Potable Water

Small System Operation and Maintenance Practices

This document is the ninth 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>***.

National Guide to Sustainable Municipal Infrastructure ®

NRC · CNRC FCM Federation of Canadian Municipalities Fédération canadienne des municipalités Canada

Small System Operation and Maintenance Practices

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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: decision making and investment planning, potable water, storm and wastewater, municipal roads and sidewalks, environmental protocols, and transit. The best practices are available online and in hard copy.

A Knowledge Network of Excellence

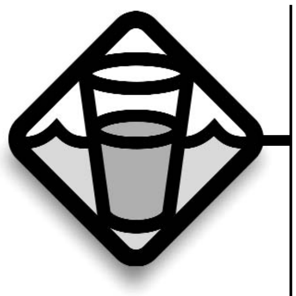
InfraGuide's creation is made possible through $12.5 million from Infrastructure Canada, in-kind contributions from various facets of the industry, technical resources, the collaborative effort of municipal practitioners, researchers and other experts, and a host of volunteers throughout the country.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

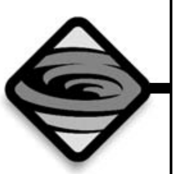
In keeping with the adage "out of sight, out of mind", the water distribution system has been neglected in many municipalities. Potable water best practices address various approaches to enhance a municipality's or water utility's ability to manage drinking water delivery in a way that ensures public 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.

TABLE OF CONTENTS

TABLES

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The purpose of any potable water system is to deliver adequate volumes of consistently high quality, chemically and biologically safe water at adequate pressure to all customers 24 hours a day, seven days a week. This can only be achieved with good design, construction, and inspection practices as well as proper operation and maintenance (O&M).

Recent events contributed to reduced public confidence in municipal water supplies, which led to extensive changes in government legislation and regulations across Canada. A comprehensive O&M program is required to ensure the continuous supply of clean and safe water to the customer's tap. It also helps raise public confidence in the water system, minimizes the frequency of system failures and the duration of outages, reduces the life cycle costs for the system, and promotes continuous improvement among operators.

This document outlines best practices for the O&M of small water systems from the source water to the customer's tap. It is based on a literature review, a survey of selected municipalities across Canada, and input from Canadian water system O&M experts. For this best practice, a small water system is defined as a potable water system that serves a population of 5,000 or less.

This best practice also provides references where more detailed information on specific practices can be found. These practices are summarized as follows:

- Produce high quality, stable water that is biologically and chemically safe and aesthetically acceptable.
- Know and understand all provincial/territorial regulations applicable to the operation and maintenance of the water system.
- Become knowledgeable with water system assets and their location.
- Become knowledgeable with the condition of the water system.
- Determine what is needed to achieve the intended level of service.
- Have a plan to upgrade inadequate components.
- Maintain an adequate disinfection residual in all parts of the system.
- Maintain positive water pressures under foreseeable operating conditions.
- Implement a backflow prevention and cross-connection control program.
- Monitor the quality of the water. This includes source water, treatment plant output, in the distribution system and at the point of use (i.e., at the tap).
- Maintain comprehensive system records and documents reporting water quality.
- Ensure proper disinfection and flushing procedures are used for all repairs and new construction.
- Monitor for internal and external corrosion and, if necessary, implement measures to reduce the rate of corrosion.
- Meter water supply and consumption to quantify water losses from the system and, if necessary, implement a leak detection program.
- Maintain the source water intake, dam or wellhead site.
- Maintain the water source, treatment plant, pumping stations, water towers, and reservoirs.
- Exercise and inspect the distribution system valves and hydrants.
- Flush and swab the water mains.
- Use a maintenance management system and geographic information system (GIS).
- Maintain a spare parts inventory.
- Prepare a contingency plan for emergencies.
- Prepare a plan to ensure the financial sustainability of the water system.

The purpose of any potable water system is to deliver adequate volumes of consistently high quality, chemically and biologically safe water at adequate pressure to all customers 24 hours a day, seven days a week.

Detailed records of the system inventory, O&M data, and condition and performance data are invaluable for proper management of the water system.

- Maintain excellent public relations through newsletters, public education, participation in public events, etc.
- Maintain adequate staffing and funding levels to undertake best practice activities and provide training for staff.

Note however, that this best practice is not a replacement for proper engineering and should not preclude or supersede regulatory requirements.

The operators of small water systems should evaluate their current O&M practices against these best practices and establish a priority list for implementation of applicable best practices. However, the first priority of any operator is water quality, and this aspect should guide the setting of priorities.

To ensure the O&M program is effective, several performance measures should be monitored regularly (e.g., the number of adverse water quality test results, the number of water quality complaints, the number of inoperable valves, the number of water main breaks). All O&M practices should be reviewed periodically to ensure they adequately address the needs of the system. To facilitate these reviews, practices should be documented and standard operating procedures developed. Detailed records of the system inventory, O&M data, and condition and performance data are invaluable for proper management of the water system.

1. General

1.1 Introduction

Over 80 percent of Canadian municipalities[1] have a population of 5,000 or less. This best practice outlines the best practice for operation and maintenance (O&M) of small water systems and should be a good resource for O&M staff in small communities. It is based on a review of existing literature, a survey of selected municipalities across Canada, and input from small water system experts.

1.2 Purpose and Scope

This document provides guidance to operators of small water systems regarding best practices for day-to-day activities. It covers most aspects of small water systems from the source water to the customer's tap. Throughout this document, the term "municipality" refers to the owner or operator/maintainer of a small water system.

1.3 How to Use This Document

It is the purpose of this best practice to determine which recommendations are applicable to a small water system, to help develop a plan for improvements, and to implement these improvements in a prioritized manner.

Sections 2 through 5 elaborate on why, what, how, and when, with respect to best O&M practices for a small water system.

Section 2 — Rationale provides justification for this best practice and describes benefits that can be achieved by following it.

Section 3 — Work Description describes a theoretical framework underlying this best practice (what should be done) and goes on to describe specifics of implementing the best practice (how to do the work).

Section 4 — Applications and Limitations describes those most likely to benefit from the best practices in this document, and notes limitations to the application of the best practices to a specific system.

Section 5 — Evaluation elaborates on measures that can be taken to assess a system's performance following the implementation of these best practices.

InfraGuide has published several other best practice documents related to water systems. Some of them include:

- *Developing a Water Distribution System Renewal Plan* (2003b) describes basic approaches to planning the renewal of water systems.
- *Deterioration and Inspection of Water Distribution Systems* (2002a) describes the reasons for deterioration and methods for inspection of distribution facilities.
- *Selection of Technologies for the Rehabilitation or Replacement of Sections of a Water Distribution System* (2003c) describes available technologies and methods for their implementation.
- *Water Use and Loss in Water Distribution Systems* (2002c) describes the basics of water auditing, cost reduction, and accountability.
- *Water Quality in Distribution Systems* (2003d) describes common water quality problems in water distribution systems and how to address them.
- *Establishing a Water Metering Plan to Account for Water Use and Loss* (2003e) describes how to establish and set up a metering plan.

