MONITORING WATER QUALITY IN THE DISTRIBUTION SYSTEM

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide to Sustainable Municipal Infrastructure

Guide national pour des infrastructures municipales durables

Canada

NRC · CNRC

Federation of Canadian Municipalities

Fédération canadienne des municipalités

Monitoring Water Quality in the Distribution System
Version No. 1.0
Publication Date: November 2004

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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 aging while demand grows for more and better roads, and improved water and sewer systems. Municipalities[1] must provide these services to satisfy higher standards for safety, health and environmental protection as well as population growth. The solution is to change the way we plan, design and manage infrastructure. Only by doing so can municipalities meet new demands within a fiscally responsible and environmentally sustainable framework, while preserving our quality of life.

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

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

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

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

Please join us.

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

ACKNOWLEDGEMENTS

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

This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal best practices and an extensive literature review. The following members of InfraGuide's potable water technical committee provided guidance and direction in the development of this best practice. They were assisted by InfraGuide Directorate staff, and by Delcan Corporation.

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The committee would also like to thank the following individual for his participation in peer review:

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

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EXECUTIVE SUMMARY

This document outlines the best practice for monitoring water quality in the distribution system. It is based on a review of existing literature, the responses to questionnaires sent to 11 municipalities, and input from water quality and distribution system experts from across Canada.

Background

The major elements of a comprehensive potable water system multi-barrier approach include source water protection, treatment to remove harmful contaminants, disinfection to kill or inactivate disease-causing organisms, proper operation and maintenance of the distribution system, and water quality monitoring "to detect, preclude or solve water quality problems before they adversely affect public health" (AwwaRF, 2002). Addressing possible problems before they impact consumers is of the utmost importance. 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.

Many municipalities have a comprehensive water quality monitoring program in place for their source water and treatment processes. Since water quality can change after leaving the treatment facility, monitoring water quality throughout the distribution system and responding to any changes is required.

By following this best practice, a municipality can reduce risks to public health by early detection and mitigation of declining or unacceptable water quality, meet legislated requirements, and provide a pro-active approach to deal with emerging water quality issues in the distribution system.

Best Practice

As a minimum in developing a comprehensive water quality monitoring program for the distribution system, municipalities must satisfy applicable legislative and regulatory monitoring requirements. In addition to satisfying these minimum regulatory requirements, developing a site-specific monitoring program is recommended as a best practice. The development of a program should include the following steps:

1. Determine monitoring parameters.
2. Determine monitoring locations.
3. Determine monitoring frequency.
4. Determine sampling techniques.
5. Manage and report monitoring data.
6. Include event-driven monitoring in the program.
7. Establish partnerships.
8. Develop response procedures for monitoring results.

9. Include community monitoring parameters in the program.
10. Maintain and update the monitoring program.

These practices are intended to apply to all drinking water systems across Canada, regardless of size. The monitoring program must be tailored for each system by looking at the unique elements of the system and the water quality challenges that the municipality has historically faced. The benefits of implementing this best practice include:

- reduces risks to public health by early detection and mitigation of declining or unacceptable water quality;
- meets legislated requirements;
- guides the decision making of the municipality in the operation and maintenance activities to address water quality in the distribution system;
- increases consumer confidence;
- supports due diligence;
- maximizes the efficiency of chemical addition at the treatment facility;
- develops water quality baseline data;
- provides support data for capital improvements that may be required in the distribution system; and
- provides a pro-active approach to deal with emerging water quality issues in the distribution system.

This document also provides the risks to implementing this best practice, discusses evolving technologies and provides information and references on on-line monitors.

1. GENERAL

1.1 INTRODUCTION

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

This best practice is based on a review of existing literature, the responses to questionnaires sent to 11 municipalities[1], and input from water quality and distribution system experts from across Canada. The questionnaire included queries about practices related to monitoring water quality changes, the use of water quality data, and monitoring health-related indicators. The municipalities that responded to the questionnaire have water systems that serve populations of less than 5,000 to more than three million people.

Most of the information in this best practice is available through various existing documents, as referenced. As such, this is a summary of information tailored for municipalities wishing to develop or enhance their water distribution system water quality program.

1.2 PURPOSE AND SCOPE

This document describes how to develop a distribution system monitoring program as well as the associated data management activities, communication with various community partners concerned with drinking water quality, and the ongoing monitoring program maintenance essential for success. The use of on-line monitoring instrumentation in the distribution system, in addition to regular analysis of grab samples and automatic sampling, is also discussed.

This best practice does not address monitoring of source water quality, water production, or water quality changes that may occur once the water enters private property. It addresses the monitoring of water quality in the distribution system between the water supply facilities and the point on the system where the piping becomes the responsibility of the property owner (usually at the property line). Ideally, all potable water systems should be operated using a multi-barrier approach (from the source to consumer taps). Other future best practices will examine the other multi-barrier components of a water supply system with the eventual integration of all the elements.

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

This document should be read and understood by the groups who are responsible for water quality (e.g., water utility, municipal water quality department, operator, etc.) as well as the groups that develop the distribution system monitoring program (e.g., in-house group, contracted-out to consultant, etc.). While this document provides general guidance on the various components of the monitoring program, the person or group that develops the program should be knowledgeable about water quality and will need to gather detailed information on the system, consult other documents that provide more prescriptive and detailed information, and use professional judgment. The monitoring framework provided is meant to educate the water quality group and provides a planning tool.

1.3 How to Use This Document

Section 2 provides a summary of the rationale for developing a distribution system monitoring program, and the associated benefits, costs and risks. Section 3 summarizes the recommended steps to develop a program tailored to the distribution system. Section 4 presents some applications and limitations. Finally, Section 5 describes measures to evaluate the effectiveness of the monitoring program. References are provided throughout this document for additional and more comprehensive information about distribution system monitoring programs.

1.4 Glossary

The following list defines some terms[2] used in this document.

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

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

Biofilm — A slimy or glue-like layer of microbiological matter that covers a surface.

Chloramination — The process of protecting water with monochloramine by the addition of ammonia to chlorinated water.

Chloramine — Disinfectant produced from the mixing of chlorine and ammonia.

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

[2] Definition of terms taken from AwwaRF (2000, pg. 289-304) and National Guide to Sustainable Municipal Infrastructure (InfraGuide) (2003, pg. 2-4).

Coliform bacteria — A group of bacteria inhabiting the intestines of humans or animals but also often found elsewhere in the environment. Presence of E.coli, fecal coliform, or other coliform bacteria in water is used as an indication of contamination (by human or animal wastes). The presence of bacteria in water is a useful indicator of water treatment or distribution system problems.

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.

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.

Escherichia coli (E. coli) — A bacteria of the coliform group that originates only in fecal matter, and indicates that contamination by human/animal waste 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) — A family of commonly occurring chlorinated disinfection by-products.

Heterotrophic plate count (HPC) — A laboratory procedure for estimating the total bacterial count in a water sample. Also called standard plate count, total plate count, or total bacterial count. Abnormal HPC levels are a useful indicator of potential distribution system problems (in the normal absence of coliform bacteria).

Municipality/Municipalities — A legally incorporated or duly authorized association of inhabitants of limited area for local governmental or other public purposes. Municipality/municipalities is intended to include all purveyors of public services as well as utilities.

Non-routine monitoring — Monitoring that is conducted based on a specific event that may or may not occur. For example, when a water main break occurs or flushing activities are conducted, non-routine monitoring is undertaken.

Pathogen — A disease-causing organism.

pH — pH is a measure of the hydrogen ion activity in a solution. 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.

Routine monitoring — Monitoring that is conducted on a regular basis throughout the year at prescribed times. The frequency at which routine monitoring is conducted can be continuous (which requires the use of on-line monitors), hourly, daily, weekly, monthly, quarterly, or annually.

Trihalomethanes (THMs) — A family of commonly occurring chlorinated disinfection by-products.

Turbidity — The scattering and absorption of light in water caused by the presence of suspended matter. A physical characteristic of water that makes the water appear cloudy.

2. RATIONALE

2.1 BACKGROUND

2.1.1 MULTI-BARRIER APPROACH

The multi-barrier approach to safe drinking water has been accepted as the current best practice to ensure that municipalities[3] produce high quality drinking water. The major elements of a comprehensive multi-barrier approach include source water protection, treatment to remove harmful contaminants, disinfection to kill or inactivate disease-causing organisms, proper operation and maintenance of the distribution system, and water quality monitoring “to detect, preclude or solve water quality problems before they adversely affect public health” (American Water Works Association Research Foundation (AwwaRF), 2002, pg. 2). Addressing problems before they impact consumers is of utmost importance. 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.

