WATER QUALITY IN DISTRIBUTION SYSTEMS

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide to Sustainable Municipal Infrastructure

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Water Quality in Distribution Systems
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FOREWORD

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

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

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

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

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments, and suggestions from various stakeholder groups, which shaped the enclosed document. Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g., geographic location, municipality size, climatic conditions).

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

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This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide's Potable Water Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and by R.V. Anderson Associates Limited in association with Hydratek Associates and Reseau Environnement.

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EXECUTIVE SUMMARY

This document outlines the best practice for maintaining water quality in distribution systems. It is based on a literature review, questionnaires sent to 10 municipalities across Canada, and input from water quality and distribution experts from across Canada.

Multi-Barrier Approach
In recent years, many municipalities have adopted a multi-barrier approach to safe drinking water that includes source water protection, treatment, disinfection, proper design, operation, and maintenance of the distribution system, and water quality monitoring. This best practice addresses the water quality changes that may occur between the water supply facilities and the point on the water service piping at the property line.

"Water can be considered a perishable product and has a shelf life (detention time), a preservative (chlorine or chloramines), and packaging (pipes and reservoirs)" (AwwaRF, 1999). Water quality problems can result from internal reactions or from interactions between water and the pipe wall. As the travel time increases through a distribution system, the potential for reactions also increases allowing additional formation of contaminants that may be of concern. The United States Environmental Protection Agency has published nine white papers that address potential health risks associated with water quality in distribution systems.

Common Water Quality Problems
Common water quality problems that can occur in distribution systems can be categorized as biological (at the micro and macro levels), chemical/physical, and aesthetic. Microbiological problems include bacterial regrowth, nitrification, and waterborne disease originating from microbial pathogens. At the macro level, worms and insects can be problematic. Chemical/physical problems include disinfection by-product formation, leaching of lead and copper, pH stability, corrosion and scale formation, by-products of coatings and linings, disinfectant residual, and sediment. Aesthetic problems include taste and odour as well as colour and general appearance. Aesthetic problems are often linked to chemical/physical issues.

Benefits and Risks
By following this best practice, a municipality can reduce risks to public health, reduce customer complaints, reduce corrective maintenance, defer costly replacement, and provide due diligence. Additional resources will be required for most municipalities to implement this best practice. If a municipality follows this best practice or similar ones, then there is potential for a decreased risk of waterborne disease outbreak and boil order advisories. Municipalities can also expect to receive fewer complaints regarding water quality with a consequent

increase in public confidence in the water utility staff and the water supply system as well as a decreased risk of liability.

Proactive approaches to water quality help to identify and mitigate problems before they occur, thus reducing potentially expensive investigative costs and providing due diligence.

Best Practices

The best practice for maintaining water quality includes the practices outlined in an AWWA Policy Statement (AWWA, 2001a) as well as several other management practices. These practices are summarized as follows:

- Produce high quality water.
- Maintain adequate disinfectant residuals.
- Maintain positive water pressures.
- Provide comprehensive water quality monitoring throughout the distribution system.
- Implement a backflow prevention program.
- Flush/swab the water mains.
- Control valve and hydrant operations.
- Implement a biofilm control program.
- Control the blending of water sources.
- Properly design and operate storage facilities.
- Regularly monitor, inspect, and maintain storage facilities.
- Properly design and operate distribution systems.
- Rehabilitate/replace water mains.
- Control internal corrosion.
- Use approved materials.
- Utilize appropriate pipe installation and disinfection procedures.
- Conduct vulnerability assessments.

- Use calibrated computer models.
- Provide operator training and certification, and utility accreditation.
- Communicate with stakeholders.
- Provide customer service.

Applications and Limitations
These practices are intended to apply to all municipalities across Canada regardless of size. However, these practices must be tailored for each municipality to reflect the size of the distribution system, source water quality, treatment, distribution system characteristics, and local regulatory requirements. Small municipalities may find it challenging to meet all the recommended practices. They typically do not have all the resources necessary to design, operate, and maintain water distribution systems in a manner recommended in this best practice. Although the practices can be tailored to each municipality, utilities must not compromise on any practices that are required to protect public health.

Evaluation
Several measures can be used to evaluate the success of the practices to maintain water quality in distribution systems, including reduction in the number of water quality complaints and non-compliant samples, reduction in the frequency of low disinfectant levels, and reduction in the cost for corrective measures thus reducing the potential for waterborne disease outbreaks and boil order advisories. The best practice recommended in this document will cost most municipalities additional resources to implement in the form of preventive measures. However, savings, while not immediate, will be realized through commitment to this best practice.

1. GENERAL

1.1 INTRODUCTION

This document outlines the best practice for maintaining water quality in distribution systems. For the *National Guide to Sustainable Municipal Infrastructure*, 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, questionnaires sent to 10 municipalities across Canada, and input from water quality and distribution experts from across Canada. The questionnaire included 21 questions that covered practices to monitor water quality changes, maintain water quality, and respond to emergencies.

1.2 PURPOSE AND SCOPE

This document describes the potential causes of water quality degradation in distribution systems, pumping stations, and storage facilities as well as the measures used to mitigate water quality degradation.

The best practice outlined in this document does not address source water protection, water production, treatment of raw water, or water quality changes that may occur once the water enters private property. Ideally, a potable water system should be operated using a multi-barrier approach (from the source to the consumer's tap). This best practice addresses the water quality changes that occur in the distribution system between the water supply facilities and the point on the water service piping at the property line. Best practices will be developed that look at the other components of a water supply system with the eventual integration of all the elements.

1.3 HOW TO USE THIS DOCUMENT

Section 2 provides a summary of the causes of common water quality problems as well as the benefits and risks associated with implementing this best practice. Section 3 summarizes the recommended practices that should be implemented to mitigate water quality degradation in distribution systems, pumping stations, and storage facilities. 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. References are provided throughout this document for additional information on specific issues.

1.4 GLOSSARY

The following list defines some terms[1] with which readers should become familiar.

Alkalinity — A measure of water's buffering capacity to neutralize acids. A property imparted principally by bicarbonates, carbonates, and hydroxides. It is expressed in units of mg/L as $CaCO_3$.

Backflow — A hydraulic condition, caused by a difference in pressures, that causes non-potable water or other fluid to flow into a potable water system.

Bacteria — A group of one-celled microscopic organisms that have no chlorophyll. Usually have spherical, rod-like, or curved shapes.

Back-siphonage — Backflow caused by negative pressure (vacuum) in the potable water system at the point of interconnection.

Biofilm — A layer of [micro]biological matter that covers a surface.

Chloramination — The process of disinfecting with chloramines [by the addition of ammonia to chlorinated water to kill disease-causing organisms].

Chloramines — 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 dioxide — Disinfectant generated on-site as alternative to chlorine and chloramines

Coliform bacteria — A group of bacteria inhabiting the intestines of humans or animals but also often found elsewhere [in the environment]. Presence of bacteria in water is used as an indication of fecal contamination (contamination by human or animal wastes). [The presence of bacteria in water is used by the operator as an indication of water treatment efficiency or distribution system problems.]

Conventional flushing — Flushing by randomly opening hydrants in a specific area of the distribution system until preselected water quality criteria are met.

Cross connection — A physical connection of a safe or potable water supply with another water supply of unknown or contaminated quality where potable water could be contaminated or polluted.

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[1] Definition of terms taken from AwwaRF (2000b).

CT requirements – The disinfection concentration (C) and contact time (T) requirements of primary disinfection.

Disinfection — The water treatment process that kills or inactivates disease-causing organisms in water, usually by the addition of chlorine [compounds].

Disinfection by-products (DBPs) — Commonly refers to chemical compounds that are formed by the reaction of disinfectants with organic compounds in water. At high concentrations, many disinfection by-products are considered a concern for human health.

***Escherichia coli* (E. coli) —** A bacteria of the coliform group [that indicates fecal contamination by human/animal wastes has occurred and whose presence in water indicates a potential for a serious threat to public health].

Fecal coliform — A bacteria of the coliform group that may indicate the presence of fecal contamination by human/animal wastes (e.g., E. coli). Some other species in the fecal coliform group are not restricted to feces but occur naturally on vegetation and in soils.