1. Municipality (or municipalities) mentioned in InfraGuide Best Practices, is intended to include all purveyors of public services as well as utilities.

This document provides guidance to operators of small water systems regarding best practices for day-to-day activities.

- *Speed and Quality of Linear System Repairs* (2004) describes how to improve on the speed of detecting leaks and how to carry out quality repairs on distribution systems.

These documents, and others, are available at InfraGuide's Web site: ***<http://www.infraguide.ca>.***

1.4 Glossary

Chloramination — The process of disinfecting with chloramines by the addition of ammonia to chlorinated water.

Chloramines — A disinfectant produced from the mixing of chlorine and ammonia.

Chlorination — The process of adding chlorine to water to kill disease-causing organisms or to act as an oxidizing agent.

Chlorine residual (CR) — The concentration of chlorine remaining in water at the end of a specified contact time. The absence of chlorine residual or any significant reduction is an immediate indication of potential water quality or treatment process concerns, and that water is not protected from contamination by microbiological organisms.

Combined chlorine residual (CCR) — The resultant compound from the reaction of chlorine with ammonia.

Cross-connection — A physical connection of a potable water system and a non-potable water system.

CT requirements — The product of the disinfection concentration (C) and contact time (T) required to achieve disinfection.

Haloacetic acids (HAAs) — Commonly occurring by-product of disinfection (with chlorine).

Maximum acceptable concentration (MAC) — Established for parameters which, when present above a certain concentration, have known or suspected adverse health effects. The length of time the MAC can be exceeded without health effects will depend on the nature and concentration of the parameter.

pH — The pH of an aqueous solution is a measure of the acid-base equilibrium achieved by various dissolved compounds. A scale of 0 to 14 is used with 0 being strongly acidic and 14 being strongly basic. By definition, the pH of pure water at at temperature of 25 degrees Celsius is 7.0. pH controls many chemical reactions, including coagulation, disinfection, water softening, corrosion, biochemical reactions, and ammonia removal.

Primary disinfection — A disinfection step, typically accomplished at the treatment plant, designed to destroy/inactivate pathogens in raw water.

Secondary disinfection — Provisions for maintaining a disinfectant residual in the distribution system, after primary disinfection at the treatment plant has occurred.

Trihalomethanes (THMs) — Commonly occurring by-product of disinfection (with chlorine).

2. Rationale

2.1 Background

Operation and maintenance activities do not get as much attention from the public as new construction. However, they are key to the reliable delivery of clean and safe drinking water. For many small water systems, current practices achieve an acceptable level of service, but problems may develop as the system ages or when changes occur in O&M staff. In addition, operators of small water systems often have limited funds to access engineering and technical support. Recent events, which reduced public confidence in municipal water supplies, led to extensive changes in government legislation and regulations across Canada. These regulatory changes and the desire to maintain public confidence are forcing water purveyors, large and small, to modify their practices.

2.1.1 Records and Staffing

Good records of all aspects of a water system are crucial. What was built and why? How has it functioned in the past? Current records provide proof of how the system is complying with regulations.

Small water systems need trained, diligent, and committed management and staff to run smoothly in normal times and to continue functioning during extreme events. Good records also allow effective planning and response during emergencies. Due diligence makes the difference between mediocre and best practices.

2.1.2 Water Quality

The key measure of success in running a small water system is the delivery of adequate volumes of consistently high quality, chemically and biologically safe water, at adequate pressure to all customers 24 hours a day, seven days a week. To maintain this high level of service, care must be taken during all stages of the supply and delivery of the water. Source water protection (i.e., measures to ensure the raw water supply is protected from degradation from any source, including urbanization, industrial, or farming practices) is the first step in producing safe water now and in the future. After the source water is protected, the next step is to treat the water correctly. The treated water must also be protected from degradation in the water distribution system to the point of use.

Distribution systems for most municipalities are designed to supply fire flows and peak hour demands. As a result, during normal conditions, water can spend considerable time in the system before being delivered to the customer. It also usually means the flow velocity in most water mains is very low, which allows particulate matter to settle in the pipe and biofilms to grow on the walls. These conditions are conducive to bacterial growth, particularly if an adequate disinfectant residual is not maintained.

Long residence times can lead to the loss of disinfection residual and degradation of water quality. Long residence times can also increase the risk of regrowth of bacteria and, if more chlorine is added, may result in higher concentrations of disinfection by-products. Occasional high flow rates or flow reversals can cause re-suspension of settled solids or sloughing of biofilms, which can lead to water quality complaints from customers.

2.1.3 Accountability

For several decades, potable water systems were taken for granted in most of Canada. They were always there, thought to be safe, and usually inexpensive. The exceptions were in small communities, often in northern regions, where it was difficult to treat the available source water properly. However, high-profile water system failures in Ontario and Saskatchewan resulted in many people becoming very ill and some people dying. These failures resulted in new regulations and a higher degree of public interest in the water supply. Municipal officials and operations staff also became more aware of their responsibilities, stewardship, and public trust.

2.1.4 CHANGING REGULATIONS

Most provinces and territories have recently changed regulations or are in the process of doing so. Some jurisdictions have also implemented regulations concerning operation certification. Other regulations for utility accreditation are under development.

2.2 Benefits

Owners/operators will:

- be able to reduce the risk to public health;

  reduce the risk of failures/outages in the water system, (i.e., improve system reliability);
- be in a better position to avoid litigation against the municipality, its officers, and staff through demonstration of due diligence;
- be able to prolong the life of their existing water system and maximize the value of any new investments. They may also experience lower power and chemical costs;
- be able to identify areas where their current practices are inadequate and where adoption of these best practices should be considered;
- be able to describe the system components, their condition, and when they might need rehabilitation or replacement;
- be able to manage source water protection and treatment processes to produce clean, safe water;
- be able to evaluate the effect of their distribution system on water quality and the reliability of the water supply.
- be better educated on the benefit of preventive rather than reactive maintenance practices. This may result in an increased awareness of required staffing levels, a reduction in unplanned water supply outages, and a reduction of water quality incidents. Preventive maintenance may also reduce staff costs as unscheduled, call-out, or overtime work is reduced;

The best practice: Water Quality in Distribution Systems (InfraGuide, 2003) provides guidance on how to maintain water quality, and covers many elements such as water production, backflow prevention, storage facility, valve and hydrant operations, and distribution system operations.

