# Study on Pathogen Inactivation in Drinking Water Systems in Newfoundland and Labrador

## FINAL REPORT

103042.00 ● Final Report. ● July 2011

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Prepared for:

Newfoundland Labrador

Department of Environment
and Conservation
Water Management Division

Prepared by:

CBCL LIMITED
Consulting Engineers

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CBCL LIMITED
Consulting Engineers

25 July 2011

Ms. Paula Dawe
Water Resources Management Division
Department of Environment and Conservation
PO Box 8700
4th Floor - Confederation Bldg - West Block
St. John's NL   A1B 4J6

Dear Ms. Dawe:

*RE:* *Study on Pathogen Inactivation in Drinking Water Systems in Newfoundland and Labrador*

As requested in the original Terms of Reference for the study entitled 'Study on Pathogen Inactivation in Drinking Water Systems in Newfoundland and Labrador' we are pleased to submit five copies of the final report for the above-noted study. The remaining deliverables associated with the project have been provided in digital format.

Yours very truly,

CBCL Limited

Greg Sheppard, P.Eng.
Project Manager
Phone:  (709) 364-8623
E-Mail:  gregs@cbcl.ca

Project No. 103042.00

1489 Hollis Street
PO Box 606
Halifax, Nova Scotia
Canada  B3J 2R7

Telephone:  902 421 7241
Fax:  902 423 3938
E-mail:  info@cbcl.ca
www.cbcl.ca

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|  | ***Reviewed By:*** |  |  | ***Issued By:*** |  |  |

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***Signed and Sealed:***

REGISTERED PROFESSIONAL ENGINEER
PEG Newfoundland and Labrador
MICHAEL P. CHAULK
SIGNATURE
July 14/11
DATE
NEWFOUNDLAND & LABRADOR

CBCL
CBCL LIMITED
Consulting Engineers

1489 Hollis Street
PO Box 606
Halifax, Nova Scotia
Canada B3J 2R7

Telephone: 902 421 7241
Fax: 902 423 3938
E-mail: info@cbcl.ca
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Phone: (709) 364-8623
E-Mail: gregs@cbcl.ca

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# Contents

# Appendices

# EXECUTIVE SUMMARY

This report summarizes the findings and deliverables of the study entitled *Pathogen Inactivation in Water Systems in Newfoundland and Labrador*. The study included:

- An initial desktop evaluation of background information relating to the disinfection of drinking water;
- An extensive field program;
- The development of a disinfection infrastructure database, CT calculator, and four GIS shapefiles;
- An evaluation of the level of compliance with the provincial *Standards for the Bacteriological Quality of Drinking Water* and recommended disinfection by-product levels achieved by 55 representative communities;
- An assessment of the current water quality standards used in the province; and
- The preparation of a report summarizing the findings of the study.

## Desktop Study

The desktop portion of the study included a detailed review of current scientific literature and regulatory guidance documents relating to the disinfection of municipal drinking water. Topics included the effects of source water quality on pathogen levels; common pathogens found in surface and GUDI water sources; the chemistry of chlorine disinfection; chlorine decay; the development and application of the CT and log reduction concepts; and the formation of disinfection by-products (DBPs). It also included a comparison of disinfection requirements in different jurisdictions in North America including:

- The *Guidelines for Canadian Drinking Water Quality* (GCDWQ);
- The province of Nova Scotia's water treatment standards;
- Legislation, regulations and guidance documents used in the province of Ontario;
- Water quality requirements in other Canadian provinces; and
- The various rules promulgated by the United States Environmental Protection Agency (US EPA) under the *Safe Water Act*.

Summaries of these can be found in Chapter 3 of the report. Most jurisdictions set disinfection requirements based on log reduction of pathogens such as *Giardia*, *Cryptosporidium*, and viruses. Some require all utilities using surface or groundwater under the direct influence of surface water (GUDI) to include, at minimum, filtration for pathogen removal and chemical or physical (ultraviolet radiation) disinfection for pathogen inactivation. Others only impose log reduction requirements when the source water has been implicated in a waterborne disease outbreak or is known to be vulnerable to contamination by human or animal wastes.

Historical water quality data was also reviewed during the desktop portion of the study. The water quality results suggest that many of the communities participating in the study supplied by surface water sources have raw water that is high in natural organic matter (NOM), with low pH, alkalinity, and turbidity. Some water sources were found to have elevated iron and manganese levels. NOM, iron, and manganese levels were frequently found to be variable, suggesting that the quality of the raw water is impacted by seasonal changes in temperature, precipitation, and runoff. These water quality characteristics have a number of effects on the quality of the water delivered to users, particularly in small communities. For example, organics, iron, and manganese are all associated with accelerated chlorine residual decay within the bulk water. This can reduce the amount of chlorine available for disinfection, resulting in poor pathogen inactivation and a low or undetectable chlorine residual within the distribution system. Either of these end results may lead to the issuance of a boil water advisory (BWA).

Not that many of the organic molecules that contribute to chlorine decay are also DBP precursors. Communities with high or periodically high organic levels who do not provide formal water treatment optimized for NOM removal run the risk of forming excess DBPs upon chlorination. This is of particular concern for communities with long retention times within the distribution system and/or water storage.

The historical BWA records, which are regularly summarized and published in the annual Department of Environment and Conservation (ENVC) water quality reports, were also reviewed in detail. It was determined that the number of BWAs issued due to malfunctioning equipment and/or poor operation and maintenance of the water system have decreased over the past ten years. BWAs issued as a result of non-compliance with the *Standards for Bacteriological Drinking Water Quality* have increased.

## Field Program and Laboratory Testing

The results of the desktop study were used to develop information collection sheets (ICS) used during the field portion of the project. The ICS included a series of questions designed to elicit relevant information from community representatives during the site visits conducted by CBCL Limited technicians.

Three CBCL technicians visited 55 communities in the summer and fall of 2010. The information gathered about the configuration and operation of the water systems was used to assess compliance with the existing provincial CT requirements. It was also used to develop and calibrate the Community Disinfection Infrastructure Database (CDID), the CT and log reduction calculator, and four GIS shapefiles. The technicians also measured the pH, temperature, and chlorine residual at the first user's tap and, where feasible, at other points within the distribution system. Water samples were collected from the raw water inlet and subsequently analyzed for chlorine decay curves.

Bulk water chlorine decay tests were conducted on the water samples collected during the field portion of the study. A first order reaction model was adequate to describe the observed chlorine decay rates for the water samples collected from most of the participating communities ($r^2$ = 0.90 to 0.99). These samples were more likely to have elevated levels of chlorine demanding substances such as NOM, iron, and manganese. The first order reaction model did not fit the chlorine decay data from the samples with low concentrations of chlorine demanding substances. These results were expected because many researchers have found that chlorine decay only follows a first order reaction mechanism when chlorine is the limiting substrate in the bulk water.

## Additional Deliverables

The results of the desktop, field, and laboratory portions of the project were used to develop the three additional deliverables; the CDID, the CT, log reduction, and chlorine contact volume calculators, and four GIS shapefiles.

The CDID is a searchable Microsoft Access (2000) database. The database includes details about each community including population, water source type, disinfection infrastructure, and historic and measured water quality. Through a series of calculations, the database divides communities into bins based on their compliance (under worst case conditions) with the *Bacteriological Water Quality Standard* and the DBP recommendations provided by the ENVC. Data for the 55 participating communities has been entered into the database; additional communities can be added using the interactive input form.

CT, log reduction, and chlorine contact volume calculators were also developed. These tools are simpler than the CDID and will be helpful for operators who wish to calculate the level of disinfection being achieved day to day. The calculators are specific to disinfection with free chlorine.

Finally, four GIS shapefiles were developed that indicate the location of the following:

- The point of disinfection;
- The point where 20 minutes contact time is achieved (where feasible);
- The location of the first user; and
- The location of any storage tanks.

Additional information associated with each point was connected to the relevant shapefile.

## Summary of Recommendations

Based on the results of this study it is advised that the province move from a contact time and CT based bacteriological water quality standard to a log reduction based microbiological water quality standard. This will bring the province in line with other North American regulatory regimes and shift the focus from chlorine contact time to pathogen reduction

If this approach is adopted, a minimum 4.0-log reduction of viruses should be considered for communities served by surface water or GUDI water supplies. Communities that have experienced outbreaks of *Giardia* and/or *Cryptosporidium* OR whose water sources are known or suspected to be vulnerable to faecal contamination should be required to provide a minimum of 3.0-log reduction of protozoa. Note that the disinfection requirements in most other jurisdictions in Canada assume that all surface and GUDI water sources are exposed to faecal contamination and thus require that all communities served by such supplies provide 2.0-log or 3.0-log reduction of *Giardia* and/or *Cryptosporidium*.

The province may or may not require that systems served by pristine groundwater provide specific levels of pathogen reduction, but should still require them to add a secondary disinfectant to maintain a residual throughout the distribution system. These recommendations are based on those provided in the GCDWQ and may help to encourage the use of filtration and alternative disinfectants.

Currently, responsibility for drinking water safety and drinking water system design is spread between four government departments, each with their own procedures, requirements, and documents. It is important that all four work together as the province moves forward with changes to the current disinfection requirements. All documents pertaining to drinking water safety and drinking water system design will then have to be updated to reflect these new requirements. This will simplify the design, construction, and operation of drinking water systems throughout the province.

The communities who participated in the current study were evaluated for compliance with the proposed pathogen reduction requirements using the CDID. When field data (pH, temperature, chlorine residual) were used to determine disinfection compliance, 94% of those who are in compliance with the existing standard would be in compliance with the proposed inactivation requirements as well. Under worst case conditions (temperature = $0.5^{o}$C, pH = 8, chlorine residual = 0.3 mg/L) 86% of the communities who are in compliance with the existing requirements would be in compliance with the proposed requirements.

Additionally, communities should be encouraged to separate primary and secondary disinfection activities by designating a specific contact volume with a known peak flow rate, and where feasible, baffling and continuous (or at minimum, daily) monitoring at the outlet. Communities should also be encouraged to provide ENVC monthly reports of flow, pH, temperature, and chlorine residual measurements that can be input into the CT and log reduction calculator to regularly track disinfection effectiveness.

Finally, the ENVC may also choose to consider developing a source water monitoring plan similar to the US EPA's LT2ESWTR or the Risk Screening Methodology prepared by the Irish EPA to establish the extent of *Giardia* and *Cryptosporidium* occurrence in water sources in the province. This will help to determine what levels of pathogen reduction should be required in individual communities.

# LIST OF ACRONYMS

| | |
|---|---|
| AWWA | American Water Works Association |
| CDID | Community Disinfection Infrastructure Database |
| CCME | Canadian Council of Ministers of the Environment |
| DBP | Disinfection by-product |
| DMA | Department of Municipal Affairs (NL) |
| DOC | Dissolved organic carbon |
| DPD | N,N-diethyl-p-phenylenediamine (chlorine detection method) |
| DVGW | Deutscher Verein des Gas -und Wasserfaches |
| ENVC | Department of Environment and Conservation (NL) |
| GCDWQ | Guidelines for Canadian Drinking Water Quality |
| GIS | Geographic Information System |
| GTR | Groundwater Treatment Rule (USA) |
| GUDI | Groundwater under the direct influence of surface water (Canada) |
| GWUDI | Ground water under the direct influence of surface water (USA) |
| HAA | Haloacetic acid |
| HOCl | Hypochlorous acid |
| IESWTR | Interim Enhanced Surface Water Treatment Rule (USA) |
| k | Chlorine decay coefficient |
| LT1ESWTR | Long Term 1 Enhanced Surface Water Treatment Rule (USA) |
| LT2ESWTR | Long Term 2 Enhanced Surface Water Treatment Rule (USA) |
| MAC | Maximum acceptable concentration |
| MF | Microfiltration |
| MOE | Ontario Ministry of the Environment |
| NF | Nanofiltration |
| NOM | Natural organic matter |
| NSE | Nova Scotia Environment |
| $OCl^-$ | Hypochlorite ion |
| PDDWO | Procedure for the Disinfection of Drinking Water in Ontario |
| RO | Reverse osmosis |
| SA# | Service area number |
| SDWA | *Safe Drinking Water Act* (Ontario, USA) |

| | |
|---|---|
| SWTR | Surface Water Treatment Rule (USA) |
| TCR | Total Coliform Rule (USA) |
| TDS | Total dissolved solids |
| THM | Trihalomethane |
| TSMG | Treatment Standard for Municipal Groundwater Source Water Facilities (NS) |
| TSMS | Treatment Standard for Municipal Surface Source Water Treatment Facilities (NS) |
| UF | Ultrafiltration |
| US EPA | United States Environmental Protection Agency |
| UV | Ultraviolet |
| UVA | UV absorption at 254 nm |
| UVT | UV transmittance at 254 nm |
| WRA | *Water Resources Act* (NL) |
| WTP | Water Treatment Plant |

# CHAPTER 1 INTRODUCTION AND BACKGROUND

## 1.1 Project Background

Over the past ten years the government of Newfoundland and Labrador has made great strides towards their goal of providing all residents of the province with clean and safe drinking water through the *Multi-Barrier Strategic Action Plan (*MBSAP). The plan was initiated by the Department of Environment and Conservation (ENVC) and aims to improve drinking water quality in ways that are culturally and economically appropriate for each community in the province. The first level of the plan encompasses the three main parts of any drinking water system; source water protection, water treatment, and water distribution. The second level of the MBSAP focuses on the operation, maintenance, and monitoring of drinking water infrastructure. Finally, Level 3 of the MBSAP includes big picture tasks including the development of water quality guidelines, standards, as well as research and development.

Despite the many successes of the MBSAP, the residents of many of the over 500 small and rural communities in the province still lack reliable access to clean and safe drinking water. In recent years, various studies commissioned by the ENVC have identified and explored the prevalence of human health concerns in these small communities. Improved pathogen reduction and the minimization of the formation of disinfection by-products (DBPs) have been identified as two of the most pressing concerns.

Many of the small, rural communities in Newfoundland and Labrador have shrinking populations, high levels of unemployment, and a limited tax base. This prevents them from constructing, operating, maintaining, and monitoring the full-scale drinking water treatment systems that would be required to remove organic DBP precursors. As a result, chlorine disinfection is the only form of drinking water treatment provided in most communities. This, and the quality of much of the surface water in the province, has resulted in an untenable situation where communities must balance their need for adequate disinfection with the potential formation of DBPs.

The *Sustainable Options Report* and *Best Management Practices for the Control of Disinfection Water Systems in Newfoundland and Labrador*, both published in 2009, provide a number of recommendations for the improvement of the design, operation, maintenance, and monitoring of existing small systems to minimize the formation of DBPs while ensuring adequate pathogen inactivation.

The current study builds upon the findings of these two projects. It was initiated by the ENVC in early 2010 to address the human health concerns raised in these and other water quality studies. A formal

Request for Proposals (RFP) was developed and advertised in April of 2010. In May 2010 CBCL Limited was awarded the project. Draft versions of all deliverables were submitted on February 8th, 2011, for review by ENVC staff.

## 1.2 Objectives

The objectives of this study, as laid out in the RFP and the original CBCL Limited proposal, are as follows:

- To collect relevant system configuration, disinfection and water quality information from approximately 50 representative communities around the province of Newfoundland and Labrador;
- To establish a water demand profile for each community based on the average daily flow and population using established peaking factors;
- To determine the effectiveness of pathogen inactivation by chlorine in each community by calculating the CT achieved;
- To identify communities where pathogen inactivation is not meeting the Newfoundland and Labrador *Standards for the Bacteriological Quality of Drinking Water*; and
- To recommend strategies that can be employed by the ENVC and/or individual communities to bring their water systems into compliance with provincial requirements.

The deliverables for the project include the Community Disinfection Infrastructure Database (CDID), a disinfection compliance calculation spreadsheet, four GIS shapefiles showing the location and properties of important components of the disinfection and distribution systems in each participating community, and a report summarizing the findings of the study.

## 1.3 Report Organization

This report is organized into eight chapters and ten appendices. The first chapter provides background information on the history and objectives of the study. Chapter 2 is a detailed review of current scientific literature as it relates to the science of drinking water pathogens and disinfection methods. Chapter 3 describes the drinking water disinfection requirements and strategies in various North American jurisdictions including Ontario, Nova Scotia, Saskatchewan, Quebec, Alberta, and the United States. The project methodology is laid out in Chapter 4. The results obtained during the desktop, field, and laboratory portions of the study are presented in Chapter 5. Chapter 6 provides detailed recommendations for the improvement of drinking water disinfection requirements in Newfoundland. Chapter 7 is a summary of the information presented in the aforementioned chapters and Chapter 8 provides a list of references used during the development of the report.

Additional field data, lab results, and background information are available in the appendices. Instruction sheets for the CDID and the disinfection compliance spreadsheet are also included as appendices. Finally, an executive summary and glossary are provided at the beginning of the report to introduce the reader the main findings of the study and the acronyms found in the report.

# CHAPTER 2 THE SCIENCE OF DISINFECTION

## 2.1 Pathogens in Drinking Water

### *2.1.1 Pathogens Found in Drinking Water*

Three major categories of microorganisms are responsible for the majority of waterborne diseases around the world: enteric bacteria; protozoa; and enteric viruses. Each category is characterized by different modes of infection and behaviour and consequently, requires special treatment considerations.

Bacteria are simple, single-celled microorganisms that come in many shapes and sizes. Most range in size from 0.5 to 8 µm in diameter. Common shapes include cocci (sphere-shaped) and bacilli (rod-shaped). Bacterial species are extremely diverse – different species have been found in nearly every environment on the planet. In recent years, researchers have begun to identify bacterial species using DNA markers, but in the past, bacteria were divided into categories based on their behaviour. For example, some bacteria, known as aerobes, can only survive in the presence of oxygen, while others, known as anaerobes, can only survive in its absence. Some bacteria are facultative anaerobes, are able to survive with or without oxygen. Most bacterial species can be removed or inactivated by common water treatment and disinfection processes.

As a result of improved source water protection and water treatment, waterborne diseases like typhoid fever (*Shigella typhi*), dysentery (*Shiella dysenteriae*), and cholera (*Vibrio cholerae*), are now uncommon in developed countries, but they persist in areas with inadequate sanitation (Post et al., 2011). Other common waterborne bacterial pathogens include *Legionella, Campylobacter, Helicobacter, Escherichia, Salmonella,* and *Yersinia*. Many of these species are enteric bacteria, that is, the majority of their life-cycle takes place in the gastrointestinal tracts of animals and they are transferred from one individual to another via the faecal-oral route. Common sources of enteric bacteria in Canadian source water include human waste (sewer outfalls, septic systems, etc.) and animal waste (wildlife, agricultural runoff, etc.).

The detection, identification, and quantification of bacteria is a necessary, but often complicated, part of providing safe drinking water. For example, some enteric bacteria, such as *E. Coli O157:H7*, are pathogenic to humans but cannot always be detected reliably with the simple tests available to utilities.

As a result, coliform bacteria (total, faecal, etc.), which are much easier to detect using inexpensive laboratory methods, are used as indicator organisms. More sensitive tests that identify bacterial species using DNA markers have been developed, but are not yet widely available among utilities.

