Potable Water

Developing a Water Distribution System Renewal Plan

This document is the sixth in a series of best practices related to the delivery of potable water to the public. For titles of other best practices in this and other series, please refer to *www.infraguide.ca.*

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Canada

Developing a Water Distribution System Renewal Plan

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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 (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

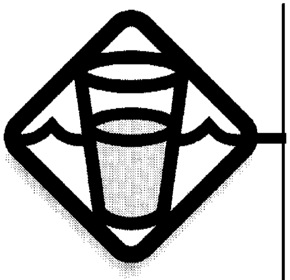
InfraGuide's creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country. 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



Potable Water

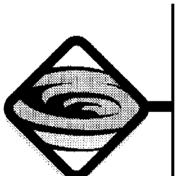
In keeping with the adage “out of sight, out of mind”, the water distribution system has been neglected in many municipalities. Potable water best practices address various approaches to enhance a municipality’s or water utility’s ability to manage drinking water delivery in a way that ensures public health and safety at best value and on a sustainable basis. The up-to-date technical approaches and practices set out on key priority issues will assist municipalities and utilities in both decision making and best-in-class engineering and operational techniques. 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.

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.



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.

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.

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.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This document describes the best practice for developing a water distribution system renewal plan. It is based on a literature review, surveys of selected municipalities across Canada, and input from Canadian water distribution experts.

In the past, most Canadian municipalities focused on the capital works required to support population growth. However, in light of ageing infrastructure, public demands for a higher level of service and accountability, as well as more stringent legislation and competition for finite financial resources, municipalities are now motivated to develop a plan for renewal of their water distribution systems. Such a plan must address not only the ongoing renewal of infrastructure that has reached the end of its useful life, but also upgrades to meet more demanding standards.

Two complementary approaches to the development of a water distribution system renewal plan — top-down and bottom-up — are reviewed. The top-down approach is used for strategic long-term planning of policies and programs whereas the bottom-up approach is used for short-term capital planning of projects.

Top-Down Approach

Using the top-down approach, the projected renewal costs for a group of assets can be estimated using replacement cost and assumed life expectancy. The total replacement cost for a water system (including water supply, treatment, storage, distribution and pumping facilities) is typically $3,000 to $4,000 per capita. The long-term average annual cost for renewal of a water distribution system is typically one to two percent of the total replacement cost for the system (AwwaRF, 2001). This assumes that the average life expectancy of the water system components is 50 to 100 years.

Bottom-Up Approach

The bottom-up approach requires a detailed inventory of the assets including their current condition, deterioration rate, and criticality. A comprehensive renewal plan will address the following needs.

- Consider replacement of water mains and services that do not conform to current standards in terms of main size, material, depth of cover as well as water service material, size and depth of cover.
- Replace or structurally rehabilitate mains that have high break rates or leaky joints.
- Rehabilitate unlined iron mains with non-structural linings if they have not experienced a high break rate but their hydraulic capacity and/or water quality is significantly impacted by deterioration.
- Replace mains that are too small (even if they were cleaned and lined) to supply required flows at adequate pressures.
- Replace valves and hydrants that are non-standard, inoperable, or leaking.

In most cases, hydrants, valves, and water services are replaced when the mains are replaced. However, in cases where a water main is still in good condition, it might be necessary to replace some of the appurtenances.

Cost-Benefit Analyses

If the rate of deterioration can be estimated, then it is possible to predict the timing for renewal of water mains using a cost-benefit analysis. The timing for renewal of water mains that experience high break rates, leaky joints, and reduced hydraulic capacity is primarily dictated by economics. However, the timing for renewal of water mains that do not conform to current design standards or impair water quality is dictated by the severity of the problem, risk, and the available funding.

Such a plan must address not only the ongoing renewal of infrastructure that has reached the end of its useful life, but also upgrades to meet more demanding standards.

Condition Rating Systems

Once the need for renewal of a water main has been established, municipalities should use a condition rating system to assist with prioritizing their renewal program. The factors included in a condition rating system will vary among municipalities depending on the size of the municipality, the available data and specific conditions within each system. Large municipalities should consider the need for a computerized decision support system to facilitate renewal planning.

Municipalities should adopt the principles of full cost recovery, user pay, and pay as you go for renewal of their distribution systems.

All municipalities should coordinate the renewal of their water distribution systems with their road rehabilitation/reconstruction program and other upgrades that might be required for new development/redevelopment in order to minimize costs and disruption.

Financial Plan

A water distribution system renewal plan should include a financial plan to ensure adequate funding is available. Municipalities should adopt the principles of full cost recovery, user pay, and pay as you go for renewal of their distribution systems. An asset condition index can be used to identify the user rates required to maintain a distribution system in good condition.

Applications and Limitations

All municipalities should project their long-term renewal costs using the top-down approach to facilitate long-term financial planning. In addition, municipalities should develop a renewal plan using a bottom-up approach based on the principles of risk management. The development of a comprehensive renewal plan using a bottom-up approach will require investment of time and money.

Evaluation

A renewal program should be reviewed every five to ten years to reflect the current condition of the system as well as the effectiveness of various renewal technologies. Municipalities should track water main break rates, water quality problems, fire flow rates, and leakage rates to establish deterioration rates and the adequacy of the program.

The application of the top-down and bottom-up approaches to development of a water distribution system renewal plan is illustrated in appendices A and B, respectively.

1. General

1.1 Introduction

This document outlines the best practice for developing a water distribution system renewal plan. For the *National Guide to Sustainable Municipal Infrastructure* (InfraGuide), a best practice is defined as state-of-the-art methodologies and technologies for municipal infrastructure planning, design, construction, management, assessment, maintenance, and rehabilitation that consider local, economic, environmental, and social factors.

This best practice is based on a review of existing literature, a survey of selected municipalities across Canada, and input from water distribution experts across Canada.

1.2 Purpose and Scope

This document outlines the best practice for developing a renewal plan for water distribution mains and appurtenances (i.e., hydrants, valves, and water services). The development of a renewal plan for water supply, wells, treatment, pumping, and storage facilities is not addressed in this document.

It should be noted that there is a fundamental difference between planning the renewal of water distribution mains and transmission mains.[1] The primary objective of a renewal plan for distribution mains is to minimize their life cycle costs, while the primary objective of a renewal plan for transmission mains is to minimize failures.[2] In some cases, it is not practical to monitor the condition of transmission mains and accurately predict the timing for their renewal. Therefore, it is often necessary to provide some redundancy in a water transmission system to allow the critical components to be taken out of service for maintenance and repairs.

The best practice presented in this document focuses on water distribution systems. Although most of the concepts are also applicable to water transmission systems, the renewal planning for transmission systems must be more proactive in light of the greater consequences arising from their failure.

In this document, renewal of water distribution systems includes both rehabilitation and replacement of the system components. Although it should be recognized that proper maintenance should extend the life of a distribution system, this document does not specifically address maintenance practices.

Although most of the concepts are also applicable to water transmission systems, the renewal planning for transmission systems must be more proactive in light of the greater consequences arising from their failure.

1. Distribution mains meet local needs whereas transmission mains are required to transmit water from supply sources to storage, distribution mains and possibly booster pumping stations. The size threshold between the categories is not absolute but does correlate somewhat with the size of the system.
2. There is essentially no difference in the objectives of a renewal plan for distribution and transmission mains if a risk management philosophy is adopted; the objective would be to minimize risks. A municipality may be prepared to accept more breaks on distribution mains, because the consequences may be limited to the costs of repairs. On the other hand, it may not be prepared to accept breaks on transmission mains, because of the significant consequences.

The best practice is based on a five-step process that is applicable to roads, water distribution, sewage collection, and storm drainage systems recognizing that decisions made on any one of these systems could impact decisions to be made on the other systems.

1.3 How to Use This Document

Section 2 presents some reasons why it is prudent to develop a water distribution system renewal plan as well as the potential risks associated with implementing this best practice. Section 3 presents two complementary approaches for development of a water distribution system renewal plan. Two examples are provided in the appendices to illustrate these approaches. Section 4 presents some of the applications and limitations of this best practice. Finally, Section 5 describes several measures that can be used to evaluate the effectiveness of this best practice in your municipality. References are provided throughout this document for additional information on specific issues.

Readers should be aware that prior to the release of this document, InfraGuide already published several other best practices that are relevant to water distribution system renewal planning, including the following.

- **Best Practices for Utility-Based Data —** This document presents a foundation and guide for Canadian municipalities that wish to begin the process of identifying, storing, and managing utility-based information and data.
- **Deterioration and Inspection of Water Distribution Systems** — This document outlines the best practice for inspecting water distribution systems to detect any system deterioration. The deterioration processes for distribution systems and the factors that can affect the rate of deterioration are also described.
- **Selection of Technologies for the Rehabilitation or Replacement of Sections of a Water Distribution System** — This document outlines the best practice for selection of available technologies for the rehabilitation or replacement of water mains and appurtenances.
- **Coordinating Infrastructure Works —** Five service delivery areas are addressed in this best practice, including coordination practices, corridor upgrades, restrictive practices, approval processes/better communication, and technical considerations.
- **An Integrated Approach to Assessment and Evaluation of Municipal Road, Sewer and Water Networks** — This document outlines the best practice for integrated evaluation and assessment of municipal infrastructure at a network level. The best practice is based on a five-step process that is applicable to roads, water distribution, sewage collection, and storm drainage systems recognizing that decisions made on any one of these systems could impact decisions to be made on the other systems.
- **Planning and Defining Municipal Infrastructure Needs —** This document outlines the best practice for planning and defining municipal infrastructure needs using five methods, namely, strategic planning, information management, building public support and acceptance, exploring new and innovative methods for continuous improvement, and prioritization models.

Additional best practices related to this subject may also be available from the Guide's Web site <*www.infraguide.ca*>.

1.4 Glossary

Asset condition index — Equal to the infrastructure deficit divided by the total replacement cost for an asset or group of assets. An asset is deemed to be in good condition if its asset condition index (ACI) is less than five percent, in fair condition if its ACI is five to ten percent, and in poor condition if its ACI is greater than ten percent.

Bottom-up approach — A detailed approach for developing a renewal plan in which the timing for renewal of an asset is based on its condition or performance.

Cathodic protection — A system for reducing the rate of corrosion of a metal by making the metal a cathode. This is done by inducing a small direct current into the metal to be protected by attaching a sacrificial anode or using an impressed current system. "Comprehensive" cathodic protection usually refers to the installation of anodes at regular intervals along an existing metallic water main (in corrosive soil). "Hot spot" cathodic protection usually refers to the installation of an anode on existing metallic water mains and/or appurtenances (in corrosive soil) when the water main or appurtenance is exposed for repair.

Infrastructure deficit — Equal to the difference between the needed investment and the actual investment in renewal; also referred to as the backlog in renewal work.

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

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.

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

Top-down approach — A simplified approach for developing a renewal plan in which the projected renewal costs for a group of assets can be estimated using their replacement cost and theoretical life expectancy.