2.1.2 MONITORING IN THE DISTRIBUTION SYSTEM

Many municipalities have a comprehensive water quality monitoring program in place for their source water and treatment processes. Since water quality can change after leaving the treatment facility, monitoring water quality throughout the distribution system and responding to any changes is required. Water systems of all sizes are subject to many possible events, reactions, and problems that can change the quality of the water produced at the treatment facility to a product that is unpalatable, or worse, not safe for consumption by the time it is delivered to the consumer. Regular monitoring in the distribution system must form part of the total water quality management program, so that any deterioration in water quality can be predicted and mitigated in an efficient manner.

2.1.3 GUIDELINES FOR CANADIAN DRINKING WATER QUALITY

The Guidelines for Canadian Drinking Water Quality (Health Canada, 1996–Last printed version) suggest routine sampling should be done for microbiological characteristics, chemical parameters, and physical parameters. The most up-to-date Guidelines may be found on Health Canada’s Web site in the “Summary of Guidelines for Canadian Drinking Water Quality.” We recommend that both the printed published version and the latest Web site “Summary” be referenced. These Guidelines recognize that:

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

> the frequency of sampling depends upon the quality of the source water, the number of water sources, the past frequency of unsatisfactory samples, the adequacy of treatment and capacity of the treatment facility, the size and complexity of the distribution system, the practice of disinfection and the size of the population served.

This means that local conditions must be considered when developing a distribution system water quality monitoring program.

The Guidelines for Canadian Drinking Water Quality have been adopted by most federal, provincial, and territorial agencies, and can be found at <www.hc-sc.gc.ca/waterquality>. As well, Health Canada's bacteriological sampling guidelines are adopted by most provinces as regulatory minimum requirements, although they often become the maximum sample set. It is recommended that, even for small systems, the municipality should take more samples than the minimum, to adequately characterize their system, and to cover any samples that might be unacceptable (late delivery, broken bottle, etc).

2.1.4 Provincial and Territorial Legislation and Regulations

In Canada, the legislative responsibility for regulation of safe drinking water generally falls to the provinces and territories (except for First Nations sites). Each province and territory has established legislation and regulations respecting drinking water. Issues that may be covered to varying degrees include source water protection, water treatment, and management of the distribution system, including monitoring. As a minimum, municipalities must satisfy applicable legislative and regulatory requirements for creating and implementing a comprehensive monitoring program in the distribution system. Requirements may be specified in operating permits, certificates of approval, or similar documents.

2.1.5 Reduce Health Risks and Water Quality Problems by Monitoring

As described in the best practice, *Water Quality in Distribution Systems* (InfraGuide, 2003), water systems can be susceptible to water quality problems, including biological, chemical/physical, and aesthetic. Some of these water quality problems could result in potential health risks if left uncorrected. The magnitude of health risks associated with biological problems alone is staggering. "The Centers for Disease Control and Prevention (CDC) estimates that each year in the United States up to 900,000 cases of illness and possibly 900 deaths occur as a result of waterborne microbial infections." (American Society for Microbiology, 1999, pg. 5). Using population-based extrapolation from the CDC estimates, Health Canada estimates that 90 deaths and 90,000 illnesses could be attributed to waterborne microbial infections each year in Canada.

To minimize water quality degradation in the distribution system, municipalities should develop and implement comprehensive monitoring programs that involve the monitoring of water quality at representative sites throughout the distribution system. The monitoring results will alert the municipality to water quality problems so that water quality degradation can be mitigated and minimized.

The *Water Quality in Distribution Systems* best practice 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. It also covers the basic elements of a distribution system monitoring program, including both routine and non-routine monitoring. This best practice builds on those elements, to provide further guidance to municipalities and other groups to develop, implement, and maintain distribution system monitoring programs.

2.2 BENEFITS

The following summarizes some of the reasons why it is beneficial to monitor water quality in the distribution system:

- reduces risks to public health by early detection and mitigation of declining or unacceptable water quality;
- meets legislated requirements;
- guides the decision making of the municipality in the operation and maintenance activities to address water quality in the distribution system;
- increases consumer confidence;
- supports due diligence;
- maximizes the efficiency of chemical addition at the treatment facility;
- develops water quality baseline data;
- provides support data for capital improvements that may be required in the distribution system; and
- provides a pro-active approach to deal with emerging water quality issues in the distribution system.

2.3 RISKS

However, there are also risks:

- higher operational cost to implement, maintain, and update the program;
- additional capital expenditures may be required;
- additional staff may be required;
- additional staff training is required;

- additional data to manage and report; and
- additional skill required to respond appropriately to monitoring data.

Most, if not all of these risks are associated with a financial cost, which ultimately is paid by the water consumers. The financial savings due to the avoidance of a water quality problem within a community must also be considered, since the direct costs and economic impacts associated with a water quality incident that can be avoided may be significant. The May 2000 water quality incident in Walkerton, Ontario resulted in an estimate of "… tangible economic impact of …more than $64.5 million" (Livernois, J., 2002, pg. 3). As such, the implementation of an appropriate monitoring program may actually result in a cost saving to water consumers.

The risk of **not** having a comprehensive monitoring program for the distribution system is that water quality problems may go unnoticed and result in human illness or death.

3. WORK DESCRIPTION

3.1 WHAT SHOULD BE DONE

As a minimum in developing a comprehensive water quality monitoring program for the distribution system, municipalities must satisfy applicable legislative and regulatory monitoring requirements. In addition to satisfying these minimum regulatory requirements, developing a site-specific monitoring program is recommended as a best practice.

Every water distribution system is unique and, therefore, it is important to have a good understanding of the distribution system so that an appropriate, effective, and efficient monitoring program can be developed. Regulations and industry-based resources provide suggested baseline or minimum monitoring programs, detailed templates with monitoring parameters and frequencies, and example programs from both field and case studies. These resources should be used along with site-specific information to tailor a program to the system. Examples of industry-based resources include the *Guidance Manual for Maintaining Distribution System Water Quality* (AwwaRF, 2000) and the *Guidance Manual for Monitoring Distribution System Water Quality* (AwwaRF, 2002). These manuals, along with others, provide very detailed information for developing a water quality monitoring program.

Most municipalities already conduct water quality monitoring throughout their distribution systems. Other groups and departments within the municipality, including those responsible for engineering, construction, operations, maintenance, management, and public health may be conducting water quality monitoring, or may want to conduct monitoring, for different purposes. The objective is to develop a program that meets the needs of all groups, with data that are accessible to all, including consumers.

The following steps provide a framework to develop a comprehensive water quality monitoring program for the distribution system.

1. Determine monitoring parameters.

2. Determine monitoring locations.

3. Determine monitoring frequency.

4. Determine sampling techniques.

5. Manage and report monitoring data.

6. Include event-driven monitoring in the program.

7. Establish partnerships.
8. Develop response procedures for monitoring results.
9. Include community monitoring of indicator parameters in the program.
10. Maintain and update the monitoring program.

3.2 How to Do the Work

The following sections describe how the ten components of the monitoring program framework listed in Section 3.1 should be implemented.

3.2.1 Determine monitoring parameters

Best Practice

The distribution system monitoring program must include parameters that will fulfill regulatory requirements and provide the municipality with an understanding of what is affecting the water quality within the distribution system.

As a minimum, water quality parameters required by regulations, operating permits, certificates of approval, and similar documents must be monitored to ensure regulatory compliance. Monitoring some parameters that are non-regulated may provide a municipality with a better understanding of what is affecting the water quality within their distribution system. Consumer inquiries (organized by type of inquiry) should also be recorded and investigated following established response protocols.

The key parameters that are commonly considered to be indicators of water quality in terms of public health are:

- chlorine residual (free and total);
- E. coli (as an indicator of fecal contamination); and
- disinfection by-products (such as trihalomethanes, haloacetic acids, etc.).

Chlorine residual is used as an indicator of protection against contaminant intrusion. It is also useful as an indicator of travel time in the water system. A decreased chlorine residual can indicate stagnation or a demand due to a contaminant intrusion. Chlorine residual can also be used to indicate nitrification in chloraminated systems.

While heterotrophic plate count (HPC) bacteria are not directly related to public health, monitoring in distribution systems may be useful as an indicator of a water quality concern, and thus, a good operational tool. The HPC bacteria level is primarily an indicator of biofilm, and tends to correlate with chlorine residual decay and nitrification problems. High levels may suggest a risk of elevated concentrations of pathogens that may survive in biofilm (e.g., aeromonas). Extremely high levels of HPC may interfere with the proper identification and/or counting of total coliforms.

Total coliforms are identified as part of the broader HPC bacteria level. In the past, total coliforms were used instead of E.coli as an indicator of potential contamination, since total coliforms were easier to monitor than E.coli. Since E. coli are now easy to monitor, and they are a much more definitive indicator of potentially unsafe water than total coliform, E. coli should be used instead of total coliform as an indicator of contamination. In a distribution system, total coliforms may be used as indicators of overall water quality, as their presence can indicate potential regrowth or post-treatment contamination problems. HPC monitoring will accomplish the same purpose, and in many respects are better since they represent more of the bacteria that can form biofilm than simply coliforms. It should be noted that the presence of total coliforms in the distribution system is not a direct indicator of water safety and, as such, should not be used as an indicator of potential adverse human health effects (total coliforms are subject to considerable variation). Therefore, monitoring of total coliforms is not included as a best practice.