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

Heterotrophic plate count (HPC) — A laboratory procedure for estimating the total heterotrophic bacterial count in a water sample. Also called standard plate count, total plate count, or total bacterial count.

Nitrification — The process of forming nitrate from reduced inorganic nitrogen compounds. For water systems practising chloramination, it is generally the conversion of ammonia to nitrite and then nitrite to nitrate by nitrifying bacteria.

Pathogen — A disease-causing organism.

pH — A logarithmic scale of 0 to 14 is used, with a value of 7 being neutral, 0 being extremely acidic, and 14 being extremely alkaline.

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

Tubercle — Deposits of ferric hydroxide on a pipe interior caused by corrosion of iron pipe.

Unidirectional flushing — Flushing by isolating pipe sections or loops in an organized, sequential manner, typically from source to periphery.

2. RATIONALE

2.1 BACKGROUND

2.1.1 MULTI-BARRIER APPROACH

Many municipalities[2] have adopted a multi-barrier approach to safe drinking water. The multi-barrier approach has been defined as "an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health" (CCME and Health Canada, 2002). A multi-barrier approach to safe drinking water contains five major elements: source water protection, treatment, disinfection, proper operation and maintenance of the distribution system, and water quality monitoring (AwwaRF, 2000b). Public education and awareness can also be an effective strategy (i.e., a virtual barrier).

Much has been said and written about the multiple barrier concept and its application in providing protection against waterborne disease. However, most of this information concentrates on the use of conventional treatment in combination with disinfection processes to provide safe and aesthetically pleasing drinking water. Little emphasis has been placed on the distribution system and its role as the final barrier in the multi-barrier approach.

2.1.2 DISTRIBUTION SYSTEMS

Water distribution systems are usually designed to provide sufficient hydraulic capacity to ensure adequate water quantity and pressure for fire flows and peak hour demands. To meet fire-fighting demands, extensive storage is usually provided in a distribution system, and the mains are usually oversized. This results in long residence times, and the distribution system can serve as a vessel for complex chemical and biological changes that can result in the deterioration of water quality. "Water can be considered a perishable product and has a shelf life (detention time), a preservative (chlorine or chloramines), and packaging (pipes and reservoirs)" (AwwaRF, 1999).

Water quality problems can result from internal reactions or from interactions between water and the pipe wall. As the travel time increases through a distribution system, the potential for reactions also increases allowing the additional formation of contaminants that may be of concern. Water quality problems can also be caused due to cross connections, backflow, and back-siphonage.

2.1.3 GUIDELINES FOR CANADIAN DRINKING WATER QUALITY

The *Guidelines for Canadian Drinking Water Quality* (Health Canada, 1996) suggest limits on substances that affect the quality of drinking water. These

[2] Reference to *municipality* (or *municipalities*) throughout this document is also intended to include *utility* (or *utilities*) or other purveyors of water.

guidelines have been adopted by most federal, provincial, and territorial agencies. These guidelines are available at www.hc-sc.gc.ca/ehp/ehd/bch/water_quality.htm.

2.1.4 Health Risks

Water distribution systems are susceptible to several pathways, sources and processes that, if not properly mitigated, could result in potential health risks.[3] These pathways, sources and processes include:

- cross connections and backflow;
- contaminant intrusion;
- internal corrosion;
- unauthorized operation of the system;
- deteriorated pipe and appurtenances;
- permeation and leaching;
- nitrification;
- storage facilities;
- water age;
- repair and replacement of water mains; and
- microbial growth and biofilms.

2.1.5 Water Quality Problems

Common water quality problems in distribution systems can be divided into three broad categories:

- biological, including microbiological and macro-biological;
- chemical/physical; and
- aesthetic.

[3] The United States Environmental Protection Agency (EPA) published nine white papers on these potential health risks. (See the entries in the references at the end of this document.) These white papers can be downloaded from www.epa.gov/safewater/tcr/tcr.html#distribution.

The quality of finished water supplied to the distribution system, detention time, and water temperature can impact water quality in the distribution system. In some cases, aesthetic problems are linked to chemical/physical problems. The following paragraphs describe common water quality problems that could occur in distribution systems and some of the causes of these problems.

2.2 BIOLOGICAL PROBLEMS

2.2.1 BACTERIAL REGROWTH

Although water may be adequately disinfected at a treatment plant, bacteria may regrow within a distribution system if the disinfectant residual is not maintained and bacteria are present in the pipe. Warm water temperature and excessive hydraulic detention time can result in a loss of the disinfectant residual and lead to bacterial regrowth. Coliform bacteria are used as indicators of water treatment efficiency and distribution system integrity.

Biofilms are a consortium of micro-organisms and related microbial materials that coat the interior of pipes and reservoirs. Biofilm formation is affected by substrate materials, water flow rates, available nutrients in the water, water temperature, as well as the type and concentration of disinfectant. Biofilms also release organic contaminants that can react with chlorine to provide undesirable chemical by-products.

Biofilms, corrosion by-products, turbidity and sediment can shield micro-organisms from disinfection and provide nutrients. High microbial counts can be experienced if these biofilms, corrosion by-products, and sediment are disturbed by sudden changes to water quality, flow velocity, or flow direction.

2.2.2 NITRIFICATION

In some systems, chloramination is used as a secondary disinfectant rather than chlorination. Chloramination is usually achieved by the addition of ammonia or ammonium compounds to chlorinated water. Chloramination provides a more stable and persistent disinfectant with fewer chlorination by-products and less chlorinous taste and odour than chlorination.

Water distribution systems that use chloramines for secondary disinfection are potentially susceptible to nitrification particularly during the summer months when water temperatures are the warmest. Maintenance of a combined chlorine residual of at least 1 ppm minimizes the susceptibility. In severe cases, some utilities switch to free chlorine for a short period of time to mitigate nitrification. Nitrification occurs when ammonia is oxidized to nitrite. Nitrification can have a number of adverse effects, including a decrease in chloramine residual, an increase in the heterotrophic bacteria population, an increase in nitrite and nitrate concentrations, and a decrease in alkalinity, pH, and the dissolved oxygen (DO) concentration.

2.2.3 Waterborne Disease

The American Water Works Association (AWWA) Manual M48 (1999d) describes more than 40 viral, bacterial, and parasitic pathogens, effective treatment practices as well as recommendations for monitoring and testing. "Waterborne disease is defined as a disease caused by a virus, bacterium, protozoan or other microorganism capable of being transmitted by water."(AwwaRF, 2000b). The main cause of waterborne disease outbreaks in North America has been problems in the water distribution system (Craun and Calderon, 2001). Breaches in the distribution system can provide pathways for pathogens. Breaches can occur due to intrusion of groundwater through leaks and joints in the distribution system, backflow from non-potable water sources, and poor operation/maintenance practices.

2.2.4 Worms/Insects

Worms and insects can enter the distribution system through finished water storage facilities and cross connections, and live in sediment in the bottom of storage facilities and water mains. Most invertebrates in distribution systems harbour bacteria and protect the bacteria from disinfection. AWWA Manual M7 (1995) describes the identification and treatment of problem organisms in water. This may also be a problem in unfiltered water supply systems where worms and insects can enter via water intakes.

2.3 Chemical/Physical Problems

2.3.1 Disinfection By-Product Formation

Disinfection by-products form when a disinfectant is applied to water containing natural organic material. THMs and HAAs are the primary disinfection by-products in chlorinated water distribution systems, and these compounds are of concern respecting human health at high concentrations.[4] In some cases, it is difficult for municipalities to maintain adequate disinfection residuals in their systems without exceeding the maximum allowable concentrations for disinfection by-products. Therefore, they should consider alternative treatment options or disinfectants.

2.3.2 Lead and Copper

Excessive lead and copper levels may occur at the customer's tap if corrosive water is exposed to lead and copper piping and plumbing materials for extended periods. Corrosion control treatment is used in some systems to minimize the corrosivity of water and control levels of copper and lead in tap water. Under low flow conditions (and in some instances under normal flow conditions) in plumbing, concentrations of lead and copper can be high enough to be of health concern.

[4] Bromate is another disinfection by-product that may form when ozone is applied to water containing bromide, which is not an organic compound.

2.3.3 pH Stability and Scale Formation

Lack of stability or extremes in pH within a distribution system can contribute to problems, such as the following.