Protozoa are single-celled eukaryotic microorganisms that occur naturally in the environment but are also present in human and animal wastes. Those that are a threat to human health are usually enteric species that are only able to grow and reproduce within a host. When they are eventually excreted by the host, they form protective cysts or oocysts, which protect them from environmental stresses. Once protected, these organisms are able to survive for long periods of time in the environment without reproducing. When they once again have access to a host, they shed their protective covering (excystation) and begin to reproduce.

*Giardia lamblia*, *Cryptosporidium parvum,* and *Cryptosporidium hominis* are examples of protozoa that can be present in poorly treated drinking water and recreational water impacted by human and/or animal wastes. *Giardia lamblia* can cause severe but self-limiting gastrointestinal illness. The various common *Cryptosporidium* species found in surface and GUDI water sources can also cause gastrointestinal illness, which can be fatal in people with weak immune systems.

The province of Newfoundland and Labrador has recorded ten major waterborne disease outbreaks in the past 25 years. All were in communities supplied by surface water and nine were determined to have been caused by *Giardia*. Approximately 30% of the raw and treated water samples taken in Newfoundland during a 1996 study were found to contain *Giardia* cysts. This was slightly higher than the numbers for Canada as a whole; *Giardia* was found in 21% of the raw and 18% of the treated drinking water samples collected for the study. *Cryptosporidium* was less frequently detected (Wallis et al., 1996).

Protozoa can be difficult and expensive to detect and enumerate. Most jurisdictions have chosen instead to specify that water treatment and disinfection processes known to remove/inactivate protozoa be included in the treatment process. *Giardia lamblia* cysts are usually larger than bacteria, ranging in size from 6 to 15 µm (Post et al., 2011), and can be effectively removed using many common water treatment processes, particularly those that include a filtration step. They are somewhat susceptible to inactivation by chlorine, but are more effectively inactivated by ozone and ultraviolet (UV) radiation. *Cryptosporidium* oocysts, which are slightly smaller (4 to 5 µm) are also removed through most filtration processes and inactivated by UV radiation, but they are resistant to chlorine and other oxidants (WHO, 2008). The GCDWQ recommend that potable water supply and treatment systems achieve 3.0-log removal of *Giardia lamblia* and *Cryptosporidium* if these organisms are known or suspected to be present in the water source. Reduction is to be accomplished using a combination of filtration and disinfection processes.

Viruses are smaller than bacteria and protozoa, ranging in diameter from 0.02 to 0.3 µm. They are only able to reproduce after infecting a host organism. Compared to bacteria, protozoa, and plant and animal cells, viruses are simple, consisting of a small amount of DNA or RNA held within a protein shell. Viruses are often host-species-specific, though not always. Human-specific viruses are associated with many diseases and conditions including hepatitis, polio, aseptic meningitis, myocarditis, and various gastrointestinal illnesses.

The most common source of human-specific viruses in source water is human waste. Viruses are partially removed in many common drinking water treatment processes including (in order of increasing effectiveness) slow sand filtration, conventional filtration, low pressure membrane filtration (MF and UF), and high pressure membrane filtration (NF, RO). Though less vulnerable than bacteria, they can be inactivated by many common disinfection processes including chlorine, UV inactivation, and ozone (WHO, 2008).

Table 2.1 provides a summary of human pathogens commonly found in surface water sources.

**Table 2.1 Common human pathogens found in drinking water sources**

| Pathogen Category | Example Organisms | Approximate Diameter |
|---|---|---|
| Bacteria | *Escherichia Coli, Legionella, Shigella* | 0.5 to 8 µm |
| Protozoa | *Giardia lamblia, Cryptosporidium parvum* | 4 to 15 µm |
| Viruses | *Adenoviruses, Enteroviruses, Noroviruses* | 0.02 to 0.3 µm |

## 2.2 Source Water Types and Source Water Protection

The characteristics of the water source chosen to supply the water system influence the number and types of microorganisms in the raw water. Surface water, which is exposed to the air, vegetation, and human and animal activities, has a higher likelihood of containing large numbers of microorganisms than groundwater, which is usually protected from these influences.

Some groundwater wells are vulnerable to contamination due to the characteristics of the well, the proximity of the well to potential sources of pathogens (i.e., wastewater collection pipes, streams, open ditches), or the quality of the surrounding soils. These wells are commonly referred to as groundwater under the direct influence of surface water, which is shortened to GUDI in Canada and GWUDI in the United States.

The US EPA defines GWUDI as:

> "Any water below the surface of the ground with significant occurrence of insects or other macroorganisms, algae, or large diameter pathogens such as *Giardia lamblia* or *Cryptosporidium* or significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity or pH, which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation."

(40 CFR 141.2 cited in US EPA, 2003)

In Ontario, a GUDI system is defined as one that uses a water source that has the following characteristics:

1. A drinking water system that obtains water from a well that is not a drilled well or from a well that does not have a watertight casing that extends to a depth of six metres below ground level.

2. A drinking water system that obtains water from an infiltration gallery.
3. A drinking water system that is not capable of supplying water at a rate greater than 0.58 litres per second and that obtains water from a well, any part of which is within 15 metres of surface water.
4. A drinking water system that is capable of supplying water at a rate greater than 0.58 litres per second and that obtains water from an overburden well, any part of which is within 100 metres of surface water.
5. A drinking water system that is capable of supplying water at a rate greater than 0.58 litres per second and that obtains water from a bedrock well, any part of which is within 500 metres of surface water.
6. A drinking water system that exhibits evidence of contamination by surface water.
7. A drinking water system in respect of which a written report has been prepared by a licensed engineering practitioner or professional hydrogeologist that concludes that the system's raw water supply is groundwater under the direct influence of surface water and that includes a statement of his or her reasons for reaching that conclusion.

(O. Reg. 170/03, s. 2 (2); O. Reg. 418/09, s. 1 (5))

Many jurisdictions require that communities served by GUDI water sources provide additional pathogen removal through filtration and/or inactivation through disinfection.

Source water protection can also influence the number and types of microorganisms present in a water source. A recent study showed that 84% of all waterborne disease outbreaks recorded in Canada between 1993 and 2008 were in communities who draw water from unprotected water sources (Wilson et al., 2009). Some common surface water protection strategies include prohibiting the dumping of garbage or sewage into a surface water source and minimizing human and agricultural activities within the watershed. Water quality in GUDI wells can also be improved through source water and wellhead protection, for example, by improving well construction to minimize the influence of surface water and by minimizing contamination of the surface water that influences the GUDI well.

Source water protection can reduce the risk posed by pathogenic organisms, but cannot entirely eradicate it. It should be viewed as one of many integral parts of a successful multi-barrier water strategy. Additional information about the development of source water protection plans can be found in 'From Source to Tap – Guidance on the Multi-barrier Approach to Safe Drinking Water', published in 2004 by the Canadian Council of Ministers of the Environment (CCME).

## 2.3 Primary and Secondary Disinfection

Disinfection is arguably the most important function of a water supply system. Advances in disinfection technology have improved human health throughout the developed world. Pathogens can be removed (filtration, etc.), inactivated (UV), or killed (chemical disinfectants). Water utilities in Canada generally provide both primary and secondary disinfection.

Primary disinfection refers to disinfection that takes place within the treatment plant. The goal of primary disinfection is to remove, kill, or inactivate a set number of pathogens. For example, the

Guidelines for Canadian Drinking Water Quality (GCDWQ) suggest that drinking water treatment systems be designed to reduce the total number of *Cryptosporidium* and *Giardia* cysts by 99.9% and viruses by 99.99% (Health Canada, 2008). Primary disinfection can be achieved through engineered filtration, chemical disinfection (chlorine, ozone, etc.), and/or UV inactivation.

The goal of secondary disinfection is to establish a disinfectant residual within the distribution system. This prevents re-infection of the water by pathogens that have developed biofilms on the inside surfaces of the distribution mains or that have entered from outside the system. Secondary disinfectants must be capable of maintaining a residual throughout the distribution system. Common secondary disinfectants include free chlorine, chloramines, and chlorine dioxide, though the latter is not recommended because its residual dissipates quickly in the distribution system. Ozone, which decays quickly, and UV, which uses radiation to inactivate microorganisms, is not able to provide secondary disinfection. The choice of secondary disinfectant will impact the effectiveness of disinfection, the level of residual, and has been shown to affect the levels of other water quality parameters. Most jurisdictions have established minimum residual levels that must be maintained throughout the system.

## 2.4 Chlorine Chemistry

Chlorine inactivates pathogens by permeating into the cell membrane and destroying specific cell components. The effectiveness of this process is governed by four variables, the temperature and pH of the water, the concentration of chlorine, and the time allowed for contact between the chlorine and the microorganisms.

### 2.4.1 Chlorine in Water

When aqueous chlorine is added to water it ionizes to form hypochlorous acid (HOCl), chloride ions and protons as shown in Equation 2.1.

$$Cl_2(aq) + H_20 = H^+ + HOCl + Cl^- \quad \textbf{Equation 2.1}$$

(Downs and Adams, 1973, as cited in Haas, 2011)

Under the right conditions, HOCl dissociates to form the hypochlorite ion ($OCl^-$) and a proton. The relative amounts of HOCl and $OCl^-$ present in the bulk water are strongly pH dependent. At a pH of 7.5 the two species are present in approximately the same amount. As the pH dips below 7, the concentration of HOCl increases. Higher pH is associated with higher concentrations of $OCl^-$. HOCl is a stronger oxidant than $OCl^-$, thus, disinfection is more effective at lower pH. HOCl and $OCl^-$ are both referred to as 'free' chlorine, meaning that they are available for disinfection of organisms.

Chlorine interacts with many parameters that are common in raw surface water and/or groundwater including:

- Ammonia;
- Natural organic matter;
- Iron; and
- Manganese.

As they are oxidized, these and other parameters consume chlorine, which is then unavailable for disinfection. These reactions can result in the formation of chloramines, disinfection by-products, and oxidized forms of various metals, which may precipitate out of solution. Chlorine is also frequently used for secondary disinfection to minimize re-infection of the treated water and control pathogen regrowth in the distribution system. As the chlorinated water travels through the water mains, some of the chlorine is consumed through reactions with biofilms and the pipe walls. The chlorine-containing compounds formed through these reactions are referred to as 'combined' chlorine. Chloramines, in particular dichloramine and trichloramine, are poor disinfectants.

The sum of all chlorine compounds present in a water sample is called 'total' chlorine, as shown in Equation 2.2.

$$\text{Total Chlorine} = \text{Free Chlorine} + \text{Combined Chlorine} \qquad \textbf{Equation 2.2}$$

The DPD (N,N-diethyl-p-phenylenediamine) chlorine analysis method used by most utilities measures both total and free chlorine.

### *2.4.2 Chlorine Decay*

Chlorine decays over time through reactions with the pathogens, organic matter, and metal species that exist in the bulk water and on the inside surface of the various components of the distribution system. The rate of chlorine decay has been shown to vary depending on:

- Initial chlorine dosage;
- Total time elapsed;
- Temperature; and
- Concentration of chlorine demanding substances.

(Powell et al., 2000a)

The concentration of chlorine available usually controls the rate of the reaction. Therefore, the decay of free chlorine is usually modeled as a first-order or pseudo-first-order reaction dependent on initial chlorine dosage and total time elapsed.

$$C_t = C_O e^{-kt} \qquad \textbf{Equation 2.3}$$

Where:
$C_t$ = chlorine residual at time't', mg/L
$C_o$ = original chlorine dose, mg/L
k = first order chlorine decay constant, $h^{-1}$
t = time, h

The first order chlorine decay can be obtained using the bulk chlorine decay test. Eight glass bottles are filled with treated but unchlorinated water and dosed with chlorine ($C_o$). The chlorine residual ($C_t$) is measured at a series of sample times (t). The natural log of the chlorine residual divided by the original chlorine concentration is then plotted against time to determine the relationship between chlorine decay and sample time. The best fit line on the graph can be use to determine k.

The first order model is only able to describe the behaviour of chlorine in the bulk water when chlorine is the limiting reagent. In actual practice, however, the decay of chlorine, particularly within the distribution system, is affected by the concentration of various chlorine-consuming species in the bulk water as well as on the inner surface of the pipe. Although the first order model is often adequate for bulk water modelling purposes (Powell et al., 2000b), its inability to explain phenomena observed in the minutes immediately following chemical application and its limited applicability to systems where the bulk water does not exert a strong chlorine demand has led researchers (Warton et al., 2006; Jonkergouw et al., 2009) to develop more complex reaction models to describe the behaviour of chlorine in the bulk water and within the distribution system.

For example, many researchers have attempted to take both bulk water decay and decay at the pipe wall into account by defining the total chlorine decay constant as the sum of the decay constant in the bulk water ($k_b$) and that at the pipe wall ($k_w$) as shown in Equation 2.4.

$$k = k_b + k_w \qquad \textbf{Equation 2.4}$$

The reactions in the bulk water and at the pipe wall are very different, however, so in recent years they have usually been modelled separately or using parallel first order reactions that separate out the two types of chlorine decay (Warton et. al, 2006).

In the bulk water, the rate of chlorine decay is usually a function of the initial chlorine demand, however, under certain circumstances, it is controlled or influenced by other parameters. For example, in treated water with low levels of chlorine-demanding substances, a parameter such as NOM may be the limiting reactant. In this case, chlorine decay would proceed quickly until the chlorine-demanding substance is consumed and then continue more slowly thereafter. This can be modelled using a limited first order reaction or parallel first order reaction (with respect to chlorine). Other models have assumed that the rate of chlorine decay is dynamically influenced by both the initial chlorine dose and that of another, chlorine-demanding substance. An excellent comparison of these and other chlorine decay models is provided by Powell et al., 2000b.

The rate of chlorine decay is also known to vary with time, in particular, the rate of decay in the first minutes and/or hours of contact is different from that over the longer term. Some researchers, including Jadas-Hecart et al. (1992), Sung et al. (2001), and Clark and Sivaganesan (2002) have proposed overall bulk water chlorine decay models that incorporate two or more time intervals that are characterized by models of different orders. These and other multiple interval models are described in detail by Warton et al. (2006) and Powell (2003). For example, the US EPA Water Treatment Plant model uses the time intervals shown in Table 2.2.

**Table 2.2 US EPA water treatment plant model (Warton et al., 2006)**

| Time Interval | Order of Reaction | Example (Powell et al., 2000) |
|---|---|---|
| < 5 minutes | Zero | $\frac{dC}{dt} = -k$ à $C_t = -kt + C_o$ |
| 5 minutes to 5 hours | Second | $\frac{dC}{dt} = -kC^2 \rightarrow C_t = \frac{C_o}{1 + C_o kt}$ |
| > 5 hours | First | $\frac{dC}{dt} = -kC \rightarrow C_t = C_o e^{-kt}$ |

## 2.5 Alternative Disinfectants

UV, ozone, chlorine dioxide and chloramines are alternative disinfection technologies that can be applied for pathogen inactivation. They are less commonly used than free chlorine for a number of reasons, but mostly due to widespread unfamiliarity.

### *2.5.1 UV Disinfection*

UV light can also be used to inactivate pathogens. The actual mode of disinfection differs from that of chlorine in significant ways, which impacts its applicability in drinking water treatment systems. UV light inactivates pathogens by directly disrupting their DNA (or RNA). These disruptions prevent pathogens from reproducing, but do not kill them directly.

UV light is particularly useful for *Giardia* and *Cryptosporidium* inactivation. *Cryptosporidium* is not destroyed effectively by free chlorine, which is the most common disinfectant used for water treatment. Instead, UV disinfection represents a relatively inexpensive way to achieve *Cryptosporidium* inactivation in communities who cannot provide sufficient removal through filtration. *Giardia* is inactivated by chlorine, but the reaction tends to be slow, resulting in a large contact volume. UV disinfection requires a much smaller footprint than free chlorine contact for *Giardia* removal.

Another advantage is that organic DBPs are not formed during UV disinfection. There are, however, two major disadvantages associated with UV disinfection. First, it only works when the water being disinfected is of relatively high quality. Some parameters, most notably turbidity, decrease the effectiveness of UV disinfection significantly. Secondly, viruses are not easily inactivated at the UV doses provided by the UV units commonly available for water treatment.

UV disinfection is less expensive (capital + operation) than chlorination, particularly at the small scale (US EPA, 1996). To be effective, however, the UV light must reach the pathogenic organisms at the proper ‘dose’. Common doses include 40 mJ/cm$^2$ for protozoa inactivation and 140 mJ/cm$^2$ for virus inactivation. Most UV disinfection system manufacturers will not assure these doses if the water being disinfected has UV transmittance below 75%. Units that have been shown to achieve adequate pathogen inactivation at specific flow rates and transmittance levels are referred to as ‘validated’. Validation methods have been developed by the US EPA (UVDGM Method) and the Deutscher Verein des Gas -und Wasserfaches (DVGW). The former is described in detail in the *Ultraviolet Disinfection*

*Guidance Manual*, which was published by the US EPA in 2006. Only validated UV units should be used for drinking water applications.

The transmittance of most surface water in Newfoundland and Labrador is well below 75% due to interferences by NOM and other UV-absorbing compounds. Under these circumstances, UV will only be feasible if treatment to remove these interferences is included ahead of disinfection, which will add to the overall cost of the treatment process.

### 2.5.2 Ozone

Ozone is a strong oxidant that is used as primary disinfectant. It is very fast acting, and can provide high log removals of pathogens such as *Cryptosporidium* and *Giardia*. It does not, however, provide an easily measurable residual, which can complicate system operation. CT tables have been developed for the inactivation of *Cryptosporidium*, *Giardia*, and viruses using ozone. Ozone can react with naturally occurring bromide to form bromate, a regulated DBP that has been linked to the development of various cancers.

Ozone disinfection is more expensive than chlorine and UV (US EPA, 1996), but it can be a good alternative to chlorine in situations where the water being disinfected is high in THM and HAA precursors and low in bromated.

### 2.5.3 Chlorine Dioxide

Chlorine dioxide is formed through the reaction of chlorine and sodium chlorite. It is a strong oxidant that can be used for both primary and secondary disinfection. It is generally restricted to the former, however, because its residual does not persist well in the distribution system. Its use for primary disinfection is also limited because of the level of operator expertise required for safe operation and the potential for disinfectant by-product formation (chlorate and chlorite).

### 2.5.4 Chloramines

Chloramines have been used for disinfection in North America for over 100 years. They are longer lasting and less reactive than free chlorine, making them ideal secondary disinfectants as they will persist throughout the distribution system and are less likely to contribute to the continued formation of DBPs. They are rarely used for primary disinfection because their lower reactivity, compared to hypochlorite, results in a need for longer contact time to achieve the same disinfection level as would be achieved using free chlorine. Chloramines can react with NOM to form DBPs but they generally do so more slowly. The change from free chlorine to chloramines has resulted in increased lead release in some communities in Canada and the United States, most notably Washington, D.C. It is thought to be related to changes in distribution system chemistry (pH, etc).

### 2.5.5 Summary of Disinfectants

Table 2.3 provides a summary of the relative effectiveness of each disinfectant discussed in this chapter for pathogen inactivation. The table was adapted directly from the CCME guideline document ‘From Source to Tap – Guidance on the Multi-barrier Approach to Safe Drinking Water’, published in 2004.