Useful parameters from an operational perspective include:

- ammonia, nitrate, nitrite (if chloramination is used);
- turbidity;
- flow; and
- pressure

Other routine parameters can be included, but the significance of the level of specific parameters will depend on each individual water system:

- temperature;
- pH;
- alkalinity;
- conductivity;
- colour
- soluble metal stemming from pipe material (e.g., lead, iron, copper);
- corrosion inhibitors (if used); and
- fluoride (if used).

Parameters related to event-driven monitoring include:

- iron and manganese;
- taste;
- odour; and
- hydrocarbons.

The quality of source water and the associated treatment process will affect the selection of parameters that are monitored. In particular, chemical additions at the treatment facility, such as chlorine or chloramines, will require the associated monitoring of chlorine residual and ammonia/nitrate/nitrite in the distribution system. Seasonal variations in source water may be experienced, especially with surface water facilities, which require changes to the treatment process and the distribution system monitoring program.

For multiple water sources, especially a combination of surface and groundwater, monitoring parameters such as pH, ammonia, alkalinity, and conductivity, can help distinguish the source of water at any particular point in the distribution system. Water from different sources will have different aesthetic qualities that may be noticeable to consumers. Understanding the mixing of water sources will help the municipality respond to consumer inquiries.

Evaluate the distribution system attributes, including the size of the system, material, age and condition of the water mains, system configuration, and maintenance practices. The selection of monitoring parameters will be influenced by the distribution system attributes and the resulting operating conditions, since these will result in water quality conditions that are specific to each municipality. For example, most municipalities have areas with low flow or dead-end mains, which may have a low chlorine residual and increased risk of bacteriological growth; therefore, monitoring of chlorine residual and bacteriological parameters at these locations will be common practice for most municipalities. Some municipalities have water mains or storage reservoirs with caulking or epoxy coatings; the monitoring of hydrocarbons for this specific condition will only be applicable to these municipalities. Monitoring of hydrocarbons is also applicable where possible leaks from fuel tanks may have occurred.

Special consumer needs may add parameters or increase the frequency of parameters selected for monitoring. Health care facilities including hospitals, nursing homes, and dialysis facilities, as well as industrial plants may also have specific water quality requirements and need assurance that particular parameters are either present or absent within specific levels. In these cases, the municipality should be aware of these consumers and their specific needs. In most cases, these consumers will be responsible for their own needs, but a municipality's monitoring program may also take some of these parameters into account.

Consider community health concerns and historical data. For example, a municipality that has experienced distribution system microbiological problems in the past, and has made infrastructure and operational changes to correct the problem, may develop a bacteriological monitoring program to satisfy the community's health concern and confirm that the changes have corrected the problem.

There may be other municipal operational requirements or special circumstances that will influence the selection of additional parameters to be included in the distribution system monitoring program.

3.2.2 DETERMINE MONITORING LOCATIONS

Best Practice

When developing a monitoring program, the locations at which various parameters are monitored should be based on regulatory requirements, historical data, distribution system characteristics, population or consumer distribution, and operational requirements.

Determine the most appropriate water distribution system monitoring locations that should be included in the monitoring program. Regulations may stipulate the required monitoring locations. For example, Quebec regulations for bacterial monitoring state that at least 50 percent of regulated samples must be collected from the outermost limits of the distribution system. Other regulations may be more or less prescriptive in terms of where to situate monitoring locations. While regulatory requirements for monitoring locations must be satisfied, it is important to evaluate the historical data, distribution system characteristics, and operational requirements to establish the appropriate monitoring locations. Table No. 1 in Appendix A provides a comprehensive list of parameters that may be applicable for distribution system monitoring, including the sampling location, the objective of monitoring the parameter and other general comments.

A good starting point is to evaluate the system historical data. If there are known problem areas (e.g., many similar consumer inquiries or consistent poor water quality results) they should be monitored so that the municipality can determine the cause of the problem and implement a solution. Monitoring should continue in these areas after the solution is implemented to ensure the problem has been rectified. If there are areas where water quality has varied historically, monitor these areas to determine the reason for the variability.

Monitoring locations should include high-risk areas that have sensitive facilities, such as hospitals, due to their sensitivity to public health. Municipalities may also want to monitor certain parameters to meet their industrial consumer's needs, such as high tech or food producing companies.

Select monitoring locations by evaluating distribution system characteristics. Establish locations that have good spatial representation, based on distance from the treatment facility(ies) or travel time within the distribution system, population density for serviced areas, and ends of the system. High flow areas should be monitored; high flows may be due to one large consumer, or connection to an adjacent municipality. Consumption patterns driven by population distribution or the presence of a high-volume consumer will be important factors. Consider the type and condition of water mains when deciding monitoring locations as well as the presence of significant distribution infrastructure, such as reservoirs or pump stations. For example, areas with unlined cast-iron water mains should be monitored to provide information on whether (and how) these water mains affect water quality.

Include monitoring locations that cover several water ages in the system. To determine the water age for large systems, a hydraulic water model or a tracer study will be necessary. For smaller systems, it may be easier to evaluate water age through a detailed review of the system. For all systems, areas with low flow or dead ends should be monitored due to the possibility of increased water age and/or poor hydraulics.

Storage facilities within the distribution system should be monitored, by taking samples at locations near the inlet pipe, outlet pipe, and if possible within the storage facility itself. Based on the volume and flow conditions of these facilities, water quality has the potential to deteriorate over time. Storage facilities are also subject to nitrification problems.

When choosing monitoring locations, consider the types of sampling equipment that can be used based on the available access, possibility of contamination, and security issues. Samples may be obtained from indoor taps, outdoor hose bibs, fire hydrants, dedicated sampling stations, directly on the water main by on-line monitors, and within storage facilities. Evaluate each location based on the potential sampling equipment, the ease or difficulty of access during normal working hours and during emergency conditions (off hours), the potential for sample contamination especially for taps, hose bibs, and hydrants, and possible site security (tampering, vandalism, staff access concerns, etc.). The retrieval of samples during various weather conditions should also be considered.

Obtaining extensive monitoring data from across the system on a frequent basis allows for better investigation of problems, since the data that has been collected can confirm the areas that have no problems, and as such can limit the extent of any area that may have a water quality concern. It can also demonstrate to regulators that any issue is very localized.

3.2.3 Determine Monitoring Frequency

Best Practice

The frequency of monitoring should allow the municipality to fulfill regulatory requirements, allow timely detection of acute changes in water quality that may affect public health or aesthetics (so appropriate countermeasures can be taken), and provide data required to operate and maintain the system appropriately.

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

Determine the frequency of monitoring for each parameter and location within the distribution system.

- Routine monitoring is conducted on a regular basis throughout the year at prescribed times. The frequency at which routine monitoring is conducted can be continuous (which requires the use of on-line monitors), hourly, daily, weekly, monthly, quarterly, or annually.
- Non-routine monitoring is conducted based on a specific event that may or may not occur. For example, when a water main break occurs or flushing activities are conducted, non-routine monitoring is undertaken.

Some parameters will be monitored within the system on both a routine and non-routine basis. For example, chlorine residuals may be monitored continuously at some locations in the distribution system. When flushing and cleaning activities are conducted, additional non-routine monitoring of chlorine residuals takes place in the vicinity of the flushing location. Other events that may trigger non-routine monitoring are discussed below.

Monitoring frequency, as required by regulations, must be met. However, the program should be designed to oversample or collect more samples than the regulations require. Oversampling provides a contingency to account for unforeseen circumstances (e.g., staff illness, broken bottle, etc.) that may prevent sample collection where on-line monitors are not used.

Many other guidelines, best practices, and manuals suggest appropriate monitoring frequencies for various parameters (see references at end of this best practice). The water industry has long recognized the importance of frequent chlorine residual monitoring. Frequent or on-line monitoring of chlorine residual in the distribution system is carried out by most, if not all, municipalities.

While sampling and analytical techniques are improving, some technological limitations will restrict the monitoring of certain parameters. On-line monitors may not be available for some parameters, may be available but not with the required accuracy, or may be cost-prohibitive. For example, current online monitors for various metals are expensive and their operation requires highly skilled technical staff (AwwaRF and CRS ProAqua, 2002, pg. 397). As well, sample hold times may prevent monitoring results from being produced for several hours, or even several days. Thus, the required monitoring frequency will affect the choice of sampling technique.

Examine the water system dynamics, variability, and vulnerability to determine the appropriate monitoring frequency. As well, source water variability and stability, anticipated temperature changes in the distribution system, and seasonal variations of certain parameters will impact the monitoring frequency. Consider the nature of the parameter, and the time it takes to affect water quality.