- With proper record keeping over time and analysis of the records for trends, operators will be able to see if the overall condition of their system is adequate, or whether any rehabilitation or replacement is required. This analysis may indicate the need for additional investment (i.e., higher user rates) to ensure the system is sustainable over the long term.
- By following these best practices, owners/operators will be better prepared to respond to emergency situations, such as a major weather event, a supply interruption, a major break or an adverse water quality test result.
- Implementation of these best practices will enable owners/operators to better accommodate changes in operation and maintenance staff.

Communication of the best practices adopted by the municipality will increase public confidence and satisfaction in the water system, as rates are reset to reflect the sustainability of systems. It will also encourage public involvement in monitoring system performance. This may result in faster detection of problems, reduced risk, and a better overall integrated water quality management program.

2.3 Risks

- Depending on current practices and the desired timeline for implementation of best practices, additional resources (i.e., staff and financial) may be required.
- There could be a lack of support for changes to existing practices from stakeholders (e.g., operators, politicians, and the public) for those systems that

have not experienced significant problems or if resources and funding have to be increased to pay for improvements.

- Some elements of this best practice depend on reliable information about the existing system condition and performance. If data are lacking or if they are unreliable, then predicting trends may be inaccurate and actions may not be effective or efficient.
- In metered systems, increases in water rates to support changes in practices could result in a decrease in water consumption and, if not accounted for in advance, revenue shortfalls. Where wastewater charges are based on metered water consumption, any decrease in water consumption could also reduce revenues generated from wastewater charges.
- Reduced water demand, either because of increased rates, water conservation measures, or reduced leakage from the distribution system, will increase treated water residence time in the distribution system, resulting in greater challenges in maintaining the chlorine residual and controlling disinfection by-products.

Monitoring can support additional endeavours, such as fulfilling regulatory requirements, prioritizing operational improvements, minimizing aesthetic problems/consumer inquiries, developing a pipeline rehabilitation strategy, and many others.

3. Work Description

3.1 What Should Be Done

The best practice for the O&M of small water systems should include the following practices:

1. Produce high quality, stable water that is biologically and chemically safe and aesthetically acceptable.
2. Know and understand all provincial/territorial regulations applicable to the operation and maintenance of the water system.
3. Become knowledgeable with water system assets and their location.
4. Become knowledgeable with the condition of the water system.
5. Determine what is needed to achieve the intended level of service.
6. Have a plan to upgrade inadequate components.
7. Maintain an adequate disinfection residual in all parts of the system.
8. Maintain positive water pressures under foreseeable operating conditions.
9. Implement a backflow prevention and cross-connection control program.
10. Monitor the quality of the water. This includes source water, treatment plant output, in the distribution system and at the point of use (i.e., at the tap).
11. Maintain comprehensive system records and documents reporting water quality.
12. Ensure proper disinfection and flushing procedures are used for all repairs and new construction.
13. Monitor for internal and external corrosion and, if necessary, implement measures to reduce the rate of corrosion.
14. Meter water supply and consumption to quantify water losses from the system and, if necessary, implement a leak detection program.
15. Maintain the source water intake, dam or wellhead site.
16. Maintain the treatment plant, pumping stations, water towers, and reservoirs.
17. Exercise and inspect the distribution system valves and hydrants.
18. Flush and swab the water mains.
19. Use a maintenance management system and geographic information system (GIS).
20. Maintain a spare parts inventory.
21. Prepare a contingency plan for emergencies.
22. Prepare a financial plan to ensure the water system is sustainable.
23. Maintain excellent public relations through newsletters, public education, participation in public events, etc.
24. Maintain adequate staffing and funding levels to undertake best practice activities and provide training for staff.

3.2 How to Do the Work

Operators of small water systems should evaluate their current practices against these best practices and establish an implementation priority list. However, the first priority of any operator should be water quality, and this should guide the prioritization of tasks.

The first priority of any operator should be water quality, and this should guide the prioritization of tasks.

3.2.1 Produce High-Quality, Safe, Potable Water

Operators should ensure that their water treatment plant is capable of properly treating the source water, recognizing that the quality of the source water could vary over a wide range. The quality of the water leaving the water treatment plant should be constant over time, with low turbidity and a stable pH, and should consistently meet all regulatory requirements. Water must be properly disinfected using chlorine, ultraviolet light, and/or ozone, and have sufficient chlorine (or chloramine) to maintain an adequate residual throughout all parts of the distribution system. The water should be aesthetically acceptable, without offensive taste, odour, or colour.

Table 3–1
Asset Identification: Components of the Small Water System

When water quality changes, even if it remains within allowable limits, there may be implications for the distribution system. Water quality may affect the distribution system components along with residential components such as taps, hot water tanks, dishwashers, etc. Warmer water can lead to faster chlorine residual decay rates, and higher pH water can also reduce the effectiveness of chlorine and chloramine as a disinfectant. Higher pH water can increase calcium carbonate precipitation (scaling) with certain source waters. Varying pH can contribute to changes in internal corrosion rates, in some cases shortening the life of the system or producing corrosion by-products, which can be problematic from an aesthetic and possibly a health point of view. For example, varying pH water in unlined iron mains may create rusty-looking or musty-tasting water, and can lead to unacceptably high concentrations of copper and lead.

In addition, some groundwater may have to be treated to reduce sodium concentrations.

3.2.2 Know and Understand All Applicable Regulations

Each water system operator should be aware of and comply with the regulatory requirements of the province or territory. Operators should review new regulations and, if uncertain about their application, ask for clarification from the regulatory agency. Operators should keep copies of all regulations, fact sheets, etc., readily available for reference. When planning a new water project, the operator should review the plan with the regulatory agency at an early stage.

3.2.3 Become Knowlegeable with the System Assets

The operator of a small water system must be knowledgeable concerning all components of the system, including their location. When they apply to a particular system, the following documents should be centrally located and accessible at all times. The operator should be familiar with the documents.