**Table 2.3 Effectiveness of various disinfectants on waterborne pathogens (CCME, 2004)**

| Disinfectant | *E.coli* | *Giardia* | *Cryptosporidium* | Viruses |
|---|---|---|---|---|
| Chlorine | Very Effective | Effective | Not Effective | Very Effective |
| Ozone | Very Effective | Very Effective | Very Effective | Very Effective |
| Chloramines | Effective | Not Effective | Not Effective | Not Effective |
| Chlorine Dioxide | Very Effective | Very Effective | Effective | Very Effective |
| Ultraviolet Radiation | Very Effective | Very Effective | Very Effective | Effective |

The relative costs of chlorine, ozone, and UV were published by the US EPA in a report released in 1996. The cost per $m^3$ and cost per day for different size systems are summarized in tables 2.4 and 2.5, which were adapted from similar tables within that document. Cost estimates for UV disinfection were prepared using information provided suppliers while costs associated with chlorination and ozonation were calculated using equations published in the US EPA's *Very Small Systems Best Available Technology Cost Document*.

**Table 2.4 Cost (per $m^3$) of three common disinfectants (US EPA, 1996)**

| Daily Flow ($m^3$) | Approximate Population (395 Lpcd) | Chlorine (5 mg/L) | Ozone (1 mg/L) | UV (40 $mJ/cm^2$) | UV (140 $mJ/cm^2$) |
|---|---|---|---|---|---|
| 91 | 200 | $ 0.74 | $ 0.92 | $ 0.45 | $ 0.48 |
| 329 | 800 | $ 0.18 | $ 0.26 | $ 0.11 | $ 0.13 |
| 1022 | 2,500 | $ 0.05 | $ 0.08 | $ 0.05 | $ 0.08 |
| 2461 | 6,000 | $ 0.05 | $ 0.05 | $ 0.05 | $ 0.05 |
| 6814 | 17,000 | $ 0.03 | $ 0.03 | $ 0.03 | $ 0.05 |

*includes 1 mg/L $Cl_2$ for secondary disinfection

**Table 2.5 Cost (per day) of three common disinfectants (US EPA, 1996)**

| Daily Flow ($m^3$/day) | Approximate Population (395 Lpcd) | Chlorine (5 mg/L) | Ozone (1 mg/L) | UV* (40 $mJ/cm^2$) | UV* (140 $mJ/cm^2$) |
|---|---|---|---|---|---|
| 91 | 200 | $ 67.20 | $ 84.00 | $ 40.80 | $ 43.20 |
| 329 | 800 | $ 60.90 | $ 87.00 | $ 34.80 | $ 43.50 |
| 1022 | 2,500 | $ 54.00 | $ 81.00 | $ 54.00 | $ 81.00 |
| 2461 | 6,000 | $ 130.00 | $ 130.00 | $ 130.00 | $ 130.00 |
| 6814 | 17,000 | $ 180.00 | $ 180.00 | $ 180.00 | $ 360.00 |

*includes 1 mg/L $Cl_2$ for secondary disinfection

Note that a UV dose of 40 $mJ/cm^2$ is required to achieve 3.0-log reduction of *Giardia* and *Cryptosporidium* while a dose of 140 $mJ/cm^2$ is required to achieve 4.0-log reduction of viruses. At either dose, UV disinfection was found to be particularly price-competitive for small communities. The US EPA study found that costs associated with chlorine, ozone, and UV for larger populations were comparable to those presented in Table 2.5 for communities of approximately 17,000.

## 2.6 Quantifying Disinfection Effectiveness

Water treatment systems are generally designed to achieve set reductions of specific organisms such as G*iardia, Cryptosporidium,* and viruses. As discussed in the *Guidelines for the Design, Construction and Operation of Water and Sewerage Systems,* the effectiveness of the disinfection is usually communicated using the log reduction concept. For example, a system that is removing or inactivating 99% of the *Giardia* present in the source water is said to be achieving 2.0-log reduction. Treatment and disinfection systems are awarded log removal or inactivation credits based on their ability to remove a given percentage of the total number of specific types of pathogens present in the water.

### *2.6.1 The Log Reduction Concept*

Log reduction is an effective way to quantify the number of pathogens removed during a disinfection process, and thus the risk reduction achieved. The relationship between log reduction and percent reduction is shown in Equation 2.5.

$$\text{log reduction} = \log\left(\frac{100}{100 - \%\ \text{reduction}}\right) \qquad \textbf{Equation 2.5}$$

Log reduction can occur through pathogen removal using ‘engineered’ filtration or pathogen inactivation using chemical or physical disinfectants. Pathogen removal is discussed in detail in Section 3.5.3. The remainder of this chapter is focused on pathogen inactivation using chemical disinfectants, in particular free chlorine, as this is by far the most common method for drinking water disinfection in Newfoundland and Labrador.

The log inactivation concept was originally developed based on the Chick-Watson model, which suggests that the inactivation of microorganisms over time can be modelled as a first-order reaction. It suggests that the time required to reduce the concentration of microorganisms by a specific amount can be predicted if the disinfectant residual is known, as shown in Equations 2.6 and 2.7:

$$\frac{dN}{dt}=-kC^nN \qquad \textbf{Equation 2.6}$$

$$\ln\frac{N}{N_o} = -kC^nt \qquad \textbf{Equation 2.7}$$

Where:
$N_o$ = original concentration of organisms
N = number of organisms remaining
C = disinfectant residual
k, n = kinetic parameters
t = time

The ‘n’ parameter is generally assumed to be equal to one.

The Hom Model can also been used to quantify disinfection effectiveness (Equation 2.8):

$$\frac{dN}{dt}=-kmC^nt^{m-1}N \qquad \textbf{Equation 2.8}$$

The Hom model is thought to describe inactivation kinetics more effectively but is not used as frequently as the first order models due to its complexity (Haas et al., 1996). Other complex inactivation equations that take chlorine decay into account have been developed (Haas et al., 1996) but have limited applicability at a municipal level because their accuracy is dependent on the availability of real-time chlorine demand information.

### *2.6.2 The CT Concept*

Equations 2.7 and 2.8 relate expected log removal to the concentration of disinfectant applied and the reaction time under specific conditions. To simplify the design and operation of a disinfection system, the CT, or concentration x contact time, concept was developed to provide a link between the design of a disinfection system and the log removal of pathogenic organisms achieved. CT is often misinterpreted as an acronym for chlorine contact time, but the two concepts are distinct from one another.

#### 2.6.2.1 CT ACHIEVED

Water disinfection systems are designed to be capable of providing the CT required to ensure a specific amount of log removal based on the quality of the water being disinfected. The CT actually achieved in a given system is a function of the concentration of disinfectant available for disinfection after all disinfectant demands have been met in the bulk water (disinfectant residual) and the time allowed for the disinfection reactions to take place (contact time). The CT achieved in a given disinfection system can be calculated using Equation 2.9.

$$CT_{achieved} = C_{HOCl} \times T \times BF \qquad \textbf{Equation 2.9}$$

Where:
$C_{HOCl}$ = Free chlorine residual at the outlet (mg/L)
T = Time (minutes)
BF = Baffling factor

Chlorine residual, contact time and baffling factors are discussed in greater detail in Section 2.6.

#### 2.6.2.2 CT REQUIRED

The required CT is usually determined by consulting CT tables (US EPA, 1991), which can be used to determine the disinfectant concentration and reaction time required to achieve a given log removal. The tables are divided based on the type of organism being inactivated and the temperature and pH of the water. pH is of particular importance as it will determine the relative amounts of HOCl and OCl- present in the water and thus, the effectiveness of disinfection (Clark et al., 1987). Lower pH is associated with higher disinfection effectiveness.

The CT values in the tables were obtained using empirical studies conducted under tightly controlled lab conditions. For the most part, this meant conducting experiments in water that was free of substances that might exert a chlorine demand. To counteract the effects of chlorine demand, the CT tables include a safety factor of 1.5 (Faust and Aly, 1998). Despite this, some researchers have suggested that inactivation rates of certain pathogens are not adequately predicted by the current CT tables (Kahler et al., 2010).

CT can also be calculated using one of a number of equations that have been developed over the years. For example, equations 2.10 and 2.11 were developed to describe the disinfection of *Giardia lamblia* using free chlorine:

**Martin (1993)**

$$CT = 0.2828pH^{2.69} \times Cl^{0.15} \times LRV \times 0.933^{T-5}$$ **Equation 2.10**

**Clark (1987)***

$$CT = 0.9847Cl^{2.7519} \times pH^{2.7519} \times T^{-0.1467}$$ **Equation 2.11**

*The equation by Clark was developed for use at temperatures between 0.5°C and 5°C and can only be used to calculate the CT required to achieve 3 - log inactivation of *Giardia lamblia*.

Equations 2.12 and 2.13 describe the inactivation of viruses by free chlorine at different temperatures (McGuire et al., 2002):

$$\text{For } T \leq 5,\ CT = \frac{\text{Log Inactivation Required}}{0.35(T^{0.18})}$$ **Equation 2.12**

$$\text{For } T > 5,\ CT = \frac{\text{Log Inactivation Required}}{0.36(1.07^{T})}$$ **Equation 2.13**

The CT required and the CT achieved can be compared using the inactivation ratio, as shown in Equation 2.14.

$$\text{Inactivation Ratio} = \frac{CT_{achieved}}{CT_{required}}$$ **Equation 2.14**

An inactivation ratio above 1 indicates that the system is achieving adequate disinfection.

## 2.7 Application of the Log Reduction and CT Concepts

As shown previously in Equation 2.9, the CT, and thus log reduction, achieved in a chlorine reaction volume is dependent on the amount of time allowed for chlorine contact, the baffling characteristics of the contact volume, and the chlorine residual at the outlet of the contact volume. These three variables are discussed in greater detail in the sections that follow.

### *2.7.1 Contact Time*

CT is calculated using the maximum instantaneous flow expected through the chlorine contact volume. Common chlorine contact volumes include chlorine reaction tanks and chlorine contact pipes. The community can only draw as much water as can be processed through the contact volume, eliminating any danger of not meeting established disinfection requirements. Oftentimes, storage is added after the chlorine contact volume to buffer changes in water demand over the course of the day and to provide fire flow.

Contact time is determined by the flow rate through the chlorine contact volume as well as its size and mixing characteristics. It is calculated by dividing the flow rate by the contact volume, as shown in Equation 2.15.

$$\text{Contact Time (h)} = \frac{\text{Peak Flow Rate}\left(\frac{\text{m}^3}{\text{h}}\right)}{\text{Contact Volume (m}^3\text{)}}$$

**Equation 2.15**

For communities that lack a defined chlorine contact volume and/or water storage between the point of chlorination and the first user CT is calculated using the peak hour flow (usually expressed in L/min) for the community. The flow rate used to calculate the CT achieved should be the peak instantaneous flow (LPM, gpm, etc.) that can occur between the point of chlorination and the first user. This includes fire flow. Calculating CT using the peak hour flow ensure that safe water is provided to residents even at times of particularly high water demand. Ideally, this should be determined in the field by monitoring the instantaneous (L/min or L/h) water demand over the course of several days. More frequently, it is approximated by applying a peaking factor to the average day flow.

The average day demand is calculated based on the historical water use in the community as recorded in a daily log sheet by the system operator. If daily water use records are not available, some jurisdictions allow system designers to apply a per capita water demand value. This approach is not recommended as it fails to take into account the unique distribution of residential, commercial, institutional, and industrial users in each community. In some cases, however, such assumptions are necessary during the design of water infrastructure and the evaluation of disinfection compliance. A summary of recommended values from different jurisdictions is provided in Table 2.6.

**Table 2.6 Recommended per capita water demand values in Canadian design guidelines, treatment standards, and research publications**

| Publication | Year of Publication | Residential | Total | Other |
|---|---|---|---|---|
| NL Design Guidelines | 2005 | 340 Lpcd | n/a | The proposed Generic Terms of Reference may require that system designers conduct a water use study in the absence of historical data. |
| Atlantic Canada Design Guidelines | 2004 | Refer to historical records | Refer to historical records | Small systems should use 1,000 to 1,500 L/unit/day for small systems (< 167 units); readers are referred to other publications for standard per capita demands. |
| Ontario Design Guidelines | 2008 | 270 to 450 Lpcd |  | Note that residential demand can vary from 260 to 1,500 Lpcd. |
| Environment Canada Survey | 2010 | 504 Lpcd | 813 Lpcd |  |
| Environment Canada Survey | forthcoming | 395 Lpcd | 804 Lpcd |  |

**Table 2.6 Recommended per capita water demand values in Canadian design guidelines, treatment standards, and research publications (continued)**

| Publication | Year of Publication | Residential | Total | Other |
|---|---|---|---|---|
| Quebec Design Guidelines | 2006 | n/a | 465 Lpcd | A study conducted by Reseau (2000) found that per capita water use varied from 360 Lpcd to 1,103 Lpcd in the province. |
| Ten State Standards | 2007 | Refer to historical records | Refer to historical records | |
| First Nations Design Standards | 2006 | Refer to historical records | Refer to historical records | |

In the absence of historical flow records, a per capita water demand of 395 Lpcd has been assumed for the sample calculations presented in this report and the disinfection compliance assessments conducted for this study. This number represents the average per capita water use reported by approximately 20 communities in Newfoundland and Labrador during a survey conducted by Environment Canada in 2009 (personal communication, July 7th, 2011). It is anticipated that the results will be published shortly. The consultant believes that this number provides a reasonable starting point given the pre-results of design and review projects conducted in Newfoundland and Labrador, as shown in Table 2.7.

**Table 2.7 Per capita water use in a selection of communities in Newfoundland and Labrador**

| Community | Population | Source Type | Average Per Capita Water Use (Lpcd) | Notes |
|---|---|---|---|---|
| Bonavista | 3,764 | SW | 1,157 | Town has a fish plant and numerous commercial and institutional users. |
| Burgeo | 1,607 | SW | 1,336 | The town has a fish plant. |
| Chance Cove | 192 | GW (3) | 200 | There are only residential users on the system. |
| Come by Chance | 260 | SW | 319 | |
| Conception Harbour | 261 | GW (3) | 118 | Users are mostly residential with some vacation homes. |
| Corner Brook | 20,103 | SW (3) | 1,174 | Industrial and commercial users account for at least 47% of total water use |
| Leading Tickles | 407 | SW | 1,518 | The town has a fish plant. |
| Mary's Harbour | 417 | SW | 2,410 | The town has a fish plant. |
| Marystown | 5,436 | SW | 1,234 | The town has a fish plant and numerous commercial and institutional users. |

The results in Table 2.7 clearly demonstrate the importance of water use monitoring and review of water use records when system components are designed or disinfection compliance is assessed.

Peak hour peaking factors can be determined from historical water use records, but are more frequently assumed based on published values or calculated using equations developed by regulators and/or researchers. A selection of these is presented in summarized in Table 2.8.

**Table 2.8 Summary of peak hour peaking factor calculation methods**

| Method | Equation | Population Limits |
|---|---|---|
| Ontario Design Guidelines (2008) | Empirical | None |
| Harmon Formula (1918) | $PF = \frac{18 + \sqrt{P/1000}}{4 + \sqrt{P/1000}}$ | $1{,}000 \le P \le 1{,}000{,}000$ |
| AWWA (2004) | $PF = \left(\frac{1095.31}{q}\right) P^{0.4}$ | $650 \le P \le 1{,}675$ |
| DVGW (2007) | $PF = 18.1(P^{-0.1682})$ | Unknown |
| PRP – Gumbel Method<br>Zhang et al. (2005)<br>(indoor use only) | $PF = 2.5 + \frac{2.18}{\sqrt{P/1000}}$ | $1{,}000 \le P \le 25{,}000$ |

Peaking factors vary inversely with population, that is, as population increases, the peaking factor will decrease. This is because individual users in small communities have higher impacts on total water use than those in larger communities. This is demonstrated in Table 2.9, which presents some of the empirical peaking factors recommended in the Ontario Design Guidelines published in 2008 by the Ontario Ministry of the Environment.

**Table 2.9 Peak hour peaking factors – Ontario Design Guidelines (MOE, 2008)**

| Population Size | Peaking Factor |
|---|---|
| 150 | 7.40 |
| 300 | 5.40 |
| 500 | 4.30 |
| 500 to 1,000 | 4.13 |
| 1,001 to 2,000 | 3.75 |
| 2,001 to 3,000 | 3.38 |
| 3,001 to 10,000 | 3.00 |

The advantages and disadvantages of each peak hour peaking factor calculation method are summarized in Table 2.10.

**Table 2.10 Advantages and disadvantages of peak hour peaking factor calculation methods**

| Method | Advantages | Disadvantages |
|---|---|---|
| Ontario Design Guidelines (MOE, 2008) | • Well established in Canada<br>• No population limits | • Empirical nature makes it difficult to implement on a large scale (i.e., database)<br>• No exact solution for populations that fall within ranges |
| Harmon Formula (1918) | • Currently used by the ENVC<br>• Applicable over a large population range | • Usually used for wastewater (i.e., only accounts for water sent to sewer) |
| AWWA (2004) | • Well established method | • Only appropriate within a specific population range<br>• May underestimate peaking factors |
| DVGW (2007) | • Corresponds well to established empirical peaking factors<br>• No (known) population limits | • Unknown limits and accuracy<br>• May overestimate peaking factors |
| PRP-Gumbel Method<br>Zhang et al. (2005) | • Corresponds well to established empirical peaking factors<br>• Alternate versions of the equation (Zhang, 2005) can be used to solve for combined indoor and outdoor use<br>• Very accurate<br>• Equation-based and thus easy to implement on a large scale (i.e., database) | • Limited applicability in very small communities<br>• Large communities must be modelled as a series of individual subdivisions |

The choice of peak hour peaking factor will impact both the design and operation of water treatment systems. For the purposes of this study, the choice of peaking factor is important because it will determine the peak hour flow used to calculate the amount of chlorine contact time occurring in the disinfection process and thus the CT and log reduction being achieved.

Log inactivation levels expected at the peak flow rates predicted by the Harmon, AWWA, DVGW, and PRP-Gumbel methods as well as the empirical peaking factors in the Ontario design guidelines are shown in Figure 2.1. Inactivation was calculated using Martin's equation for *Giardia* inactivation using free chlorine (Equation 2.10) and assuming a temperature of 15$^{o}$C, a pH of 6.5, a chlorine residual of 0.3 mg/L, and a contact volume of 100,000 L with a baffling factor of 1 (plug flow).