2. Rationale

2.1 Background

In the past, most Canadian municipalities focused on the capital works required to support population growth with little consideration of the need to renew their distribution system. However, in recent years, there has been a growing need for municipalities to develop a water distribution system renewal plan, because of an ageing infrastructure, higher level of service, more stringent water quality legislation, shrinking financial resources, and increased accountability.

2.1.1 Ageing Infrastructure

Some municipal water systems in Canada were installed over 100 years ago. Although some components of these original systems have already been replaced, there are still many of these original components still in service that should be replaced. Furthermore, most Canadian municipalities experienced significant population growth (post World War II) (Figure 2–1). The infrastructure constructed during the 1950s is now over 50 years old and, in many cases, is due for renewal in the near future. The investment in renewal will have to increase significantly when the infrastructure that was constructed in the 1950s has to be renewed.

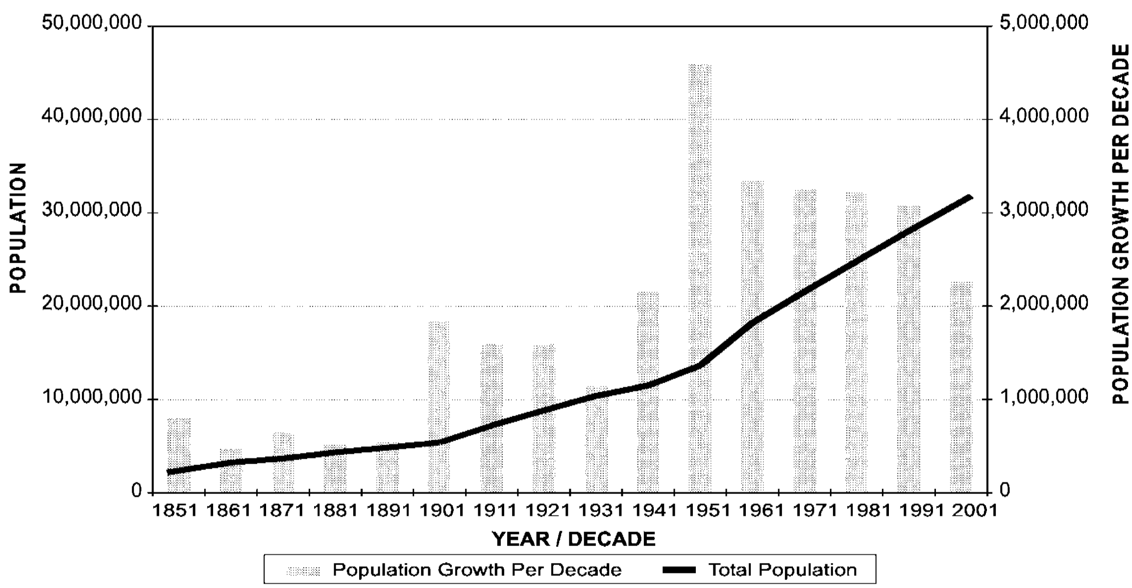
2.1.2 Higher Level of Service

The level of service expected by the Canadian public has increased significantly over the years. The public now expects a continuous supply of safe and aesthetically acceptable water at an adequate and stable pressure. There is little tolerance for even occasional

Figure 2–1
Population growth in Canada

The public now expects a continuous supply of safe and aesthetically acceptable water at an adequate and stable pressure.

Figure 2–1: Population growth in Canada



A comprehensive water distribution system renewal plan provides a systematic method to address technical, economic, and business issues, such as level of service, cost of service, and risk management.

disruptions to the water supply. Furthermore, water demands and fire flow requirements have increased over the years resulting in the need for larger water mains and services in some cases. To maintain a high level of service, it will be necessary for municipalities to develop and implement a renewal plan for their distribution system.

2.1.3 More Stringent Water Quality Legislation

It is now widely recognized and accepted in the water industry that water quality may deteriorate as it travels through a distribution system. In many cases, renewal of a water distribution system is often necessary to meet the regulatory requirements for water quality.

2.1.4 Shrinking Financial Resources

In the past, many Canadian municipalities relied on grants from provincial and federal governments to fund major infrastructure renewal projects. However, in recent years, there has been a significant reduction in senior government grants for renewal of water distribution systems. This reduction is forcing municipalities to move toward full cost recovery for their water distribution systems which, in turn, promotes the need for a financial plan to meet renewal needs.

2.1.5 Increased Accountability

In light of the demands for a higher level of service and rising costs, the Canadian public is now demanding a more transparent decision-making process. In 1999, the Governmental Accounting Standards Board (GASB) in the United States introduced a requirement, known as GASB34, for state and local governments to account for their capital infrastructure assets and submit an annual report. There are similar requirements in other countries, including the United Kingdom and Australia. In 2002, the Ontario government passed Bill 175 *(The Sustainable Water and Sewage Systems Act)*. This Act makes it mandatory for Ontario municipalities to assess and report on the full costs of providing water and sewage services, and then to prepare and implement plans for recovering those costs. Every municipality in Ontario will have to develop a water distribution system renewal plan to quantify the full costs of providing water. Similar legislation may be enacted in other parts of Canada over time.

A comprehensive water distribution system renewal plan provides a systematic method to address technical, economic, and business issues, such as level of service, cost of service, and risk management. A water distribution system renewal plan should have the following goals:

- Protect public health.
- Provide a high level of service.
- Minimize life cycle costs.
- Minimize risks.
- Ensure the water distribution system is sustainable.
- Ensure renewal funding is sufficient and efficiently spent.

2.2 Benefits

The following list summarizes some reasons why it is beneficial to develop a water distribution system renewal plan.

- Municipalities will be able to manage the renewal of their systems in a proactive manner, thereby minimizing the costs for reactive measures and the risks associated with socio-economic impacts. In other words, a proactive approach should minimize life cycle costs and risks.
- Municipalities will be able to quantify the life cycle costs for their systems. This will improve long-range planning (both technical and financial) and risk management. Long-range planning is particularly important for municipalities with declining populations (i.e., revenue base).
- A comprehensive renewal plan will facilitate transparent decision making and provide a measure of accountability to the customers.
- A comprehensive renewal plan should promote full cost recovery through user rates which, in turn, will ensure stable and adequate funding and promote efficient use of resources.
- A comprehensive renewal plan should enable integrated planning of municipal infrastructure (i.e., water distribution systems, sewage collection systems, storm drainage systems, roads, sidewalks and other utilities) to minimize total costs and disruptions to residents and businesses.
- A plan is a valuable tool for educating, explaining, and demonstrating the level of investment to the politicians charged with the responsibility of approving water system budgets and to the public who will be "paying the bill."

2.3 Risks

There are potential risks in following this best practice.

- Additional resources (i.e., staff and equipment) will be required to develop and maintain a renewal plan.
- There could be a lack of support for a renewal plan from stakeholders (e.g., operators, politicians, and the public) for those systems that have not yet experienced significant problems or if water rates have to be increased to pay for it.
- A renewal plan may not be credible if data are lacking or if it is not based on sound engineering principles.
- Increases in water rates to support a renewal plan could result in a decrease in water consumption and, if not accounted for in advance, revenue deficiencies.

In other words, a proactive approach should minimize life cycle costs and risks.

3. Work Description

3.1 What Should Be Done

The framework for a water distribution system renewal plan can be described in terms of seven questions.

1. What do you have?
2. What is it worth?
3. What is its condition?
4. What needs to be done?
5. When do you need to do it?
6. How much will it cost?
7. How will you pay for it?

There are two complementary approaches to the development of a water distribution system renewal plan: top-down and bottom-up. These two approaches differ in the detail needed for preparation and how the results can be applied. The top-down approach uses more readily available "system" data and is used for strategic long-term planning of policies and programs, whereas the bottom-up approach looks at individual assets and is used for short-term capital planning of projects. Short-term planning typically covers a period of less than 10 years and long-term planning typically covers a period of 10 to 100 years.

Using the top-down approach, the projected renewal costs for a group of assets can be estimated using replacement cost and assumed life expectancy. The top-down approach is consistent with the accrual accounting method common in the business world and regulated utilities in which capital cost expenses include depreciating the value of an asset over its theoretical useful life.

The bottom-up approach requires a detailed inventory of the assets including the current condition and deterioration rate for each asset. Although not constrained by accounting method, the bottom-up approach lends itself to the cash accounting method, which predominates in Canadian water utilities. With the cash accounting method, net capital outlays are expensed on an annual basis. To confirm that the investment in renewal is sufficient to sustain the water distribution system over the long term, a condition assessment is required on a regular basis.

The magnitude of projected costs for renewal of a water distribution system over the long term can be quickly determined using the top-down approach. On the other hand, it may take several years to develop a comprehensive annual renewal plan for large systems using the bottom-up approach in light of the fact that a detailed inventory and condition assessment is required. Over time, the results of the bottom-up approach can be used to refine the top-down approach.

To confirm that the investment in renewal is sufficient to sustain the water distribution system over the long term, a condition assessment is required on a regular basis.

3.2 How to Do the Work

3.2.1 Top-Down Approach

This section describes the top-down approach to development of a water distribution system renewal plan. An application of the top-down approach is demonstrated in Appendix A.

1. What do you have?

Even though a municipality may not have a detailed inventory of its water distribution system, it should be possible to estimate the total length of water main and the number of appurtenances using the following assumptions[3]:

- total length of water main — typically 4 m to 6 m per capita;
- total number of hydrants — typically one hydrant for every 150 m to 250 m of water main;
- total number of valves — typically one valve for every 100 m to 150 m of water main;
- total number of water services — typically 0.2 to 0.3 services per capita; and
- total number of water meters — typically equal to the total number of water services.

3. Based on studies conducted by R.V. Anderson Associates Limited for seven Canadian municipalities with populations ranging from 50,000 to 500,000.

To compile a complete inventory of a water distribution system, municipalities should also compile the rated capacity for each water treatment plant, well, pumping station, and storage facility. This information is usually available from design reports, operations and maintenance manuals, and permits.

2. What is it worth?

Several methods can be used to quantify the value of a water distribution system (e.g., original cost, depreciated cost, replacement cost). With the top-down of water distribution system components can be estimated using input from other municipalities, local contractors, recent construction contracts, or technical reports (AwwaRF, 2001; NRC, 2002). The total replacement cost for a water distribution system (including supply, treatment, distribution, storage and pumping) is typically $3,000 to $4,000 per capita.[4]

3. What is its condition?

For the top-down approach, the age of the distribution system components is typically the most useful and simplest indicator of condition. It should be recognized that age is not always a good indicator of condition since many physical, environmental and operational factors can affect the condition of a watermain. (e.g. pipe material, lining, coating, wall thickness, soil type and characteristics). Ideally, the total length of water main in a system should be broken down into homogeneous groups (e.g., different combinations of pipe material and soil type) to account for the different life expectancies of the groups. It is important to note here that the more detailed bottom-up approach (covered under section 3.2.2) requires utilities to have more detailed data on their distribution system so that they can eliminate as much guess work out of their selection process.