Table 3–1: Asset Identification: Components of the Small Water System

Assets	O & M	Engineering	Regulatory & Financial
■ System maps ■ Valve location sheets ■ Original construction record drawings/as-built plans/blueprints/shop drawings ■ Operations and maintenance manuals ■ Inventory records, tools, and equipment records	■ Source water, treatment plant and distribution system water quality test results ■ Operations and maintenance daily logs ■ Source water protection plan ■ Wellhead protection plan and contaminant source inventory ■ Emergency response plans and contingency plans ■ Flow meter records, pumpage records ■ Hydrant and pump flow tests	■ Engineer's reports and condition assessments ■ Feasibility studies and hydro geological studies ■ Raw water quality assessments/source water characterization reports ■ Design reports ■ Well drilling records (drillers logs)	■ Provincial and federal water regulations ■ Permits to take water/water rights ■ Provincial/federal ministry of environment approvals/certificate of approval (C of A) ■ Capital investment plan ■ Operating permits and conditions

3.2.4 Become Knowlegeable with the System's Condition

The water system operator needs to be fully aware of the condition of all the components of the system. This is the first step in understanding any problems that may be encountered during operation of the system and when planning upgrades or expansions. In many jurisdictions, regulations mandate the need to monitor and document the condition of the system, and require that plans be in place to upgrade any components not performing satisfactorily or not meeting current regulation or code requirements. A well-operated small water system must have maintenance and testing logs and log books, which are used to keep a record of all activities, routine and non-routine, undertaken on the system. The documents and records listed in **Table 3–2** should be obtained (as appropriate), reviewed, and acted upon. Any missing information should be taken into account when determining what studies and inspections need to be performed.

Hydraulic studies (including pressure testing, flow testing, water loss studies, C–factor testing, and calibrated computer modelling for pressure, transient analysis, residence time, chlorine residual, and contaminant dispersion, as well as community complaints) can all provide useful information regarding inadequacies in the existing system.

An operational performance assessment performed by a qualified person can identify weaknesses in current O&M activities. The potable water best practice, *Deterioration and Inspection of Water Distribution Systems* (InfraGuide, 2002a), provides guidance regarding water distribution system condition assessments. *Best Practices for Utility-Based Data* (InfraGuide, 2003a), provides additional recommendations regarding data collection and management. (There is more discussion regarding record keeping in **Section 3.2.11**).

Table 3–2
Documentation Tracking Water System Conditions

In many jurisdictions, regulations mandate the need to monitor and document the condition of the system, and require that plans be in place to upgrade any components not performing satisfactorily or not meeting current regulation or code requirements.

Table 3–2: Documentation Tracking Water System Conditions

Documents	Description
Reports	■ Engineering reports (mandated in some provinces): These describe the current state of the system and any upgrades required to meet current regulations. ■ Inspection: Intake or wellhead (down hole and site), treatment plant, reservoirs, dams, distribution system components (pipelines, valves, and hydrants). ■ System reports: Loss reports, water audits, and leak detection studies. ■ Watershed management implemented plans. ■ Studies: Feasibility and hydrogeological.
Tests	■ Results: Well Water Level Step test, drawdown test, pump and motor tests (capacity, vibration, megohmmeter), calibration, and electrical inspections.
Records	■ Outages, breaks, and repairs. ■ Hydrant flushing records, valve exercise records, maintenance logs, and diaries. ■ Maintenance records: Maintenance logs and diaries. ■ Water quality complaint records. ■ Water main flushing records. ■ Frozen water services list. ■ Well maintenance. ■ Reservoir cleaning.

For most small water systems, operators are the only people able to understand all aspects of the system and should be consulted on the development of plans for investments in system expansion and upgrade.

3.2.5 Determine What is Needed for Intended Levels of Service

Each small water system has a specific mandate, established by the owner or by regulation. The service standards the system should be meeting—water quality standards, aesthetic standards, minimum pressure, reliability, water main break repair response time, standby capacity in case of source water supply disruption (storage) or power supply disruption (standby power)—must be established so system performance can be measured against them and areas for improvement can be determined. Additional recommendations on this topic are available in *Developing Levels of Service* (InfraGuide, 2002b).

3.2.6 Have a Plan to Upgrade Inadequate Components

For most small water systems, operators are the only people able to understand all aspects of the system and should be consulted on the development of plans for investments in system expansion and upgrade. Depending on the condition of the system and the experience and training of the operations staff, external expertise may be required to facilitate development of the plan. Operators should have a plan to address employee and public safety as well as protection of public health.

Improvements should be prioritized based on their cost-benefit ratio in terms of providing safe, reliable water and complying with current and anticipated regulations. The plan may have short- and long-term activities, depending on the situation. In the past, many operators paid insufficient attention to protecting their source water, and did not have source or wellhead protection plans in place. Such plans should be completed as soon as possible. One improvement that may arise from these plans is a groundwater protection policy. They are typically implemented through the planning process, and restrict land uses and activities in the capture zone of the well or wells. For surface water sources, protection of the watershed can usually be achieved by working with other stakeholders and agencies.

When considering improvements to the distribution system, operators should evaluate system reliability, the need for looping and main sizes to reduce residence times or increase fire flows (determined by hydraulic modelling and fire flow testing, chlorine residual testing, and water quality complaint records). Other considerations include rehabilitation or replacement of mains with a limited remaining useful service life. These topics are further elaborated in *Developing a Water Distribution System Renewal Plan* (InfraGuide, 2003b) and *Selection of Technologies for Rehabilitation or Replacement of Sections of a Water Distribution System* (InfraGuide, 2003c).

3.2.7 Maintain Disinfection Residuals

Primary disinfection in a water treatment plant is standard practice to kill or inactivate microbiological organisms, thereby reducing the threat of waterborne disease outbreak. Once water is treated and enters the distribution system, many mechanisms can contribute to the deterioration of the quality of the water and, in some cases, the water can become unsafe to drink. Some of these mechanisms are discussed below in the sections on maintaining minimum system pressures and preventing backflow. The system may also contain bacteria or other micro-organisms that are present as a biofilm on the walls of pipes or in sediments within the pipes.

Maintaining an adequate disinfection residual (also known as secondary disinfection) and positive pressure of greater than 140 kPa (20 psi) in all parts of the distribution system will help ensure that the water being delivered to customers is safe. Chlorination or chloramination (the addition of ammonia or ammonium compounds to chlorinated water) is recommended (and often mandated by regulations) to protect water quality after it leaves the treatment plant and enters the distribution system. With an adequate disinfectant residual, the water should be as safe as it was when it left the supply facility unless a backflow or breach of the system occurs. Residual monitoring is, therefore, extremely valuable as a relatively quick and inexpensive means to assess the micro-biological safety of the water in the distribution system.

Regulations governing operations of water systems and best practices dictate that the operator implement a set plan of action if a chlorine residual test fails (i.e., the residual level of free chlorine measured in the sample is below the regulatory minimum). It is considered a best practice to maintain a target residual-free chlorine level, which is higher than the regulatory minimum in all parts of the water system. The action plan to be implemented if a chlorine residual is lower than the regulatory minimum will be influenced by regulations and operational permits, but should include retesting, flushing, and notification of the medical officer of health, ministry of the environment, and other appropriate regulatory agencies. The plan of action should also outline the procedure to restore the required chlorine residual in the system and prove its presence with retesting. In addition, this action plan should be implemented when the chlorine residual changes suddenly. The action plan should include an investigation of the causes of the reduction in chlorine residual.