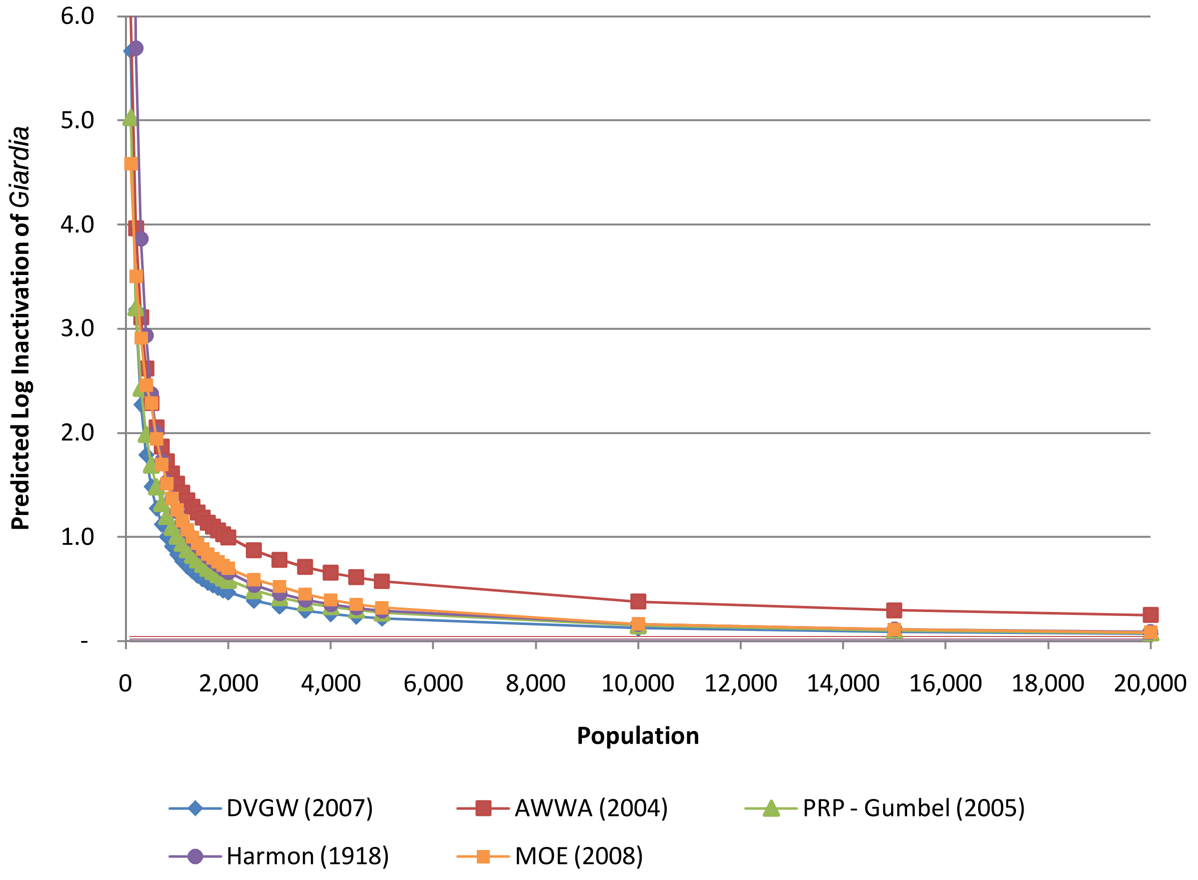


**Figure 2.1** **Log inactivation predictions made using different peaking factor calculation methods (population < 20,000)**

The log inactivation predictions made using the PRP-Gumbel method at low populations fall between the most liberal (Harmon) and most conservative (DVGW). They are slightly more conservative than those made using interpolations of the MOE recommended values, but in general the two are well correlated ($p < 0.05$, $r^2 = 0.92$).

The basis for choosing the PRP-Gumbel method over the others is discussed in greater detail in '*Water Quality and Demand on Public Water Supplies with Variable Flow Regimes and Water Demand'* (forthcoming). The province may consider using another method for CT calculations and system design at their own discretion, or may opt to use different peaking factor calculations depending on the size of the community. For example, the PRP-Gumble method could be used for populations between 1,000 and 25,000 while MOE recommended values could be used outside of this range.

Note that chlorine contact volumes associated with treatment plants are generally not sized to meet the peak instantaneous system demand. Instead, they are sized to handle the maximum output of the treatment system. This strategy minimizes the footprint of the water treatment plant but can only be employed in conjunction with additional treated water storage, which is then used to buffer peak demands.

Most of the communities participating in the current study do not have dedicated chlorine contact volumes and/or storage facilities before the user. For these communities, the peak hour flow must be used to calculate CT to ensure that water being sent to users is consistently in compliance with disinfection requirements.

### *2.7.2 Baffling Factor*

Contact volumes should be designed to encourage effective mixing. This may take the form of baffles installed within a chlorine contact chamber or a weir at the outlet of the chamber. Each contact chamber is assigned a 'baffling factor' based on the amount of volume that is utilized within it, which corresponds to the effectiveness of the contact. The baffling factor is defined as the ratio between the total retention time in the contact volume and the time required for 10% of the influent water to travel from the inlet to the outlet of the chlorine contact volume ($T_{10}$). For example, water will travel more quickly through a short, unbaffled tank than through a longer, baffled tank. The closer the $T_{10}/T$ ratio gets to 1, the closer the water is to plug flow and the longer the chlorine contact time.

The baffling factors shown in Table 2.11 are commonly used to approximate the $T_{10}/T$ ratio for different contact chamber configurations.

**Table 2.11 Commonly used baffling factors (US EPA, 2003)**

| Baffling Factor | $T_{10}/T$ Ratio | Baffling Description |
|---|---|---|
| Unbaffled (mixed flow) | 0.1 | None, agitated basin, very low length to width ratio, high inlet and outlet velocities. |
| Poor | 0.3 | Single or multiple unbaffled inlets and outlets, no intra-basin baffles. |
| Average | 0.5 | Baffled inlet or outlet with intra-basin baffles. |
| Superior | 0.7 | Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders. |
| Perfect (plug flow) | 1.0 | Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles. |

A baffling factor of 0.3 corresponds to a tank with one inlet, one outlet, and minimal mixing. A baffling factor of 1 corresponds to the plug flow scenario that can develop in reaction chambers with very high length to width ratios, such as pipes. A transmission main can be considered an effective chlorine contact volume with a baffling factor of 1 provided that it is long enough to ensure that the required CT is met before the first user at the highest flow rate possible within the pipe.

### *2.7.3 Chlorine Residual*

The CT calculation requires that an estimate be made of the concentration of free chlorine available for disinfection in the chlorine contact volume. As discussed in Section 2.3.2, chlorine added for disinfection decays over time due to reactions with chlorine consuming substances in the bulk water or on the surfaces of water treatment and distribution system components. Thus, the safest and most conservative estimate of the concentration of available free chlorine is that at the outlet of the chlorine contact volume. This is referred to as the free chlorine residual and can be measured continuously using an in-stream chlorine monitor (preferred) or using a handheld chlorine measuring device.

### *2.7.4 Log Removal Using Filtration and Chemical/UV Disinfection*

The GCDWQ recommend that utilities provide 3.0-log removal of *Giardia* and *Cryptosporidium* when a source water is known or suspected to be contaminated by human-infectious cysts or oocysts (GCDWQ, 2010). They also recommend that 4.0-log removal of viruses be provided if the water source is exposed to faecal contamination and/or if past disease outbreaks have been linked to the presence of enteric viruses. In practice, most surface water and GUDI water sources are exposed to some level of faecal contamination due to human and animal activities. Therefore, many jurisdictions take the default position that all surface water supplies are contaminated with enteric pathogens and require that water treatment systems be designed to provide for the reduction of indicator organisms such as *Giardia* and *Cryptosporidium*.

Although these recommendations can be met with chemical (or UV) disinfection, a combination of filtration and chemical (or UV) disinfection is often used to ensure timely removal of all pathogens of interest. For example, at a pH of 7 and a temperature of 0.5$^{o}$C it takes approximately 210 minutes at a concentration of 1 mg/L to inactivate 3.0-log of *Giardia* with free chlorine alone (assuming plug flow). If, instead, a system were to achieve 2.5-log removal of *Giardia* through conventional filtration and 0.5-log through chlorination, the chlorine contact time would decrease to 35 minutes.

Various filtration processes can be employed to remove pathogens, including bacteria, protozoa, and viruses. Table 2.12, adapted from *'From Source to Tap – Guidance on the Multi-barrier Approach to Safe Drinking Water'* (CCME, 2004) summarizes the range of log removals *Giardia* and viruses that can be achieved in different filtration processes.

**Table 2.12 Log reduction of *Giardia* and Viruses in various filtration processes (CCME, 2004)**

| Filtration Process | *Giardia* | Viruses |
|---|---|---|
| Direct Filtration/In-line Filtration* | 1.5 to 4.0 | 1.0 to 2.0 |
| Conventional Filtration | 2.0 to 6.0 | 2.0 to 3.0 |
| Slow Sand Filtration | >3.0 | 1.0 to 3.0 |
| Membrane Filtration | >6.0 | >2.0 |

*Includes coagulation, rapid mix, and filtration

It should be noted that the actual log removal achieved for these pathogen with each treatment process is dependent on:

- Influent water quality;
- Operational characteristics; and
- Instantaneous filter performance.

Individual countries and provinces have assigned log removal values to specific treatment processes to help engineers design effective water treatment systems. The values adopted by various jurisdictions are discussed in detail in Chapter 3 of this report.

The guideline values for log removal achieved in various filtration processes and the CT tables used to determine log inactivation are approximations that simplify the design of disinfection systems. Both include a number of safety factors. This conservative approach is necessary to ensure that disinfection targets are met under all circumstances, however, it can have undesirable consequences. These might include the formation of DBPs or excessive chemical consumption. Balancing the need for adequate disinfection with the formation of DBPs, in particular, has become an important priority for utilities throughout North America. To accurately optimize their treatment and distribution systems, many utilities have found that they must go beyond the simplistic design guidelines. The Integrated Disinfection Design Framework (IDDF) is one tool that has been developed to help utilities achieve the necessary balance between pathogen reduction and DBP formation.

The IDDF was developed by Bellamy et al. (1998). It makes use of detailed information about the operation of the disinfection process, the quality of the raw water (i.e., chlorine decay characteristics) and the hydraulic configuration of the contact volume to approximate the amount of pathogen inactivation occurring over time.

Preliminary IDDF case studies conducted at utilities in the western United States showed that disinfectant dosages could be reduced by 8 to 35% without compromising the level of pathogen inactivation. The percent reduction varied based on the pathogen of interest, the disinfectant used, and the configuration of the disinfection system (Bellamy et al., 2000).

The effectiveness of any disinfection process must be monitored continuously to ensure that pathogens are being removed adequately. The test must be capable of ensuring that the filter is removing particles at its rated removal rate. Monitoring can be direct (ex. hole or pathogen detection) or indirect (ex. measuring an indicator parameter). They can also be characterized as continuous or periodic. The monitoring regime is direct and continuous. This is rarely feasible, however, and most treatment standards require that the performance of filters be monitored continuously using an indirect method. For example, media filter effluents are usually monitored for turbidity, an indirect monitoring parameter. In contrast, the performance of membrane filters is usually assessed using a direct, pressure-based integrity test.

## 2.8 Disinfection By-Products

DBPs are compounds formed through the reaction of disinfectants such as chlorine, ozone or chloramines and naturally occurring chemical parameters present in the source water. These might include nitrogen-based compounds, bromide, or natural organic matter (NOM). The term ‘NOM’ does not refer to one individual type of molecule, but rather, to an array of heterogeneous molecules that share a common source. These include proteins, hydrophobic humic and fulvic acids, hydrophilic acids, and lignins. Although these molecules tend to share many physical and chemical characteristics, they differ in reactivity. Not all NOM molecules will react with chlorine or other disinfectants to form DBPs. This makes it very difficult to predict DBP levels using common organic water quality parameters such as dissolved organic carbon (DOC) and colour, which do not differentiate between different types of NOM.

Trihalomethanes (THMs) and haloacetic acids (HAAs) are the most common disinfection by-products formed in disinfection systems employing free chlorine. Some trihalomethanes and haloacetic acids have been linked to various cancers and reproductive issues in animals and thus, are considered possible carcinogens in humans (Health Canada, 2006, Health Canada, 2008). Consequently, the US EPA and many Canadian provinces have set legal limits on the levels of THMs and HAAs permitted in drinking water. The GCDWQ recommends a limit of 100 µg/L for THMs and 80 µg/L for HAAs. Many additional DBPs have been identified in treated drinking water, some of which are believed to pose a greater risk to human health than those that are currently regulated (Karanfil et al., 2008).

Utilities can minimize the formation of DBPs by choosing a surface water source with low concentrations of DBP precursors, installing water treatment equipment designed to remove DBP precursors, optimizing the disinfection system through monitoring and/or using alternative disinfectants, and designing and/or operating the distribution system to prevent excessive water age and stagnation.

Smaller communities served by surface water sources with elevated colour and DOC levels and lacking water treatment processes optimized to remove NOM are at risk of developing high levels of DBPs, particularly in dead ends, storage tanks, and other locations with increased water age. In Newfoundland and Labrador, these communities often have elevated concentrations of NOM in their raw and treated water. When the water is disinfected the NOM exerts a strong chlorine demand, which in turn results in the need to apply large amounts of chlorine to ensure disinfection and achieve required residual levels. It also results in the formation of DBPs. As the water ages in the distribution system, the chlorine and NOM react to form even more DBPs, resulting in high THM and HAA readings throughout the community.

At present, the province of Newfoundland and Labrador has not formally adopted enforceable limits on any DBPs. Information and mitigation strategies are available on the government website and in government-published reports. The ENVC also samples for THMs and HAAs in communities across the province quarterly. The results are available to the public on the ENVC website.

One recent report published by the ENVC in 2009 provides an in-depth analysis of the factors influencing the formation of DBPs in the province of Newfoundland and Labrador. Best management practices that could be implemented by the province and/or by individual water treatment facilities to minimize the formation of DBPs are also identified (ENVC, 2009). Over 70 recommendations for best management practices are provided in the report, including the following:

- **Policy measures:**
  Ex. In very small communities with DBP levels significantly above the guideline values, a policy of point of use household treatment devices can be implemented as a temporary or emergency measure.

- **Source based control measures:**
  Ex. Where a land area is to be flooded to create a surface water reservoir, vegetation must be removed from the area prior to inundation as per permit requirements.

- **Chlorine demand management:**
  Ex. A contact time or CT factor value for inactivation of *Giardia* should only be used when the distribution system has experienced a previous *Giardia* contamination event and relies on chlorine disinfection as its only form of treatment.

  Ex. The application point of the chlorine dose should be as close to the first user as possible while still achieving primary and secondary disinfection objectives.

- **Retention time management:**
  Ex. Water retention times in storage tanks should be minimized.

- **Water demand management:**
  Ex. Effort should be made to locate new water connections and manual and automated flushing sites on areas of the distribution network with high retention times so that demand is increased in these areas.

- **Water distribution system operational and infrastructural measures:**
  Ex. Decay of chlorine at the pipe wall is the leading contributor to overall chlorine decay in the distribution system. Pipe wall decay of chlorine can be reduced by regular system flushing, chemical flushing, swabbing, pigging, or relining pipe.

- **Alternative disinfectants:**
  Ex. In order to provide a disinfectant residual in the distribution system, ozone and UV must be paired with a disinfectant that does leave a residual, such as chlorine.

- **Source water treatment:**
  Ex. A water treatment plant (WTP) on a distribution system will not necessarily reduce THM levels if the WTP has not been designed specifically to remove DBP precursors or if the treatment system has not be adequately designed.

  Ex. Water treatment plants in communities with DBP issues must be designed for the removal of DBP precursors.

- **Point of use/Point of entry measures:**
  Ex. There should be demonstrated community support for the installation of a PWDU.

- **Water system design measures:**
  Ex. The NL Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems should be updated at least every 10 years.

- **Operator education and training:**
  Ex. Communities should require that their water system operators be certified.

Though many of the best management practices outlined in the report are expected to minimize the formation of THMs and HAAs, it must be emphasized that communities attempting to reduce DBPs must continue to provide adequate disinfection. Care should also be taken to ensure that changes made to minimize DBP formation do not result in the development of other, potentially more dangerous, water quality issues.

# CHAPTER 3 DISINFECTION REGULATIONS

## 3.1 Guidelines for Canadian Drinking Water Quality

The GCDWQ are guidelines, not treatment standards, and as such are not legally binding unless adopted by individual provinces and/or federally administered communities. The current GCDWQ do not provide recommendations with regards to appropriate processes for the removal or inactivation of pathogens, nor do they differentiate between surface, groundwater, and GUDI water supplies. Some guidance on these and other water quality issues is provided in the guideline technical documents, including those on enteric viruses (Health Canada, 2004) and enteric protozoa (Health Canada, 2004). For the most part, however, it has been left to individual provinces to establish appropriate disinfection standards and treatment requirements.

The GCDWQ and the accompanying technical guidance documents place emphasis on the multi-barrier approach, which includes source water protection, adequate water treatment, and monitoring of the distribution system.

The GCDWQ recommend the use of indicator bacteria to determine the relative risk associated with a particular water sample. Faecal bacteria such as *E.coli* can be used as a proxy for other types of enteric bacteria, which are of particular concern. The recommended maximum acceptable concentrations (MACs) for *E.coli* and total coliforms in drinking water is 0 organisms per 100 mL of water.

Enteric protozoa are difficult to monitor and quantify, so the existing guideline technical document recommends using treatment technologies that are capable of removing set amounts of two major types that are of particular concern for human health and are thought to be representative; *Giardia* and *Cryptosporidium*. This approach is used instead of a MAC value as is used for most other health-based guidelines.

The most recent version of the GCDWQ recommends that communities who know of or suspect the presence of protozoa, viruses, and/or faecal contamination in their source water provide water treatment and/or disinfection to remove or inactivate 99.9% (3.0-log) of *Giardia* and *Cryptosporidium* and 99.99% (4.0-log) of viruses.

The proposed guideline technical document for enteric protozoa recommends that source waters known to be infected with *Giardia* or *Cryptosporidium* be protected using a watershed protection plan or wellhead protection plan. This would include, for example, communities that have experienced outbreaks of illness related to enteric protozoa in the past. The guidelines suggest that utilities aim for a minimum 3.0-log reduction of protozoan cysts and oocysts in the municipal water treatment system. Higher log removals are recommended for water sources where elevated concentrations of enteric protozoa are known to exist.

A treatment train that includes coagulation, filtration, clarification, and filtration followed by disinfection with an oxidant (chlorine, chloramines, ozone, etc.) is specifically recommended for the removal of enteric protozoa. The guidelines note, however, that *Cryptosporidium* oocysts are more difficult to remove and/or inactivate than *Giardia* cysts and that, consequently, it may be necessary to add treatment steps beyond the conventional treatment train or additional disinfection capacity to ensure their removal and /or inactivation. Information about direct filtration, membrane filtration, and UV disinfection is also provided.

The current guideline technical document for enteric viruses recommends that communities whose source waters are exposed to faecal contamination or who have experienced disease outbreaks related to enteric viruses implement source water protection measures and provide treatment for virus reduction. If treatment is warranted, a minimum of 4.0-log reduction is suggested. The document also notes that the presence of *E. Coli*, an enteric bacteria, can often indicate the presence of enteric viruses, although these viruses may also be present in the absence of *E.coli*. A summary of the current GCDWQ recommendations is provided in Table 3.1.

**Table 3.1 Recommended pathogen removal levels (GCDWQ, 2010)**

| Pathogen | MAC | Recommended Log Reduction |
|---|---|---|
| Total Coliform | 0 per 100 mL | n/a |
| *E.coli* | 0 per 100 mL | n/a |
| *Giardia* | None | 3.0-log |
| *Cryptosporidium* | None | 3.0-log |
| Viruses | None | 4.0-log |

A new version of the guideline technical document for enteric protozoa was released for public consultation in December 2010. Additional measures for the quantification of *Giardia* cysts and *Cryptosporidium* oocysts and the risks they pose to human health are discussed. For example, it is suggested that routine source water assessments be used to characterize the microbiological quality of a given water source and determine the amount of log removal required to ensure that users are not exposed to dangerous levels of enteric protozoa. Quantitative microbial risk assessment (QMRA), a process that can be used to establish the burden of disease faced by a community with a given source water and treatment process, is also discussed in detail. Public health risks are quantified using ‘disability-adjusted life years’ or DALYs. A reference risk level of $10^6$ DALY/person/year has been proposed for municipal water systems. This includes the source water protection plan, treatment process, and distribution system.