It should also be noted that some rehabilitation technologies are only applicable to certain pipe materials. For example, non-structural linings are only applicable to unlined iron and steel mains.

Cathodic protection is applicable to iron mains, steel mains, concrete pressure pipe, and metallic appurtenances (e.g., valves, hydrants, copper services) that are installed in corrosive soil and have not been protected by other means (e.g., pipe coatings, polyethylene encasement). Cathodic protection might also be applicable to metallic appurtenances on non-metallic mains (e.g., PVC and HDPE).

If the year of construction for each water distribution system component is not readily available, it would be reasonable to assume the distribution system expanded at about the same rate as the population growth in the municipality. Historical population data can be obtained from municipal records and Statistics Canada. The first year of municipal water service should also be available from municipal archives. The year of construction of buildings can also be used to estimate the age of the water mains along a street.

4. What needs to be done?

Water mains can be renewed by various rehabilitation or replacement technologies. (Refer to InfraGuide's *Selection of Technologies for the Rehabilitation or Replacement of Sections of a Water Distribution System*.)

Deteriorated mains can be replaced using open trench or trenchless techniques. Mains can also be rehabilitated with structural linings if replacement is too costly or disruptive.

Internal corrosion of unlined iron water mains can cause water quality problems and possible reductions in hydraulic capacity. These mains can be rehabilitated by non-structural lining if they have not experienced high break rates. The feasibility of lining and/or cathodically protecting a main depends on its structural condition and other local factors.

4. Based on studies conducted by R.V. Anderson Associates Limited for seven Canadian municipalities with populations ranging from 50,000 to 500,000.

Hydrants, valves, and water services are normally replaced within the road allowance when the mains are replaced or rehabilitated. However, in some cases, it may be necessary to replace these appurtenances before the main is replaced. The life expectancy for hydrants, valves, and water services should be estimated based on local factors.

5. When do you need to do it?

The service life of water distribution system components varies depending on several factors, such as construction materials, quality of construction, soil conditions, water quality, and level of maintenance. For the purposes of the top-down approach, a service life can be assumed for each system component based on industry averages. As a result, the remaining life of each component can be estimated by subtracting the age of the component from its assumed service life.

To quantify the life cycle costs for a water distribution system, it is necessary to project costs for each component over at least one life cycle. Since some components could have a life cycle of several decades, costs are typically projected over a 100-year planning horizon. Furthermore, life cycle costs are typically projected in 10-year increments commensurate with the accuracy of the analysis.

The projected replacement costs can be calculated and graphed using an electronic spreadsheet. A computer model can also be used to project replacement costs. Examples include KANEW (AwwaRF, 1999), WARP (NRC, 2001a), and Nessie (AwwaRF, 2001).

6. How much will it cost?

The projected costs for replacement of a water distribution system can be estimated by summing the projected replacement cost for each system component. The projected costs for rehabilitation of iron water mains can be estimated based on the total length of iron mains to be rehabilitated and unit costs for non-structural lining. The timeframe for rehabilitation of iron water mains will depend on available funding and the urgency of the needs.

The long-term average annual cost for renewal of a water distribution system is typically one to two percent of the total replacement cost (AwwaRF, 2001). This assumes the average life expectancy of the water system components is 50 to 100 years. Since most water systems in Canada experienced a significant growth rate in the 1950s and 1960s, it is expected that renewal costs will increase significantly over the next few years as the components that were installed during this period reach the end of their service life. The resulting "hump" in costs, when graphed is sometimes referred to as the "Nessie Curve" (AwwaRF, 2001).

7. How will you pay for it?

An AwwaRF report (2001) states:

> The challenge of funding infrastructure renewal is not really a financial challenge so much as it is a planning challenge. Raising cash for operations and capital for reinvestment are straightforward tasks. Knowing how much reinvestment to make and at what rate is the hard part. Without a confident means of knowing that the rate of replacement has been optimized to mitigate the impact of demographic echoes on utility finances, a utility cannot offer the financial markets complete assurance that this risk is being effectively managed.

Municipalities should adopt the following principles when developing their water distribution system renewal plan.

- **Full cost recovery** — all operating, maintenance, and capital renewal costs should be recovered through water rates.
- **User pay approach** — directly charge water customers in proportion to the cost of providing water service.
- **Pay as you go approach** — investment in renewal of a water distribution system will have to be ongoing and, therefore, current revenue sources should be sufficient to cover this ongoing cost. However, debenture financing is commonly needed for large one-time capital expenditures (e.g., water treatment plant expansion) or large emergency requirements.

The challenge of funding infrastructure renewal is not really a financial challenge so much as it is a planning challenge.

The bottom-up approach should incorporate risk management principles where the probability of failure and the consequences of failure are both considered in the decision-making process.

It is important to project renewal costs over at least one life cycle for each component so a financial plan can be developed that anticipates any projected increases in costs.

One technique to assess the adequacy of funding for renewal of a water distribution system is referred to as the asset condition index (ACI).[5] The ACI can be calculated in any given year by dividing the infrastructure deficit by the asset value. Infrastructure deficit is the difference between the needed investment and the actual investment, which can accumulate over time. A system is considered to be in good condition if the ACI is less than five percent; in fair condition if the ACI is between five and ten percent, and in poor condition if the ACI is greater than ten percent.

Several scenarios should be analyzed to identify the rate increases that would be required to maintain the ACI below ten percent over the long term. It should be noted that small increases in water rates over the short term could significantly increase revenues in the longer term due to the compounding effect. In some cases, it is prudent to establish a reserve or depreciation fund so funds can be set aside for significant increases in investment that may be required in the future.

Another technique would be to establish a level of service standard and estimate the level of funding that would be required to maintain the system at the established level of service standard. The level of service standard may vary with the criticality factor if using a risk management approach (e.g., five breaks/km/year for residential mains with a low criticality factor vs. one break/km/year for mains that are more critical).

3.2.2 Bottom-Up Approach

Unlike the top-down approach that focuses on the long-term costs for renewal of a *group of assets,* the bottom-up approach attempts to quantify the short-term costs for renewal of *each component* in a distribution system. The bottom-up approach follows the same framework as outlined above for the top-down approach. An application of the bottom-up approach is demonstrated in Appendix B.

The bottom-up approach should incorporate risk management principles where the probability of failure and the consequences of failure are both considered in the decision-making process. In the past, many municipalities have been prioritizing water distribution system renewal plans to minimize capital costs without considering socio-economic costs, such as traffic impacts, impacts on sensitive customers (e.g., hospitals), property damage, damage to other infrastructure, and loss of economic activity.

Adopting a risk management approach would improve the level of service provided to customers as well as minimize life cycle costs and risks. The AwwaRF has published a report (2002) on the costs of infrastructure failure, which states:

> In developing maintenance plans and making repair-replace-refurbish decisions, there is a choice to make between the development of lower cost water systems with periodic failure rates that impose social costs on customers and systems that minimize failure at the expense of higher operating costs for customers (page 1).

This AwwaRF report reviewed several methods developed by other industries for estimating social costs, including:

- customer outage;
- traffic disruption;
- flood damage; and
- direct and indirect economic loss.

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5. The ACI was developed by the National Association of College and University Business Officers to quantify the significance of deferred maintenance for building portfolios

1. What do you have?

The bottom-up approach requires a detailed inventory and condition assessment of each component. Table 3–1 summarizes some of the physical data that should be included in an inventory of water mains. All municipalities should compile the basic physical data. Municipalities should also consider the need to compile some of the other advanced physical data listed in Table 3–1 to facilitate the development of a renewal plan.

In light of the significant amount of data required to develop a comprehensive renewal plan, municipalities should compile the inventory in electronic databases together with an interface to a geographic information system (GIS). This inventory should be coordinated with other applications, such as a maintenance management system. InfraGuide has published a document entitled *Best Practices for Utility-Based Data* that describes a framework for managing information as well as the basic data elements.

2. What is it worth?

Ideally, the cost data incorporated into the bottom-up approach should be sufficiently accurate for capital budgeting purposes.

If the inventory is compiled in an electronic database, it is possible to develop "look-up tables" that include unit costs for replacement of water mains, valves, hydrants, and water services. It should be clearly indicated whether the unit costs include restoration, engineering, contingencies, and taxes.

The databases could also include cost multipliers to reflect the relative difficulty in constructing water mains based on location (e.g., local road, arterial road) or environmental conditions (e.g., high water table, difficult soil/rock conditions). The databases could also include an estimate of the potential cost savings if a water main is replaced when the road or a sewer is reconstructed.

Table 3–1: Water Distribution System Condition/Performance Indicators

Factor	Basic	Advanced	
Physical	Pipe length Pipe diameter Pipe material Year of construction	Pipe wall thickness Pipe coating Pipe manufacturer Cathodic protection/year Polyethylene encasement	Water service material Water service diameter Density of water services Water table depth Road classification
Structural	Break rate	Break trends Pit depth	Soil type Soil resistivity
Hydraulic	Fire flow Internal water pressure	C factor Pressure drop when hydrant is open Flow velocity/head loss during high demand	
Water quality	Number of complaints Pipe lining/year Chlorine residual Turbidity	Iron concentration Lead concentration	
Leakage	Number of leaks Leakage volume	Type of joint IWA Infrastructure Leakage Index	
Conformance to current design standards	Pipe material Separation from sewers	Pipe depth	
Importance/hazard potential/consequence of failure	Pipe diameter Pipe material	Impacts of service disruption Public safety Traffic disruption Potential property damage Repair cost	

Municipalities with high water main break rates should consider the need for a more detailed analysis of water main deterioration using statistical or physical models.

3. What is its condition?

Deterioration of water distribution systems can be described in terms of four general categories: structural, hydraulic capacity, leakage, and water quality. Some physical, environmental, and operational factors that contribute to water system deterioration are identified in another best practice document, *Deterioration and Inspection of Water Distribution Systems.*

The best practice for investigating the condition of water distribution systems is based on a two-phase approach. The first phase involves a preliminary assessment of the potential problems using data that should be collected by every municipality on a routine basis. The second phase involves a more detailed investigation of specific problems based on findings of the preliminary assessment. Table 3–1 lists some conditions for structural, hydraulic capacity, leakage, and water quality performance indicators.

Municipalities with high water main break rates should consider the need for a more detailed analysis of water main deterioration using statistical or physical models.

Statistical Models

The National Research Council (NRC) has conducted a comprehensive review of statistical models that have been developed to quantify the structural deterioration of water mains based on historical performance data (Kleiner and Rajani, 2001). The statistical models have been classified into two groups: deterministic and probabilistic models. Deterministic models predict breakage rates for homogenous groups of water mains based on pipe age and breakage history. Probabilistic models can account for other variables that might impact breakage rates (e.g., soil type, operating pressure, pipe vintage, number of previous breaks).

Physical Models

The NRC has also conducted a comprehensive review of physical models that have been developed to quantify the structural deterioration of water mains (Rajani and Kleiner, 2001). Physical models have been classified into two groups: deterministic and probabilistic models. These models attempt to quantify factors, such as corrosion, frost load, pipe–soil interaction, residual structural resistance, and temperature effects.