- Unstable pH can exacerbate corrosion. Corrosion control treatment requires a stable pH.

- pH can rise if water has a long detention time in asbestos cement and cement-lined pipes. Such a situation can accelerate the formation of THMs. Water with a high pH should be neutralized before it is flushed into a storm sewer or watercourse since water with a high pH can be detrimental to fish.

- At a relatively high pH (depending on water chemistry), calcium carbonate can be precipitated from water sources with high alkalinity and calcium.

- High pH will negatively impact residual chlorine effectiveness in the distribution system. At a pH above 10.0, chloramines and chlorine lose much of their efficacy as a disinfectant.

2.3.4 By-Products of Coatings and Linings

Chemicals in protective coatings and linings in water mains and storage facilities may leach into the finished water under certain conditions. In particular, volatile organic compounds can be leached into water from coatings and linings that are not properly cured. Organic paints and coatings may contain nutrients that can support the growth of bacteria. Appropriate materials for drinking water systems (e.g., use of AWWA standards and NSF/ANSI Standard 61) should be selected when constructing or rehabilitating water distribution systems to minimize leaching of harmful chemicals.

2.3.5 Disinfectant Residual

The presence of a disinfectant residual in a distribution system is used as a surrogate to monitor microbial water quality on-site. Disinfectant residuals will decay as a result of reactions with compounds in the bulk water and reactions occurring at the pipe walls. Disinfectant residuals are usually the lowest in the dead-ended mains and remote parts of the distribution system where the turnover rate is low. Disinfectant decay rates vary by water quality, water temperature, pipe material, pipe diameter, and internal condition. Disinfectant decay rates are typically the highest in the summer months when water temperatures are the warmest. Decay rates also vary by type of disinfectant with chloramines being much more stable than free chlorine in a distribution system.

2.3.6 Sediment

Sediment accumulates within all water mains and storage facilities albeit at varying rates depending on the level of treatment. Iron and manganese may precipitate from groundwater to form sediment in distribution systems.

Corrosion by-products can also form sediment. Algae sediment may also occur in systems where treatment is lacking. Alum can precipitate from treated surface waters where the coagulation process has not been optimized. Sediment can also be introduced into pipes through poor transportation, handling, storage and installation practices. Sediment can serve as a nutrient source to micro-organisms and can shield them from disinfectants. Sediments can also create aesthetic problems if the flow direction or velocity changes suddenly and can also reduce the hydraulic capacity of mains.

2.4 AESTHETIC PROBLEMS

2.4.1 TASTE AND ODOUR

Taste and odour problems can be a result of numerous factors and can originate in the source water, from treatment and chemicals as well as in the distribution system itself. High chlorine dosages are a major cause of chlorinous taste and odour complaints in many systems. Corrosion of unlined iron mains can cause a metallic taste and a musty odour. Sulfides can be generated from the source water or in stagnant zones of distribution systems if sulfate is present in the water. This could cause "rotten egg" odours. Tastes and odours resulting from algae growths can also be a major source of customer complaints in some systems.

2-methylisoborneol (MIB) and geosmin frequently occur in Canadian surface waters during later summer and fall. These chemicals are naturally occurring but can generate taste and odour problems at very low concentrations. These need to be addressed at the source or treatment facility.

2.4.2 COLOUR AND GENERAL APPEARANCE

Water can turn several colours due to source water quality, treatment plant problems, reactions with piping and plumbing materials, chemical reactions within the bulk water, or sudden changes in flow. The following list summarizes some common colour problems that may be attributed to the distribution system.

- Red water is usually caused by the entrainment of corrosion by-products/rust found in unlined cast iron mains during turbulent flow conditions. It can also be caused by the addition of chlorine to groundwater containing high concentrations of iron.

- Black water is usually attributed to the formation of iron sulphate or manganese dioxide.

- Blue water and blue-green stains are usually caused by corrosion of copper plumbing.

- Brown or discoloured water may be attributed to the resuspension of sediment that has accumulated in water mains and reservoirs.

- A variety of unusually coloured water may be associated with backflow conditions.
- Milky/white water may be caused by air bubbles or zinc dissolved from galvanized piping.
- Colloidal iron may cause water to be yellow in appearance.

2.5 Benefits

The following list summarizes some of the reasons why it is beneficial to maintain high water quality in distribution systems:

- reduce risks to public health;
- meet legisated requirements;
- reduce customer complaints;
- defer costly replacement;
- reduce liability;
- increase confidence in water utility staff and the water supply; and
- reduce costly reactive investigation time and mitigation factors.

2.6 Risks

The following list summarizes some of the risks associated with following these best practices:

- higher cost for operation, monitoring, maintenance, and renewal of the distribution system;
- higher water rate charges;
- additional staff required;
- additional training;
- reduction in hydraulic capacity and fire protection capabilities (when downsizing mains to reduce hydraulic detention time); and
- increase in disinfection by-products through increased chlorine residual leading to the need for enhanced treatment to remove organic precursors.

3. WORK DESCRIPTION

3.1 WHAT NEEDS TO BE DONE

To minimize water quality degradation in distribution systems, the following practices should be followed;

1. Produce high quality water.
2. Maintain adequate disinfectant residuals.
3. Maintain positive water pressures.
4. Provide comprehensive water quality monitoring throughout the distribution system.
5. Implement a backflow prevention program.
6. Flush/swab the water mains.
7. Control valve and hydrant operations.
8. Implement a biofilm control program.
9. Control the blending of water sources.
10. Properly design and operate storage facilities.
11. Regularly monitor, inspect, clean and maintain storage facilities.
12. Properly design and operate distribution systems.
13. Rehabilitate/replace water mains.
14. Control internal corrosion.
15. Use approved materials.
16. Utilize appropriate pipe installation and disinfection procedures.
17. Conduct vulnerability assessments.
18. Use calibrated computer models.
19. Provide operator training and certification, and utility accreditation.

20. Communicate with stakeholders.

21. Provide customer service.

3.2 HOW TO DO THE WORK

The following sections describe how each of the 21 practices listed in Section 3.1 should be implemented. A tabular summary of the common water quality problems, potential causes, and mitigating measures is provided in Appendix A.

3.2.1 PRODUCE HIGH QUALITY WATER

An AWWA policy statement (AWWA, 2001a) recommends that water supplied to the distribution system should be biologically and chemically safe, should not precipitate chemical constituents, should not corrode the conveyance and storage systems, and should not cause excessive encrustations. Water should also be aesthetically pleasing to customers. The distribution system should be viewed as an extension of the treatment plant. The objective should be to provide high water quality at the point of use in addition to at the treatment plant. Source water protection also plays an important role in the delivery of high quality water.

Best Practices

Several practices can be used to optimize source water treatment to improve water quality in the distribution system:

- stabilize pH;
- consider choices for **primary** disinfection for their effectiveness in protecting public health and to reduce disinfection by-products (e.g. chlorine, chloramines, chlorine dioxide, ozone, ultraviolet (UV) light);
- consider choices for **secondary** disinfection for their effectiveness in protecting public health and to reduce disinfection by-products (e.g. chlorine, chloramines, chlorine dioxide);
- provide corrosion control treatment; and
- reduce turbidity and natural organic matter using well adjusted chemically assisted filtration/coagulation.

3.2.2 MAINTAIN ADEQUATE DISINFECTANT RESIDUAL

Chlorination

Disinfection is standard practice in water treatment to kill or render harmless microbiological organisms and thereby reduce the threat of waterborne disease outbreaks. Chlorination is the most widely used primary and secondary disinfectant in Canada, because it is effective against a broad spectrum of pathogens (including many bacteria, some viruses, and some protozoa). It also provides a persistent residual, and is relatively simple to apply. In fact, the presence of a consistent chlorine residual in a distribution system is the only practical surrogate available to monitor microbial water quality continuously on-site. AWWA Manual M20 (1999c) provides additional information on water chlorination principles and practices. Chlorination is required under most regulatory jurisdictions in Canada. Concerns about the effectiveness of chlorine for control of *Cryptosporidium* have caused greater interest in alternative disinfectants, such as ozone,and ultraviolet (UV) light. Other treatment technologies, such as membranes and cartridge filters, can be used to remove *Cryptosporidium*. Some of these other treatment technologies are also effective in the removal of other micro organisms.