Based on the chosen monitoring frequency, the collection of water samples should be spread out in time. For example, if a parameter is monitored on a weekly basis, all the samples should not be collected in one day or on the same day each week. Samples spread over time will give a better indication of water quality variability within the system. The monitoring frequency should allow the municipality to form a history of the water quality throughout the system, so that problem areas can be identified quickly and easily.

3.2.4 DETERMINE SAMPLING TECHNIQUES

Determine the sampling technique to use for each parameter and monitoring location in the distribution system. Sampling techniques include:

- on-line instruments

  On-line instruments for monitoring water quality are permanently installed in the water system, function without operator intervention (except for routine maintenance and regular calibration), and sample, analyze, and report on certain water quality parameters with a regular frequency (e.g., seconds or minutes apart).

- automatic samplers

  Automatic water quality samplers operate without operator intervention to collect water samples of a prescribed volume, over a defined time period; the water samples must then be manually retrieved and analyzed in the field or laboratory.

- manual samples

  Manual samples are obtained by a staff member by flowing a tap, hose bib, fire hydrant, or dedicated sampling station, and can be analyzed in the field or laboratory.

Best Practice
The monitoring program should include a combination of on-line instruments and manual sampling techniques in the distribution system. On-line monitors should only be installed in the distribution system after a full evaluation of their appropriateness.

Regulatory requirements may dictate the sampling technique acceptable for demonstrating regulatory compliance. The regulated frequency may also dictate the sampling technique. For example, if continuous measurements are required, on-line instruments should be used.

Apart from regulatory requirements, determining the sampling technique to use is based on a number of factors:

- required frequency of monitoring;
- monitoring locations, especially for remote locations;
- costs associated with the sampling technique, including capital and operating costs;
- operation and maintenance of sampling equipment;
- availability of on-line monitoring technology;
- availability of accredited laboratory and analytical facilities;
- storage, preservation and transportation of samples;
- potential contamination of samples due to the sampling technique; and
- staff and equipment availability and capability.

Manual samples are generally easy to collect, but require staff availability and training, may be at risk of sample contamination if proper sample collection techniques are not used, and may require extensive travel based on the size of the distribution system. All staff members responsible for sample collection should have proper training in aseptic techniques for manual sampling. Where possible, dedicated sampling stations should be used for manual sample collection to avoid contamination. Automatic samplers may also reduce the potential of sample contamination, but still require staff availability, and travel to retrieve the samples. Automatic samplers are not commonly used in water distribution systems.

Most municipalities use on-line monitoring to ensure that high-quality water enters (i.e., at the discharge of the treatment facility) the distribution system. Some municipalities also use on-line monitoring at pumping stations, storage facilities, and other locations in the distribution system to provide continuous water quality results (e.g., chlorine residual, pressure, and flow). An excellent resource to consult for information regarding on-line monitors is *Online Monitoring for Drinking Water Utilities* (AwwaRF and CRS Proaqua, 2002).

Table No. 2 in Appendix A provides current information on the technological development of on-line monitoring equipment for various parameters. This table is reproduced in part from *Online Monitoring for Drinking Water Utilities* (AwwaRF and CRS Proaqua, 2002, pg. 396-399), courtesy of AwwaRF.

The following discussion points will help the municipality decide whether to use on-line monitors. For more detailed information, consult other sources referenced at the end of this best practice.

- On-line monitors can help mitigate the risk of water quality deterioration in the distribution system by providing a municipality with timely information on the parameter being monitored.
- On-line monitors can increase consumer confidence by providing real-time, continuous monitoring results.
- On-line monitors can provide monitoring results 24 hours per day, 7 days per week.
- Regulatory standards for on-line equipment must be followed.
- It is useful to complete a cost–benefit analysis for on-line monitors versus manual sampling, including capital costs, operating costs, cost savings, and benefits to water quality, operations, and regulatory compliance.
- Many municipalities are using on-line monitors at water treatment facilities, pumping stations and storage facilities.
- On-line chlorine monitors, pressure gauges, and flow monitors are widely available and being used in the distribution system by many municipalities.
- On-line monitors should only be used in the distribution system if they are used in the treatment facility.
- If the decision is made to install on-line monitors, determine their locations by examining manual sampling results, historical water quality data and equipment maintenance/retrieval capabilities.
- Supervisory Control and Data Acquisition (SCADA), data loggers/chart recorders or other communication systems must be used with on-line monitors, with appropriate data recording, transfer, retrieval and backup, and alarm functions.
- On-line monitors require regular maintenance, replenishment of reagents, and staff training to operate.
- On-line monitors require regular calibration to ensure accuracy of data. The requirement for laboratory accreditation of data should be considered.
- Power requirements, availability of a drain, and other operational issues must be considered when selecting on-line monitors.
- It may be challenging to maintain on-line monitors in Northern climates due to equipment limitations in cold weather. Appropriate enclosures may be required based on the location and weather conditions.

For any sampling technique that is used by the municipality, it is important to consider the time that is required to take the sample, process and analyze the parameter, and receive the water quality results. Techniques should be chosen that allow for the fastest possible receipt of water quality results. Where manual sampling is used, analytical techniques should be chosen that have rapid and accurate processing methods. For example:

- on-line chlorine monitors provide immediate analysis;
- where manual sampling is used for chlorine residual and turbidity, the samples should be analyzed in the field so that the results are available immediately;
- where manual sampling is used for bacteriological parameters, enzyme-substrate testing should be used, since it can offer results in 18-20 hours. This allows samples collected during the day to be processed at the end of the day, with results available by mid-day on the following day.

3.2.5 MANAGE AND REPORT MONITORING DATA

Best Practice
Develop a data management system that will store all water quality data, allow access by many parties, but can only be edited by select staff, and will automatically screen data against established limits. Using the data management system, the municipality should prepare reports to demonstrate regulatory compliance and provide water quality information to consumers.

The monitoring program will produce a large amount of water quality data. This data will be of little practical use unless the municipality can manage it effectively and report the results for regulatory compliance, for consumers and for their own operational and maintenance activities.

The municipality should set up a data management system that will store all water quality data in one central location, and be accessible from many locations. Computerized data should have appropriate backup measures and procedures in place. Many types of data management systems are acceptable, including standard database and spreadsheet software, laboratory-based management systems, such as a laboratory information management system (LIMS), commercially available packaged water quality management systems, and custom-built management systems. Paper-based data management systems are quickly becoming obsolete, and are not recommended as a best practice since they do not allow for quick access by multiple parties, nor do they allow for easy graphical analysis, trending, or reporting. However, managing data using a paper-based system may still be appropriate (especially for small systems), but the user should be aware of its limitations.

The data management system should incorporate the ability to screen data automatically against the established normal or acceptable water quality limits, and produce flags or alarms. This should occur for both types of occurrences when response procedures are activated: (i) when the monitoring results approach an unacceptable level, and; (ii) when the monitoring results reach an unacceptable level. If the system is not capable of automatic screening, a manual screening process will be necessary whereby the municipality must rely on staff who operate the management system to manually check the data and produce flags or alarms when necessary. In these cases, the municipality should have more than one staff member responsible for screening.

If the monitoring program is linked to a SCADA system, the SCADA system should have automatic data screening and alarm functions. The municipality should ensure that the SCADA system is linked to the data management and reporting systems so historical data are captured, recorded, and reported.

For all water quality data, the municipality should have a quality control process to ensure that inaccurate or misleading data is treated as such. For example, if an on-line monitor fails but still continues to report erroneous results, or a manual sample becomes contaminated by the operator, these results should be noted so that they are not included as valid data in the reporting process.

Water quality data should be reviewed daily if possible, to track changes, trends, and problem areas. Graphs and charts should be used to provide a visual summary of the data.

The municipality should consider using other linkages to the data management system that will facilitate a spatial and/or temporal analysis of water quality results. For example, linking the data to a geographic information system (GIS) allows staff to superimpose water quality results on maps that show the system layout. The municipality can then assess if water quality problems or consumer inquiries are clustered in certain areas or are spread through the system. Similarly, data may be examined to determine temporal effects.

The data should be accessible to all appropriate parties. It should only be edited or added to by select staff members who are responsible for water quality. The data may be accessed for many reasons:

- to identify problem areas, and assess the extent of the problem;
- control of treatment processes;
- development of performance indicators;
- compilation of water quality reports, including regulatory compliance reports and consumer reports;
- consumer access to water quality results (e.g., consumer inquiry, website access, etc.);
- data trend analysis or statistical analysis;
- hydraulic and water quality modelling;
- linkages to GIS and other systems; or
- compilation of data to support capital improvements in the distribution system.

The municipality must report the water quality results to achieve regulatory compliance. In addition, the municipality should prepare an easy-to-read, comprehensive water quality report for consumers, and make it available through a combination of means including bill inserts, paper reports available in public offices, and Web-based reports. These reports may cover monthly or quarterly results, but as a minimum, should be produced annually. Information on the source water, treatment process, monitoring results, and any other important issues should be included.