The AwwaRF has published a report (2002b) that describes a mechanistic model that can be used to prioritize rehabilitation and replacement of cast iron mains. This model is made up of four modules:

- a pipe load module to estimate the maximum probable internal and external loads on a pipe and the resulting pipe stresses;
- a pipe deterioration module to estimate the depth of external corrosion and the theoretical remaining strength;
- a statistical correlation module to estimate the residual strength of the pipe as a function of remaining wall thickness; and
- a pipe break module to estimate the ratio (i.e., factor of safety) of residual pipe strength to maximum stress on a pipe.

The output can be used to develop a prioritized replacement plan by ranking pipes according to their safety factor.

In some cases, old water mains may not exhibit significant deterioration, but they are too small (e.g., less than 150 mm diameter) to supply current fire flow requirements or have inadequate cover and therefore, they should be considered for replacement.

Valves and hydrants have a renewal approach and life cycle that is different from mains. They should be routinely inspected and exercised to ensure they are accessible, operable, conform to current design standards, and are not leaking. Valves and hydrants that do not meet these requirements should be repaired or, if necessary, replaced.

Each component should be assigned a criticality factor that reflects the consequences of its failure. Criticality factors may consider traffic volumes, customer types, location (e.g., business district), hydraulic importance, road type (e.g., bridge), etc. A transmission main would have a higher criticality factor than a distribution main on a residential street.

4. What needs to be done?

Figure 3–1 illustrates a flow chart for selection of alternative water main renewal technologies. If a pipe does not conform to current design standards or is undersized, then it should be replaced and is not a candidate for rehabilitation. Similarly, if a main is in poor structural condition, then it is not a candidate for non-structural rehabilitation (i.e., cleaning and lining).

It is also apparent from Figure 3–1 that there are several alternative renewal technologies for each condition/performance indicator. A report (NGSMI, 2003) prepared for InfraGuide documents the best practice for selection of water distribution system renewal technologies. Similarly, the AwwaRF (2002a) has developed a decision support system to select the most appropriate renewal technology for water mains.

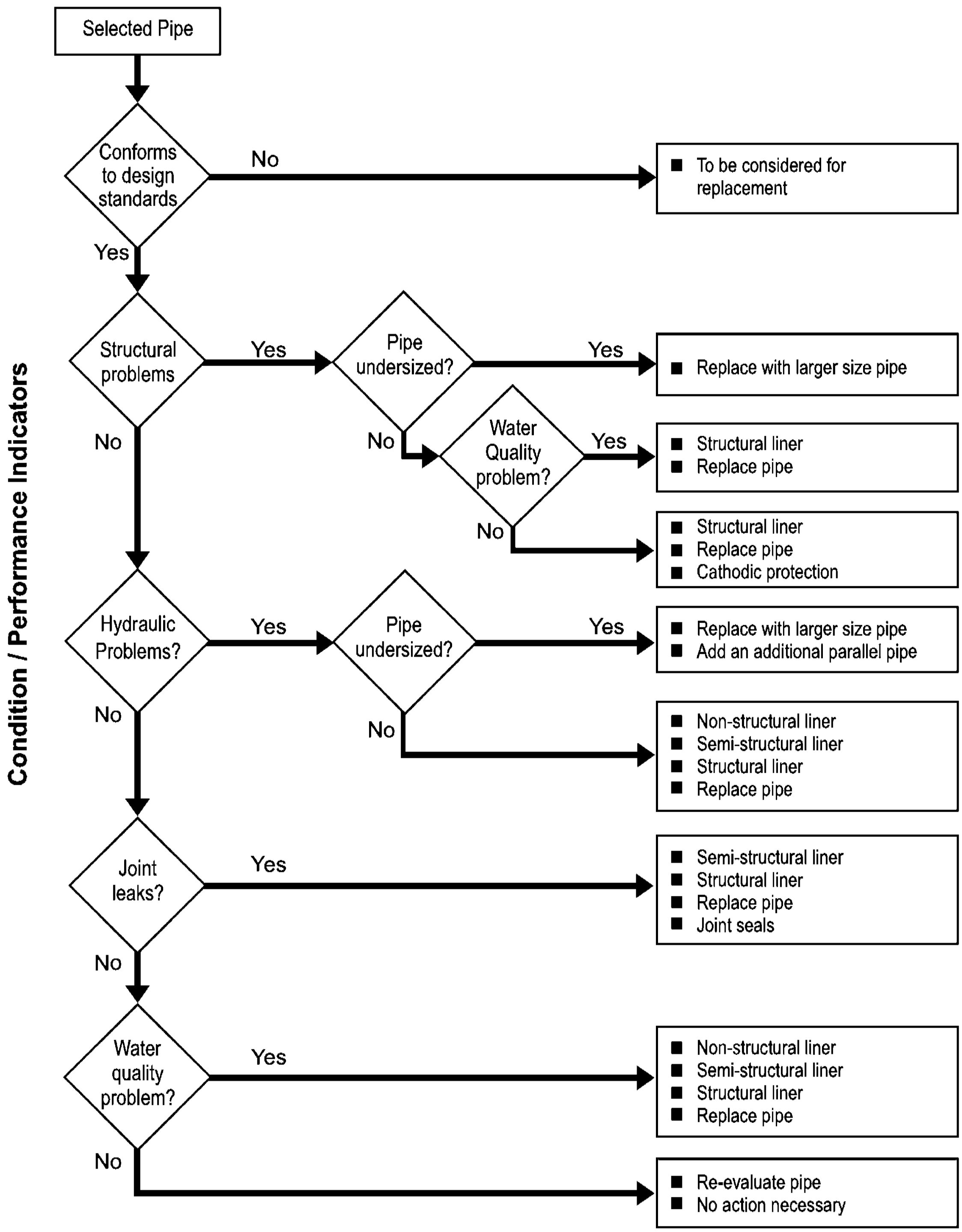
It should be noted that there might be several technically feasible renewal technologies for a section of water main. However, these alternative technologies may have different life expectancies. Therefore, the most cost-effective technology should be selected on the basis of a life cycle analysis that determines the lowest present worth.[6] The life cycle analysis should not only consider costs for infrastructure repair, rehabilitation, and replacement, but also socio-economic costs.

The life cycle analysis should not only consider costs for infrastructure repair, rehabilitation, and replacement, but also socio-economic costs.

6. 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.

Figure 3–1
Selection of alternative water main renewal technologies

Figure 3–1: Selection of alternative water main renewal technologies (Adapted from AwwaRF, 2002a)



A comprehensive water distribution plan will establish the following needs.

- Water mains and services that do not conform to current design standards in terms of pipe size and/or material, depth of cover as well as water service size, material and cover should be considered for replacement.
- Replace or structurally rehabilitate mains that have high break rates or leaky joints.
- Rehabilitate unlined iron mains with non-structural linings if they have not experienced a high break rate, but their hydraulic capacity and/or water quality is significantly affected by deterioration.
- Replace mains that are too small (even after being cleaned and lined) to supply the required flows at adequate pressures.
- Cathodically protect metallic water mains, fittings and appurtenances if they are installed in corrosive sols.
- Replace or rehabilitate highly critical mains before they fail.
- Repair or replace valves and hydrants that are non-standard, inoperable, or leaking.

Many factors will affect the selection of the most appropriate renewal technology for each section of water mains. It should be noted that some renewal technologies are not available locally. It should also be noted that due to the high mobilization costs of some rehabilitation technologies, they are only cost effective when a significant quantity of water main is to be rehabilitated.

5. When do you need to do it?

Cost–benefit analyses should be undertaken to determine the most efficient timing for the following.

- Is it more cost effective to replace or structurally rehabilitate a main rather than continue to repair it?
- If the soil is corrosive, is it cost effective to cathodically protect a metallic water main and/or other metallic components (e.g., valves, hydrants, fittings) to extend their life?
- Is it more cost effective to rehabilitate an unlined iron main rather than continue to pay higher pumping costs and/or construct additional mains to provide the required hydraulic capacity?
- Is it more cost effective to rehabilitate leaky joints in large diameter mains rather than continue to lose water?
- Is it more cost effective to coordinate the work with other projects (e.g., road reconstruction, sewer replacement) to achieve synergistic benefits?
- Socio-economic factors (criticality) and environmental factors need to be considered. If socio-economic factors are considered, it may be more economical to replace or rehabilitate a main before it ever breaks.

If the rate of deterioration can be estimated, then it is possible to predict the timing for renewal of water mains using a cost–benefit analysis. The timing for renewal of water mains that experience high break rates, leaky joints, and reduced hydraulic capacity is primarily dictated by economics. However, the timing for renewal of water mains that do not conform to current design standards or impair water quality is dictated by the severity of the problem and the available funding.

To minimize costs and disruption, the proposed water main renewal program should be coordinated with sewer and road reconstruction projects as well as upgrades that might be required for new development/redevelopment. In addition, the individual sections of water main to be renewed should be grouped according to geographic area to minimize cost and disruption.

In most cases, hydrants, valves, and water services are replaced when the mains are replaced. However, when a water main is still in good condition, it might be necessary to replace some appurtenances before replacing the water main.

Often, water plus sewer costs are in the same range as cable or satellite TV services, which many find affordable.

Once the need for renewal of a water main has been established, municipalities should use a condition rating system to assist with prioritizing a renewal program. Several factors can be used to quantify the condition or performance of a water main in terms of structural condition, hydraulic capacity, leakage, and water quality. The condition rating systems should also incorporate information on the importance and hazard potential of each water main.

The number of factors 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 within each system. Large municipalities should consider the need for a computerized decision support system to facilitate renewal planning.

6. How much will it cost?

The projected renewal costs for water distribution system components can be estimated using input from other municipalities, local contractors, recent construction contracts, and technical reports (AwwaRF, 2001; NRC, 2002). Note that cost estimates for some renewal technologies are very site specific.

The projected renewal costs should be compared with those estimated using the top-down approach to ensure the short-term plan is consistent with the long-term plan.

7. How will you pay for it?

User rates are the preferred source of revenue for renewal to ensure a stable and adequate level of funding is available and to promote efficient use of the resources. In some cases, municipalities have added a surcharge to the water bills to generate added revenues to cover the cost for renewal of the distribution system (e.g., cast iron replacement programs) and to enhance awareness for the need for such programs.

Since water distribution system renewal programs are ongoing and the investment requirements do not change radically year to year, the use of current funds is preferred. Municipalities should track the renewal costs for their water distribution system separately in their capital budget to ensure spending is sufficient and efficient.

Affordability is the concept of ability to pay, as opposed to willingness to pay, to which decision makers are more sensitive. Affordability is often evaluated by expressing water charges as a percentage of median household income (MHI). The U.S. Environmental Protection Agency provides information on drinking water affordability (EPA, 1997) with affordable water generally considered being one to two percent of the MHI. A British study (Sawkins, J.W. and Dickie, V.A., 2002) cited a benchmark affordability level for water plus sewage charges of three percent of MHI. The 2000 median Canadian family income was $51,000 (Statistics Canada, 2002), which at 1.5 percent would mean an annual water bill of $765 should be affordable, on average. Of course, local conditions will vary.