Best Practices
The free chlorine residual should be greater than 0.2 mg/L throughout the distribution to maintain an adequate disinfectant residual. This is consistent with regulations required in several Canadian provinces. In some cases, it might be necessary to modify contact chambers or clearwells to increase residence time (by plug flow) and improve CT values.

As noted in Section 2.2, in some cases, ammonia is added to the chlorinated water to produce chloramines. If chloramination is used, a higher residual (i.e., at least 1 ppm) should be maintained and the system monitored for signs of nitrification.

Care needs to be exercised when discharging chlorinated or chloraminated water via a planned activity or by accident as there are potential impacts on aquatic life.

As noted in Section 2.3, chlorine reacts with the naturally occurring organic matter in water to produce disinfection by-products such as THMs and HAAs. Several measures can be implemented to minimize the formation of disinfection by-products. The control of THMs and HAAs in drinking water can be approached in three ways: treatment to remove precursors (e.g., optimize treatment, shift chlorine application); the use of alternative disinfectants (e.g., chloramines); and removal of THMs and HAAs themselves. Disinfection by-products are also created by other disinfectants, such as ozone and chlorine dioxide.

Chlorine Booster Stations
In some systems where chlorination is used, it may not be practical to increase the chlorine dosage sufficiently at the point of supply to maintain adequate chlorine residuals in the remote parts of the distribution system. Calibrated computer models can be used to simulate the chlorine decay throughout a distribution system to optimize the location of chlorine booster stations and the chlorine dosages. If modelling is not available, tracking persistent areas of low chlorine residuals can be used for this purpose.

Monitoring should be conducted to ensure adequate disinfectant residuals are maintained throughout the system recognizing that chlorine consumption will vary depending on water demand, water temperature, time of travel, and water quality.

Best Practices
In these cases, chlorine booster stations may be used within the distribution system (i.e., at pumping stations and reservoirs).

3.2.3 Maintain Positive Water Pressures

Contaminant Intrusion
Water distribution systems are normally designed to supply required fire flows while maintaining pressures above 140 kPa (20 psi). Intrusion is defined as the entry of contaminants into the distribution system through leaks and orifices during periods of low or negative pressures. Low pressures can occur if valves are inadvertently closed or if high demands exceed the capacity of the distribution system, such as during a major fire.

Best Practice
A minimum residual pressure of at least 140 kPa is required to provide a factor of safety against backflow and intrusion of groundwater into the distribution system.

Pressure Transients
A pressure transient is caused by a sudden change in the velocity of water that may be due to rapid action of any of the following:

- pumps are started or stopped;
- valves are opened or closed;
- hydrants are opened or closed; and
- water mains rupture.

The magnitude of pressure transients depends on many factors including the flow velocities in the water mains, water main materials, topography, the presence of elevated storage, pump operation, and the adequacy of surge control equipment. The potential for intrusion of contaminants depends on many factors including the number and size of leaks and orifices, the frequency, duration, and magnitude of the pressure transient, as well as the presence and concentration of contaminants in the vicinity of the leaks and orifices.

Best Practices
Several measures can be used to mitigate the potential for intrusion of contaminants, including the following.

- Maintain the distribution system in good condition to reduce the number of leaks and orifices.
- Maintain adequate clearance between water mains and sewers.
- Provide elevated storage to maintain positive pressures when pumps are stopped.
- Install surge control equipment (e.g., air chambers, pump control valves, variable frequency drives on pumps, air/vacuum valves, surge relief valves).
- Provide drains (with check valves) in air valve chambers to avoid the submergence of air valves.
- Interconnect pressure zones with pressure-reducing valves and check valves.
- Provide back-up pumps and standby power for pumps.
- Open and close valves and hydrants slowly.
- Ensure dry barrel hydrants are adequately plugged where groundwater levels will prevent hydrants from draining. This will eliminate the need to add possible contaminants, such as hydrant freeze protection agents, to the system.

3.2.4 PROVIDE COMPREHENSIVE WATER QUALITY MONITORING

The distribution system should be seen as an extension of the water treatment facility "where the goal is to consistently produce safe, high quality drinking water as cost effectively as possible. Even in the absence of strong regulatory pressures, continuous monitoring systems have been installed" (AwwaRF, 2002c). The ability to measure, monitor, and control all aspects of your distribution system water quality is mandatory to ensure safe water, to assess the seriousness of a situation during an emergency and to prove due diligence.

A monitoring program should address both routine and non-routine monitoring. It should constitute part of a water quality management system that includes source water monitoring, treatment process monitoring, consumer tap monitoring, and complaints.

Best Practice
Recognizing that water quality may change as it travels through a distribution system, municipalities should implement a comprehensive monitoring program to demonstrate ongoing compliance with water quality standards and to identify water quality problems.

Routine Monitoring

A routine monitoring program should be used to identify potential water quality problems that might occur within the distribution system. Sampling sites, sampling frequencies, and test parameters should be selected to identify and quantify potential problems. Regular sample sites should be representative of their intended area and should accurately reflect the water quality found in the local underground piping system. A check of the piping system drawings and a water quality comparison with nearby homes/facilities should be made to ensure that a site can be accepted as a representative sample location.

Municipalities should establish standard water quality sampling and testing procedures and protocols to assess their water treatment efficiency, detect any problems in the distribution system, and meet all public health requirements. Ideally, dedicated sampling stations could be used to reduce the potential for contamination of the samples as an enhancement to the continuous monitoring sites in the distribution system.

Temperature, turbidity, pH, colour, continuous disinfectant residual, odour, iron, lead, copper, disinfection by-products, HPC bacteria, and total coliform bacteria are commonly used to assess the water quality in a distribution system. It is now possible to test routinely for E.coli, and therefore it should be a routine monitoring practice, given that it does indicate a potential public health risk.

For a comprehensive approach, the water quality monitoring data could be linked to a geographical information system (GIS) to facilitate a spatial and temporal analysis. Large municipalities should consider implementing a laboratory information management system (LIMS) to manage their water quality data. Continuous on-line analyzers can be linked to supervisory control and data acquisition (SCADA) systems for control of treatment processes, historical data captured, management of water quality data, and alarm purposes.

Best Practice

A routine monitoring program should take the following factors into account:

- the age of the water throughout the system (using computer models and/or tracer studies);
- locations where water sources are blended;
- the location of storage facilities;
- the type and condition of water mains; and
- the location of critical facilities (e.g., hospitals).

Non-Routine Monitoring
Non-routine monitoring may be conducted in response to customer complaints, to assess specific problems (e.g., storage facilities), and to monitor construction and maintenance activities as well as emergencies.

3.2.5 Implement Backflow Prevention Program

Although it is difficult to detect backflow incidents, depending on the circumstances, there may be several indicators of backflow, including customer complaints, drops in operating pressure, drops in disinfection residual, a change in pH, a change in colour, water meters running in reverse, and coliform detections. AWWA Manual M14 (1990) outlines a recommended practice for backflow prevention and cross-connection control.

Best Practices
Several measures can be used to mitigate the potential for backflow, including the following:

- Provide physical separation between potable water and non-potable water systems.
- Install backflow prevention devices and assemblies. The choice depends on the health hazard of the actual or potential cross connection.
- Implement cross-connection control and backflow prevention programs.
- Maintain disinfectant residual in the distribution system.
- Maintain positive pressures in the distribution system.
- Maintain the water distribution system in good condition.
- Conduct sanitary surveys of field sampling sites.
- Implement a workplace maintenance management system.

3.2.6 Flush/Swab Water Mains

Flushing, swabbing, and pigging are three techniques used to remove biofilms, sediment, and corrosion by-products from water main interiors. This generally improves on water quality and hydraulic capacity.

Flushing
In most municipalities, water distribution systems are routinely flushed in the spring and/or fall to maintain good water quality. Water mains are also flushed periodically throughout the year in response to customer complaints as well as for non-compliant samples. In parts of a system where the age of water is excessive, some hydrants can be identified for use by street sweepers and water

haulers, thereby reducing hydraulic detention time. However, caution must be exercised to ensure the operation of hydrants does not aggravate other problems (e.g., red water). Flushing is used for control of internal corrosion of unlined mains, sediment removal, control of colour, turbidity, and low disinfectant residuals, biofilm problems, stagnant water at dead ends, and to improve hydraulic performance. Conventional flushing may aggravate short-term water quality problems and lead to more complaints in some systems. Some municipalities are now beginning to look at and practise uni-directional flushing.