Other issues addressed in the proposed new guideline technical document include:

- Source water protection;
- The effectiveness of various treatment processes;
- GUDI designation; and
- Short-term degradation of water quality.

Some or all of the changes to the existing guideline technical document are expected to be included in the final version.

Continuous monitoring of the performance of water treatment processes used for pathogen reduction is also recommended in the guidelines. For example, the turbidity of the effluent from the final filter in the treatment train is commonly monitored to ensure that the filter continues to remove particles effectively. The suggested GCDWQ treatment filter effluent turbidity limits are summarized in Table 3.2.

**Table 3.2 Filter effluent turbidity limits**

| Filtration Type | 95% of Readings Not to Exceed | Absolute Maximum |
|---|---|---|
| Chemically Assisted (Coagulation) | 0.3 NTU | 1.0 NTU |
| Slow Sand/Diatomaceous Earth | 1.0 NTU | 3.0 NTU |
| Membrane | 0.1 NTU | 0.3 NTU |

The GCDWQ refer to the UV inactivation table for *Cryptosporidium* and *Giardia* inactivation and the CT tables for the inactivation of *Giardia* and viruses using chlorine, chloramines, ozone, and chlorine dioxide that were originally developed for the US EPA.

## 3.2 Newfoundland and Labrador

In Newfoundland and Labrador, drinking water quality is governed under the *Water Resources Act* (WRA). Numerous regulations, policy directives, and standards have been derived from the WRA. Of these, the *Standards for Bacteriological Quality of Drinking Water*, which were released in 2008, are the most relevant to the current study. It provides guidance on disinfection and monitoring in drinking water systems throughout the province. One of the basic requirements of the standard is that a free chlorine residual be detectable in all parts of the distribution system. Additionally, every public water system must be sampled regularly for total coliforms and *E.coli*. If any water sample contains *E.coli* or if more than 10% of consecutive samples from the same site are found to contain total coliforms, the water system is considered to be out of compliance with the standard.

The standard also recommends that the following be provided before the water reaches the distribution system:

- A minimum contact time of 20 minutes;
- A minimum chlorine residual of 0.3 mg/L; and
- The equivalent CT value.

CT is calculated by multiplying the contact time by the chlorine residual at the outlet of the contact volume. Thus, the equivalent CT value would be 6. A CT value of 6 corresponds to different log removal values depending on the pathogen of interest, the temperature and pH of the water and the type of disinfection process used.

The *Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems* were developed by the ENVC to provide guidance on the design of water treatment and disinfection systems in the province. The guidelines state that: "Continuous disinfection is mandatory for all public water supplies." (ENVC, 2005). The disinfection requirements provided in the *Standards for Bacteriological Quality of Drinking Water* are reiterated in the design guidelines, which also recommend that pH, ammonia, temperature, bacterial water quality, and DBP formation potential be considered during the design of disinfection systems. They also note that basins used for disinfection should be designed to avoid short circuiting, potentially through the inclusion of baffling.

The log reduction concept is explained in detail in the design guidelines, however, currently there is no requirement that utilities achieve a set amount of log inactivation and/or removal of any particular pathogen.

The water quality standard and design guidelines have been written assuming that free chlorine is used for disinfection. This is indeed the case for the majority of communities in the province, particularly small, rural communities. Both documents explain that alternative disinfectants, including ozone and chlorine dioxide, are permitted for primary disinfection but must be followed by chlorine addition for secondary disinfection. Background information on alternative disinfection methods is provided in the design guidelines.

Boil water advisories (BWAs) are issued under the conditions described in Table 3.3.

**Table 3.3 BWA reasons and reason codes used in Newfoundland and Labrador**

| Code | Reason |
|---|---|
| A | Water supply has no disinfection system |
| B1 | Chlorination system is turned off by the operator due to taste or other aesthetic considerations |
| B2 | Chlorination system is turned off by operator due to perceived health risks |
| B3 | Chlorination system is turned off by operator due to lack of funds to operate |
| B4 | Chlorination system is turned off by operator due to Non-consumption Order |
| C1 | Disinfection system is off due to maintenance or mechanical failure |
| C2 | Disinfection system is off due to lack of chlorine or other disinfectant |
| D1 | Water distribution system is undergoing maintenance or repairs |
| D2 | Cross connection has been discovered in the distribution system |
| D3 | Inadequately treated water was introduced into the system due to fire flows, flushing operations, minor power outage or other pressure loss |
| E1 | Water entering the distribution system or facility, after a minimum 20 minute contact time does not have a free chlorine residual of at least 0.3 mg/L or equivalent CT value |

**Table 3.3 BWA reasons and reason codes used in Newfoundland and Labrador (continued)**

| Code | Reason |
|---|---|
| E2 | No free chlorine residual detected in the water distribution system |
| E3 | Insufficient residual disinfectant in water system primarily disinfected by means other than chlorination |
| F1* | Total coliform count is more than 10 (counts per 100 mL) |
| F2* | Total coliform or Escherichia (E. coli) detected and repeat samples cannot be taken as required |
| F2T | Total coliform detected and repeat samples cannot be taken as required |
| F2E | Escherichia coli (E. coli) detected and repeat samples cannot be taken as required |
| F3 | Total coliforms detected and confirmed in repeat sample |
| F4 | Escherichia coli (E.coli) detected in an initial sample(s) is considered extensive and the water system has other known problems |
| F5 | Escherichia coli (E.coli) detected and confirmed in repeat sample |
| F6 | Viruses detected (e.g., Hepatitis A, Norwalk) |
| F7 | Protozoa detected (e.g., Giardia, Cryptosporidium) |
| G | Water supply system integrity compromised due to disaster (e.g. contamination of water source from flooding, gross contamination, major power failure, etc.) |
| H | Waterborne disease outbreak in the community |

*Categories no longer in use

## 3.3 Other Canadian Provinces

Small communities in other Canadian provinces, particularly in northern areas, face many of the same challenges as those in Newfoundland and Labrador: small populations; remoteness; and a lack of operational capacity. Nonetheless, all provinces except for New Brunswick and Prince Edward Island have adopted enforceable disinfection requirements for municipal drinking water systems. Note that most provinces have opted to approach drinking water disinfection using the log reduction concept.

### *3.3.1 Ontario*

#### 3.3.1.1 LEGISLATION AND GUIDELINES

Ontario has had drinking water regulations in place for over 50 years, but the events that occurred in Walkerton in 2000 spurred the provincial government to overhaul the province's drinking water regulatory system dramatically. This began with the passing of the *Safe Drinking Water Act* (SDWA) in 2002 (2002, S.O. 2000, c.32). Many of the requirements that it contains were drawn from the findings of the Walkerton Inquiry (2001).

The SDWA*,* which includes regulations 169/03 and 170/03, and the *Clean Water Act* (2006, S.O. 2006, c.22) currently govern the protection, design, and operation of water systems in Ontario.

Regulation 169/03 provides the following requirements for the microbiological quality of drinking water (O. Reg. 169/03, Sched. 1):

- *Escherichia coli* – not detectable; and
- Total Coliform – not detectable.

Specific disinfection requirements for large and small residential systems are laid out in Regulation 170/03. Large municipal systems are defined as those that serve a large residential development that includes more than 100 private residences while small municipal systems are those that serve a large residential development with fewer than 101 private residences (O.Reg. 170/03, S.1). Both large and small municipal water systems that use surface water are required to treat their raw water using chemically assisted filtration or other methods of treatment that are deemed by regulators to be capable of providing water of equal or better quality.

The SDWA recognizes three types of water sources: surface water; groundwater; and GUDI. All public water supplies, irrespective of source type, are required to develop a source water protection plan. The procedure for the preparation of the plan is set out in the *Clean Water Act* (2006). The plan must establish the characteristics of the watershed(s) that impact the raw water source and identify any vulnerabilities that may affect the quality of water drawn from the source.

The document *Procedures for Disinfection of Drinking Water in Ontario* (PDDWO), released by the MOE in 2008, provides design guidelines for pathogen reduction systems. This document has been 'adopted by reference' as a supporting document for Ontario Regulation 170/03 (S.1. and S.2). The MOE also recommends that water treatment system designers refer to the *Ten State Standards* (2007) for guidance during the design process.

#### 3.3.1.2 IMPLEMENTATION OF THE SAFE DRINKING WATER ACT IN ONTARIO

Communities and operators were not expected to conform to all of the requirements of the SDWA immediately. Instead, a number of government programs were put in place to help communities determine what upgrades were required to bring their systems into compliance with the new regulations and to help them implement the upgrades in a timely fashion.

All communities with pre-existing water treatment systems were required to assess whether their systems were in compliance with the new regulations. This was done by the communities themselves, though they received technical guidance from the MOE and benefitted from funding programs implemented by the Ministry of Infrastructure (MOI).

The resulting system assessment reports were reviewed by the MOE (with the assistance of outside consultants). A certificate was issued to each community that outlined the system upgrades required to achieve compliance along with the timelines permitted to implement them. Additional funding programs were established by the MOI to help communities pay for the necessary upgrades. Communities who brought their systems into compliance were issued Certificates of Approval, which covered the water treatment system itself as well as its operation.

The province is currently in the midst of implementing the ‘Municipal Drinking Water Licensing Program’, which will include Drinking Water Works Permits (DWWP) as well as Municipal Drinking Water Licenses for system operation. The latter will need to be renewed every five years. The program is being implemented in a staggered fashion; larger communities were required to apply for their licenses by February 2010 while smaller ones were allowed until June of 2010. Details on this new program are available in the *Overview Guide for the Municipal Drinking Water Licensing Program* (2007). Details of this publication are provided in the ‘Recommended Reading’ section in Appendix A of this report.

A summary of the implementation of the water quality and treatment requirements of the SDWA is provided in Figure 3.1.

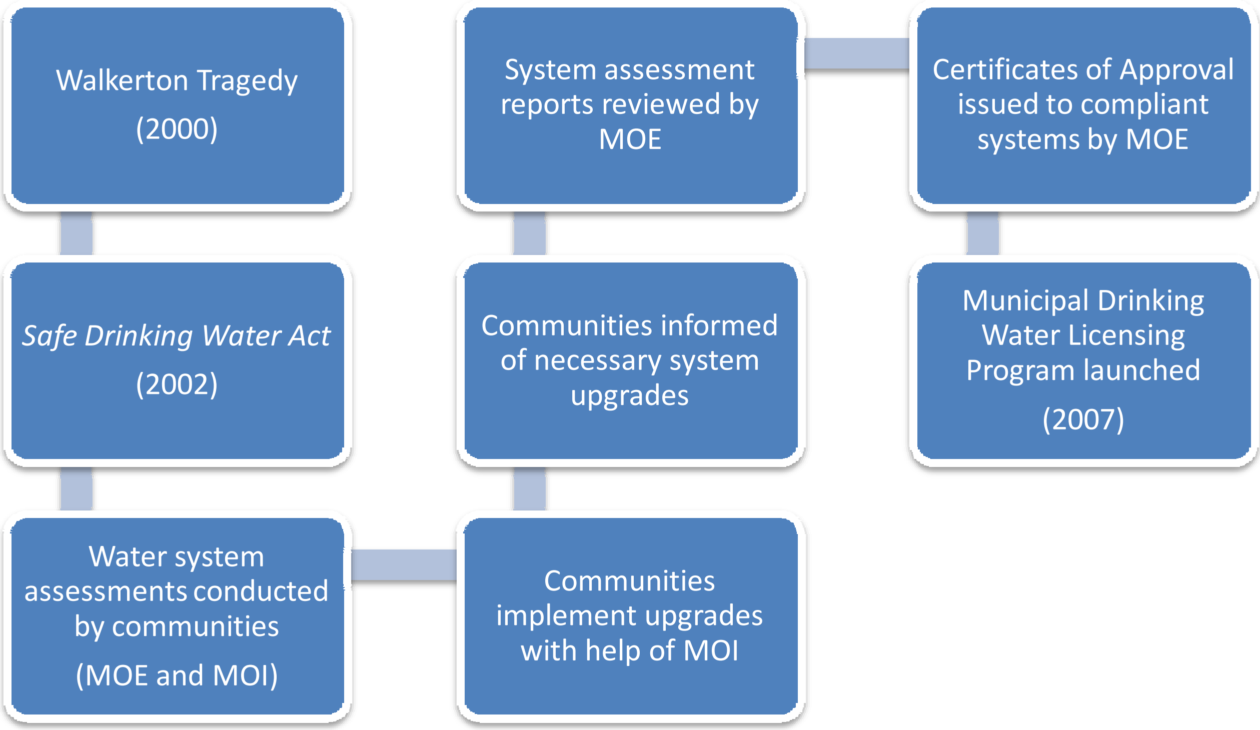


**Figure 3.1** **Implementation of the *Safe Drinking Water Act* in Ontario**

The province of Ontario has faced ongoing challenges related to the implementation of drinking water quality and treatment requirements in non-municipal systems. The owners of these, which include institutional, commercial, and temporary residential water systems (i.e., campgrounds), were not able to access the funding provided by the MOI for water system assessments or water infrastructure improvements. They are also unlikely to have access to sufficient capital to complete either of these steps. The province is currently working on a number of programs to bring these small non-municipal systems into compliance. Details can be found on the Drinking Water Ontario website.

### 3.3.1.3 TREATMENT AND PRIMARY DISINFECTION

Like those in many other jurisdictions, the regulations in Ontario are based on the log reduction and CT concepts. Specific reduction levels that must be achieved during primary disinfection for water systems supplied by surface water, groundwater, and GUDI sources are summarized in Table 3.4.

**Table 3.4 Pathogen removal requirements for municipal water systems in Ontario (MOE, 2008)**

| | Surface Water | GUDI | Groundwater |
|---|---|---|---|
| *Giardia* | 3.0-log | 3.0-log | None |
| *Cryptosporidium* | 2.0-log | 2.0-log | None |
| Viruses | 4.0-log | 4.0-log | 2.0-log |

An assessment of the raw water source is also recommended; sources that are vulnerable to contamination by sewage or agricultural runoff may be required to provide treatment to ensure higher log removals of *Cryptosporidium*.

A minimum of 0.5-log reduction *of Giardia* and 2.0-log reduction of viruses must be provided by the primary disinfection system. The remaining log removal credits must be provided by at least one of the following:

- Chemically assisted conventional filtration (coagulation, flocculation, sedimentation, filtration);
- Chemically assisted direct filtration (coagulation, flocculation, filtration);
- Slow sand filtration; or
- Membrane filtration (microfiltration, ultrafiltration, cartridge filters, etc.).

The turbidity of the effluent of any filter used for pathogen removal must be monitored continuously to be awarded the log removal credits listed in Table 3.5. For example, the effluent turbidity from conventional and direct filtration treatment systems must remain at or below 0.3 NTU 95% of the time to achieve compliance. Membrane filters must achieve an effluent turbidity of 0.1 NTU 99% of the time.

**Table 3.5 Log removal credits assigned to different treatment processes (MOE, 2008)**

| Treatment Process | *Giardia* | Viruses | *Cryptosporidium* |
|---|---|---|---|
| Conventional Filtration | 2.5-log | 2.0-log | 2.0-log |
| Direct Filtration | 2.0-log | 1.0-log | 2.0-log |
| Slow Sand Filtration | 2.0-log | 2.0-log | 2.0-log |
| Diatomaceous Earth Filtration | 2.0-log | 1.0-log | Requires specific testing and confirmation of *Cryptosporidium* (or surrogate particle) removal |
| Membrane Filtration | 3.0-log (and greater) | Up to 2.0-log (and greater) | Requires specific testing and confirmation of *Cryptosporidium* (or surrogate particle) removal |
| Cartridge/Bag Filters | Up to 2.0-log (and greater) | none | Requires specific testing and confirmation of *Cryptosporidium* (or surrogate particle) removal |

Systems that employ chlorination for primary disinfection do not receive any inactivation credit for *Cryptosporidium*. They can, however, achieve log inactivation credits for *Giardia* and viruses. The log inactivation of these two types of pathogens can be determined by evaluating the hydraulic characteristics of the chlorine contact volume (US EPA, 2003) and referring to the CT tables (US EPA, 1991).

Validated UV disinfection units may also be used for primary disinfection, though a number of caveats apply. First, systems that use surface water or GUDI sources may not rely on UV disinfection alone because the presence of turbidity and/or UV absorbing parameters in the water will impact the effectiveness of pathogen inactivation. For these systems, UV may only be used in conjunction with chemically assisted filtration or an equivalent technology. When the water source is impacted by sewage or agricultural effluent, chemically assisted filtration followed by UV alone will not be adequate for the reduction of some enteric viruses. In these situations, the primary disinfection system should include both chlorine and UV disinfection.

Under specific conditions, water systems using GUDI water sources may be exempt from the need to provide chemically assisted filtration in addition to primary disinfection. Such an exemption will only be provided if the well conforms to wellhead protection standards and a hydrogeologist has confirmed that the aquifer provides adequate in-situ filtration to ensure the removal of protozoa. If these two conditions are met, a two-stage primary disinfection system consisting of UV and chlorination can be used to provide a minimum of 4.0-log inactivation of viruses.

The use of alternative disinfectants, including ozone and chlorine dioxide, is permitted, but their efficacy must be demonstrated and documented.

It should be noted that all pathogen removal and/ or inactivation must happen within the treatment and primary disinfection systems. No additional log credit is provided for chlorine inactivation beyond the dedicated chlorine contact volume.

#### 3.3.1.4 SECONDARY DISINFECTION

Secondary disinfection is also regulated by the SDWA. All municipal systems are required to maintain a disinfectant residual throughout the distribution system. The minimum, maximum, and optimum residual concentrations for different disinfectants are summarized in Table 3.6.

**Table 3.6 Minimum, maximum, and optimum disinfectant residual levels for distribution systems in Ontario (MOE, 2008)**

| Disinfectant | Minimum | Maximum | Optimum |
|---|---|---|---|
| Free Chlorine* | 0.05 mg/L | 4 mg/L | 0.2 mg/L |
| Chloramines** | 0.25 mg/L | 3 mg/L | 1.0 mg/L |
| Chlorine Dioxide | 0.05 mg/L | 0.8 mg/L | not indicated |

*maximum pH of 8.5

**measured as combined chlorine

#### 3.3.1.5 MONITORING

All treatment and disinfection systems used for pathogen control must be monitored to ensure adequate operation. This includes filters, primary disinfection systems, and secondary disinfectant residuals. All monitoring systems must include alarms to indicate non-compliant readings. The requirements discussed below apply to most municipal water systems, with specific exceptions provided for certain groundwater and non-residential municipal systems (details available in the PDDWO).

The integrity of the treatment system is ensured by continuously monitoring the turbidity of the filter effluent. Turbidity limits are set based on the type of filter used. Systems fed by surface or GUDI water sources must also monitor the turbidity of the raw water.

The efficacy of primary disinfection systems must be monitored continuously. Systems using free chlorine for disinfection must measure the free chlorine residual after the chlorine contact volume but before the addition of post-disinfection chemicals (fluoride, pH control, etc.). Ideally, CT and/or log inactivation should be evaluated on a continuous basis. Systems using alternative disinfectants must also monitor disinfection efficacy continuously.