3.2.6 INCLUDE EVENT-DRIVEN MONITORING IN THE PROGRAM

Best Practice

Monitor water quality in the distribution system when specific events occur. The monitoring program should include procedures based on events that will probably occur either on a regular or infrequent basis. Concentrate on probable events based on past experience, rather than imagining every possibility. Compare event-driven monitoring results with routine monitoring results, to determine whether a problem exists.

All municipalities receive inquiries on a regular basis about water taste, odour, appearance, etc. Many municipalities have annual construction activities related to new water infrastructure or rehabilitation of existing infrastructure. Water main breaks may occur frequently or infrequently, fires may affect the system for a short time due to fire hydrant use, and power outages and operational activities may occur sporadically. All of these events, plus many others, should trigger monitoring in the distribution system and may identify localized problems before they become a system-wide concern.

Inquiries received from the public usually pertain to appearance, taste, or odour of tap water. Staining on bathtubs (from manganese or iron) or clothing (from iron which produces "red water"), health concerns, and air or sediments in the water may also be reported. The staff member that receives the inquiry should obtain as much information as possible. Depending on the nature of the inquiry, a staff member with water quality expertise should review the inquiry information to determine if a problem is associated with the water treatment facility, in the distribution system, or on the consumer's premises. In some cases the problem may be explained by available data. If monitoring in the distribution system is necessary, obtain samples near the location of the inquiry, both upstream and downstream. For example, monitoring parameters may include chlorine residual, turbidity, pH, and bacterial parameters, plus additional parameters based on the nature of the inquiry. The inquiry should be investigated until a resolution is obtained.

Consumer inquiries related to hydrocarbon odours may be related to leaks from underground storage tanks. These inquiries should be investigated to determine if a leak has occurred, regardless if the municipality is aware of an underground storage tank. Where there are areas known to have underground storage tanks, periodic monitoring should be done to confirm if leaks have occurred.

In the case of a suspected localized or widespread health problem associated with drinking water, the municipality should immediately monitor to determine the source of the problem and take steps necessary to isolate the problem if it lies in the distribution system. Example parameters are chlorine residual, turbidity, pH, and bacteriological parameters, plus any additional parameters based on the type of health problem. Since this is likely a regulatory compliance issue, it is imperative that the municipality involve health officials and provincial regulatory officials in the development of the monitoring program and follow-up activities.

Water main breaks can introduce contaminants into the system if the break results in extremely low (<35kPa, or 5 psi) or negative pressures. As soon as the break is discovered, the municipality should monitor the water pressure in the area of the break to ensure that no water quality impacts have occurred. Should low pressure concerns exist in the area of the break, monitoring of specific parameters should take place. For example, monitoring may include chlorine residual, turbidity, pH, and bacteriological parameters. Conversely, routine monitoring results that indicate a sudden increase or loss of chlorine residual, increase in turbidity, or change in pH can signal that a main break has occurred, if it has not already been discovered.

Water main flushing and cleaning is essential to maintaining and improving overall water quality and addressing specific concerns. For example, a specific concern may be the desire to remove older water from the system to improve the chlorine residual, or remove contaminated water from a portion of the system (AwwaRF, 2000, pg. 184). The municipality should monitor the parameters related to the specific concern at the beginning, middle, and end of the flushing activity. This will ensure that the objectives have been met, and that the flushed water can be disposed of properly (e.g., dechlorination or pH adjustment). Monitor pressures both upstream and downstream of the flushed area to ensure minimum pressures are being maintained. Monitoring parameters typically associated with flushing include HPC bacteria, turbidity, chlorine residual, coliform bacteria, and colour.

Firefighting may result in high flows through the distribution system for extended periods of time, possibly resulting in lowered system pressures. The Fire Department should advise the municipality of fire fighting events so that appropriate monitoring can be undertaken if necessary. Example monitoring parameters are pressures, both upstream and downstream of the fire, chlorine residual, and turbidity. These parameters should also be monitored during any other event that causes localized low pressures.

Construction activities will likely affect water quality in the distribution system. Construction on other utilities adjacent to water infrastructure may cause main breaks due to accidents or structurally challenged pipes. Construction to install new water infrastructure, repair a main break, or replace/rehabilitate existing water infrastructure may expose the water system to many potential external contamination sources. Internal contamination sources include the pipe material itself (e.g., increased pH from concrete pipe), caulking, coatings, and lubricants. Flushing and disinfection is required before mains are returned or placed into service. The ANSI/AWWA C651-99 Disinfecting Water Mains (American Water Works Association (AWWA), 1999) standard should be followed as a minimum, in the absence of more stringent local standards. Bypass piping or temporary services may be used during construction activities and are subject to damage from vehicles or pedestrians, as well as higher/lower temperatures due to pipe exposure to the elements. With the many potential hazards from these associated construction activities, monitoring is required both during and after construction. Example monitoring parameters are chlorine residual, turbidity, pH, odour, colour, and bacteriological parameters. If caulking, linings or coatings are used on pipes or storage facilities, another applicable parameter to monitor is volatile organic compounds. Testing for the presence of pipe lubricants requires specific tests like UV absorbance scans. Coatings and caulking should be cured properly to avoid introducing this material into the system. Excessive use of lubricant can lead to musty, rancid odours and consumer complaints.

Many operational activities may affect water quality, including failure of the treatment facility, cleaning and/or drawdown of storage facilities, loss of power, loss of communication system (for municipalities with SCADA or other communication systems), or cross connections. Based on the type of activity, determine appropriate monitoring procedures as well as corrective actions and follow-up monitoring. For loss of power or communication systems, on-line monitors without backup systems will be affected and may trigger the need for manual monitoring procedures and re-setting the on-line instruments when power is restored. Municipalities usually determine that a cross connection has introduced contaminants into the system either by the monitoring results or by consumer inquiries. A new best practice will be released by the InfraGuide in early 2005 to provide further guidance to municipalities on the methodologies for setting a cross connection control program.

Some municipalities experience large changes in water usage due to seasonal populations (tourism), industrial activities including plant shutdowns, and other events. Determine whether these events require additional monitoring in the distribution system, either due to higher or lower flows than normal operation and the associated water quality risks.

Floods and other extreme weather can affect source water quality, which should be dealt with at the treatment facility. Floods and extreme weather can also introduce contaminants within the distribution system, especially if main breaks occur during these conditions. Determine appropriate monitoring procedures for probable extreme weather, if applicable to the municipality.

In summary, the events that should trigger monitoring include:

- consumer inquiries;
- suspected localized or widespread health problem associated with drinking water;
- water main break;
- water main flushing and cleaning;
- fire fighting;
- construction activities;
- operational activities (failure of treatment facility, cleaning and/or drawdown of storage facilities, loss of power that may affect water pressure or flow, loss of communication system, cross connections, etc.);
- large changes in water usage (seasonal populations, industrial activities, etc.); and
- floods and other extreme weather.

3.2.7 ESTABLISH PARTNERSHIPS

Best Practice

The municipality should establish partnerships that will help contribute to the maintenance of acceptable water quality in the distribution system. This includes partnerships with stakeholders, and public and private groups, because information about potential water quality problems can be exchanged, and groups that may have an impact on the distribution system can be educated.

As part of the information exchange, the municipality should provide water quality data to its partners, and obtain information from the partners. For example, when a contamination event is detected, the municipality must notify the health department so appropriate measures can be taken. Or, when the fire department responds to a major fire, it should notify the water quality department so that they can initiate the appropriate event-driven monitoring.

In educating partners that may affect water quality, the goal is to improve water quality. By educating these groups, the municipality will mitigate events that may lead to water quality degradation. For example, it is useful to co-ordinate or provide training on the proper use of pipe lubricants by contractors to avoid contributing to water quality degradation. More examples of information exchange and education are included in Appendix B.

To exchange information effectively, the municipality needs to establish these partnerships in advance, set up regularly scheduled meetings and establish communication protocols with each partner. Discuss timelines for providing information, making sure the partner understands the importance of timely notification where water quality may be compromised or public health may be at risk. For educating groups that may impact water quality, determine if the municipality can contribute to existing training programs, or set up new programs.

The municipality should establish partnerships with some or all of the following groups:

- health department;
- fire department;
- provincial ministry of environment or other similar ministries;
- regulatory agencies and other approval boards;
- emergency preparedness, emergency response, or emergency measures groups;
- building and plumbing inspection departments;
- other applicable municipal, provincial and federal departments;
- laboratories;
- pharmacies;
- wholesale consumers, water co-operatives, or other third-party consumers;
- consultants, contractors, constructors, and equipment suppliers;
- industry — groups that have specific water quality needs, or that may adversely impact water quality; and
- special interest groups.