Water quality complaints should be monitored geographically. All municipalities should use some type of data management system to track these water quality complaints to optimize their flushing program. Larger municipalities (and smaller municipalities with significant water quality problems) should use a GIS system to track complaints and analyze monitoring data.

Computer models can be used to simulate the water age and disinfectant residuals throughout a distribution system. This information can then be used to identify the areas that require more frequent flushing. Computer models can also be used to identify flushing sequences (based on the uni-directional flushing method) and the expected flushing velocity for each section of water main.

Best Practice
Municipalities should implement a uni-directional flushing program, in which individual sections of water main are isolated to control the direction of flow through the mains and to achieve a flow velocity of 1.5-2.0 m/s. A uni-directional flushing program should start at the water source and progress into the system from the largest to the smallest mains. Uni-directional flushing is more costly and time consuming than conventional flushing; however, uni-directional flushing is more effective and uses less water.

Swabbing
Swabbing is more effective than flushing although it is more costly and typically requires the installation of swab launchers and a temporary water supply system. Swabbing may not be effective where pipes are heavily tuberculated. As swabbing may release significant levels of asbestos fibres from asbestos cement water mains, its use in such situations should be reviewed.

Best Practice
It is not practical to achieve adequate flushing velocities through some water mains including those that are larger than 300 mm in diameter due to the large volumes of water that would be required. In these cases, swabbing with soft foam swabs may be required to clean these mains effectively.

Pigging
A variety of devices are used for pigging water mains, including wire brushes, scrapers, and rigid plastic pigs. Although pigging is more effective than flushing

and swabbing, it requires considerable expertise, materials, and time. Pigging unlined iron and steel mains may expose bare metal and increase the potential for red water problems for several weeks afterward as the bare metal is more rapidly oxidized.

Best Practice
Pigging is usually not recommended unless a pipe lining, such as cement mortar or epoxy, is being installed before placing the pipe back into service.

3.2.7 CONTROL OF VALVE AND HYDRANT OPERATIONS

Valves and hydrants should be exercised regularly to ensure they are accessible and remain operable. Critical valves should be exercised more frequently than others. In some systems, the operation of valves and hydrants can cause sudden flow changes that disturb sediments and encrustations that may adversely affect water quality. Rapid operation of valves and hydrants can generate pressure transients, which could result in intrusion of contaminants into the distribution system (refer to Section 3.2.3).

Qualified and responsible personnel should oversee the operation of valves and hydrants to ensure they are operable and valves are left in the proper position. A broken valve operator may seem to function normally, but if the valve is left in the closed position, two dead ends may be created and go undetected until consumers complain of poor water quality.

Municipalities should control the non-emergency use of hydrants by all parties external to the water utility (e.g., contractors, fire department, parks department, road department). Municipalities should designate specific hydrants for use by other parties. All water used in such cases should be metered or otherwise accounted for. Tamper proof locks can be installed on hydrants to control their use.

Best Practices
Municipalities should have an inspection and maintenance program to maintain their valves and hydrants in good condition and to document any previous water quality issues caused by the operation and maintenance of the valves and hydrants. Effective preventive and corrective maintenance programs should have readily available historical maintenance data as well as appropriate contingency planning. The operation of valves and hydrants should be carefully controlled and documented to mitigate the above noted concerns.

3.2.8 IMPLEMENT BIOFILM CONTROL PROGRAM

Municipalities should implement an active biofilm control program to minimize the regrowth of micro-organisms in pipes and storage facilities. This biofilm control program should be co-ordinated with other water quality control programs to maximize effectiveness and minimize cost.

Best Practices

- Nutrient control – control the source of carbon and other nutrients, such as phosphorus and nitrogen, through filtration (if currently unfiltered) or biological treatment (if already filtered). Other treatment possibilities would include advanced oxidation, or membrane processes such as nanofiltration.

- Control of contamination from materials and equipment – provide adequate disinfection and flushing of water main break repairs and new construction as well as proper operations and maintenance procedures.

- Control and mitigation of hydraulic problems – use cleaning practices such as flushing, swabbing, and pigging (only if the pipe is to be lined). Municipalities should also eliminate dead-ended mains and low flow areas. In addition, municipalities should maintain positive pressures (to prevent contaminant intrusion) and avoid sudden changes in flow (to prevent the biofilm from sloughing off the pipe wall).

- Practise cross-connection control and backflow prevention.

- Maintain disinfectant residuals (chloramination is more effective at controlling biofilms than chlorination).

- Provide internal corrosion control for aggressive or soft waters and unlined water mains (e.g., pH and alkalinity adjustment, corrosion inhibitors, calcium adjustment).

- Rehabilitate and replace infrastructure.

- Properly maintain storage facilities.

3.2.9 Control Blending of Water Sources

Some municipalities have more than one source of water, and these sources may be blended to meet daily or peak demands, or to deal with emergency situations. Blending can either improve or deteriorate water quality in the distribution system.

In some cases, blending could trigger an oxidation/reduction reaction in unlined cast iron mains if the pH is increased. This could lead to shedding of corrosion by-products off the pipe wall. Blending of surface water and groundwater sources could result in precipitation of iron and manganese. In other cases, blending may reduce inhibitor dosages or change pH/alkalinity that can reduce the performance of corrosion control treatment. Blending can also result in flow changes that result in the resuspension of particulate matter, red water, and higher microbial counts. As a result, blending water sources is generally not recommended.

Depending on the results of the blending analysis, it may not be prudent to blend the sources in which case separate pressure zones should be maintained even if the second source is only required for a short term. Computer modelling can be used to assess the zones of influence of each source and to select the most appropriate boundary between pressure zones.

Best Practice
Blending should always be done in a controlled manner. A detailed blending analysis should be conducted to determine the chemical compatibility of the two sources, predict the blended water quality characteristics, and assess the impacts of blending ratios on pipe materials.

3.2.10 PROPERLY DESIGN AND OPERATE STORAGE FACILITIES

Water storage facilities can be classified as ground storage or elevated storage. Air chambers, hydro pneumatic tanks, and surge tanks are special types of storage facilities. Ground storage can be constructed below ground, partially below ground, or above ground, and may be accompanied by pumping stations. Elevated storage facilities can be elevated tanks or standpipes. The most appropriate type of storage facility to construct and its location is usually governed by hydraulics, availability of land, costs and aesthetic considerations.

Water Quality Problems
Water quality problems may develop in storage facilities due to the following reasons.

- The most common cause of water quality problems in storage facilities is a long detention time due to underutilization of the water in a reservoir and/or short circuiting within a reservoir. Long detention times can lead to the loss of disinfectant residual, microbial growth, formation of disinfection by-products, nitrification (if chloramination is used), as well as taste and odours. If possible, water in a storage facility should be turned over at least every three to five days.

- Uncovered reservoirs should not be used to store potable water. Even reservoirs with floating covers are susceptible to contamination from untreated water that collects on the cover surface, particularly if the cover is damaged.

- Covered reservoirs are susceptible to contamination if the bug screens on the vents and overflows are damaged, or if access hatches are not properly constructed.

- In-ground reservoirs are susceptible to contamination from groundwater intrusion if they do not have an adequate drainage system.

- Reservoirs are susceptible to chemical leaching from incompletely cured coatings and corrosion.

Best Practices
The report entitled: *Maintaining Water Quality in Finished Water Storage Facilities* (AwwaRF, 1999) addresses several design and operational practices that are outlined below.

- Storage facilities should not be oversized for short-term demands to ensure the detention time is not excessive. Consideration should also be given to constructing two or more cells within a storage facility to allow each cell to be drained for inspection and maintenance while maintaining sufficient storage in the other cells.

- The detention time in standpipes can be significant if the total storage volume is significantly greater than the useful storage volume (i.e., the volume above the normal hydraulic grade line in the system).

- All open finished reservoirs should be abandoned until they are covered. Floating covers on reservoirs should be designed in accordance with AWWA Manual M25 (1996).

- Provide waterproof membranes/roofing over concrete storage reservoirs.