The distribution system must be monitored for disinfectant residual (as provided in Table 3.6) and turbidity through the collection and analysis of regular grab samples. The disinfectant residual should be monitored continuously in the effluent from re-chlorination facilities.

#### 3.3.1.6 ADDITIONAL NOTES

The PDDWO recommends that in primary disinfection systems that rely on chlorine the free chlorine residual at the end of the contact volume should be at least 80% of the total chlorine reading. This will maximize disinfection and lead to a more effective secondary chlorine residual within the distribution system.

The PDDWO also suggests that utilities with sufficient resources make use of the IDDF (see Section 2.7.4) to optimize pathogen inactivation while minimizing disinfection by-product formation and chemical costs.

### *3.3.2 Nova Scotia*

In Nova Scotia, the disinfection of water intended for human consumption is regulated by Nova Scotia Environment (NSE). The criteria for compliance are provided in *Treatment Standard for Municipal Groundwater Source Water Facilities* (TSMG) and '*Treatment Standard for Municipal Surface Source Water Treatment Facilities*' (TSMS), both released by NSE in 2003. Many of the requirements in the treatment standards can be adapted to the needs of specific municipalities through consultation with NSE.

The treatment standards represent the culmination of a process that began in 1991 with the *Clean Water Task Force Report*. This was followed by the *Sustainable Development Strategy for Nova Scotia* in 1992 and the passing of the *Environment Act* in 1995. The *Environment Act* designated Nova Scotia Environment as the department in charge of drinking water for the province, established regulations for water and wastewater facilities, required that all municipal water systems be classified depending on their level of complexity, instituted mandatory operator certification, and established new rules for well construction. In 2000, the health-based recommendations in the GCDWQ were adopted as law and in

2002 the standards for drinking water systems were updated (NSE, 2002). The release of an updated treatment standard that will combine the surface and groundwater treatment standards into one document is anticipated in the near future. Figure 3.2 provides a summary of the history of water quality management in Nova Scotia.

1991
- **Clean Water Task Force report published**

1992
- **Sustainable Development Strategy for Nova Scotia report published**

1995
- ***Environment Act* passed**
  - NSE designated as department in control of drinking water
  - Regulations for water and wastewater systems
  - Mandatory operator certification

2000
- **Health based recommendations in GCDWQ adopted as law in Nova Scotia, drinking water regulations updated**

2003
- **Drinking water treatment standards released**
  - *Treatment Standard for Municipal Surface Source Water Treatment*
  - *Treatment Standard for Municipal Groundwater Source Water Facilities*
  - *Protocol for Determining Groundwater Under the Direct Influence of Surface Water*

2011?
- **Anticipated release of the combined *Municipal Treatment Standard***

Figure 3.2 History of drinking water quality management in Nova Scotia

#### 3.3.2.1 IMPLEMENTATION OF TREATMENT STANDARDS IN NOVA SCOTIA

The province of Nova Scotia updated its disinfection requirements in 2002 by releasing treatment standards for surface water and groundwater supplied water treatment systems. These were implemented gradually over a five year period to allow utilities sufficient time to assess their existing level of compliance and line up sufficient funding to make necessary improvements.

The TSMS came into effect in April of 2003. Newly constructed water treatment systems were required to conform to the disinfection requirements contained in the standard immediately. Existing systems were required to conduct a system assessment and determine what corrective measures were required to bring their water treatment plants into compliance with the new standard. Systems that were found to be out of compliance were required to meet a number of interim requirements and all corrective measures were required to be in place by 2008.

The TSMG *Facilities* came into effect in May of 2003. All municipalities were required to prepare a system assessment report and conduct Step 1 of the *Protocol for Determining Groundwater Under the Direct Influence of Surface Water* before April 2004. Those that passed this step were allowed to work towards compliance with the TSMG. Systems that did not pass Step 1 were required to conduct the remaining GUDI assessment steps before April 2005. All groundwater sources determined to be GUDI were required to conform to the TSMS by 2008.

The implementation of the surface and groundwater treatment standards is summarized in Figure 3.3.

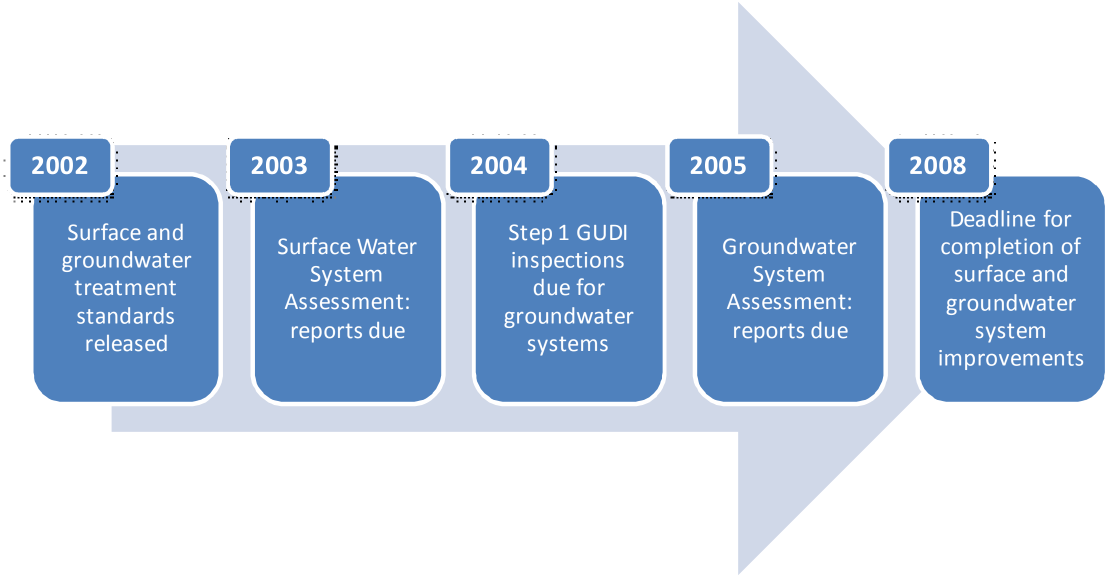


**Figure 3.3 Summary of the implementation of the surface and groundwater treatment standards in Nova Scotia**

#### 3.3.2.2 Treatment Processes for Pathogen Removal

A summary of recognized treatment processes commonly employed in water treatment plants and the log-removal credits awarded to them in Nova Scotia is provided in Table 3.7.

**Table 3.7 Log removal credits assigned to filtration processes (*Treatment Standard for Municipal Source Water Treatment Facilities*, NSE, 2003)**

| Treatment Process | *Giardia* | Viruses |
|---|---|---|
| Conventional Filtration | 2.5-log | 2.0-log |
| Direct Filtration | 2.0-log | 1.0-log |
| Slow Sand Filtration | 2.0-log | 2.0-log |
| Diatomaceous Earth Filtration | 2.0-log | 1.0-log |
| Membrane Filtration | 2.5-log | 2.0-log |

Other treatment processes may also be accepted at NSE's discretion. Log inactivation credits for primary disinfection, including that achieved using free chlorine, chlorine dioxide, ozone, and UV disinfection, are calculated using the CT and $T_{10}$ concepts described in Chapter 2.

A new, combined municipal treatment standard has been developed by NSE and was provided for public comment in early 2010. It is expected that many of the proposed changes to the existing standards will be included in the final version of the new municipal treatment standard, including the expanded table of engineered filtration options for log removal of pathogens provided in Table 3.8.

**Table 3.8 Summary of proposed log removal credits for engineered filtration processes (Draft: *Nova Scotia Treatment Standard for Municipal Drinking Water Systems*, 2010)**

| Treatment Process | *Giardia* | *Cryptosporidium* | Viruses |
|---|---|---|---|
| Conventional Filtration | 2.5-log | 3.0-log | 2.0-log |
| Direct Filtration | 2.0-log | 2.5-log | 1.0-log |
| Slow Sand Filtration | 2.0-log | 3.0-log | 2.0-log |
| Diatomaceous Earth Filtration | 2.0-log | 3.0-log | 1.0-log |
| Microfiltration | Requires demonstration and challenge testing | Requires demonstration and challenge testing | None |
| Ultrafiltration | Requires demonstration and challenge testing | Requires demonstration and challenge testing | Requires challenge and direct integrity testing |
| Reverse Osmosis/Nanofiltration | None | None | None |

#### 3.3.2.3 SURFACE WATER

The current surface water treatment standard requires that all water systems with a surface water source must include both filtration and primary disinfection. Redundant filters and disinfection equipment must be provided. Components must be designed to prevent the passage of non-treated/non-disinfected water into the later stages of the treatment train or the distribution system. The full treatment system must provide a minimum of 3.0-log reduction of *Giardia* and 4.0-log reduction of viruses. At least 0.5-log of this must be achieved during the primary disinfection stage.

The proposed municipal standard includes updated microbial reduction requirements for water systems using surface water sources. These updates bring the Nova Scotia regulations closer to compliance with existing and upcoming Health Canada recommendations for disinfection in municipal treatment systems. For example, the current treatment standard provides specific reduction requirements for *Giardia* and viruses but does not address the need to remove *Cryptosporidium*. As well, the proposed municipal treatment standard emphasizes the importance of source water characterization and specifies treatment requirements based on the characteristics of the watershed and the quality of the raw water.

Under the proposed new standard, all water treatment systems that use raw surface water will need to include engineered filtration. Engineered filtration is generally understood to include the five processes listed in Table 3.7 and their various permutations. The total amount of log reduction required for any given system will depend upon the characteristics of the surrounding watershed and the measured raw water quality. For example, a system using a highly impacted surface water will be required to provide 5.5-log removal of *Giardia* and *Cryptosporidium* and 7.0-log removal of viruses, as shown in Table 3.9.

**Table 3.9 Proposed disinfection requirements for systems using surface water (Draft:** ***Nova Scotia Treatment Standard for Municipal Drinking Water Systems*****, 2010)**

| Source Water | *Giardia* | *Cryptosporidium* | Viruses |
|---|---|---|---|
| Secure Surface Water | 3.0-log | 3.0-log | 4.0-log |
| Lightly Impacted Surface Water | 4.0-log | 4.0-log | 5-log |
| Moderately Impacted Surface Water | 5-log | 5-log | 6-log |
| Highly Impacted Surface Water | 5.5-log | 5.5-log | 7-log |

If the proposed treatment standard is adopted as is, the source water used by each municipality will have to be assessed and non-compliant water treatment systems will have to be upgraded.

### 3.3.2.4 GROUNDWATER

The current groundwater treatment standard states that all water treatment facilities that use groundwater sources must provide 4.0-log inactivation of viruses. This can be provided through chlorination or alternative disinfection methods. It also states that GUDI designated wells are regulated under the municipal surface water treatment standard. As such, facilities fed by these wells must provide 3.0-log removal of *Giardia* and 4.0-log reduction of viruses through a combination of filtration and disinfection using chlorine or alternative disinfection methods.

Table 3.10 summarizes the disinfection requirements for facilities supplied by groundwater sources under the current treatment standards.

**Table 3.10 Current disinfection requirements for surface water (*****Treatment Standard for Municipal Groundwater Source Water Facilities*****, 2003 and** ***Treatment Standard for Municipal Surface Source Water Treatment Facilities*****, 2003)**

| Microorganism | Groundwater | GUDI |
|---|---|---|
| *Giardia* | Not Applicable | 3–log |
| Viruses | 4–log | 4–log |

Wells are designated GUDI based on the results of a three step assessment procedure outlined in the *Protocol for Determining Groundwater Under the Direct Influence of Surface Water* (NSE, 2003). The first is a screening step that establishes whether a well has GUDI characteristics such as being located in a sensitive setting or close to a surface water body, having poor well construction, and/or testing positive for microorganisms. Step 2 of the GUDI assessment process establishes whether or not a hydraulic connection exists between the well and a nearby surface water source. Raw water quality data is collected from both the well and the surface water source for a year and compared. Wells that fail Step 2 of the GUDI assessment process must continue to Step 3. Step 3 establishes the microbiological quality of the well through Microscopic Particulate Analyses (MPA) conducted at different times of the year.

The level of risk associated with different GUDI wells is determined based on the strength of the 'GUDI signal'. The GUDI signal is determined through an assessment of the results of the MPA. Currently, wells with low risk GUDI signals are regulated as groundwater while those with medium or high risk GUDI signals are regulated as surface water.

Medium risk GUDI wells are eligible for a natural filtration credit to account for filtration that occurs as water travels through the surrounding soil. The steps required to apply for a natural filtration credit are listed in the *Guidelines for the Determination of Natural Filtration Credit for Log Removal of Giardia* (NSE, 2006). A facility that is awarded a 1.0-log natural filtration credit for *Giardia* for their medium-risk groundwater supply is not required to provide additional filtration for pathogen removal. Instead, the remaining log reduction can be provided through increased chlorine contact time or the use of alternative disinfection technologies such as UV.

If a well is found to have high risk GUDI signals, it is not eligible for a natural filtration credit and is, for all intents and purposes, regulated as though it was a surface water source. As a result, engineered filtration for pathogen removal must be provided. This might include chemically assisted filtration (coagulation) or membrane filtration.

Under the proposed new municipal drinking water treatment standard, water treatment facilities in Nova Scotia using surface water or GUDI sources will have to provide 3.0-log reduction of *Cryptosporidium* in addition to 3.0-log removal of *Giardia* and 4.0-log removal of viruses. Medium risk GUDI wells will continue to be eligible for a 1.0-log natural filtration credit.

Table 3.11 summarizes the disinfection requirements for groundwater as provided in the draft of the proposed municipal treatment standard.

**Table 3.11 Proposed disinfection requirements for groundwater (Draft:** ***Nova Scotia Treatment Standard for Municipal Drinking Water Systems*****, 2010)**

| Microorganism | Secure Groundwater | Medium Risk GUDI | High Risk GUDI |
|---|---|---|---|
| *Giardia* | Not Applicable | 2–log * | 3–log |
| *Cryptosporidium* | Not Applicable | 2–log * | 3–log |
| **Viruses** | 4–log | 4–log | 4–log |

*assuming that a 1.0-log natural filtration credit has been awarded

### 3.3.2.5 DISINFECTION MONITORING

The groundwater treatment standard specifies the frequency with which various parameters related to disinfection effectiveness should be measured, recorded, and reported by the operator. For example, if the free chlorine residual is found to be below 0.2 mg/L in the distribution system the incident must be reported to NSE.  Also, turbidity, which can be used as an indicator of filter performance, must be monitored at numerous locations in the water system. Turbidity and chlorine residual monitoring requirements are summarized in Tables 3.12 and 3.13 respectively.

**Table 3.12 Summary of turbidity monitoring requirements (NSE, 2003)**

| Sample Location | Frequency | Maximum Value | Notes |
|---|---|---|---|
| Raw Water | Continuous or grab sample | None | |
| Filtered Water | Continuous | 1.0 NTU | 0.2 NTU 95% of the time |
| Filter to Waste | Continuous or grab sample | None | 0.5 NTU before returning filter to normal operation after backwash |
| Distributed Water | Grab sample* | 5.0 NTU | |

*frequency determined by population

**Table 3.13 Summary of chlorine monitoring requirements (NSE, 2003)**

| Sample Location | Frequency | Maximum Value | Minimum Value | Notes |
|---|---|---|---|---|
| Disinfected Water | Continuous | n/a | n/a | |
| Outlet of Storage Facility | Continuous | n/a | n/a | |
| Distributed Water | Grab sample* | 4.0 mg/L | 0.2 mg/L | Free chlorine |

*frequency determined by population

Monitoring requirements for systems using alternative secondary disinfection methods (ex. chloramines) are set by NSE.

Utilities in Nova Scotia turn to the *Guidelines for Monitoring Public Drinking Water Supplies* for guidance on microbiological sampling and the issuance of BWAs. Utilities are required to collect monthly water samples for total coliforms and *E.coli.* The number of samples required depends upon the total population served by the water system, as shown in Table 3.14.

**Table 3.14 Minimum number of monthly microbiological samples required for utilities in Nova Scotia (Adapted from the GCDWQ)**

| Population Served | Minimum Number of Samples per Month |
|---|---|
| < 5,000 | At least 4 |
| 5,000 – 90,000 | 1 per 1,000 people |
| > 90,000 | 90 + (1 per 10,000 people) |

If a sample tests positive for total coliforms or *E.Coli,* the utility is required to report it to NSE immediately.

BWAs can be issued by the utility, NSE, or the Medical Officer of Health (MOH) under the following circumstances:

- Faecal contamination of drinking water indicated by a positive E.Coli sample;
- Evidence of an outbreak of waterborne illness;
- No disinfection;
- Inadequate disinfection – treatment/disinfection process parameters are outside of acceptable limits;
- Treatment/disinfection equipment malfunction or failure; or
- Untreated or inadequately treated water is introduced into the distribution system.

A BWA may also be issued under other circumstances at the discretion of NSE or the MOH.

### *3.3.3 Québec*

Disinfection requirements in Québec are part of the *Règlement sur la qualité de l'eau potable* (RQEP), which was passed in 2001. Pathogen reduction levels are determined based on the risk associated with a given water supply. The province recognizes three different classes of water supply:

- Surface water/GUDI;
- Groundwater with a history of faecal contamination; and
- Groundwater with no history of faecal contamination.

These are described in detail in the G*uide de conception des installations de production d'eau potable* (Guide), details of which are provided in the Recommended Reading section in Appendix A of this report. Minimal disinfection requirements are laid out for each class as shown in Table 3.15, but designers are encouraged to take into consideration the characteristics of individual surface and GUDI water supplies and the turbidity of the finished water. Log reduction levels are to be adjusted to a value above the minimum requirements accordingly.

**Table 3.15 Disinfection requirements in Québec (G*uide de conception des installations de production d'eau potable*, 2006*)***

| Class of Water Supply | Disinfection Requirements |
|---|---|
| Surface water or GUDI | 2.0-log *Cryptosporidium*, 3.0-log *Giardia*, 4.0-log viruses |
| Groundwater with history of faecal contamination | 4.0-log reduction of viruses |
| Groundwater with no history of faecal contamination | None required |

Disinfection of water from surface water and GUDI supplies is to be accomplished using a combination of filtration and chemical/UV disinfection except in specific cases, which are described in the Guide. The Guide also provides direction regarding log removal credits for different treatment processes, the calculation of CT for log inactivation of pathogens, and the minimization of DBP formation.

### *3.3.4 Manitoba*

Until recently, Manitoba's disinfection requirements were based on chlorine contact time. Like Newfoundland and Labrador, a minimum of 20 minutes contact time was required for systems to be in compliance. Regulations passed in 2007 under the *Drinking Water Safety Act* now require that municipal water systems served by surface or GUDI water supplies provide 3.0-log reduction of *Giardia* and *Cryptosporidium* as well as 4.0-log reduction of viruses. Provincial guidelines recommend that at least 0.5-log reduction of *Giardia* and *Cryptosporidium* and 2.0-log reduction of viruses be accomplished through chemical or UV disinfection. Information regarding the use of filtration for pathogen removal and the selection and design of disinfection equipment is available on the Manitoba Water Stewardship website.