Sometimes, water costs are compared with other services to encourage approval of higher rates. Often, water plus sewer costs are in the same range as cable or satellite TV services, which many find affordable.

4. Applications and Limitations

4.1 Applications

All municipalities across Canada should be using both the top-down and bottom-up approaches for developing a water distribution system renewal plan. These approaches must be tailored for each municipality to reflect the size and age (i.e. condition) of their system. In some cases, particularly small municipalities where in-house expertise in renewal planning is not present, it may be necessary to retain a qualified engineering consultant to assist with the development of renewal plans.

Ideally, a comprehensive water distribution renewal plan would be in place before serious deficiencies accumulate, allowing an ordered approach to be developed. A comprehensive water distribution system renewal plan becomes particularly important for those municipalities that already have a significant backlog of renewal work to be completed. Furthermore, a renewal plan is critical for those municipalities that are expecting a decline in population and revenue base. For those municipalities not experiencing significant problems, a renewal plan should identify opportunities for improving the management of their systems.

4.1.1 Top-Down Approach

All municipalities should project their long-term renewal costs using the top-down approach. For small municipalities, the top-down approach can be applied using an electronic spreadsheet. For larger municipalities, computer models such as KANEW, WARP, and Nessie can be used. Regardless of the tools used, it is prudent to illustrate graphically the projected renewal costs to communicate clearly the magnitude of projected increases in costs.

4.1.2 Bottom-Up Approach

All municipalities should develop a water distribution system renewal plan using a bottom-up approach based on the principles of risk management. All municipalities should compile an inventory of their distribution system to facilitate operation and maintenance as well as renewal planning. This inventory should include a criticality factor for each component.

Life cycle cost analyses should be conducted to identify the optimum timing for renewal of each component as well as the most appropriate renewal technology. The life cycle cost analyses should consider socio-economic costs.

All municipalities should implement a condition rating system to facilitate renewal planning using the bottom-up approach. The number of condition rating parameters, performance criteria, and technology tools will vary among municipalities depending on physical, environmental, and operational factors. Large municipalities should consider the need for a computerized decision support system to facilitate renewal planning.

4.1.3 Financial Plan

All municipalities should recognize that a financial plan setting out annual investment levels, revenue sources, and financing options is an integral part of the long-term renewal plan to ensure adequate funds are available to sustain the distribution system. It is critical that all stakeholders adopt this financial plan, together with the long-term renewal plan that identifies infrastructure renewal needs, reasons, and priorities.

All municipalities across Canada should be using both the top-down and bottom-up approaches for developing a water distribution system renewal plan.

4.2 Limitations

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

The plan will only be as good as the data. Municipalities with incomplete inventory data or insufficient performance data will have some limitations until they are able to complete data acquisition.

The bottom-up approach will require investment of time and money.

5. Evaluation

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

- Compare and rationalize the projected renewal costs derived using the top-down and bottom-up approaches.
- Track water main break rates, water quality parameters, customer complaints, and leakage to establish deterioration rates.
- Monitor the infrastructure deficit and asset condition index (ACI).
- Conduct pilot studies to assess the effectiveness of various renewal technologies.
- Monitor spending on renewal of the distribution system to ensure it is sufficient and efficient. In particular, monitor the spending on reactive maintenance to ensure it is not increasing dramatically over time (i.e., the spending on reactive maintenance should not increase dramatically if the investment in renewal is sufficient).
- Monitor disruptions to service in terms of the number of customers affected (as well as customer class) and the time spent out of service.
- Conduct customer satisfaction surveys.

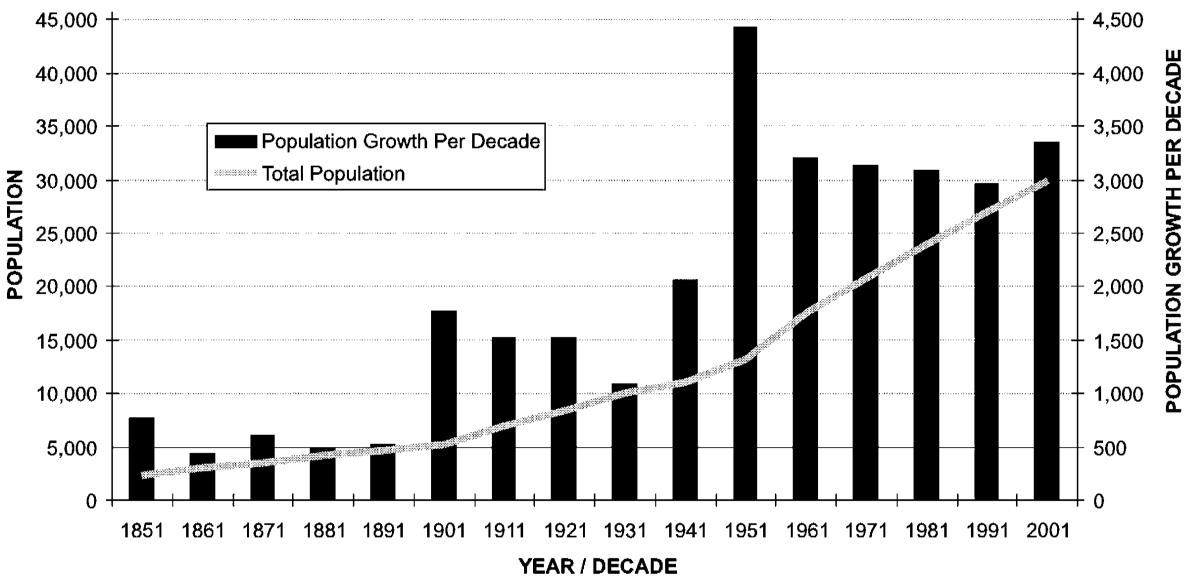
A water distribution system renewal program should be updated every five to ten years to reflect the current condition of the system as well as the updated renewal programs for the roads and sewers.

Appendix A:
Application of Top-Down Approach

Introduction

This appendix describes an example of the top-down approach for developing a water distribution system renewal plan. This example is based on a fictitious municipality (referred to as Small City) with a population of 30,000 and a population growth rate as shown in Figure A–1. Small City experienced significant growth in the 1950s.

Figure A–1: Population growth in Small City



It should be noted that the assumptions used in this example (e.g., unit costs, life expectancies) are only provided for illustrative purposes. Municipalities should use unit costs and life expectancies that are appropriate for their systems.

A. Application of Top-Down Approach

Figure A–1
Population growth in Small City

A. Application of Top-Down Approach

Table A–1
Replacement cost of water system components in Small City

Figure A–2
Replacement cost breakdown for water system components in Small City

1. What do you have?

Small City has approximately 150 km of water mains (i.e., 5 m per capita). The total length of water mains is broken down as follows:

- 60 percent are unlined cast iron (constructed prior to 1960);
- 20 percent are lined ductile iron (constructed between 1960 and 1980); and
- 20 percent are PVC (constructed since 1980).

Small City has approximately 1500 valves, 1000 hydrants, as well as 8600 water services and meters.

2. What is it worth?

Table A–1 summarizes the estimated replacement cost for the water distribution system components. The total replacement cost for the water distribution system in Small City is approximately $100 million or $3,333 per capita.

Table A–1: Replacement cost of water system components in Small City

	Quantity	Unit Cost	Replacement Cost (million $)
Water mains	150 km	$500/m	$75.0
Hydrants	1000	$3,500 each	$3.5
Valves	1500	$1,500 each	$2.3
Water services	8600	$2,000 each	$17.2
Water meters	8600	$240 each	$2.1
Total Replacement Cost			**$100.0**

Figure A–2: Replacement cost breakdown for water system components in Small City

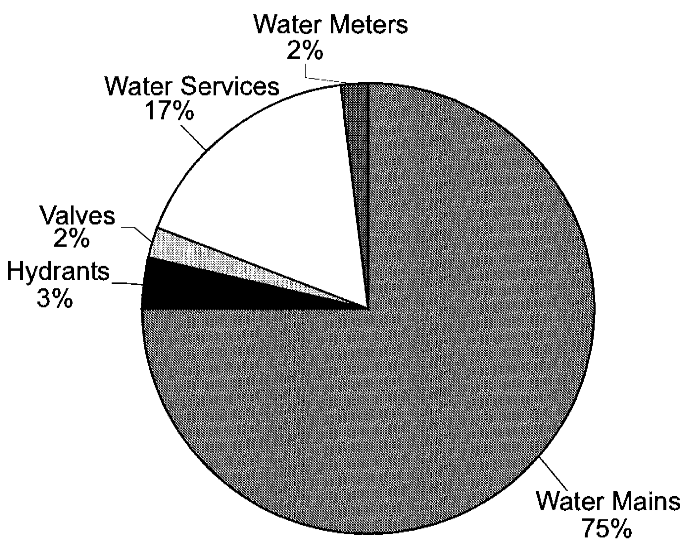


Figure A–2 illustrates the breakdown of the total replacement cost for the water distribution system in terms of the various asset groups. It is apparent the water mains account for 75 percent of the total replacement cost with appurtenances representing the remaining costs.

Table A–2
Average annual renewal cost for water system for Small City

Table A–3
Small City – Expansion of water distribution system

3. What is its condition?

Table A–2 summarizes the life expectancy of each of the water distribution system components in Small City.

Table A–2: Average annual renewal cost for water system for Small City

Water System	Replacement Cost (million $)	Service Life (years)	Average Annual Investment (million $)
Water mains	$75.0	80	$0.94
Hydrants	$3.5	80	$0.04
Valves	$2.3	80	$0.03
Water services	$17.2	80	$0.22
Water meters	$22.1	20	$0.10
	$100.0 (weighted average) 75		**$1.3**

The average annual costs for replacement of the water distribution system over the long term can be estimated by dividing the replacement cost by the assumed life expectancy. In this case, the average annual cost for replacement of the water distribution system components is estimated to be $1.33 million or $44 per capita. The weighted average life expectancy of the components is 75 years. This would suggest that 1.3 percent of the distribution system should be replaced each year on average (i.e., 1/75 years).

To project the replacement costs over the long term (i.e., at least one life cycle), it is necessary to estimate the historical growth rate of the system. In this example, it has been assumed that the water distribution system was expanded at the same rate as the population growth.

Table A–3 summarizes the length of water main as well as the number of hydrants, valves, and water services constructed in each decade over the past 100 years. It has been assumed that a municipal water system was first implemented in 1900 in Small City.