- Provide bug screens over reservoir vents.

- Coatings on steel tanks should comply with NSF/ANSI Standard 61. Coatings should be properly applied and cured to prevent chemical leaching. Cathodic protection systems are normally required on steel water storage facilities to mitigate corrosion.

- The site and roof drainage should be designed so stormwater run-off drains away from the storage facility. Access hatches should be designed to prevent contaminated water and debris from falling into the facility when the hatches are opened. Secondary containment should be provided for fuel tanks and chemicals located at nearby pumping stations. Vehicle parking (with leaking contaminants) on storage facility roofs should be avoided.

- To prevent dead zones in storage facilities, it may be necessary to design the facility to promote complete mixing of the water or, alternatively, to promote plug flow through the use of baffles. Plug flow may be necessary in some cases to achieve the required contact time for a disinfectant.

- A distribution system should be operated to maximize the turnover rate in its storage facilities. Turnover may be accomplished by partially draining and refilling a storage facility on a regular basis.

- Automatic controls should be provided to facilitate the draining and filling of the storage facility.

- Storage facilities should be equipped with security systems, such as perimeter fencing with lockable gates, lockable access hatches, and alarms that are monitored continuously.

- Continuous on-line monitoring and sampling ports should be installed at the inlet and outlet as well as at other key locations in a storage facility to identify mixing or contamination problems.

- In some cases, it may be prudent to install a chlorine booster station at the inlet or outlet of a storage facility.

3.2.11 Regularly Monitor, Inspect, and Maintain Storage Facilities

Inspection
Storage facilities should be regularly inspected and maintained to minimize the potential for water quality problems and to maximize the service life of the facility.

Best Practices
A report (AwwaRF, 1999) describes best practices for inspection of storage facilities as follows.

- **Routine inspections** should be conducted on a daily, weekly, or monthly basis to monitor the exterior of the storage facility and grounds for evidence of intrusion, vandalism, coating failures, security, and operational readiness.

- **Periodic inspections** should be conducted on a monthly or quarterly frequency to check hatches, bug screens, cathodic protection equipment, and coatings.

- **Comprehensive inspections** should be conducted every three to five years. The AwwaRF report describes several inspection methods, including visual, float down, wet, structural, and sanitary. Cathodic protection systems and leakage should also be checked. Water quality, biofilm, and sediment monitoring should be used to predict maintenance needs. AWWA Manual M42 (1998b) describes a procedure for inspection of steel water storage tanks.

Monitoring/Cleaning
The AwwaRF report (AwwaRF, 1999) also describes several methods for cleaning storage facilities as well as their advantages and disadvantages. The conventional method requires the facility to be taken out of service and drained. Storage facilities can also be cleaned using commercial divers and remote

operated vehicles. Storage facilities should be disinfected in accordance with AWWA C652-92 after they are cleaned and before they are returned to service.

Best Practices
Water quality monitoring, biofilm monitoring, and sediment sampling will determine the need to clean storage facilities.

Maintenance
The AwwaRF report (AwwaRF, 1999) also describes the maintenance requirements for water storage facilities including structural repairs, coatings, appurtenances, cathodic protection systems, and floating covers.

Best Practice
An outage plan should be developed before a storage facility is removed from service for inspection, cleaning, and maintenance.

3.2.12 Properly Design and Operate Distribution Systems

Dead-ended water mains are one of the most common causes of water quality problems in distribution systems. "Dead ends are not considered to be best practice and should be avoided because they reduce fire flows, lead to the deterioration of water quality, and can cause corrosion. Dead ends can also affect water pressure, flushing operations, and water service during main repair and maintenance"(Angers, 2002). Water quality problems in dead ends can include a buildup of sediment, extended detention time with the consequent reduction in the disinfection residual, and an increase in microbial counts, as well as taste and odour complaints.

Best Practices
Wherever possible, water mains should be looped to allow the water to circulate. Water mains should be constructed using proper drinking water materials (NSF/ANSI Standard 61). In some cases, it is necessary to close a valve to separate pressure zones, and this creates two dead ends, one on either side of the valve. In these cases, a pressure-reducing valve can be installed at the zone boundary to allow water to flow from the upper pressure zone to the lower pressure zone to augment fire flows, increase the security of supply, and eliminate dead ends.

Most distribution systems have some unavoidable dead-ended mains. In these cases, hydrants, blow-offs, or automatic flushing devices should be installed at dead ends to allow them to be flushed. Automatic flushing devices can be installed on dead-ended mains to reduce the detention time of the water. These flushing devices are typically operated using an adjustable timer. Although it may not be practical to operate these flushing devices during the winter months, water quality problems are typically more prevalent during the summer months when water temperatures are higher.

Water mains are typically oversized to supply fire flows, and this causes long detention times. In some cases, water mains are oversized to supply projected demands 20 to 30 years into the future. In these cases, the detention time in the mains may be excessive during the initial few years of operation. The design of water distribution systems should address the staging of development.

3.2.13 REHABILITATE/REPLACE WATER MAINS

As water mains age, they may experience external corrosion in the presence of aggressive soils. They may also experience internal corrosion if the main is unlined, as well as deposition of silt and precipitated chemicals all of which are conducive to the regrowth of bacteria. These problems are most prevalent in unlined cast iron mains. Sediments may be resuspended when flow direction or water velocity changes, which could lead to water quality complaints (e.g., red water, turbidity, colour), and high microbial counts.

Although flushing and swabbing will remove loose deposits from mains, it will not remove all the corrosion by-products on the inside of unlined cast iron mains. These encrustations are conducive to the regrowth of bacteria, and they reduce the hydraulic capacity of the mains.

Best Practices
In cases where there are frequent water quality complaints and elevated iron, turbidity, and colour are chronic problems, it is necessary to rehabilitate or replace the main. The National Guide has published a best practice document entitled: "Deterioration and Inspection of Water Distribution Systems."

Rehabilitation
Structural linings include slip lining with polyethylene or cured-in-place linings. The most common non-structural linings are cement mortar and epoxy. Care must be exercised to ensure that the linings are approved for drinking water (NSF/ANSI Standard 61) and that they are properly cured. Some waters may affect the cement mortar and the AwwaRF has published a report that addresses the control of water quality deterioration caused by the deterioration of cement mortar linings (AwwaRF, 1991b).

Best Practice
Unlined iron water mains can be rehabilitated using either structural or non-structural linings. AWWA Manual M28 (2001b) provides guidance on the rehabilitation of water mains. The National Guide has also published a best practice document entitled: "Selection of Technologies for Rehabilitation or Replacement of Sections of a Water Distribution System."

Replacement
If there are lead services connected to a deteriorated water main or if the services are too small according to current standards, then it may be prudent to replace the water main and services rather than rehabilitate the main. Water mains can be

replaced using the conventional cut and cover method, pipe bursting, or other trenchless technology methods.

Best Practice
If a water main experiences a high breakage or leakage rate, or does not have sufficient hydraulic capacity, then it will likely be necessary to replace it.

3.2.14 CONTROL INTERNAL CORROSION

Unlined metallic water mains and appurtenances are susceptible to internal corrosion. The AwwaRF has published a manual titled Economics of Internal Corrosion Control (AwwaRF, 1991a). This manual enables municipalities to determine the cost impacts of internal corrosion as well as the economic benefits of a corrosion control program. Health Canada is developing a guideline for internal corrosion control (Bernard, 2002).

Lead
Lead services were installed in many municipalities across Canada during the 1940s and 1950s. Lead was also used in solder and plumbing fixtures. However, in recent years, it has been recognized that leaching of lead from pipes and plumbing materials can have adverse health effects for humans. The AwwaRF has conducted a study to develop procedures for evaluating rehabilitation and replacement technologies for water services (Boyd et al., 2001).

Many municipalities have adopted a policy in which the municipality will replace a lead service between the water main and the property line when property owners replace the lead service on their property. In some cases, where lead levels are high and corrosion control treatment is not effective, the municipality should accelerate its lead service replacement program and assist property owners with the replacement of lead services on private property. In addition, public education on lead control should be provided through the distribution of pamphlets and the municipality’s Web site.

Best Practice
Although corrosion control treatment can be used to mitigate the leaching of lead, municipalities should adopt a plan for the eventual replacement of all lead services in their distribution systems.