### *3.3.5 Saskatchewan*

Saskatchewan passed the *Water Regulations* (2002) in the wake of the North Battleford *Cryptosporidium* outbreak. *A Guide to Waterworks Design,* released in 2008, provides practical guidance on the application of the disinfection requirements laid out in the *Water Regulations*. Water treatment systems using surface or GUDI water supplies should provide 3.0-log reduction of *Giardia* and *Cryptosporidium* as well as 4.0-log reduction of viruses through filtration and chemical/UV disinfection. Some surface and GUDI supplies may be exempt from filtration if they meet specific criteria. Systems served by pristine groundwater supplies must achieve 4.0-log reduction of viruses.

There are over 700 water systems in Saskatchewan, most of which serve small populations. During a phone interview Bill Miller, the Field Manager for the North Unit Environmental Services Section of Saskatchewan Ministry of the Environment, described how many of these smaller systems have struggled to comply with provincial disinfection requirements. When these requirements were first instituted, systems were assessed and deemed to be compliant or non-compliant. Communities with non-compliant drinking water systems were initially put on a drinking water advisory and provided with a list of required upgrades. Over time, all but one community in the province came into compliance with the regulations, though in some cases it was necessary for the provincial government to prosecute communities who were not upgrading their systems as required (personal communication, July 6, 2011).

Some communities who were unable to meet the new regulations were allowed to apply to be designated 'hygienic use systems'. These systems are allowed to provide water that does not meet provincial disinfection regulations as long as it is only used for non-potable applications such as personal hygiene. A community with a hygienic water system is required to provide an alternative potable water source. This may include bottled water, a 'pail and fill system' (analogous to a potable water dispensing system), or individual point-of-use/point-of-entry treatment systems (SME, 2006).

### *3.3.6 Alberta*

Alberta has some of the most stringent drinking water quality and disinfection requirements in the country. The *Standards and Guidelines for Municipal Waterworks, Wastewater, and Storm Drainage Systems* (2006) explain that all systems using surface water and GUDI water supplies must provide both filtration and chemical/UV disinfection to ensure reduction of *Giardia, Cryptosporidium*, and viruses. Communities must conduct source water monitoring to determine what level of pathogen reduction is required for their system.

Water sources with less than one *Giardia* cyst and less than 7.5 *Cryptosporidium* oocysts per 100 L of water are required to achieve 3.0-log reduction of *Giardia* and *Cryptosporidium* and 4.0-log reduction of viruses. Reduction requirements increase with increasing concentrations of pathogens. Systems that opt not to conduct source water monitoring must achieve 5.5-log reduction of *Giardia* and *Cryptosporidium* and 4.0-log reduction of viruses.

Some GUDI water supplies can be exempted from filtration at the discretion of the provincial government as long as they achieve 3.0-log reduction of *Giardia* and *Cryptosporidium* and 4.0-log reduction of viruses using chemical/UV disinfection. Systems using pristine groundwater supplies must provide a minimum of 4.0-log reduction of viruses.

Additional guidance on GUDI determination, log removal credits, turbidity monitoring, the use of CT, and alternative disinfectants is provided in the *Standards and Guidelines for Municipal Waterworks, Wastewater, and Storm Drainage Systems*, which is included in the recommended reading list in Appendix A of this report.

### *3.3.7 British Columbia*

Unlike Newfoundland and Labrador most of the raw source water used in British Columbia originates in pristine mountainous areas and is of very high quality. Levels of turbidity, natural organic matter, and pathogens is frequently well below those found in Atlantic Canada. As a result, the province has not laid out any specific pathogen reduction requirements. It has, however, adopted the microbial water quality limits recommended in the GCDWQ.

Water systems supplying surface water to users must include disinfection, and the distribution system must be monitored for coliforms (frequency determined by population). Instead of specific disinfection requirements, however, system designers are referred to the local health office for guidance on disinfection requirements (Ministry of Environment, 2007).

One of these, Interior Health, has released the 4-3-2-1-0 Drinking Water Objective. This requires that systems within Interior Health's jurisdiction achieve (or plan to achieve) 4.0-log removal of viruses as well as 3.0-log removal of *Giardia* and *Cryptosporidium* using a minimum of two treatment processes (i.e., filtration and chlorination). Finished water turbidity must be below 1 NTU and the water must have 0 faecal coliform and *E.coli* per 100 mL of water (Interior Health, 2009).

## 3.4 United States Environmental Protection Agency

The drinking water regulations drawn up by the US EPA are viewed as a standard throughout much of the rest of the world. As with most jurisdictions, the US EPA has a separate set of regulations for surface water and groundwater. All rules governing watershed protection, filtration, disinfection, and disinfection by-product formation fall under the *Safe Drinking Water Act*. A summary of the current rules is provided in Figure 3.4. Like Canada, the United States is a massive, diverse country with many distinct regions that demand different approaches to drinking water treatment and delivery. Regulations are developed by the US EPA and implemented by individual states.

### *3.4.1 Total Coliform Rule*

The *Total Coliform Rule* (TCR), promulgated in 1989, established a (monthly average) maximum contaminant level (MCL) for total coliform and provided updated coliform monitoring requirements. The rule currently applies to all public water systems.

The MCL for total coliform is zero. Monthly MCL violations are triggered if the number of positive total coliform tests is above 1 per month (for communities with fewer than 33,000 users) or greater than 5% of the total routine and/or repeat samples collected (for larger communities). Monthly MCL violations must be reported to water system users within 14 days. Acute MCL violations occur when faecal coliform or *E.coli* is detected in a repeat sample. Acute MCLs violations must be reported to the public within 72 hours. Proposed revisions to the TCR would result in a new MCL of zero for *E.coli*, rather than total coliform.

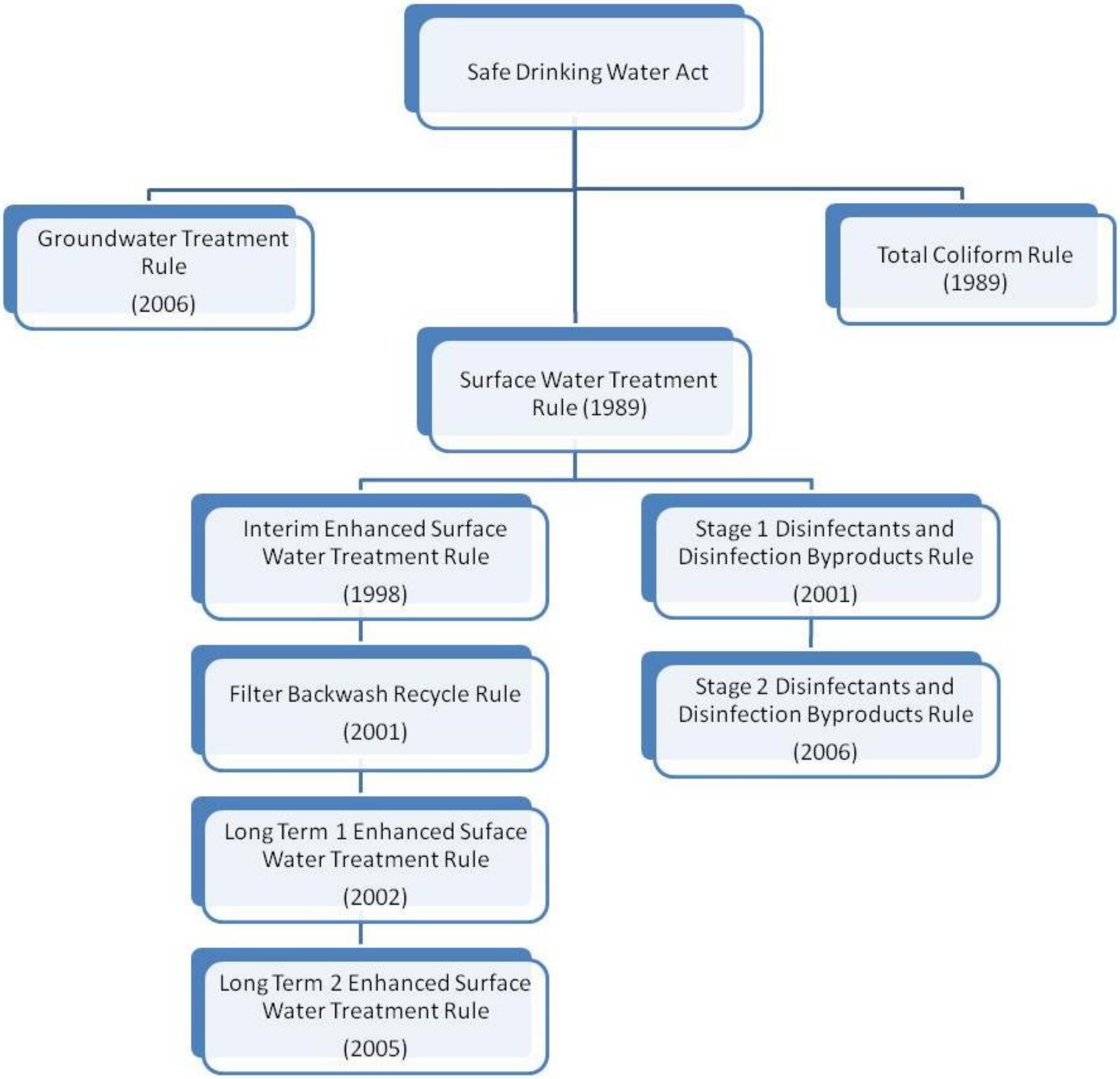


**Figure 3.4** **US EPA disinfection and disinfection by-product rules (1989 to present)**

Utilities are required to monitor for total coliform at representative sites on a regular basis. Sampling sites are laid out in a sample siting plan, which is developed by the utility and reviewed by the state authorities. The frequency of sampling is set based on the number of users on the system. A positive test for total coliform triggers a more elaborate sampling process. Repeat samples must be taken from the location where the original positive test was found. All samples that test positive for total coliform must be tested for faecal coliform or *E.coli*. Small systems that use a groundwater source and are free of sanitary defects are eligible for a reduced monitoring frequency. The proposed revisions to the Total Coliform rule would see increased monitoring of high-risk small systems with a history of non-compliance.

### *3.4.2 Groundwater Treatment Rule*

The *Groundwater Treatment Rule* was finalized in 2006 and includes four main components.

1. Periodic sanitary surveys are to be conducted to evaluate the vulnerability of groundwater sources to microbiological contamination.
2. Groundwater sources may be monitored for bacteria under certain conditions.
3. Systems identified as being vulnerable to contamination must implement corrective actions including:
    a. Correct well-construction deficiencies identified in sanitary survey.
    b. Eliminate the source of contamination.
    c. Water treatment/disinfection to provide 4.0-log removal of viruses.
    d. Providing an alternate water source.
4. If treatment/disinfection is provided, the system will be continuously monitored to ensure compliance.

### *3.4.3 Surface Water Treatment Rule*

The *Surface Water Treatment Rule*, which forms the backbone of the current US EPA drinking water strategy, was released in 1989. At that time, it mandated 3.0-log removal of *Giardia*, 4.0-log removal of viruses, a 0.2 mg/L free chlorine residual at the beginning of the distribution system, a detectable residual throughout the distribution system, and specific limits on the level of turbidity in filter effluents. It also introduced the requirement that all drinking water systems be maintained by qualified personnel (as specified by individual states). Small communities and communities with high quality source water were exempt from some (but not all) of these requirements under certain conditions.

### *3.4.4 Interim Enhanced Surface Water Treatment Rule*

In 1998, the *Interim Enhanced Surface Water Treatment Rule* (IESWTR) was released. It applied specifically to communities with more than 10,000 users that use surface water or GUDI wells as source waters. A new protozoan pathogen, *Cryptosporidium*, was introduced into the regulations. A maximum contaminant level goal (MCLG) of 0 was set and utilities were required to remove 2.0-log of *Cryptosporidium* oocysts in addition to 3.0-log *Giardia* cysts and 4.0-log viruses. *Cryptosporidium* removal was to be achieved through filtration (for systems employing filtration) or watershed protection (for unfiltered systems). The rule also provided guidance on the preparation of ‘sanitary surveys’, which were designed to evaluate the design and operation of individual water systems. Smaller communities, which were deemed less capable of making the changes required under the new rule, were only asked to complete the sanitary surveys to establish appropriate disinfection and operation goals.

### 3.4.5 Long Term 1 Enhanced Surface Water Treatment Rule

A new rule focused on systems with fewer than 10,000 users, the *Long Term 1 Enhanced Surface Water Treatment Rule* (LT1ESWTR) came into effect in 2002. It required that smaller systems with filtration provide 2.0-log removal of *Cryptosporidium* and that systems without filtration update their watershed protection programs to minimize contamination by cysts and oocysts. Uncovered finished water reservoirs were also prohibited as part of this rule.

### 3.4.6 Long Term 2 Enhanced Surface Water Treatment Rule

The *Long Term 2 Enhanced Surface Water Treatment Rule* (LT2ESWTR) has recently come into effect. Under the LT2ESWTR, systems with 'high risk' source waters are required to achieve greater log removal and/or inactivation of *Cryptosporidium*. High risk water sources will be identified based on the results of two years of monthly source water sampling. Large systems and small unfiltered systems must monitor *Cryptosporidium* levels while small filtered systems may choose to monitor *E. Coli*, an indicator of *Cryptosporidium,* to minimize costs. Systems will be assigned to various 'bins' based on the results of this monitoring. Those in the higher risk bins will be required to provide an additional 1.0 to 2.5-log reduction of *Cryptosporidium*.

### 3.4.7 Additional Rules

Additional rules that relate to disinfection that have been released by the US EPA include *the Filter Backwash Recycling Rule* (FBRR) and the Stages 1 and 2 of the *Disinfectants and Disinfection By-products Rule* (Stage 1 and Stage 2 DBPR).

The FBRR was promulgated in 2001 and applies to utilities that:

- Use surface or GUDI water sources;
- Practice conventional or direct filtration; and
- Recycle filter backwash, thickener supernatant, or liquids from a dewatering process.

The rule mandates that the recycle stream be returned to the head of the treatment process or to an alternate point approved by the state. This requirement aims to reduce the concentration rate and passage of pathogens, in particular *Cryptosporidium*, through the treatment system and into the treated water. When the rule was first released, utilities were asked to prepare and submit 'recycle notifications' to provide regulators with the information required to designate a recycle return point and to develop appropriate filter backwash recycle strategies.

In 2001, the US EPA released the Stage 1 DBPR. This rule established maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) for chlorine, chloramines, and chlorine dioxide, as shown in Table 3.16.

**Table 3.16 Maximum residual disinfectant level goals and maximum disinfectant residual levels (Stage 1 Disinfectants and Disinfection By-products Rule, 2001)**

| Residual | MRDLG | MRDL | Compliance Based On |
|---|---|---|---|
| Chlorine | 4 mg/L as $Cl_2$ | 4 mg/L as $Cl_2$ | Annual average |
| Chloramine | 4 mg/L as $Cl_2$ | 4 mg/L as $Cl_2$ | Annual average |
| Chlorine Dioxide | 0.8 mg/L as $ClO_2$ | 0.8 mg/L as $ClO_2$ | Daily samples |

Maximum contaminant level goals (MCLGs) and maximum contaminant levels (MCLs) for various disinfection by-products, including THMs, HAAs, chlorite, and bromate were also included in the Stage 1 DBPR. A summary of these is provided in Table 3.17.

**Table 3.17 Maximum contaminant level goals and maximum contaminant levels for DBPs (Stage 1 Disinfectants and Disinfection By-products Rule, 2001)**

| Disinfection By-Product | MCLG | MCL | Compliance Based On |
|---|---|---|---|
| TTHM (total THMs)<br>• Chloroform<br>• Bromodichloromethane<br>• Dibromochloromethane<br>• Bromoform | n/a<br>n/a<br>0 mg/L<br>0.06 mg/L<br>0 mg/L | 0.080 mg/L | Annual Average |
| THAA (total HAAs)<br>• Dichloroacetic acid<br>• Trichloroacetic acid | n/a<br>0 mg/L<br>0.3 mg/L | 0.060 mg/L | Annual Average |
| Chlorite | 0.8 mg/L | 1.0 mg/L | Monthly Average |
| Bromate | 0 mg/L | 0.010 mg/L | Annual Average |

Finally, the Stage 1 DBPR provided specific total organic carbon (TOC) removal requirements for water systems based on the source water TOC, the source water alkalinity, and the type of organic removal system employed.

The Stage 2 DBPR was promulgated at approximately the same time as the LT2ESWTR and includes provisions designed to minimize the risk of DBP formation while providing adequate log removals of the various regulated pathogens. These include:

- Preparation of an 'Initial Distribution System Evaluation' to identify areas with high concentrations of DBPs;
- Calculation of 'locational running annual average' DBP levels at various points within the distribution; and
- Identification of a DBP operational evaluation level at which the utility must take action to prevent the formation of excessive levels of THMs and HAAs.

All public water systems that serve more than 25 residential or institutional users are covered by the Stage 2 DBPR, though the exact requirements vary based on the number of users.

### 3.4.8 Summary

Implementing the numerous and complex rules that fall under the American *Safe Drinking Water Act* is a daunting task. State regulators provide significant support to utilities to ensure that the requirements are met in an appropriate manner. The requirements that are most applicable to the current study are as follow:

**Pathogen reduction (vulnerable groundwater sources):**

- 4.0–log reduction of viruses.

**Pathogen reduction (surface water and GUDI):**

- 2.0–log reduction of *Cryptosporidium* (higher log-removals required for high risk water sources);
- 3.0–log reduction of *Giardia*; and
- 4.0–log reduction of viruses.

**Chlorine residual:**

- Minimum concentration of 0.2 mg/L at the inlet of distribution system; and
- Maximum concentration level of 4.0 mg/L (annual average).

**Disinfection by-products:**

- TTHM maximum concentration level of 0.080 mg/L (annual average);
- HAA5 maximum concentration level of 0.060 mg/L (annual average);
- Chlorite maximum concentration of 1.0 mg/L (monthly average); and
- Bromate maximum concentration of 0.010 mg/L (annual average).

Supporting documents, including guidance manuals and fact sheets, have been developed to help utilities achieve all of these requirements. These supporting documents include detailed information about watershed protection and monitoring, groundwater vulnerability assessments, the amount of log removal expected in different treatment processes, the determination of baffling factors for chlorine contact chambers, and the application of the CT concept. A selection of these is provided in Appendix A.

## 3.5 Other Jurisdictions

The challenges facing small communities in Newfoundland and Labrador are not exclusive to the province. Regulators in Alaska, Ireland, and Scotland, among others, are also responsible for numerous small rural communities in temperate and subarctic climates. Alaska is bound by the US EPA disinfection requirements discussed in the previous section and Ireland and Scotland are held to the water quality standards provided in the European Union Council Directive 98/83/EC (EU, 1998)

Though the ENVC might choose to review the regulations in each jurisdiction, it may be more beneficial to conduct an in depth study of the strategies used in each country/state to achieve compliance with their individual disinfection requirements. For example, many surface water sources in Ireland and Scotland have water quality similar to that found in much of Newfoundland and Labrador (high colour, low pH, low turbidity, etc.) and some have implemented small scale water treatment processes optimized to remove organic material. Small and remote communities in Alaska have turned to 'washeterias' to provide residents with clean and safe drinking water. These systems share many of the characteristics of the potable water dispensing units (PWDUs) in use in seven communities in Newfoundland and Labrador. Specific strategies used in these jurisdictions are discussed in greater detail in Chapter 6 of this report.