Table A–3: Small City – Expansion of water distribution system

Year	1901	1911	1921	1931	1941	1951	1961	1971	1981	1991	2001
Population	5,179	6,950	8,474	10,006	11,096	13,161	17,587	20,798	23,934	27,030	30,000
Water mains material	Cast Iron						Ductile Iron		PVC		**Total**
Length of Water mains (km)		35	42	50	55	66	88	104	120	135	150
No. of Hydrants		232	282	334	370	439	586	693	798	901	1,000
No. of Valves		347	424	500	555	658	879	1,040	1,197	1,351	1,500
No. of Water Services and Meters		1,992	2,429	2,869	3,181	3,773	5,042	5,962	6,861	7,749	8,600

A. Application of Top-Down Approach

Figure A–3
Life cycle costs for water system in Small City

4. What needs to be done?

For the purposes of this example, it has been assumed the water mains will be replaced at the end of their assumed life expectancy. In some cases, when the soil is corrosive, it may be cost effective to install cathodic protection on iron and steel mains (as well as metallic components associated with non-metallic mains) to reduce the rate of external corrosion and increase life expectancy.

Small City experiences rusty water complaints in the older parts of its system that are serviced by unlined cast iron mains. For this example, it has been assumed that 50 percent of the unlined cast iron mains will be rehabilitated by cleaning and lining over the next 20 years and the other 50 percent will be replaced over the next 20 years due to high break rates.

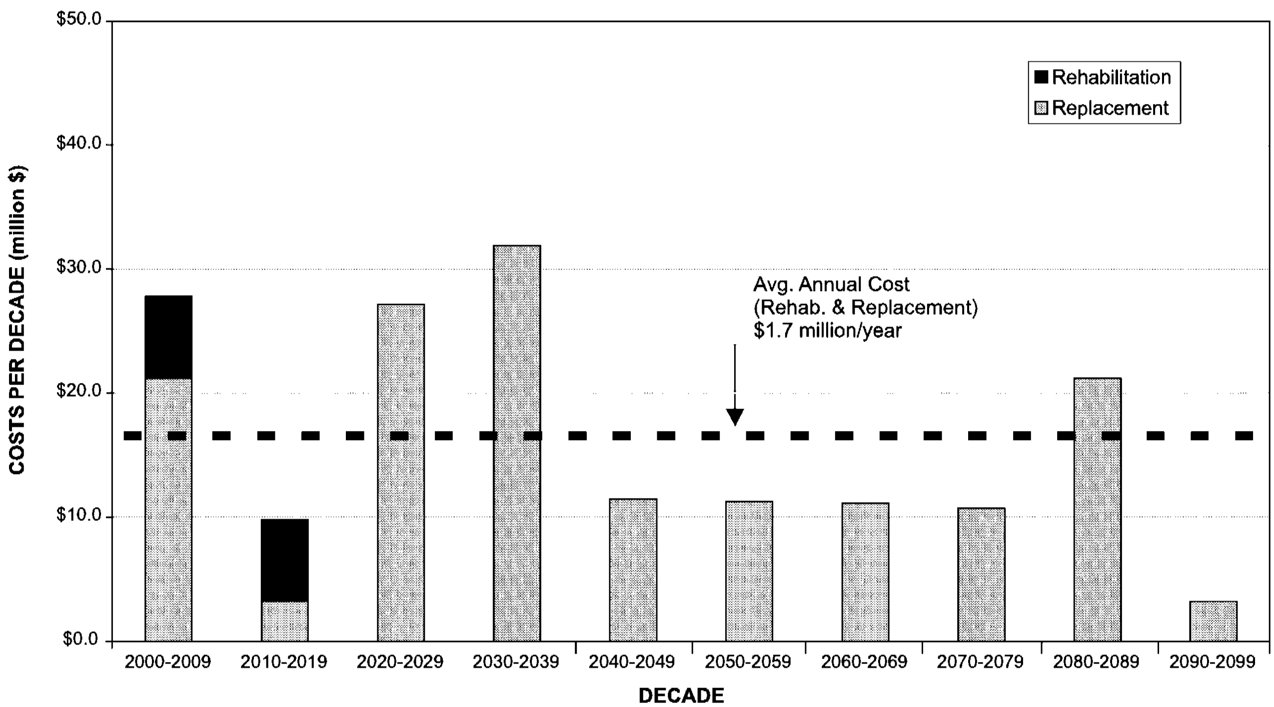
5. When do you need to do it?

The projected replacement costs for the water distribution system are based on the age of the components (Table A–3), their assumed life expectancy (Table A–2), and the unit costs for replacement (Table A–1). The remaining life for each component is equal to the difference between life expectancy and current age.

6. How much will it cost?

Figure A–3 illustrates the projected costs for rehabilitation and replacement of the water distribution system over the next 100 years. This analysis does not include any allowance for inflation.

Figure A–3: Life cycle costs for water system in Small City



It is apparent from Figure A–3 that the projected replacement costs over the next decade are high, since it has been assumed that a significant percentage of the system has already reached the end of its service life. It is also apparent that the replacement costs are expected to increase significantly within the next 20 to 30 years as the infrastructure installed in the 1950s reaches the end of its service life. The average annual cost over this period is estimated to be $1.66 million.

7. How will you pay for it?

Small City currently invests $1.5 million per year in the renewal of its water distribution system. The total annual water budget is $3 million. This includes operation, maintenance, and renewal of the water supply and distribution system. However, the budget does not include works required to support population growth, since developers fund these works. Small City's water budget is funded entirely by water rates.

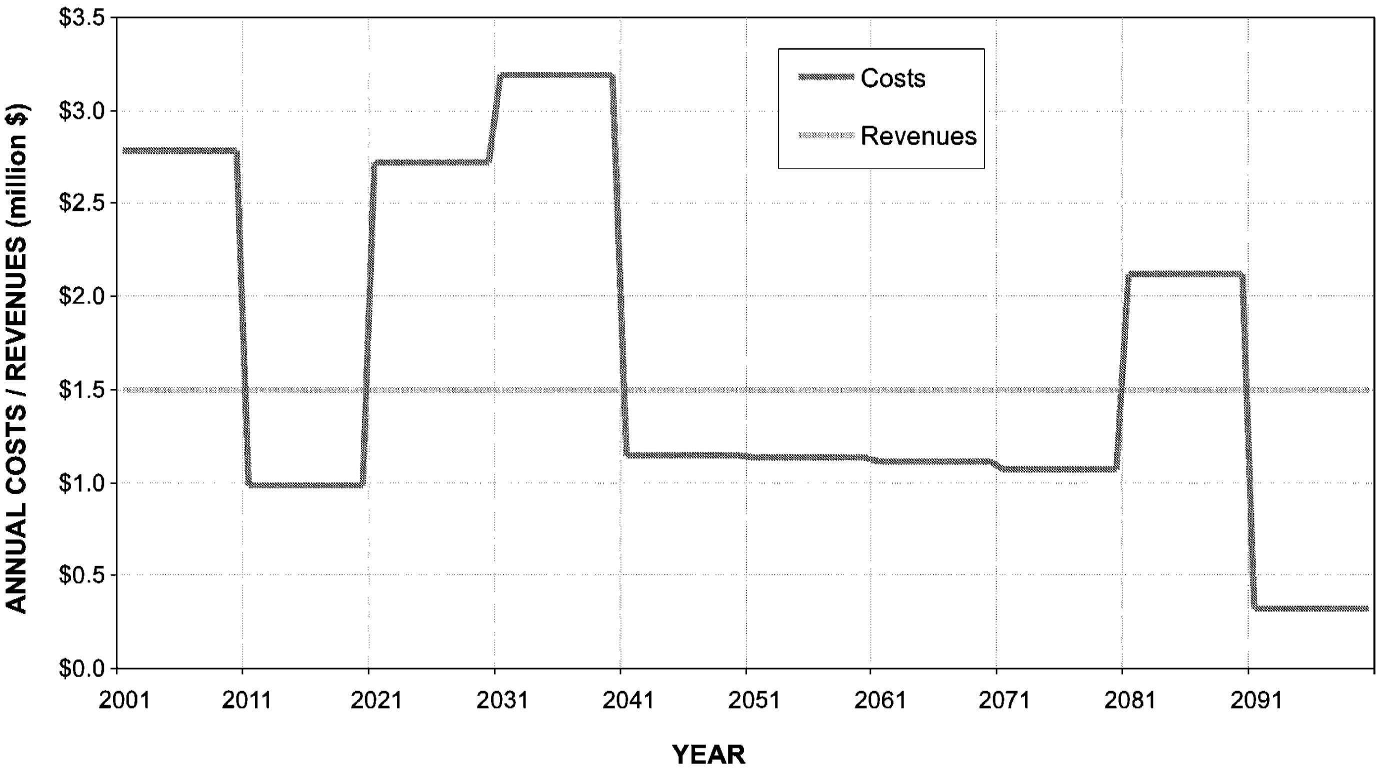
To cover the projected $1.66 million annual costs for renewal of the water distribution system, Small City will have to increase revenues by $160,000. To do this, the city will have to increase water rates by about five percent (i.e., [$3.16 million/$3.0 million] - 1).

Figure A–4 illustrates the projected costs and current revenues for water distribution system renewal assuming their operating costs remain constant and debt remains minimal. It is apparent the current revenues will be inadequate.

A. Application of Top-Down Approach

Figure A–4
Annual costs and revenures for Scenario 1

Figure A–4: Annual costs and revenues for Scenario 1



A. Application of Top-Down Approach

Figure A–5
Cumulative costs and revenues for Scenario 1, Small City

Figure A–6
Asset condition index vs. time (Scenario1)

Figure A–5 illustrates the cumulative costs and cumulative revenues (assuming revenues remain constant) over the next 100 years. The difference between the cumulative costs and cumulative revenues (i.e., the infrastructure deficit) would reach a maximum of $36 million by 2040.

Figure A–6 illustrates the asset condition index[7] (ACI) assuming revenues remain constant. It is apparent the ACI exceeds 20 percent due to the significant backlog of renewal work. By 2040, the ACI would exceed 35 percent if revenues are not increased and, by that time, the level of service would be unacceptable.