3.2.15 USE APPROVED MATERIALS

The Canadian Standards Association (CSA) has published standards that cover plumbing materials. Water mains and appurtenances can react with the water as well as the external environment to create water quality problems. Although permeation of contaminants through the wall of common water main materials is uncommon, gaskets in pipes are vulnerable to permeation. Leaching of metals, organic contaminants and asbestos from the interior wall/linings of pipes and reservoirs can also occur. Some municipalities have reported turbidity and odour problems as a result of the excessive use of pipe lubricants.

If it is necessary to install a water main in contaminated soil, the selection of pipe material, joints, and appurtenances should be carefully reviewed. Consideration should be given to the use of petrochemical resistant elastomers (e.g., nitrile) in these cases. The construction of a reservoir in contaminated soils deserves special attention.

Prevention of permeation and leaching requires proper material selection and installation practices as well as high quality water. Municipalities should test water quality in new mains or rehabilitated mains prior to commissioning. Water quality testing should be conducted for total coliform bacteria, HPC, pH, disinfectant residual, turbidity, and odour as well as other parameters based on the materials used and site-specific environmental conditions.

Best Practice
All materials in contact with drinking water should comply with standards for health effects (i.e., NSF/ANSI standards 60 and 61).

3.2.16 Use Appropriate Disinfection Procedures for Water Mains

Water quality problems can arise if there is inadequate disinfection or inadequate flushing of the disinfected water. In addition, the potential for backflow (from a new main to the existing distribution system) exists during a hydrostatic pressure test of a new main.

Best Practices
AWWA Standard C651-99 describes procedures for the disinfection of new mains, connections to existing mains, and repairs to mains. Appendix B summarizes the best practices for disinfection of water mains.

3.2.17 Conduct Vulnerability Assessment

Water distribution systems are susceptible to disruption of supply as a result of physical disruption and cyber attacks against SCADA systems. Water distribution systems are also vulnerable to biological, chemical, and radiological contamination. Various vulnerability reduction measures can be implemented in the form of physical protection systems, operation systems, and consequence mitigation.

Best Practices
Appendix C lists some resources for vulnerability assessments.

3.2.18 Use Calibrated Computer Models

Several computer models have been developed to assess the movement and fate of contaminants within distribution systems. The AWWA has published a textbook that discusses the use of water quality models and their potential for enhancing understanding of the factors affecting water quality (AWWA, 1998a).

Calibrated computer models can be used for many types of water quality analyses, including the following.

- Constituent analysis – determine the movement and fate of non-conservative parameters such as chlorine and THMs.

- Source trace analysis – determine the percentage contribution of each source to the total water supplied to each node. This information is useful for blending analysis (refer to Section 3.2.9).

- Water age analysis – residence time in the distribution system is a critical factor influencing water quality. This information is useful for purposes of selecting sampling locations and developing flushing programs.

- Tank mixing – identify the effects of tank design on water quality.

- Vulnerability assessment - determine the reliability of the system.

- Emergency response planning – select the valves to close in order to isolate the contamination, develop a flushing strategy, and identify customers who will be affected.

Best Practice
If practical/economical, develop a calibrated computer model of the distribution system.

3.2.19 Operator Training and Certification, and Utility Accreditation

In light of the increasing complexity of water distribution system operations as a result of emerging technologies and more stringent regulations, ongoing training of operators is becoming more important than ever. Most jurisdictions in Canada use the Association of Boards of Certification for examination and certification of operators. The Canadian Water and Wastewater Association is working to develop a national program for operator training, education, and certification.

The AWWA is developing a standard for total distribution system operation and management (G200) that promotes accreditation of water utilities by establishing uniform performance standards. Some municipalities have implemented continuous improvement programs through AWWA's QualServe program, ISO 9000, and ISO 14000, and others have developed an environmental management system. A new ISO standard (ISO/TC 224) is being developed to address service activities related to drinking water supply and sewerage.

Best Practices

Formal training programs should be developed that emphasize the importance of maintaining water quality in the distribution system. In addition, more emphasis should be placed on, and adherence to, operator certification requirements.

3.2.20 STAKEHOLDER COMMUNICATION

Stakeholders could include operators from the treatment plant and distribution system as well as representatives from the fire department, municipal medical officers, provincial health department, provincial environment department, large water consumers, neighbouring municipalities, and the public. Frequent communication may be required among some stakeholders in those municipalities whose distribution systems are particularly susceptible to water quality problems or where distribution systems may be shared by various municipalities.

Best Practice

Municipalities should regularly host meetings with all stakeholders, especially the local medical officer of health, to discuss water quality issues, operational protocols, capital planning, and emergency response plans.

3.2.21 CUSTOMER SERVICE

In light of the public's demand for more transparent decision making, fiscal responsibility, and accountability, excellent customer service is becoming an important and increasing component of the business of delivering potable water. The provision of information to customers is very important. Some municipalities have developed water quality indices to provide a simple means to communicate the quality of water in their system. Municipalities can also distribute pamphlets to educate the public on water quality issues, such as flushing programs, lead in drinking water, backflow prevention, common water quality problems, and system security.

Best Practices

Municipalities should adopt a standard procedure for responding to water quality complaints. Similar to water quality data, this information should be properly documented and geographically referenced. Electronic systems exist that support documentation, trend analysis, problem solving, and reporting. Water quality complaints provide a practical means of monitoring public perception and acceptance respecting the water provided. At a minimum, the following data should be documented for each water quality complaint:

- location;
- date and time;
- name of complainant;

- description of complaint;
- probable cause of complaint;
- remedial action;
- notifications; and
- follow-up, including level of satisfaction.

4. APPLICATIONS AND LIMITATIONS

4.1 APPLICATIONS

The practices outlined in Section 3 are intended to apply to all drinking water systems across Canada, regardless of size. The practices must be tailored for each municipality to reflect source water quality, treatment, distribution system characteristics, and regulations. Municipalities should recognize that decisions made at any point in the life cycle of a distribution system have the potential to impact water quality. Municipalities should establish clear goals, performance expectations and accountability for results.

Municipalities should review each practice outlined in Section 3 and develop an action plan to maintain/improve water quality in their distribution system. This action plan should prioritize the needs and include cost estimates as well as a time frame for implementation. Actions required to protect public health and to comply with regulations should be given a high priority. All the stakeholders should adopt this action plan.

4.2 LIMITATIONS

Small municipalities may be challenged to provide all the resources recommended in this best practice to design, operate, and maintain water distribution systems to maintain high quality water. However, municipalities cannot compromise on any practices that are required to protect public health. This may necessitate outsourcing water distribution system operations in some municipalities. Municipalities must remember that due diligence will always remain with the “owner” even after contract outsourcing. Proper water quality management procedures and adequate oversight should be entrenched in any outsourcing agreement.

Municipalities should strive for full cost accounting and full cost recovery through equitable water rates in order to sustain a high level of service throughout the entire life cycle of their distribution system. Municipalities should also strive to maintain an adequate complement of qualified and highly motivated staff to manage their water distribution system.

As noted in Section 1, this best practice document does not address source water protection, water treatment, or private plumbing.

5. EVALUATION

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

Are there reductions in:

- the number of water quality complaints?
- the number of non-compliant samples in the distribution system?
- the number of waterborne disease outbreaks?
- the number of boil water orders/advisories?
- the cost for corrective measures?
- costly reactive investigation time?

Overall, are there improvements in general water quality?

