updated assessment. It may also provide information to affect change in design and construction practices, which ultimately result in improved infrastructure life cycles.

It is commonly accepted that preventive maintenance of municipal infrastructure is generally more cost effective than reactive maintenance.

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Notes