3.2.8 DEVELOP RESPONSE PROCEDURES FOR MONITORING RESULTS

Best Practice

Develop response procedures for water quality monitoring results that are outside of normal or acceptable limits. These procedures must be documented and understood by all staff involved with water quality in the distribution system. At a minimum, regulatory requirements for reporting abnormal results must be followed.

Determine the normal or acceptable limits for each water quality monitoring parameter based on regulations, guidelines, and historical monitoring results throughout the distribution system. Similar to the Hazard Analysis and Critical Control Point (HACCP) principle of establishing critical limits[4], the municipality should have a response procedure based on two occurrences:

- when the monitoring results **approach** an unacceptable level; and
- when the monitoring results **reach** an unacceptable level.

Having a response procedure based on a parameter that "approaches" an unacceptable level requires a good understanding of the water quality within the distribution system. For example, the free chlorine residual level "approach" value for a municipality may be 0.4 mg/L, based on two factors; (i) the minimum acceptable regulatory requirement (for example, 0.2 mg/L), and; (ii) the municipality's intent on having an average free chlorine residual of, for example, 0.8 mg/L.

The response procedures must incorporate the appropriate corrective actions including flushing, chemical dosage adjustments, valve operation, shutdown of facilities, public notices for boil-water advisories/orders[5], etc. Re-sampling procedures should be included as part of the response procedures. For example, if sampling results indicate a high level of HPC bacteria, it may be appropriate to re-sample in that area since sample contamination can often lead to misleading results.

Internal and external communication protocols should also be listed, along with 24-hour contact information for the medical officer of health, head of water quality, and regulatory agencies. Reporting requirements should be clearly stated for both regulatory compliance reports and internal water quality reports.

The monitoring program should also include response procedures for consumer inquiries, whether or not they are due to water quality that is outside normal or within acceptable limits. The municipality should follow up with the consumer to ensure concerns have been adequately addressed, and provide information on the water quality concern, if any is available.

[4] The risk management system called Hazard Analysis and Critical Control Point (HACCP) provides a step-by-step process to ensure food safety, and is being applied to drinking water systems. The HACCP system provides a process to identify hazards and preventative measures, identify critical control points, establish critical limits, identify monitoring procedures, and establish corrective action procedures.

[5] The municipality should determine the applicability and responsibility for issuing boil water advisories or orders. In some jurisdictions, the Health Department is responsible for these and therefore the municipality should coordinate with them.

Regular updates on water quality should be communicated with the local public health authority. Adverse water quality results should be communicated immediately by the testing laboratory to the municipality for action. In many cases, the testing laboratory should also communicate the adverse water quality results to the public health authority. Communication of adverse water quality results to the public should be a joint decision by the health authority and the municipal water authority, and must meet regulatory requirements.

3.2.9 INCLUDE COMMUNITY MONITORING PARAMETERS IN THE PROGRAM

Best Practice

The municipality should monitor health-related community parameters that may signal potential problems in the distribution system water quality. Acute problems as well as seasonal or chronic conditions that may be related to drinking water quality should be monitored.

Apart from physical water quality data, monitoring of community parameters is valuable and can signal potential water quality problems. Consider monitoring gastrointestinal medication purchases, hospital emergency and medical walk-in clinic attendance, and cases of disease that may be transmitted through drinking water. These may signal acute problems that may be related to drinking water quality. Tracking seasonal and chronic problems, and comparing local conditions to regional, provincial, or national averages may provide information on the long-term effects of water quality changes.

The municipality will have to determine if it is appropriate for them to monitor these health-related community parameters, or whether the Health Department should be involved, as a partner, to provide this information. Regardless of which group obtains and manages this information, it should be shared between the municipality and the health department so that both acute and possible chronic problems can be monitored.

The monitoring of gastrointestinal medication purchases may be difficult for large municipalities, due to the number of pharmacies where these medications are sold. For small municipalities, especially where there are only a handful of pharmacies, it is quite manageable to establish a partnership so the pharmacy will alert the water quality or health department of a sudden increase in purchases of gastrointestinal medication.

3.2.10 MAINTAIN AND UPDATE THE MONITORING PROGRAM

Best Practice

To continually maintain the monitoring and response program, train staff, calibrate, replace, and upgrade instruments, and perform regular quality assurance checks. Thoroughly document the program, communicate it, and update it at least annually.

To maintain the program, the municipality should ensure that staff receives appropriate training and that training is updated when new equipment or processes are introduced. Municipalities should ensure that instrument replacement and upgrades are done on a regular basis, and the instruments are calibrated (based on manufacturers' guidelines). Laboratory accreditation requirements must be fulfilled, along with regular quality assurance checks and audits of the program.

An important part of maintaining the program is to ensure the monitoring program is properly documented and communicated to appropriate parties, and updated on a regular basis. As part of the documentation, a summary table should be included that describes the monitoring program, and provides all routine sampling locations, parameters, monitoring frequencies, and sampling techniques. A system map that shows sampling locations is also recommended.

The monitoring program needs to evolve and change to keep pace with growth and other substantive changes to the distribution system. Criteria for change (i.e., population growth, or new construction) should be developed so the monitoring program will be adjusted automatically as these milestones occur. The sampling frequency as well as the number of samples collected should be adjusted based on the growth of the distribution system.

To update the monitoring program, the municipality should do a thorough review of the program at least annually and encourage staff to communicate program strengths and weaknesses when they are noticed, instead of waiting for the annual program review. Keep these communications on file so they are available and are reviewed when updating the program. As regulatory requirements change, and new instruments and technologies are introduced, the monitoring program will have to be updated accordingly.

3.3 EMERGING TECHNOLOGIES

The field of water quality monitoring is constantly evolving. Regulatory requirements will continue to change and will likely require increased monitoring (both increased parameters and frequency of monitoring). New guidelines, programs, and services will be developed, as will new monitoring technologies, equipment, and instruments. These reasons are further evidence of the importance of reviewing and updating the distribution system monitoring program on a regular basis.

The most rapidly evolving and exciting area of emerging technology is in on-line monitors, which are readily available, well developed, and commonly used for chlorine and turbidity (AwwaRF and CRS Proaqua, 2002). On-line monitors for other parameters vary from available, but not commonly used, to under development or not available. Most notably is the absence of a rapid monitoring method for microbiological parameters. Research is being conducted to develop monitors that will reduce the lengthy processing of microbiological samples that will enable municipalities to respond quickly to positive microbiological results.

The municipality should try to stay informed about emerging technologies that may be useful to the distribution system monitoring program. To obtain information, consult industry publications and associations like the Canadian Water and Wastewater Association (CWWA), the American Water Works Association, the AWWA Research Foundation, the International Water Association (IWA), and others. It is also useful to maintain contact with other municipalities throughout Canada, to learn from their experience and knowledge.

4. APPLICATIONS AND LIMITATIONS

4.1 APPLICATIONS

The steps to develop, implement, and maintain a distribution system monitoring program outlined in Section 3 are intended to apply to all drinking water systems across Canada, regardless of size. The monitoring program must be tailored for each system by looking at the unique elements of the system and the water quality challenges that the municipality has historically faced.

4.2 LIMITATIONS

Developing a comprehensive monitoring program will result in a considerable amount of work. Any municipality, regardless of size, may have difficulty in obtaining the required expertise, staff, and resources necessary to develop the program. This is especially true if regulatory monitoring requirements are already being fulfilled. However, municipalities must realize the benefit to ensuring that the high-quality water produced at the treatment facility is not compromised in the distribution system.

Smaller municipalities may be particularly challenged in this regard. These systems typically experience limitations in the availability of staff and expertise to carry out the many functions of a monitoring program. The benefits of the program may not be immediately apparent to the political and administrative leaders of the community and therefore, adequate funding may not be available. A comprehensive monitoring program is of paramount importance to the smaller municipalities since they are highly vulnerable to water quality issues in the distribution system.

5. EVALUATION

To evaluate the success of the development of the distribution system monitoring program, the municipality should answer the following questions:

- Does the program provide adequate warning in the case of poor water quality so corrective actions can be taken?
- Are all areas of the distribution system covered by the monitoring program?
- Is higher-quality water being delivered to consumers? Is water quality more consistent throughout the system?
- Is the cause of historical water quality problems being determined so it may be rectified?
- Has consumer confidence increased?
- Is regulatory compliance for distribution system monitoring being met?

APPENDIX A: MONITORING OF VARIOUS PARAMETERS AND STATUS OF ON-LINE SENSORS

The following Table No. 1 provides a comprehensive list of parameters that may be applicable for monitoring within a water distribution system. The table also provides information on the possible sampling location, the objective of monitoring the parameter and other general comments. This is a very inclusive list of all the parameters that can be considered in developing a distribution system monitoring program. The appropriate parameters to include will depend on the municipalities regulatory requirements, the treatment process, the water quality, the distribution system characteristics, and other issues discussed in this best practice that are unique to each water system.