APPENDIX A: COMMON WATER QUALITY PROBLEMS, POSSIBLE CAUSES AND MITIGATING MEASURES

Problems	Possible Causes	Mitigating Measures
1. Biological		
1.1 Bacterial regrowth	• Inadequate water treatment • Inadequate disinfectant residual • Excessive detention time • Biofilm • Poor maintenance practices • Pipe contamination due to poor transportation, handling, storage and installation practices • Pathogen intrusion from cross connection	• Produce high quality water • Maintain adequate disinfectant residual • Flush/swab water mains • Implement biofilm control program • Properly design and operate storage facilities • Properly design and operate distribution systems • Upgrade water quality monitoring • Deliver pipes with end caps
1.2 Nitrification (in chloraminated systems)	• Improper chlorine to ammonia ratio • Excessive detention time • Loss of chloramine residual	• Check chlorine to ammonia ratio • Flush/swab water mains • Properly design and operate storage facilities • Properly design and operate distribution systems • Upgrade water quality monitoring • Increase chloramine residual • Install chlorine booster stations in remote locations • Revert to high free chlorine residual until problem is cleared
1.3 Waterborne disease	• Inadequate water treatment (i.e., filtration) • Inadequate primary disinfection • Contaminant intrusion • Backflow from non-potable sources • Poor maintenance and repair practices • Main breaks • Inadequate disinfection of new mains/equipment • Terrorism or vandalism	• Produce high quality water • Maintain adequate disinfectant residual • Maintain water pressures above 140 kPa • Implement backflow prevention program • Control valve and hydrant operations • Properly design and operate storage facilities • Properly design, operate, and repair distribution systems • Use appropriate disinfection procedures for new mains and repairs • Provide security
1.4 Worms/insects	• Inadequate water treatment • Poor design/construction/ maintenance of storage facilities • Inadequate flushing/swabbing program • Problems with water intake in unfiltered systems	• Produce high quality water • Properly design and operate storage facilities • Regularly monitor, inspect, and maintain storage facilities • Check water intake for holes through or around screens
2. Chemical/Physical		
2.1 Disinfection by-products (THMs)	• Inadequate water treatment (precursors, organic matter) • Excessive detention time • Excessive chlorine use • Inappropriate chlorine injection location • High pH	• Remove naturally occurring organic matter • Produce high quality water • Alternate primary disinfectant • Properly design and operate storage facilities • Properly design and operate distribution systems • Optimize pH adjustment for balance of corrosion control and DBPs
2.2 Lead and copper	• Internal corrosion • Unstable water • Naturally low pH and alkalinity water (soft water)	• Implement corrosion control treatment • Raise finished water pH • Raise finished water alkalinity (e.g. add soda ash to create buffer activity) • Consider alternate corrosion inhibitors to pH and alkalinity adjustment • Flush regularly • Educate public • Rehabilitate/replace water services • Use approved materials

Problems	**Possible Causes**	**Mitigating Measures**
2. Chemical/Physical (continued)		
2.3 pH stability and scale formation	• Inadequate water treatment • Excessive detention time in cement pipes • Unstable water	• Produce high quality water • Control blending of water sources • Properly design and operate distribution systems
2.4 By-products of linings and coatings	• Leaching of chemicals • Unstable water	• Use approved materials • Properly cure linings and coatings
2.5 Low disinfectant residual	• Inadequate disinfection residual • Poor source water quality (high DOC) • Inadequate water treatment • Excessive detention time • Contaminant intrusion • Poor maintenance and repair practices • Poor distribution system design • Aging distribution system • Pipe contamination due to poor transportation, handling, storage and installation practices	• Produce high quality water • Maintain adequate disinfectant residual • Implement biofilm control program • Properly design and operate storage facilities • Properly design, operate, and repair distribution systems • Rehabilitate/replace water mains • Use appropriate disinfection procedures for new mains and repairs • Install chlorine booster stations • Consider chloramination • Flush/swab water mains • Deliver pipes with end caps
2.6 Sediment	• Inadequate prefiltration pH control • Inadequate water treatment (inadequate or lack of filtration) • Poor maintenance and repair practices • Cross connection • Ageing distribution system • Unstable water	• Produce high quality water • Flush/swab water mains • Control valve and hydrant operations • Control blending of water sources • Regularly monitor, inspect, and maintain storage facilities • Implement backflow prevention program • Rehabilitate/replace water mains • Maintain positive pressures
3. Aesthetic		
3.1 Taste and odour	• Poor raw water quality • Inadequate water treatment • High chlorine concentrations • Internal corrosion of unlined mains • Excessive detention time • Blending of chlorinated and chloraminated water • Stratification during ammonia addition for chloramination • Leaching chemicals from water main linings	• Upgrade treatment – select optimum process • Produce high quality water • Maintain adequate disinfectant residual • Flush/swab water mains • Properly design (with respect to size and turnover) and operate storage facilities • Properly design and operate distribution systems • Implement corrosion control treatment • Rehabilitate/replace water mains • Use approved materials that are suitable for Canadian climate (e.g., paint) • Ensure linings are cured properly in new water main construction
3.2 Colour and appearance	• Inadequate water treatment • Internal corrosion of unlined mains • Excessive detention time • Sediment in water mains	• Produce high quality water • Control blending of water sources • Implement corrosion control treatment • Rehabilitate/replace water mains • Eliminate dead ends • Flush/swab water mains

APPENDIX B

BEST PRACTICES FOR DISINFECTION OF WATER MAINS

Disinfection of New Mains

The following points highlight some practices that should be used to minimize the risk of contamination when constructing new mains.

- Pipes should be delivered to the site with end caps.

- A watertight plug should be placed on the end of the pipe when pipe laying is completed at the end of each day.

- The trench should be kept dry and sanitary.

- The new water main should be isolated from the active distribution system using a temporary connection with an approved cross-connection control device until satisfactory bacteriological testing has been completed and the disinfectant has been flushed out.

- The water main should be swabbed with a hydraulically propelled foam pig prior to disinfection.

- The water main should be disinfected using one of the methods outlined in AWWA C651-99 (i.e., tablet, continuous feed, and slug).

- The water main should be thoroughly flushed after disinfection, and bacteriological samples should be collected.

- A standard operating procedure for disinfection of mains should be developed. Municipalities should also provide training for staff and contractors on this standard operating procedure. In some cases, a municipality may elect to disinfect mains with its own forces, rather than delegating the responsibility to contractors. All aspects of this section must be documented in the workplace maintenance management system and reviewed annually.

Disinfection of Temporary Water Distribution Systems

This procedure outlined above for disinfection of new mains should also be used for the disinfection of temporary water distribution systems.

Disinfection of Connections

AWWA C651-99 outlines an optional disinfection procedure when connecting a new main to an existing main. If the length of the connection is less than one pipe length (5.5 m), the connection should be spray disinfected or swabbed with a minimum of a one to five percent solution of chlorine just before installation.

If the length of the connection is greater than one pipe length (5.5 m), the procedure calls for the pipe (that is required for the connection) to be set up above ground, disinfected, flushed, and tested for bacteriological contamination. After satisfactory bacteriological results are received, the pre-disinfected pipe can be used to connect the new main to the active distribution system. This procedure could be adapted for the disinfection of pumps, valves, and other appurtenances.

Disinfection of Repairs

AWWA C651-99 states “leaks or breaks that are repaired with clamping devices while the mains remain full of water may present little danger of contamination and therefore may not require disinfection.” In cases where there is no positive pressure in the main and there is risk of contamination, the section of main should be isolated as quickly as possible and the authorities and affected parties should be notified immediately of the potential for contamination.

AWWA C651-99 outlines a disinfection procedure when cutting into or repairing existing water mains. This procedure includes applying hypochlorite to the trench, swabbing the interior of all pipes and fittings with a one percent hypochlorite solution, and flushing toward the repair from both directions if possible. Where practical, the main should also be isolated, flushed, and chlorinated, and then flushed again until discoloured water is eliminated and the chlorine concentration is no higher than the chlorine residual in the adjacent parts of the system. The turbidity should also be checked and a water sample should be collected for bacteriological analysis.

APPENDIX C: RESOURCES FOR VULNERABILITY ASSESSMENT

Several agencies have developed methodologies for vulnerability assessment and emergency planning, including the following.

- Sandia National Laboratories has developed a risk assessment methodology (RAM-W) for water infrastructure.

- The Association of State Drinking Water Administrators (ASDWA) and the National Rural Water Association (NRWA) have published *Security Vulnerability Self-Assessment Guide for Small Drinking Water Systems.*

- The EPA (2002c) has published a document, *Guidance for Water Utility Response, Recovery and Remediation Actions for Man-Made and/or Technological Emergencies.*

- The Association of Metropolitan Sewerage Agencies (AMSA) is developing a vulnerability self-assessment software tool (VSAT) for public water utilities.

- AWWA Manual M19 (1999b) describes emergency planning for water utility management.

- Hazard analysis of critical control points (HACCP) protocols have been developed by the International Food Safety Standard.

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