Water quality management includes various activities to ensure the water delivered to the customer meets all regulatory and aesthetic requirements set for the system. These activities could include monitoring, analyzing test results for trends, modelling residence time and deterioration of disinfection residual, regular flushing of portions of the system with excessive residence times, and system improvements (such as the installation of looping mains and pressure-reducing valves) to improve circulation and reduce residence time for water in the system.

When chlorine reacts with natural organic material found in some source waters, disinfection by-products, such as THMs[2] and HAAs[3] can form. The concentration of these by-products is regulated in all provinces and territories because, in high concentrations, they can pose a risk to human health. If the operator maintains too high a chlorine residual in portions of the distribution system, and high levels of organics are present, then unacceptably high levels of disinfection by-products may result. The challenge for the operator is to maintain an adequate chlorine residual in the most remote parts of the system (e.g., farthest from the water treatment plant) while not creating too high a chlorine level in the system. Occasionally, structural changes, such as looping, automatic (or manual) flushing, or chlorine booster stations, are required to achieve this balance.

The best practice, *Water Quality in Distribution Systems* (InfraGuide, 2003d) provides additional information and recommendations regarding maintenance of water quality in distribution systems. *Water Chlorination Principles and Practices* (AWWA, 1992a), provides more detail regarding the use of chlorine in water systems.

3.2.8 Maintain Positive Water Pressures

If a part of the system experiences negative pressures (i.e., vacuum), groundwater or soil may enter the system at the location of a leak. Negative pressure can be due to pump failure, pressure transients from a pump starting and stopping, valve operation, or electrical outages. Negative or reduced pressures may also cause backflow (also known as back siphonage). Backflow is a concern when chemicals or non-potable water are drawn back into the distribution system from a customer's premises. Negative pressure in one part of a system may result from pressure transients, or abnormally high flows in another part of the system, such as a water main break, opening several hydrants to fight a large fire, or improper valve operations that can shut down supply to a portion of the system. Pressure transients can also occur if hydrants are opened or closed too quickly.

Regulations governing operations of water systems and best practices dictate that the operator implement a set plan of action if a chlorine residual test fails (i.e., the residual level of free chlorine measured in the sample is below the regulatory minimum).

2. Trihalomethanes (THMs) — Commonly occurring by-product of disinfection [with chlorine].

3. Haloacetic acids (HAAs) — Commonly occurring by-product of disinfection [with chlorine].

Contractors should not be permitted to operate valves or hydrants without approval from the municipality, or diverge from accepted operating practices.

To prevent frequent occurrences of negative pressures in the distribution system, the system needs to be designed to maintain at least 140 kPa (20 psi) during maximum day demand operating conditions, including fire flows. If a portion of a distribution system cannot maintain at least 140 kPa, then a boost station or other measures may be required. Sudden pump stoppages due to a power failure are a common cause of pressure transients. Some small water systems are equipped with hydro-pneumatic tanks to provide positive pressure until a backup generator can start. In other cases, elevated storage can maintain positive pressure without pumps running. These design issues should be considered if any upgrades or expansions are planned, or if negative pressure situations have been identified as a problem.

A cross-connection occurs when a potable water supply line in a facility is connected to a non-potable line, such as wash water in a barn or manufacturing facility.

The risk of contaminant intrusion into the water system is a function of the number of leaks, the frequency and severity of negative pressure situations, and the presence of contaminants in the ground and groundwater surrounding the water mains. Certain measures may be undertaken by the operator to minimize the risk of loss of system pressure.

- Carry out standard O&M procedures for valves and hydrants. Monitor pressure on the upstream or downstream side of a hydrant during flow tests; operate valves slowly to prevent pressure transients; plug drain ports and vacuum out water in hydrants where the water table is high; do not use antifreeze in hydrants since it could be drawn into the distribution system.
- Maintain the distribution system in a good state of repair, to minimize the size and number of leaks and freezing incidents. Have a plan to rehabilitate or replace deteriorated mains.
- Install and maintain surge control equipment at pumps and other critical locations. Surge control devices include air chambers, air/vacuum valves, surge relief valves, check valves, pressure-reducing valves, elevated storage or hydro-pneumatic tanks, pump control valves and variable speed pumps.
- Install and maintain backup pumps and a backup power supply (usually diesel generator sets).
- Ensure underground chambers are cleaned and dewatered to prevent water from entering a vacuum relief valve. Drain chambers to a storm sewer.

3.2.9 Implement Backflow Prevention and Cross Connection Control Programs

Backflow may occur if a customer has a water line connected to a chemical mixing tank or dirty water sink without an air gap or suitable backflow prevention device. Backflow can also occur if a directly connected mixing pump in a private facility generates higher pressures than the water line pressure, and causes flow from the plant into the water system. Private wells and cisterns can also be sources of contamination. A cross-connection occurs when a potable water supply line in a facility is connected to a non-potable line, such as wash water in a barn or manufacturing facility.

Backflow can also occur during improper filling of a water truck. Filling should only be done with a suitable air gap or a reduced pressure backflow device. This, and other risks from hydrant usage, can be mitigated by installing a bulk water station, where an air gap is maintained during all filling operations. The fire department may also introduce contamination if it uses a fire truck in a rural environment (drawing non-potable water) and then hook up the same truck to a hydrant.

The small water system operator should audit the system for potential backflows and cross-connections, and implement a public/industrial user/agricultural user education program. Many water systems require all new non-residential customers to install a backflow prevention device on their domestic sprinkler service lines. It is recommended that a municipality create a backflow bylaw as the first part of a backflow/cross-connection program. *Recommended Practice for Backflow Prevention and Cross-Connection Control* (AWWA, 1999a) provides detailed information on implementing a program of backflow prevention and cross-connection control. Methodologies for Setting a Cross Connection Control Program (InfraGuide, forthcoming) is also an excellent reference document.

3.2.10 Monitor Water Quality

Regulatory Requirements
Most jurisdictions in Canada require the small water system operator to perform tests to confirm the water delivered to customers is chemically and biologically safe in accordance with the Guidelines for Canadian Drinking Water Quality. As noted earlier, testing to prove chlorine or chloramine residual in all parts of the distribution system is a surrogate method of confirming the absence of microbiological contaminants and waterborne disease. Specific conditions on the provincial ministry of environment certificate of approval or permit to operate may dictate more frequent testing or testing for other parameters. **Appendix A** lists standard water quality tests and typical test frequency and maximum acceptable concentrations for various water quality parameters.