This table has been compiled from sources including AwwaRF (2002, pg. 193-265) and input from water quality and distribution system experts from across Canada.

For the monitoring objective, fulfillment of regulatory requirements has not been specifically included in the table. Regulatory requirements must always be fulfilled, and will differ based on the municipality.

The location "point of entry" in the following table refers to the point where potable water enters the distribution system, which is usually close to the discharge point of the treatment facility. In cases where the treatment facility is located a long distance from the distribution system, or a municipality receives potable water from an adjacent water provider, the point of entry would be where the distribution system begins.

Table No. 1: Monitoring of Various Parameters in a Water Distribution System

Parameter	Distribution System Monitoring Location	Monitoring Objective	General Comments
Aldehydes	• Point of entry • Distribution system locations	1. Research shows that ozone promotes aldehyde, formaldehyde formation. 2. Affects quality of water being distributed.	1. When ozonation is applied. Systems using ozone usually also have biological filtration, which should resolve any aldehyde concerns.
Alkalinity	• Point of entry • Distribution system locations	1. Indicator of buffering capacity and amount of carbonate. 2. Alkalinity relates to the stability of the water in the distribution system that affects corrosion control.	1. Changes (increase/decrease) often accompany a contamination event. 2. A rapid pH change may also indicate a chemical over-feed at the treatment facility.
Aluminum	• Point of entry • Distribution system locations	1. Operational objective. 2. Aesthetics.	1. Discoloration of water at levels above 0.2 mg/L.

Parameter	Distribution System Monitoring Location	Monitoring Objective	General Comments
Ammonia, free or total	• Point of entry • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for prediction of the onset of nitrification.	1. Primarily a concern for systems that chloraminate or those that have naturally high ammonia concentrations.
Assimilable Organic Carbon (AOC) or Biodegradable Dissolved Organic Carbon (BDOC)	• Point of entry	1. Organic matter that can cause biofilm growth and related problems.	1. When ozonation is applied. Systems using ozone usually also have biological filtration, which should resolve any AOC & BDOC concerns. 2. Municipalities that experience extensive microbiological growth in their system should consider.
Brominated DBP	• Point of entry	1. Ozone known to oxidize bromide to bromate at doses >0.5 mg/mg TOC.	1. When ozonation is applied. Measuring at the point of entry should be adequate as bromate should not change within the system.
Calcium (as $CaCO_3$)	• Point of entry • Distribution system sites	1. Component of hardness - aides in scale formation.	
Chloramine	• Point of entry • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for predicting onset of nitrification.	
Chlorate	• Point of entry • Distribution system sites	1. Health effects possible.	1. When chlorine dioxide is applied.
Chlorine dioxide	• Point of entry • Distribution system sites	1. Excess free chlorine can produce chlorite and chlorate ion. 2. Health effects possible.	1. When chlorine dioxide is applied.
Chlorine, Total	• Point of entry • Distribution system sites • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for predicting onset of nitrification.	1. Water quality indicator. 2. Chlorinous taste and odour.
Chlorite	• Point of entry • Distribution system sites	1. Excess free chlorine can produce chlorite and chlorate ion. 2. Health effects possible.	1. When chlorine dioxide is applied.
Coliform	• Distribution system sites	1. Disinfectant effectiveness	

Parameter	Distribution System Monitoring Location	Monitoring Objective	General Comments
Colour	• Point of entry • Distribution system sites	1. Aesthetics.	
Conductivity	• Point of entry • Distribution system sites	1. Predicts corrosion and/or scale forming potential of water. 2. Provide baseline water quality information and to identify problem areas.	1. Changes (increase/decrease) often accompany a contamination event. 2. A rapid pH change may also indicate a chemical over-feed at the treatment facility.
Copper	• Point of entry • Distribution system sites • Residential sites	1. Operational objectives.	1. Metallic taste; blue/green staining of porcelain.
Dichloramine	• Reservoirs • Coliform monitoring stations • Dead end sites • Low flow sites	1. Presence of dichloramine leads to taste and odour problems. Dichloramine formation increases at low pH and/or high chlorine to ammonia ratios (>5:1).	
Dissolved Organic Carbon (DOC)	• Point of entry	1. DOC entry into distribution system may lead to DBPs.	1. Measuring at the point of entry should be adequate as DOC should not change within the system.
Dissolved Oxygen	• Reservoirs • Reservoir outlets • Dead end sites	1. Locate specific conditions causing nitrification.	1. Nitrification consumes DO, but water with < 2 mg/L may limit nitrification.
E.coli	• Throughout distribution system	1. Human health concern	
Formaldehyde	• Point of entry • Throughout distribution system	1. Research shows that ozone promotes aldehyde, formaldehyde formation. 2. Affects quality of water being distributed.	1. When ozonation is applied. Systems using ozone usually also have biological filtration, which should resolve any formaldehyde concerns.
Heterotrophic plate counts (HPC)	• Point of entry • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for predicting onset of nitrification. 2. Possible indictor of water quality.	1. High HPC can interfere with identification of total coliform.
Hydrogen sulfide	• Coliform monitoring stations • Dead end sites • Low flow sites	1. Baseline data may reveal increases in these parameters correlating with water flows / pressures - depending on water demands.	1. 'Rotten egg' odour.
Iron	• Distribution system sites	1. Corrosion products exert chlorine demand; aesthetics.	1. Increase in iron based coagulant dosage, or switch from alum to a ferric coagulant may increase dissolved iron levels in the finished water. 2. Bitter metallic taste; staining of laundry, rusty colour, sediment.
Lead	• Point of entry • Distribution system sites • Residential sites	1. Possible health concerns. 2. Operational objectives.	

Parameter	Distribution System Monitoring Location	Monitoring Objective	General Comments
Magnesium (as $CaCO_3$)	• Finished water • Distribution system sites	1. Component of hardness - aides in scale formation.	
Manganese	• Distribution system sites	1. Aesthetics.	1. Can impact taste. 2. Staining of laundry and fixtures; black to brown color, black staining.
Nitrate	• Point of entry • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for predicting onset of nitrification.	1. Primarily a concern for systems that chloraminate or those that have naturally high ammonia concentrations.
Nitrite	• Point of entry • Reservoir inlets/outlets • Coliform monitoring stations • Selected dead end sites • Low flow sites	1. Develop baseline data for predicting onset of nitrification.	1. Primarily a concern for systems that chloraminate or those that have naturally high ammonia concentrations.
Nitrogen, organic	• Point of entry • Reservoirs • Dead end sites	1. Locate specific conditions causing nitrification.	1. If organic amines are present, chlorine preferentially binds with them, and competes with the formation of inorganic chloramines.
pH	• Point of entry • Distribution system sites	1. pH stability in distribution system.	1. Low pH - bitter metallic taste, corrosion. 2. High pH - slippery feel, soda taste, deposits. 3. Changes (increase/decrease) often accompany a contamination event. 4. A rapid pH change may also indicate a chemcial over-feed at the treatment facility.
Phosphate	• Point of entry	1. Provide baseline water quality information and to identify problem areas. 2. Often limiting nutrient for microbiological growth in distribution systems.	
Phosphate inhibitors	• Point of entry • Distribution system sites • Residential sites	1. Check for adequate residual if applied for corrosion control. 2. Check for excess phosphate - can promote biological growth.	1. When phosphate corrosion controls are applied.
Silicate	• Point of entry	1. Provide baseline water quality information and to identify problem areas.	
Stability / marble test	• Point of entry	1. Check for scale forming potential, corrosion potential or for scale build up.	
Sulfate	• Point of entry • Distribution system sites	1. Corrosivity evaluations.	1. Salty taste; laxative effects.

Parameter	Distribution System Monitoring Location	Monitoring Objective	General Comments
Taste and Odour	• Distribution system sites	1. Secondary impact of chlorination.	1. 'Rotten egg,' musty or chemical smell. 2. Indicator of algae, long detention time, coatings / linings used in the distribution system.
Temperature (C)	• Point of entry • Reservoirs • Dead end sites	1. Taste and odour. 2. Locate specific conditions causing nitrification.	1. Nitrification most commonly occurs at temperatures greater than 15 C.
Total Organic Carbon (TOC)	• Point of entry • Distribution system sites	1. Causes THM/DBP formation with free chlorine. 2. Exerts chlorine demand.	1. Measuring at the point of entry should be adequate as TOC should not change within the system.
Total suspended solids	• Storage tank bottom near sediment.	1. Determine if tank sediment is affecting water quality.	
Trihalomethanes / Disinfection By-Products	• Distribution system sites	1. Monitoring formation of DBPs.	
Turbidity	• Point of entry • Distribution system sites	1. Exerts chlorine demand.	
Volatile Organic Carbon	• Sites upstream and downstream of the new facility or main. • Inside new facility if it is large (pipelines, reservoirs, etc.)	1. Evaluate whether water quality is acceptable immediately before and after a facility or main is brought on-line and during disinfection and flushing activities.	
Zinc	• Point of entry	1. Provide baseline water quality information and to identify problem areas.	1. Metallic taste, corrosion.