Figure A–5: Cumulative costs and revenues for Scenario 1, Small City

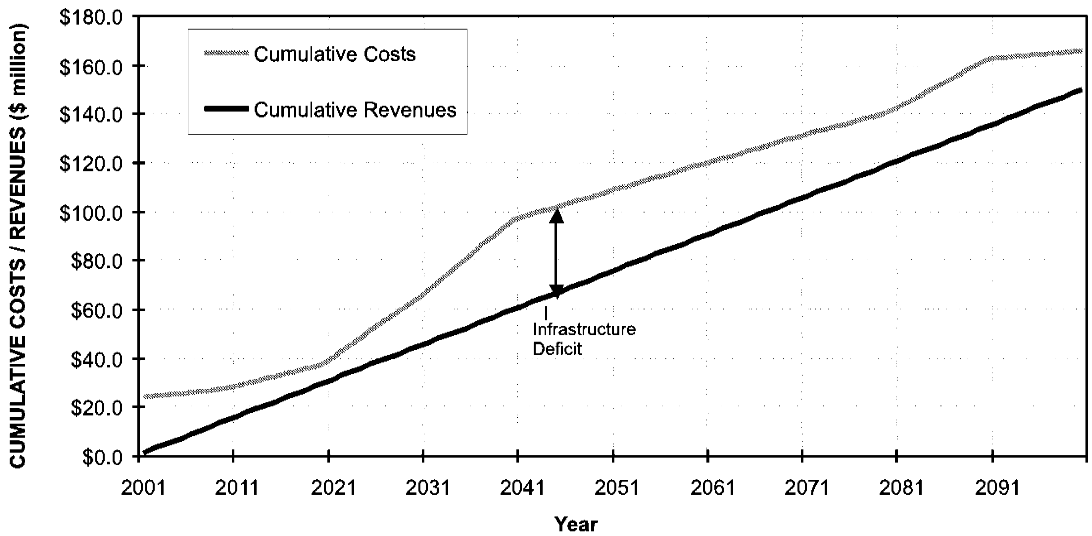
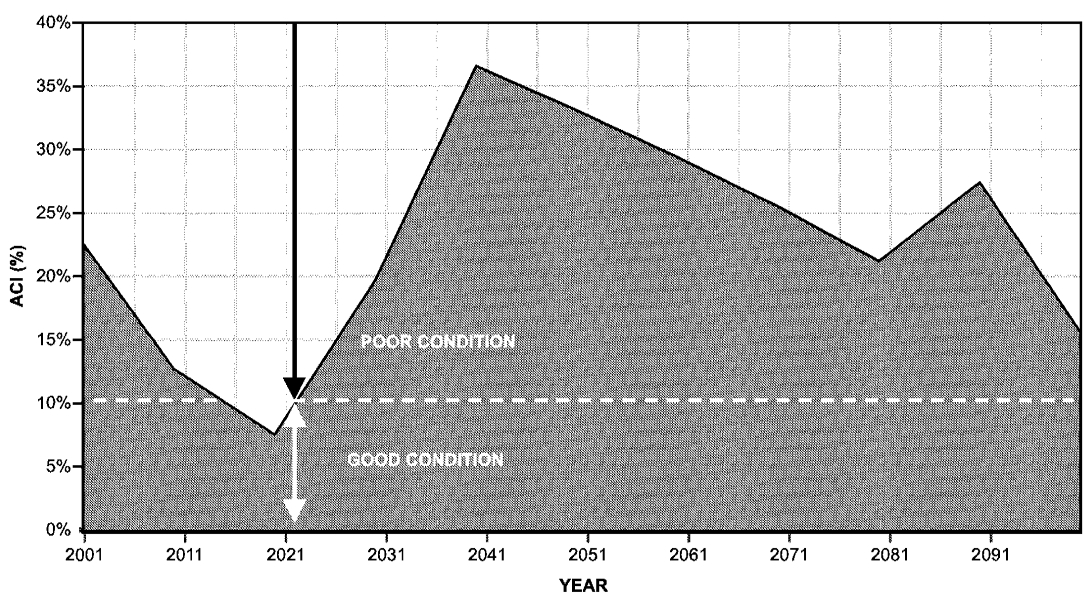


Figure A–6: Asset condition index vs. time (Scenario 1)



7. Asset condition index = infrastructure deficit/total replacement cost.

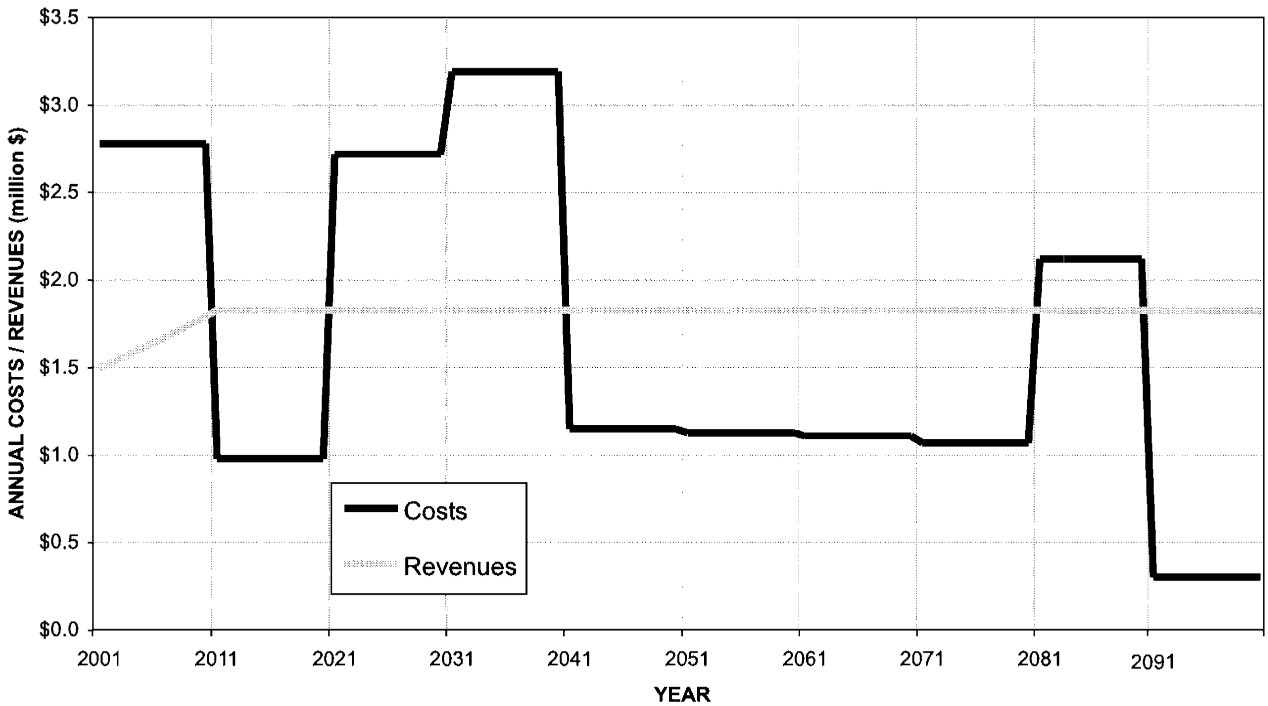
Figure A–7
Annual costs and revenues for Scenario 2

Scenario 2

One method to generate sufficient revenues to cover the projected costs is outlined below. It has been assumed that water rates are increased by one percent per year over the next 10 years. In this case, the water rates in 2011 and beyond will be 11 percent greater than the current rates. The average annual revenues over the next 100 years would be $1.81 million compared to the average annual cost of $1.66 million.

Figure A–7 illustrates the projected costs and revenues for Small City. The average annual revenues match the average annual costs over the next 100 years.

Figure A–7: Annual costs and revenues for Scenario 2



A. Application of Top-Down Approach

Figure A–8
Cumulative costs and revenues for Scenario 2, Small City

Figure A–9
Asset condition index vs. time (Scenario 2)

Figure A–8 illustrates the cumulative costs and cumulative revenues. It is apparent the infrastructure deficit is less than that indicated in Figure A–5.

Figure A–9 illustrates the asset condition index assuming the water rates are increased by one percent per year over the next 10 years. It is apparent the ACI would be less than that shown in Figure A–6. However, the ACI would still reach 25 percent in 2040 and, therefore, additional rate increases would be warranted by 2030.

Figure A–8: Cumulative costs and revenues for Scenario 2, Small City

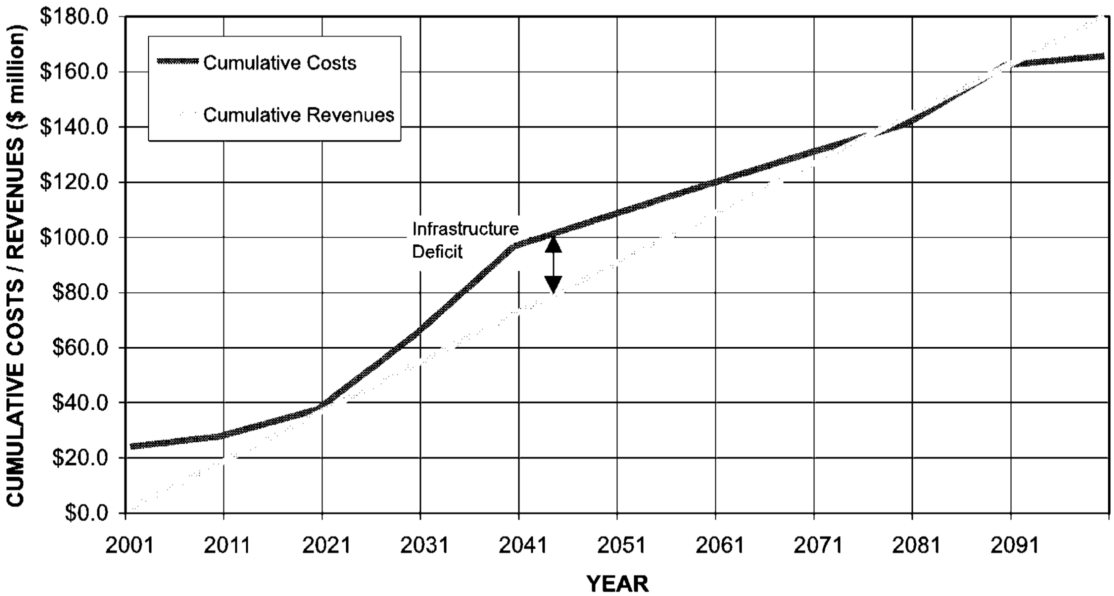
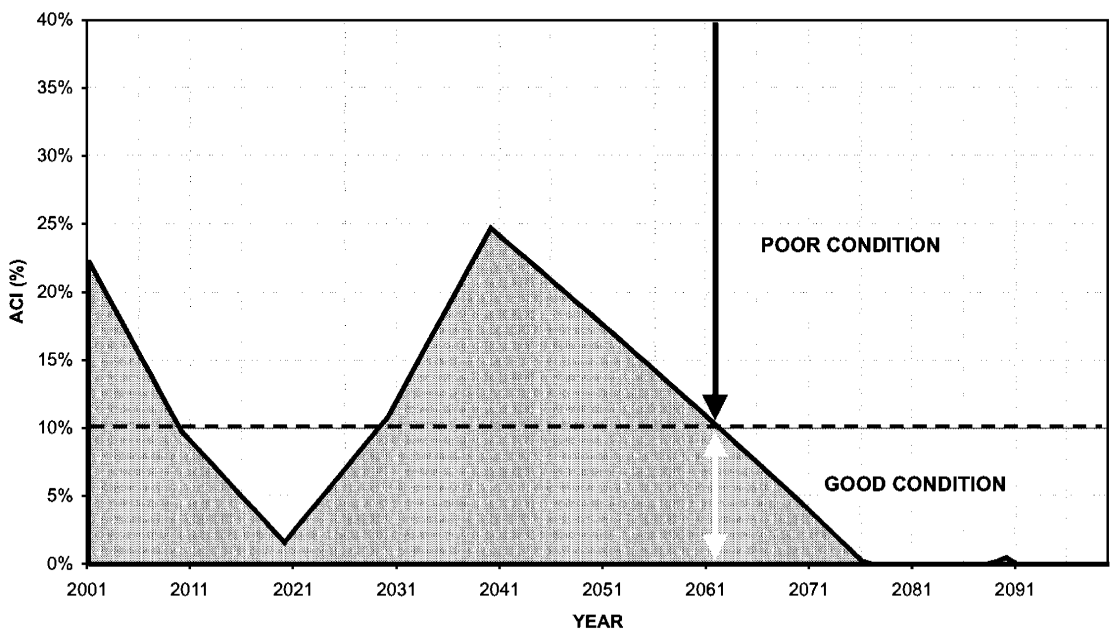


Figure A–9: Asset condition index vs. time (Scenario 2)



Appendix B:
Application of Bottom-Up Approach

Introduction

This section describes an example of the bottom-up approach to development of a water distribution system renewal plan. It includes 20 sections of water main with different sizes, materials, ages, and conditions to demonstrate the range of considerations.