Routine Monitoring Beyond Regulatory Requirements
In some cases, the operator may need to monitor for other parameters (or at higher than regulated frequency) to optimize the treatment processes to ensure delivery of high quality water to the customer. Reasons for additional testing may include specific characteristics of source water (taste and odour), system layout, flows, materials, critical users (e.g., hospitals), contaminated areas (e.g., hydrocarbons can permeate through some pipe and gasket materials under positive pressures) and areas with a history of complaints.

Non-Routine Monitoring
The small water system operator should institute special sampling and testing to assess non-routine events, such as power failure, flooding or very heavy rains in the watershed, receipt of a water quality complaint, a water main break, construction of a new water main, or connection of a new customer.

3.2.11 Maintain Comprehensive Programs

Small water system operators need to maintain water quality testing and complaint records (refer to **Appendix D**), analyze them, and act on the findings. They also need to maintain records of water main breaks and repairs, unusual events (e.g., extreme weather, natural disasters, power outages), and records of all studies, upgrades, and expansions of the system (water source, treatment plant, reservoir, distribution system).

Operators must be able to refer to historical test and repair data as well as previous studies, reports, and drawings to identify trends over time. Ideally, a water system operator would have a centralized database containing water quality monitoring test results (source water, treatment plant, and distribution), system information (drawings and maps), equipment and pipes (materials, ages, repairs), customer information (usage, contact numbers, complaints, responses to complaints), as well as planning and financial information (growth forecasts, capital and operating budgets, and records of actual operating costs including labour, electricity, chemicals, supplies, and equipment).

Electronic storage of data is preferred over paper-based systems, because it is easier to store and analyze the data and maintain an off-site backup. Paper-based storage systems need to be secure, and consideration should be given to retaining copies of critical information at a second location.

Operations records, including test results, should be retained for at least five years or as specified in provincial regulations. Water quality complaints and repair records are often stored by street address and are

Although this best practice deals specifically with water quality monitoring within the distribution system, it is highly recommended that continuous online monitoring of both chlorine residual and turbidity take place at the entry point to the distribution system.

sometimes referenced by map grid co-ordinates. Some water systems use a geographic information system (GIS), which links databases to computer-based mapping so data can be retrieved by clicking with a computer mouse on a hydrant, valve, or address shown on a map. Others use a global positioning system (GPS) to record the location of new construction or repairs, and map precisely the location of visible appurtenances, such as hydrants, valves, and curb stops. A GIS or GPS may be an option for a small water system if funds are available.

Analysis of source water changes over time can indicate trends that may require changes in the design or operation of the water treatment plant.

A water system operator should review test results and water quality complaints to determine any trends. Analysis of source water changes over time can indicate trends that may require changes in the design or operation of the water treatment plant. Analysis of treated water changes over time can indicate whether the treatment plant is producing the desired water quality and may also indicate problems with some of the equipment.

A spatial and temporal analysis of break records will provide an indication of the structural condition of water mains. Analysis of frozen water services and correlation with air temperature records can be used to create a predictive model and allow the operator to issue instructions to specific customers to run their taps to prevent the occurrence of a frozen service.

Records can also be analyzed for water main age and materials, break records and inspection reports, along with information about aggressive soils, to predict the remaining service life of water main segments. This information can be used to plan replacements so they can be budgeted for and co-ordinated with surface road reconstruction or sewer replacement.

The *Best Practice for Utility-Based Data* (InfraGuide, 2003a), provides additional information and recommendations regarding collection and uses of water system data.

3.2.12 Ensure Repars and New Construction Follow Prrocedures

Repairing broken mains, valves, hydrants, and services must be done in a manner that is safe for the worker, the public, and the water customer. During a repair, if the water is turned off, the isolated line is no longer pressurized, and leaks and joints provide an opportunity for contaminant intrusion. The specific site where the break is exposed must be kept sanitary, and all water system components must be disinfected by immersing or swabbing with a chlorine solution or other disinfectant so the risk of contamination is minimized.

On completing the repair, an assessment must be made as to how the line is to be returned to service without risking contamination to the rest of the system. Depending on the nature of the break, it may be necessary to keep the line out of service long enough to disinfect it, charge it with potable water, and test for chlorine residual. As a minimum, the line should be completely flushed through available hydrants or other discharge outlets. The water should then be tested to confirm an adequate disinfection residual before being reconnected to the potable water system. Standard operating procedures for preventing contaminant intrusion, isolation of the work area, repair, methods of disinfection, flushing, monitoring, safe disposal of flushing water (i.e., the water may need to be dechlorinated if discharging to sensitive streams), bacteriological samples, and dechlorination should be developed and implemented.

For new water mains in the system or for connecting new plumbing to the system, very stringent procedures for disinfection, removal of any construction debris following installation (by swabbing or other means), charging the main, conducting leakage tests, proving the main is safe by testing for microbiological quality and chlorine residual, and then connecting, are necessary.
A co-ordinated approach between the water system operator and the plumbing inspector will help ensure proper practices are followed on private property.

American Water Works Association (AWWA) **Standard C651–99** describes procedures for disinfection of repairs, new mains, and connections to existing mains. The best practice, *Water Quality in Distribution Systems* (InfraGuide, 2003d), provides additional recommendations.

All repairs and construction should use approved materials. Water system components are expected to provide service for decades, and care should be taken to ensure that approved, durable, and safe products are always used.

The small water system operator will benefit from establishing a standard list of approved products. The water system is easier to operate and maintain if all valves are standardized with respect to the direction to open, all hydrants have the same internal workings, and all pipe materials are standardized. This practice means fewer pipe and clamp sizes, appurtenances, and replacement parts have to be stocked. Water system components should meet appropriate CSA standards and NSF/ANSI Standards 60 and 61. The AWWA also produces standards for water system components, such as valves and hydrants.

3.2.13 Monitor Corrosion

Corrosion of metallic components of the water system causes several problems including water quality complaints (rusty or red water), water quality health risks (elevated lead levels in the water), leaks and breaks, and reduced service life. External corrosion is caused by damage, or lack of protective measures, and by aggressive soils. Corrosion to the inside of metallic water mains can occur if they are unlined and soft, or aggressive waters are present, or the water has a low pH (more acidic). Note that the relative corrosiveness of low pH water is affected by its softness; the softer the water, the more corrosion potential there is for unlined metallic pipes.

Small water system operators should know the pipe age and materials in their system, and monitor for problem areas, which may indicate aggressive soils. Observing the external and internal condition of the pipe at any new connection or break locations will also indicate the severity of corrosion in the system. Where problems are encountered, mitigation measures, such as cathodic protection, can be evaluated for cost effectiveness. Internal corrosion needs to be controlled to maintain water quality and prolong the life of the unlined water mains. Internal corrosion of unlined cast iron water mains can be addressed by corrosion control measures (including managing the pH of the water) and can be prevented by rehabilitating pipes with cement or epoxy. In some cases, it may be necessary to replace metallic pipes and appurtenances.