Legend:

+++ = available, well developed, and commonly used;
++ = available but not commonly used;
+ = under development; 0 = not available.
TOC-total organic carbon.
DOC-dissolved organic carbon.
UV-ultraviolet.
VOC-volatile organic compound.

The following Table No.A–2 is taken directly from *Online Monitoring for Drinking Water Utilities* (AwwaRF and CRS Proaqua, 2002, pg. 396-399). This information presents the status of on-line sensors for water intended for human consumption, and is current as of the printing of the reference material (i.e.,2002). Please note that some of the analytes listed may only be used for monitoring within water treatment facilities and not in the distribution system. These include: Particle counting; Streaming current; Ozone; Cyanide; Fluoride; TOC/DOC; VOC; and Algal pigment.

Table A– 2: Status of on-line sensors for water intended for human consumption

Analyte	Status of On-line Technology	Comments
Physical Monitors		
Turbidity	+++	Improvement in discernment ability at turbidities below 0.1 ntu is required. Consistency in response between instruments using different measuring principles is a challenge. Need for autocleaning and automatic calibration.
Particle counting	++	Increasingly used in North America, but not commonly used in Europe. Online calibration and intercalibration between instruments to ensure comparable results is challenging.
Colour	+	High turbidity may interfere with color measurement. Standard procedures (including specifications of wavelength, etc.) required. Optical design of online colorimeters has not been standardized and there is currently no standard method for spectrophotometric color determination. Lower detection limits and better sensitivity at low color levels is required.
Conductivity/ total dissolved solids	+++	Probe must be removed from the flow stream for maintenance and calibration. All online measurements of total dissolved solids are estimates based on conductivity.
Total suspended solids	++	No approved calibration procedure is available to relate light attenuation to actual gravimetric analysis of suspended solids for all samples. Currently, a relationship between gravimetric suspended solids and instrument reading must be developed for each individual application. Need for autocleaning, online fouling error indication, and autocalibration.
Hardness	++	Online titration units are an automated batch system, requiring reagents and frequent maintenance. Need for autocleaning and automatic calibration of ion-selective electrodes.
Alkalinity/ acidity	++	Online titration units typically provide batch-automated analysis. Online alkalinity determination is not common in drinking water treatment plants in either Europe or North America.
Streaming current	++	In-plant calibration procedures need to be developed. Fouling of sensor surfaces by precipitation of raw water constituents and coagulants changes response. Features such as automated cleaning and indications of fouling interferences are required. Coagulation dosing based on charge neutralization is not applicable to all source water types. Improvements in discernment ability in cold, low-turbidity waters is required.
Radioactivity	++	Calibration of online radioactivity analyzers is complex, requiring handling of radioactivity standards. Need for improved ruggedness, autocleaning and autocalibration features.
Redox potential (ORP)	++	Electrodes have severe drift; therefore, difficult to get a correct absolute signal. However, shifts between oxic, anoxic, and anaerobic states are clearly detected.
Temperature	+++	Need for autocleaning and autocalibration features.
Inorganic Monitors		
pH	+++	Need for improved ruggedness, autocleaning and autocalibration features as well as miniature sensors for use at the consumer's tap.
Chlorine	+++	Miniature sensors to install in the distribution network are needed for field measurements.

Analyte	Status of On-line Technology	Comments
Chlorine dioxide	+++	Chlorine dioxide, chlorine and chlorite are not easily distinguished.
Ozone	+++	Online technologies to rapidly detect ozone and avoid loss of gas are required.
Dissolved oxygen	+++	Technology well developed. Electrodes with no change of electrolyte and membrane preferred (transducer including membrane and electrolyte available as consumable). Development of optical sensors holds promise to simplify maintenance and operation; membrane fouling affects results.
Metals (aluminium, chromium, iron, magnesium, manganese)	++	Complicated colorimetric methods require frequent preparation of reagents and calibration standards. Instrumentation is expensive and operation requires highly skilled technical staff.
Cyanide	++	Complicated colorimetric method requires preparation of reagent solutions and calibration standards. Instrumentation is expensive and operation requires highly skilled technical staff.
Phosphorus	++	Colorimetric methods (low and high range). Requires calibration standards and reagent solutions. Instrumentation is expensive and operation often requires highly skilled technical staff. However, instruments with autocalibration and simple change/disposal of chemicals are available.
Ammonia	++	Colorimetric. Ammonia gas electrode or ion selective electrode methods. All methods require calibration standards and reagent solutions. Instrumentation is expensive and operation often requires highly skilled technical staff. However, instruments with autocalibration and simple change/disposal of chemicals are available.
Nitrite	++	Ultraviolet absorbance or colorimetric methods. Both methods require calibration standards and the colorimetric method also requires reagent solutions. Instrumentation is expensive and operation often requires highly skilled technical staff. However, instruments with autocalibration and simple change/disposal of chemicals are available.
Nitrate	++	Ultraviolet absorbance, colorimetric or ion selective electrode methods. All methods require calibration standards and the colorimetric and ion selective methods also require reagent solutions. Instrumentation is expensive and operation often requires highly skilled technical staff. However, instruments with autocalibration and simple change/disposal of chemicals are available.
Fluoride	+++	Need for automatic cleaning, prevention of electrode contamination.
Organic Monitors		
TOC/DOC	+++	Present technology is costly and involves high maintenance. Improved low-level sensitivity and reliability required.
UV_{254}	+++	A surrogate of organic carbon (natural).
VOC	++	

Analyte	Status of On-line Technology	Comments
Hydrocarbons	++	
Disinfection by-products	++	Trihalomethanes are detected through the same methods used for VOCs.
Pesticides	++	Limited to herbicides only, detectable through high-pressure liquid chromatography.
Drug metabolites, endocrine disruptors	0	Area of active research and development; improved sensitivity and online technology are critically needed.
Parasites, bacteria and virus identification and enumeration	0	Area of active research and development.
Algal pigments	++	Several optical technologies. Laboratory validation required. Good for algal bloom detection.
Toxicity (biomonitors)	+	Many different tests. High maintenance. Difficult to interpret. Poor sensitivity. Issues with reliability (false positives and false negatives).
Taste & odour	0	Area of active research and development; automation, sensitivity, and specificity improvements are critically needed.
Flow, Level, and Pressure Monitors		
Flow sensors	+++	Technologies are well developed and sensors using many different operating principles are available. Improved low-level flow sensitivity and reliability are required, particularly under low pressure situations. Miniaturization of technology would be advantageous in some applications.
Level sensors	+++	Technologies are well developed and sensors using many different operating principles are available (mechanical, capacitive, hydrostatic, ultrasonic, guided microwaves, radar, microwave barriers, vibration monitors, conductive, bubbler). Miniaturization of the technology would be advantageous in some applications.
Pressure sensors	+++	Technologies are well developed and sensors using many different operating principles are available (manometer, mechanical, electronic). Miniaturization of the technology would be advantageous in some applications.

+++ = available, well developed, and commonly used;
++ = available but not commonly used;
+ = under development;
0 = not available.
TOC-total organic carbon; DOC-dissolved organic carbon.
UV-ultraviolet.
VOC-volatile organic compound.

APPENDIX B: EXAMPLES OF PARTNERSHIPS

1. Building and plumbing inspectors can be educated to look for potential areas of cross connection, and areas with pipe corrosion.

2. Fire department protocols for flowing hydrants can be obtained to evaluate potential distribution system impacts.

3. The municipal planning group can be consulted to establish new development standards to minimize dead ends, and standardize installation methods, and materials.

4. The municipal construction department, consultants, contractors, and constructors can be trained on the use of pipe lubricant and other coatings, disinfection and flushing procedures to avoid water quality problems.

5. Protocols can be established with laboratories for immediate notification of lab results that show acute water quality problems.

6. Agreements for after-hours access to laboratories can be set up to ensure availability during critical event-driven monitoring.

7. The health department can advise the water quality department of suspected water-related illness occurrences.

8. The water quality department can advise the health department of incidents that may result in water-related illness.

9. The health department can provide information on acute or chronic health conditions compared with regional, provincial, or national averages, as well as establish community benchmarks for disease/sickness that are capable of being transmitted by drinking water.

10. The health department can monitor seasonal medical conditions that may be related to drinking water.

11. The municipality can work with regulatory bodies and provide feedback on the success of monitoring certain parameters based on technological limitations, staffing requirements, or laboratory availability.

12. The municipality can work with the fire department, police, provincial ministry of environment, and municipal drainage department to develop joint protocols on reacting to spills, and dealing with the cleanup, and with rapid communication of such events to the municipality.

13. Industry can advise the municipality of spills or other events that may affect water quality.

14. Industry can advise the municipality of certain water quality needs.

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