It should be noted that the assumptions and approach used in this example are only provided for illustrative purposes. Municipalities should use an approach that is appropriate for their system.

1. What do you have?

Table B–1 presents a basic inventory of 20 sections of water main with the following materials:

- eight sections of unlined cast iron (CI-U);
- two sections of lined cast iron (CI-L);
- two sections of lined steel (STL);
- two sections of asbestos cement (AC);
- three sections of lined ductile iron (DI); and
- three sections of polyvinyl chloride (PVC).

The total length of water mains is 1,517 m.

2. What is it worth?

Table B–1 presents a summary of the replacement cost for each of the 20 sections of water main based on the following unit costs.

Pipe Dia. (mm)	Unit Cost ($/m)
150	$350
200	$360
250	$380
300	$410

The total replacement cost for these 20 sections of water main is $552,000.

B. Application of Bottom-Up Approach

Table B–1
Water Distribution System Inventory

3. What is its condition?

Table B–1 also summarizes the break rate and C factor for each of the 20 sections of water main. Since the cast iron mains are not lined, they are heavily tuberculated and, consequently, the Hazen-Williams C factors are relatively low. Furthermore, the municipality receives rusty water complaints whenever hydrants are opened in those areas serviced by unlined cast iron mains.

Table B–1 indicates there are two sections of cast iron water main that do not conform to current design standards in terms of the main diameter (i.e., 150 mm is normally the minimum size for fire protection in single family residential areas).

Table B–1: Water Distribution System Inventory

Link ID	Length (m)	Dia. (mm)	Material	Unit Cost	Replace Cost	No. of Breaks	Breaks/ km/yr	C Factor
1	55	100	CI-U	$350	$19,250	0	0.00	50
2	45	100	CI-U	$350	$15,750	1	2.22	50
3	114	150	CI-U	$350	$39,900	1	0.88	60
4	98	150	CI-U	$350	$34,300	1	1.02	60
5	103	150	CI-U	$350	$36,050	0	0.00	60
6	89	150	CI-U	$350	$31,150	3	3.37	60
7	85	200	CI-U	$360	$30,600	3	3.53	70
8	71	200	CI-U	$360	$25,560	1	1.41	70
9	57	200	CI-L	$360	$20,520	0	0.00	110
10	82	250	CI-L	$380	$31,160	0	0.00	110
11	68	150	DI	$350	$23,800	0	0.00	100
12	22	150	DI	$350	$7,700	0	0.00	100
13	98	150	DI	$350	$34,300	0	0.00	100
14	74	150	AC	$360	$26,640	3	4.05	100
15	66	200	AC	$350	$23,100	0	0.00	110
16	80	300	STL	$410	$32,800	0	0.00	120
17	110	300	STL	$410	$45,100	0	0.00	120
18	27	150	PVC	$350	$9,450	0	0.00	100
19	47	200	PVC	$360	$16,920	0	0.00	110
20	126	250	PVC	$380	$47,880	0	0.00	110
Total	**1517**				**$551,930**	**13**		

4. What needs to be done?

Table B–2 summarizes the renewal requirements.

Mains that do not conform to current design standards

Two sections of 100 mm unlined cast iron water main should be replaced with larger mains when the roads are reconstructed or sooner if fire protection is deemed inadequate.

Mains that have high break rates

An economic analysis was conducted for this municipality to determine when it is more cost effective to replace a water main rather than continuing to repair it. Based on this analysis, a water main with a break rate of greater than 3.0 breaks per km per year should be replaced as soon as possible. As a result, two sections of unlined cast iron and one section of asbestos cement water main should be replaced in this example.

Mains that do not have adequate hydraulic capacity and/or cause water quality problems

Four other sections of unlined cast iron main should be cleaned and lined to restore hydraulic capacity and mitigate water quality problems. The municipality should identify whether services are substandard, such as lead services or those that are less than 19 mm, since this would affect the decision to rehabilitate them.

Mains and appurtenances that should be cathodically protected (retrofit with anodes or impressed current system)

A corrosion survey should be conducted to confirm the corrosiveness of the soil and an economic analysis should be conducted to confirm that it is cost effective to cathodically protect metallic components. Based on this survey and analysis, it was determined that two sections of steel water main, two sections of ductile iron main and two sections of lined cast iron should be cathodically protected.

5. When do you need to do it?

The proposed water main renewal program should be coordinated with road reconstruction projects and upgrades that might be required for new development/redevelopment.

The following condition rating system was used to determine the overall point rating for each section of watermain as summarized in Table B–2.

Structural Score	Breaks/km/year
1	0 – 0.30
2	0.31 – 0.60
3	0.61 – 0.90
4	0.91 – 1.20
5	1.21 – 1.50
6	1.50 – 1.80
7	1.81 – 2.10
8	2.11 – 2.40
9	2.41 – 2.70
10	> 2.70

Hydraulic Capacity Score	C Factor
1	> 100
2	91 – 100
3	81 – 90
4	71 – 80
5	< 71

Water Quality Score	Pipe Material
1	Others
5	CI-U

Importance Score	Pipe Dia. (mm)
1	≤ 150
2	200
3	250
4	300
5	> 300

B. Application of Bottom-Up Approach

Table B–2
Water Distribution System Renewal Requirements

Table B–2: Water Distribution System Renewal Requirements

Link ID	Length (m)	Dia. (mm)	Material	Unit Cost	Replace Cost	No. of Breaks	Breaks/ km/yr	C Factor	Break Rate	C Factor	Water Quality	Dia.	Total
Replace mains that are too small to supply required fire flow													
1	55	100	CI-U	$350	$19,250	0	0.00	50	1	5	5	1	**12**
2	45	100	CI-U	$350	$15,750	1	2.22	50	8	5	5	1	**19**
	100				**$35,000**								
Replace mains that have high break rates													
6	89	150	CI-U	$350	$31,150	3	3.37	60	10	5	5	1	**21**
7	85	200	CI-U	$360	$30,600	3	3.53	70	10	5	5	2	**22**
14	74	150	AC	$350	$25,900	3	4.05	100	10	2	1	1	**14**
	248				**$87,650**								
Rehabilitate mains that do not have adequate hydraulic capacity and/or cause water quality problems													
3	114	150	CI-U	$150	$17,100	1	0.88	60	3	5	5	1	**14**
4	98	150	CI-U	$150	$14,700	1	1.02	60	4	5	5	1	**15**
5	103	150	CI-U	$150	$15,450	0	0.00	60	1	5	5	1	**12**
8	71	200	CI-U	$150	$10,650	1	1.41	70	5	5	5	2	**17**
	386				**$57,900**								
Cathodically protect steel and iron mains in corrosive soils (as warranted by corrosion surveys)													
9	57	200	CI-L	$55	$3,135	0	0.00	110	1	1	1	2	**5**
10	82	250	CI-L	$55	$4,510	0	0.00	110	1	1	1	3	**6**
11	68	150	DI-L	$55	$3,740	0	0.00	100	1	2	1	1	**5**
12	22	150	DI-L	$55	$1,210	0	0.00	100	1	2	1	1	**5**
15	80	300	STL	$55	$4,400	0	0.00	120	1	1	1	4	**7**
16	110	300	STL	$55	$6,050	0	0.00	120	1	1	1	4	**7**
	419				**$23,045**								

The total score for each section of water main is equal to the sum of the scores for the structural, hydraulic capacity, water quality, and importance factors. In this case, the maximum score would be 25 (poor condition) and the minimum score would be 4 (good condition). The structural score accounts for 40 percent of the total score whereas the other factors each account for 20 percent of the total score.

It is apparent from Table B–2 that the unlined cast iron mains with high break rates are the highest priority for replacement.

6. How much will it cost?

Table B–3 summarizes the recommended renewal program assuming the works will be completed over the next 10 years. The average annual renewal cost over this period is $20,360.

For purposes of comparison, the long-term average annual renewal cost for these 20 sections of water main is estimated to be $7,900 assuming the average life expectancy is 70 years.

7. How will you pay for it?

It has been assumed the renewal costs will be recovered through user rates. An analysis of the impact of the costs on customers should be carried out and a strategy for implementing the need charges developed. This would include warning customers of changes in rates as well as a public information program demonstrating the need for investments.

B. Application of Bottom-Up Approach

Table B–3
Renewal Program (10 Years)

Table B–3: Renewal Program (10 Years)

Link ID	Length (m)	Dia. (mm)	Material	Unit Cost	Replace Cost	Total Score	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Replace mains that are too small to supply required fire flow																
1	55	100	CI-U	$350	$19,250	12									$19,250	
2	45	100	CI-U	$350	$15,750	19						$15,750				
	100				**$35,000**											
Replace mains that have high break rates																
6	89	150	CI-U	$350	$31,150	21	$15,575	$15,575								
7	85	200	CI-U	$360	$30,600	22			$15,300	$15,300						
14	74	150	AC	$350	$25,900	14					$25,900					
	248				**$87,650**											
Rehabilitate mains that do not have adequate hydraulic capacity and/or cause water quality problems																
3	114	150	CI-U	$150	$17,100	14								$17,100		
4	98	150	CI-U	$150	$14,700	15							$14,700			
5	103	150	CI-U	$150	$15,450	12										$15,450
8	71	200	CI-U	$150	$10,650	17							$10,650			
	386				**$57,900**											
Cathodically protect steel and iron mains in corrosive soils (as warranted by corrosion surveys)																
9	57	200	CI-L	$55	$3,135	5			$3,135							
10	82	250	CI-L	$55	$4,510	6				$4,510						
11	68	150	DI-L	$55	$3,740	5						$3,740				
12	22	150	DI-L	$55	$1,210	5										$1,210
15	80	300	STL	$55	$4,400	7	$4,400									
16	110	300	STL	$55	$6,050	7		$6,050								
	419				**$23,045**											
				Total	**$203,595**		**$19,975**	**$21,625**	**$18,435**	**$19,810**	**$25,900**	**$19,490**	**$25,350**	**$17,100**	**$19,250**	**$16,660**

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Notes