Lead water services and lead joints on old cast iron pipe can leach lead into the water, particularly when the pH of the water is low or very high (over 8.5). Exposure to lead is considered a health risk. To address this problem, water system owners should implement programs to replace all lead water services and lead jointed pipe. Where systems are known to have lead services, residents should be reminded regularly to run their taps before using the water for drinking or cooking, particularly when the water pH is below 7.

The manual, *Economics of Internal Corrosion Control* (AwwaRF, 2002), can be used to determine the most cost-effective method of addressing internal corrosion. The AwwaRF has also conducted a study specifically looking at rehabilitation and replacement of water services (Boyd et al., 2001[4]). Health Canada is developing a guideline for internal corrosion control (Bernard, 2002[5]).

Where problems are encountered, mitigation measures, such as cathodic protection, can be evaluated for cost effectiveness. Internal corrosion needs to be controlled to maintain water quality and prolong the life of the unlined water mains.

4. AwwaRF Study (Boyd, et al, 2001)

5. Health Canada Guidelines for internal corrosion control (Bernard, 2002)

The potable water best practices, Establishing a Metering Plan to Account for Water Use and Loss (InfraGuide, 2003e), *Water Use and Loss in Water Distribution Systems* (InfraGuide, 2002c), *and Speed and Quality of Linear System Repairs* (InfraGuide, 2004) *provide additional information and recommendations regarding this topic.*

3.2.14 Determine Water Losses From the System

Many small water systems have no (or few) flow meters, and the operator has little information about the distribution of water demands in the system. Metering customer usage and billing based on usage encourages conservation. Strategically placed meters can be very helpful in identifying major leaks within the water system, and fixing these leaks can result in reduced costs for chemicals and electricity. Metering the water drawn from the source and the output from the water treatment plant, plus analysis of customer meter records can provide a good estimate of water use and loss. This includes leakage, worn (underreporting) and unmetered uses, such as bulk water taking, street flushing, water main breaks, water main flushing, and firefighting. Unmetered uses and underreporting meters can be estimated, providing an estimate of leakage from the system. Higher leakage rates cost money and indicate higher risk of contaminant intrusion.

If a small water system has inappropriate water losses (either apparent or real), it may be economically worthwhile investigating the losses and taking action to reduce them. Multi-zone water systems can implement zone pressure monitoring and zone metering to assist in leak detection.

The potable water best practices, *Establishing a Metering Plan to Account for Water Use and Loss* (InfraGuide, 2003e), *Water Use and Loss in Water Distribution Systems* (InfraGuide, 2002c), and *Speed and Quality of Linear System Repairs* (InfraGuide, 2004) provide additional information and recommendations regarding this topic.

3.2.15 Maintain Source Water Intakes, Dams, Wellhead Sites, and Aquifers

If dams, intakes, and wells are remote, they may not be visited frequently by the water system operator. Remote sites may be more susceptible to vandalism and therefore, should incorporate minimum security measures, such as fencing with locked gates. The water system operator should regularly inspect the site and maintain records of the inspections. If the intake is only accessible by diving, inspections should be conducted at least annually. Similarly, wells may require routine rehabilitation to maintain water quality and quantity. A down hole camera inspection and testing may also provide useful information to maintain proper operation. A poorly performing well can generally be rehabilitated, if the problem is detected and acted upon promptly.

The intake, dam, or wellhead should be evaluated and a protection plan developed to identify measures to improve the site. Items to be evaluated include security, safety, contaminant intrusion, wildlife, power supply, access, drainage, erosion, and flooding. In some jurisdictions, regulations mandate submission of intake, dam, and well inspection reports.

3.2.16 Maintain the Water Treatment Plant, Pumping Stations, and Storage Facilities

Small water systems may incorporate a wide range of water treatment methods, equipment, and facilities, depending on the size of the system, when it was constructed, and the nature of the source water for the system. The intended use of the water and the regulations will also determine, to a large extent, what level of treatment is required.

The water system operator needs to ensure the water treatment plant is operating as intended and is producing the desired quality of water. The operator should be aware of seasonal fluctuations in raw water quality that might affect the treatment process. In addition, the operator must regularly inspect, monitor, and maintain the equipment to ensure reliability. Most treatment plants have an O&M manual that gives guidance on operations, maintenance, and inspection procedures. If an O&M manual does not exist, it should be prepared.

The operator is responsible for ensuring that adequate chemicals, cartridge filters, supplies, and spare parts are on hand to allow the plant to operate and carry out maintenance and minor repairs promptly. All activities at the plant must be carried out in a manner that is safe for both the worker and the water supply. As with all other aspects of operation, activities and monitoring at the plant must be properly documented. If the plant includes a laboratory for routine testing, the operator must ensure the lab is properly equipped with supplies and maintained in a clean state.

If upgrades are considered for the water treatment plant, expert advice is usually required. If treatment plant expansion is contemplated, it may be prudent to design parallel systems, so if one side is taken off-line for repair, water treatment capability remains, albeit at a reduced capacity.

Small water systems may also utilize pumping stations and storage reservoirs. These facilities also require that regular inspection, monitoring, and maintenance activities are carried out to ensure reliability. An O&M manual is also recommended to provide guidance on operations, maintenance, and inspection procedures.

3.2.17 Exercise and Inspect Valves and Hydrants

The small water system may have a limited water main network, and every valve may have to be operable to isolate a break in the system. If a valve does not work when needed, the entire system may need to shut down. The operator should ensure that each valve is fully operable. This is achieved by regularly exercising (operating) each valve, inspecting it during the operation, and recording the findings. The operators should know and document the locations of valves for the whole water system, from isolating the source to a section of the distribution system. The location plans should be easily accessible.

Hydrants are critical for fire protection and represent a possible pathway for contaminants to enter the water system. Hydrants, with their isolation valves, must also be exercised and inspected at least annually (or more frequently if required by the provincial fire code), with critical locations (such as the valve at the wellhead) checked more frequently. Air release, vacuum breaker, or pressure-reducing valves should be inspected at least every six months. These valves will usually have an O&M manual, which describes how they are to be inspected and maintained.

Valves and hydrants should always be operated in accordance with standard operating procedures to ensure the operation is done safely and with minimal risk of creating a pressure surge (water hammer) that may lead to negative pressures in the system, stir up sediment in the pipes, or damage some component of the system (such as a water main break). See AWWA (1999b).

The operators should know and document the locations of valves for the whole water system, from isolating the source to a section of the distribution system.

3.2.18 Flush and Swab Water Mains

Water mains can accumulate sediment, biofilms, and corrosion-related encrustations over time, and these materials can be entrained in the water during unusually high flows or flow reversals. Even if they are not loosened, these materials can become a refuge for bacterial growth, which can lead to water quality problems. The small water system operator should consider flushing (discharging high volumes of system water out through hydrants) or swabbing (flushing foam swabs through the main and out at a dismantled hydrant) to address water quality concerns in a particular area. Furthermore, operators should consider having a regular program of flushing and swabbing water mains so buildup is removed from the system before it becomes problematic. Flushing is commonly used in low demand areas (e.g., dead-ended mains) to reduce residence time. Swabbing can be used to clean mains to restore their hydraulic capacity.

Uni-directional flushing is the most effective method of flushing a water distribution system. A uni-directional flushing program should start at the source and progress into the system from the largest to the smallest mains in a systematic manner. It achieves greater benefit with less water than random flushing of hydrants. A flushing program requires

A maintenance management system will help the operator plan and implement routine maintenance and will facilitate record keeping of planned and emergency maintenance activities.

notifying users, monitoring adjacent system pressures (to avoid negative pressures), testing water quality after flushing, managing traffic around work sites, and maintaining public safety (especially where hydrants are discharging). To achieve biofilm removal, the flow velocity through the main must be at least 1.5 m/s. This flow rate requires lots of water for larger diameter water mains. If the system cannot provide that water, and maintain at least 20 psi (140 kPa) throughout the system, then flushing will not be effective for biofilm removal, and swabbing may be considered.

Swabbing can be undertaken in the same manner as flushing, and requires less water; however, it takes more time and is more costly. The swabs must be introduced into the main before they can be flushed in a certain direction, usually via disassembly at a hydrant and temporary installation of swab launchers. Care must be taken to ensure that the swab does not have any opportunity to travel in the wrong direction and get lost in the system. Swabs should be moving at a minimum velocity of 0.75 m/s to gain maximum benefit (effectively agitate the water for debris removal and to provide effective contact with the pipe wall). Velocities above 0.9 m/s enable the swab to ride over debris. Swabs come in varying degrees of density, with the denser swabs being more abrasive on encrusted mains, but they are harder to launch and retrieve. Pigs (which are like swabs but rigid and much more abrasive) should only be used as part of a relining or other rehabilitation program, and are not recommended for routine maintenance activities.

3.2.19 Use a Maintenance Management System

A maintenance management system is a tool used to record and plan maintenance activities. Computerized systems are available for any size system and offer trend analysis and reporting. A maintenance management system will help the operator plan and implement routine maintenance and will facilitate record keeping of planned and emergency maintenance activities. Preventive maintenance may also reduce staff costs as unscheduled call-outs or overtime work is reduced.

3.2.20 Maintain a Spare Parts Inventory

Water system operators must maintain an adequate inventory of spare parts, equipment, repair clamps, pipes, and valves along with proper tools to allow prompt response to breakdowns. Operators should evaluate what critical or long delivery parts should be stocked and estimate demand based on historical usage of parts and the historical life of equipment. As a minimum, one of each spare part item (e.g., valve) should be stocked for each 10 km of water main in your system. Where geographic proximity makes it feasible, water departments/ utilities in adjacent municipalities may want to share an inventory of some spare parts to reduce inventory cost and storage requirements. It may be possible to arrange with suppliers/dealers to stock some spare parts in convenient locations. In addition to spare parts, it is essential to have on hand the tools and equipment needed to do the work.

3.2.21 Prepare a Contingency Plan for Emergencies

Water systems must be reliable under all operating conditions. The small system operator should know how the system responds to unusual operating conditions. This knowledge can be challenging to obtain. The small water system operator can develop a series of “what if” scenarios (e.g., “What if we have an ice storm and lose power for three weeks?”) and note the relative risk, and likely consequences that could occur for each event. The higher-risk or higher-consequence events can be prioritized, and response plans developed for each scenario. One method of learning how the water system will perform under unusual conditions is hydraulic modelling. A computer model can be created and calibrated with actual hydrant flow tests. Then the model can be used to represent various emergency scenarios.

Many of the unusual operating conditions experienced with water systems also involve the fire department. As partners in providing fire protection for the municipality, operators need to share knowledge of the water system based on past experiences and the findings of current study activities, and agree on standard operating practices (e.g., for hook up to hydrant, shut down hydrant flow, fire pump operation).

Operators should meet regularly with the stakeholder teams (e.g., public health, fire, regulatory agency personnel, and large customers), develop emergency response plans, contingency plans, and public/media contact protocols. In most jurisdictions, regulations dictate who is in charge in the event of an emergency. This should be discussed and understood by all stakeholders. If there is a local emergency operations centre, the water department should be an active member.

Emergency preparedness involves learning from past events and being aware of how to respond quickly when an event unfolds. Whenever an event is underway which may pose an unusual operating condition, a licensed operator should be assigned to monitor and operate the water system components, and report on the event. Advice on planning for emergencies can be found in *Emergency Planning for Water Utilities* (AWWA, 1999c).

Another study and planning area for the water system is the evaluation of risk of water system contamination by physical disruption or terrorist attacks. Vulnerability assessments should be conducted on all components of the water system. Considerations that arise from these assessments include controlling access, access alarms, and performing security background checks on all staff.

3.2.22 Prepare a Financial Plan to Ensure System is Sustainable

Small water system operators are the principal individuals concerned with the way the system functions on a daily and long-term basis. Operators should know the unit cost of production of water, including staff, electricity, and chemical costs. Operators should also know the regulatory requirements in their province/territory regarding management of water systems, which may include mandated financial planning for the full life cycle costs of their systems. Operators should also develop short- and long-term capital spending plans for all components of their system (source water, water treatment plant, distribution system) and provide input to capital budgets. *Investment Parameters for Municipal Infrastructure* (InfraGuide, 2003f) and *Alternative Funding Mechanisms* (InfraGuide, 2002d) provide additional information and recommendations regarding this topic.

3.2.23 Maintain Excellent Public Relations

Operators should provide prompt and courteous customer service. The importance of customer confidence and satisfaction is increasing as water costs increase, and in light of recent events in Canada. Operators should establish standard operating practices for recording, addressing, and following up on customer water quality or other complaints.

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It is important to maintain communications with customers and other stakeholders. Operators should make available to their customers routine water quality test results. Operators should communicate with customers before shutting off the water, explain the reason for the shutdown and predict the duration of disruption. For some customers, such as home dialysis patients, research facilities, and many food-processing industries, water disruptions can be critical. Other stakeholders include the medical officer of health, ministry of the environment, regulatory agencies, fire department, major industries, conservation authorities, non-governmental organizations,