## 3.6 Summary of Disinfection Requirements

Table 3.18 provides a summary of the disinfection requirements discussed in the previous sections.

**Table 3.18 Disinfection recommendations and/or requirements in various jurisdictions**

| | Disinfection Requirements | |
|---|---|---|
| | *Surface Water and GUDI* | *Secure/Pristine Groundwater* |
| **GCDWQ*** | 3.0-log reduction of *Cryptosporidium*<br>3.0-log reduction of *Giardia*<br>4.0-log reduction of viruses | |
| **Newfoundland** | 20 minutes contact time or CT = 6 | 20 minutes contact time or CT = 6 |
| **Nova Scotia** | 3.0-log reduction of *Giardia*<br>4.0-log reduction of viruses | 4.0-log reduction of viruses |
| **British Columbia** | Reduction specified by local health office/drinking water officer, disinfection required (log reduction), GCDWQ recommended | |
| **Ontario** | 2.0-log reduction of *Cryptosporidium*<br>3.0-log reduction of *Giardia*<br>4.0-log reduction of viruses | 2.0-log reduction of viruses |
| **Quebec** | 2.0-log reduction of *Cryptosporidium***<br>3.0-log reduction of *Giardia***<br>4.0-log reduction of viruses | History of faecal contamination:<br>4.0-log reduction of viruses<br>No history of faecal contamination:<br>0-log reduction of viruses |
| **Alberta** | 3.0-log reduction of *Cryptosporidium***<br>3.0-log reduction of *Giardia***<br>4.0-log reduction of viruses | 4.0-log reduction of viruses |
| **Manitoba** | 3.0-log reduction of *Giardia*<br>4.0-log reduction of viruses | |
| **Saskatchewan** | 3.0-log reduction of *Cryptosporidium***<br>3.0-log reduction of *Giardia***<br>4.0-log reduction of viruses | 4.0-log reduction of viruses |
| **US EPA** | 2.0-log reduction of *Cryptosporidium***<br>3.0-log reduction of *Giardia*<br>4.0-log reduction of viruses | 4.0-log reduction of viruses for systems using vulnerable groundwater sources |

*recommendations for communities with water sources known to be affected by faecal waste and/or known to contain *Cryptosporidium, Giardia*, or viruses

**more stringent requirements for utilities with high risk water supplies

# CHAPTER 4 STUDY METHODOLOGY

## 4.1 Desktop Study

The desktop portion of the study began very shortly after the project was awarded. The findings and results of this portion of the study were used to develop the materials used by technical staff in the field.

First, a detailed review of current literature on disinfection was conducted to provide the reader with a firm understanding of the scientific principals underlying the disinfection methods and regulations used for drinking water treatment. Subjects addressed include:

- Common pathogens and waterborne illnesses;
- The effects of source water quality on pathogen occurrence;
- Chlorine chemistry and decay;
- The development of the CT tables;
- The log reduction concept; and
- Disinfection by-products.

Historical water quality data provided to CBCL Limited by the ENVC was evaluated to establish the average and worst case raw and tap water quality in each participating community. CBCL was also provided with the database used by the ENVC to track BWAs around the province. Trends in BWA types and total numbers were identified and assessed.

The information collected during the desktop phase was used to develop the information collection sheets that were used by CBCL technical staff during site visits. The sheet outlines the necessary field testing procedures and system checklists and provides space for manual data entry. It also includes a detailed operator questionnaire. The operator questionnaire includes a number of standard questions that were used to gather useful quantitative and qualitative information from the operator.

A sampling schedule was also prepared during this stage. The schedule was designed to ensure that the technician was afforded sufficient time in each community to complete a thorough assessment of the water system and the ICS. In practice, however, it was difficult for the technicians to adhere to the schedule due to circumstances outside of their control. A more flexible schedule was eventually adopted that allowed the technicians to visit most of the communities recommended by the ENVC and a few others besides.

## 4.2 Field Program and Laboratory Analysis

During each site visit the technician met with the operator and/or another community representative. The following information was collected through observation and by interviewing the system operator(s):

- Type of treatment and disinfection equipment installed;
- Contact tank configuration (if applicable);
- Location of point of chlorination;
- Location of first user in the distribution system;
- Pipe length and diameter from the point of disinfection to the first user on the distribution system;
- Location and capacity of any water storage tank located between the point of disinfection and the first user; and
- Chlorine dose applied at the point of disinfection.

The technician also took photographs of any treatment equipment, chlorination equipment, gauges and/or storage tanks that were shown during the tour of the water system.

The information obtained during the site visit was recorded in information collection sheets and later transferred to the CDID. The technician also gathered available recorded flow data in order to establish the average daily demand (flow) in the water system. The technician also attempted to gather information related to the maximum day flow, peak hourly flow, flushing flow and fire flow in the system. These values were rarely available, however, and had to be estimated during later portions of the project.

During the site visit, the technician conducted an assessment of the field conditions including temperature, pH and chlorine residual at each sample location. Sample locations included the outlet of the chlorine contact volume, the first user on the distribution system and, if applicable, the outlet of any storage tank or at any chlorine boosting station between these two locations. The results of this testing were written on the collection sheets and later input into the relevant databases for analysis. A 2.0 L water sample was gathered ahead of the point of disinfection and shipped to the lab for analysis.

Water samples gathered during the field visits were spiked with a known dose of chlorine and the residual was measured over time. The natural logarithm of the measured residual divided by the original chlorine dose was plotted against time and a linear regression was performed. The slope of the resulting line was taken as k. The procedure used by the lab is provided in Appendix C and the results of the testing are provided in Appendix D.

## 4.3 Data Analysis

The information collected during the site visits and through laboratory testing was used to determine the following for communities using free chlorine for disinfection:

- Total contact time in the contact volume at peak flow;
- CT achieved in the contact volume at peak flow;
- Total chlorine contact time between the point of disinfection and the first user at peak flow;
- CT achieved at the first user;

- Log inactivation achieved (*Giardia, Cryptosporidium*, viruses) at the first user; and
- The location of the 20 minute contact point based on peak flow.

The CT achieved in each of the systems assessed was compared to the required CT as provided in the Newfoundland standard for bacteriological quality. The log removal of *Giardia*, *Cryptospordium* and viruses achieved in each system was compared to the recommendations provided in the GCDWQ. Using information collected in Phases 1 and 2, each of the fifty systems was assigned a pass or fail grade based on their compliance with the Newfoundland and Labrador standard for bacteriological water quality and the GCDWQ limits for DBPs (THMs, HAAs).

Systems were then classified as shown in Figure 4.1.

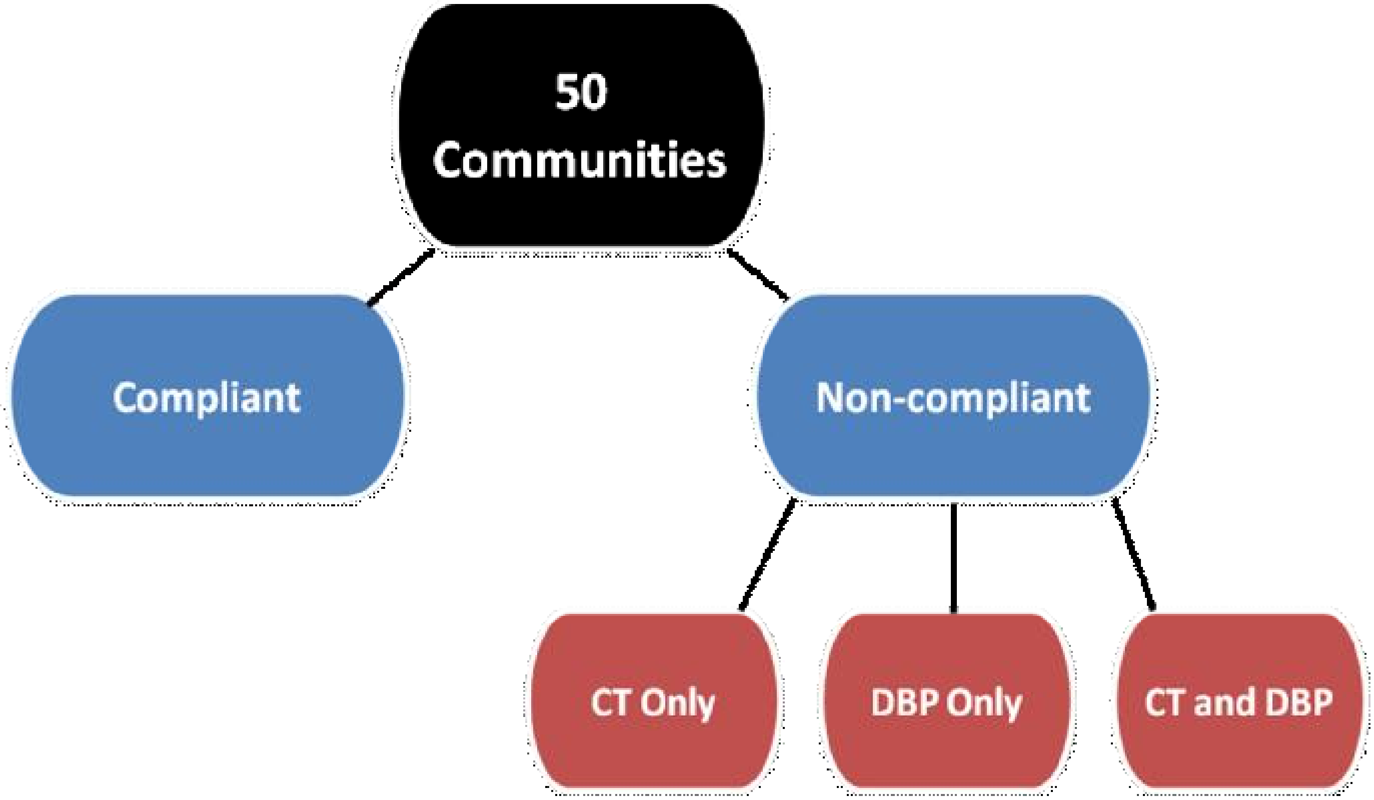


**Figure 4.1 Classification of communities based on compliance with disinfection requirements and DBP recommendations**

Chlorine decay curves were provided to CBCL Limited by the laboratory. The chlorine decay constant (k) for each water sample was determined using a first order decay model. The $r^2$ value for the regression was determined and used to evaluate the appropriateness of the first order chlorine decay model for each water sample. The k value was confirmed by minimizing the error between the measured and modelled chlorine concentrations using the least squares method.

The k and $r^2$ values were then assessed in light of the water quality data obtained during the site visits and evaluated during the desktop portion of the study to try to establish links between decay rates and water quality.

## 4.4 Deliverables

### *4.4.1 Community Disinfection Infrastructure Database*

The CDID was developed to allow the ENVC to enter relevant community infrastructure data and calculate peak flow, contact volume, effective contact time, and compliance with provincial CT requirements and federal log reduction recommendations. The database also contains information relating to DBP compliance.

The database can only be used to evaluate pathogen inactivation with free chlorine. Though allowances have been made for log reduction through engineered filtration and/or alternative disinfectants where feasible, the database is unable to evaluate the actual log reduction achieved through some treatment processes such as ozone oxidation and UV radiation.

Detailed instructions for CDID users are provided in Appendix G.

Community Information

The following information has been added to the CDID for each participating community:

- Community code;
- Community name;
- Region;
- Source type (SW, GW, GUDI);
- SA number;
- Serviced population;
- Industrial user;
- Tourism;
- History of waterborne disease outbreak;
- Existing water treatment;
- Contact pipe dimensions (where applicable);
- Contact volume (where applicable);
- Historical pH and DOC averages;
- pH, temperature, and chlorine residual values gathered during CBCL site visits;
- Historical DBP averages; and
- Chlorine decay constant (k) determined during the laboratory phase.

#### 4.4.1.1 CONTACT VOLUME CALCULATIONS

Infrastructure dimensions and details were collected during site visits and supplemented by existing information stored in ENVC databases. This includes the diameter and length of any mains used for chlorine contact, the total volume of any reaction tanks or storage facilities, and baffling factors. Pipe diameters provided during the site visits were assumed to represent inner pipe diameter. Some communities were unable or unwilling to provide enough information to determine the total contact volume. These communities were deemed non-compliant with CT requirements and sorted accordingly.

#### 4.4.1.2 PEAK FLOW CALCULATIONS

Calculation of the average day flow in each participating community based on water demand records is outside the scope of this project. Instead, in places where the average day flow is unknown it has been calculated based on the population of the community and soon-to-be-published averaged per capita water demand values for the province of Newfoundland and Labrador.

In the future, average day flows for each community and/or industrial user can be input by the database user if they are known. If they are not known, the following default values will be used:

- Communities with fewer than 1,000 people = 395 Lpcd (residential only); and
- Communities with more than 1,000 people = 804 Lpcd (residential and commercial).

The ENVC currently uses a per capita value of 340 Lpcd in their CT calculations. As discussed briefly in Section 2.6 of this report and at length in the report prepared for another ENVC project entitled *Study on Water Quality and Water Use in Communities with Variable Water Demands* (forthcoming), this value may not be an appropriate default as many communities in Newfoundland and Labrador have been found to have per capita water demands less than or in excess of this number. The ENVC can change the default value used in the CT calculator at their discretion.

Attempts were originally made to establish reasonable flow allowances for large industrial users and tourism in the peak flow calculations. These were subsequently rejected when data collected as part of the aforementioned study suggested that the percentage contribution of a large industrial user to the overall water demand is highly specific to each community.

The CDID calculates CT based on the maximum instantaneous flow expected through the chlorine contact volume. In cases where the maximum flow through the contact volume is known, the user can input it into the database. This value will be used to calculate the effective contact time and eventually the CT achieved.

For communities that lack a defined chlorine contact volume and/or water storage between the point of chlorination and the first user CT is calculated using the peak hour flow (usually expressed in L/min) for the community. If this flow is not known, it is determined by multiplying the average day flow (L/hour) by a peaking factor calculated using the PRP-Gumbel method proposed by Zhang (2005). This method was determined to be the most appropriate for the province of Newfoundland and Labrador because it predicts less extreme log inactivation rates than other common methods, including those developed by Harmon (1918) and AWWA (2004). It can also be easily adapted to take into account different levels of indoor vs. outdoor water use. If all water use is assumed to be indoors, the PRP-Gumbel method predicts total peak flows that fall between the highest (DVGW) and lowest (AWWA) predictions and are nearly in line with the two remaining methods. For populations above 100,000, the PRP-Gumbel method predicts peak flows above those predicted by the other methods.

#### 4.4.1.3 WATER QUALITY

The database user can input instantaneous measured or historical water quality data (average or worst case) for use in the various calculations made to determine log reduction levels. The existing database uses instantaneous pH, temperature, and chlorine residual data collected by CBCL Limited technicians during site visits to participating communities. Communities where data was not available were assigned a chlorine residual of 0.3 mg/L. The ENVC may choose to collect this information from communities being added to the database or use historical water quality data. Historical TTHM, HAA5, DOC, and UVA/UVT data has been included in the database.

#### 4.4.1.4 EXPECTED CT AND LOG REMOVAL CALCULATIONS

Queries have been developed that calculate compliance with:

- Provincial CT requirements (CT = 6);
- Approximate 20 minute effective contact time (distance); and
- Proposed recommendations for log reduction for surface water, GUDI, and groundwater fed systems (depending on source water type and/or prior detection of *Giardia* and/or *Cryptosporidium*).

Equations 2.10 and 2.12/2.13 are used to calculate log inactivation of *Giardia* and viruses when the database determines compliance with the proposed disinfection requirements. The contact time required to inactivate *Cryptosporidium* oocysts is too long to be feasible in most water treatment systems, therefore, *Cryptosporidium* inactivation using chlorine is not calculated in the database. Allowances have, however been made for *Cryptosporidium* removal through filtration and inactivation using UV.

Communities with existing water treatment and/or alternative disinfection methods have been assigned log reduction credits as provided in Table 4.1.

**Table 4.1 Log reduction credits assigned to treatment processes included in the CDID (adapted from MOE, 2008 and the CT tables for Ozone and UV Inactivation)**

| Treatment or Disinfection Process | Log Reduction Credit(s) |
|---|---|
| Conventional Filtration | 2.5-log *Giardia,* 2.0-log *Cryptosporidium*, 2.0-log viruses |
| Dissolved Air Flotation | 2.5-log *Giardia,* 2.0-log *Cryptosporidium*, 2.0-log viruses |
| Direct Filtration | 2.0-log *Giardia and Cryptosporidium*, 1.0-log viruses |
| Membrane Filtration (MF/UF/NF/RO) | None* |
| Ozone Oxidation | 3.0-log *Giardia*, 1.0-log *Cryptosporidium*, 4.0-log viruses |
| UV Radiation | 3.0-log *Giardia* and *Cryptosporidium* |

*no log reduction credits assigned due to limited information about the manufacture and/or operation of membrane-based treatment systems in the province (should be reviewed if/when the CDID is adopted)

The log removal credits assigned to systems with pre-existing filtration systems in the CDID were taken from the 'Procedure for Disinfection of Drinking Water Ontario' (MOE, 2006). Other jurisdictions, including Nova Scotia, Health Canada, and the US EPA assign different log reduction credits to these processes. For example, the current municipal treatment standard in Nova Scotia assigns *Giardia* and virus removal credits to some membrane filtration systems, however, their proposed new municipal treatment standard may require that manufacturers demonstrate log removal levels through challenge testing before any credits are assigned. Health Canada quotes many studies and regulations from other jurisdictions but does not make any specific recommendations for log removal credits. Various US EPA documents do make reference to log removal credits for different treatment processes, but the current implementation of their pathogen reduction requirements requires frequent and/or continuous system monitoring and was determined to be overly complex for the current application.

#### 4.4.1.5 DBP COMPLIANCE

DBP compliance is assessed using a query that refers to historical data collected by the ENVC. This can be updated regularly by ENVC staff if desired.

#### 4.4.1.6 TOTAL COMPLIANCE

The database sorts communities into one of four bins (Table 4.2) based on their compliance with existing CT requirements and DBP recommendations.

**Table 4.2 Disinfection and DBP compliance bins**

| Bin | Description |
|---|---|
| A | CT and DBP compliant |
| B | CT non-compliant<br>DBP compliant |
| C | CT compliant<br>DBP non-compliant |
| D | CT non-compliant<br>DBP non-compliant |

If insufficient information was provided to calculate CT, the community was counted as non-compliant for CT. Some of these communities were found to be DBP compliant and therefore sorted into Bin B. Those that were not in compliance with the recommended DBP limits were sorted into Bin D.

It is recognized that communities with large industrial users, tourism, or anticipated development may require greater scrutiny to establish whether or not CT is being met at times of peak flow. This will require access to at least one year’s worth of detailed flow records that can be used to establish water use in the community during periods of peak demand.

#### 4.4.1.7 FUTURE IMPROVEMENTS

The database can be modified to update compliance requirements. This will affect the bin assignment for each community. It could also be updated to include *Cryptosporidium* reduction requirements.

### *4.4.2 Contact Volume, Instantaneous CT, and Log Reduction Calculators*

Instantaneous contact volume, CT, and log reduction calculators have been developed to provide water utilities with tools to track their ongoing disinfection compliance.

The CT and log reduction calculators rely on the same calculations and assumptions as the CDID, but in a simplified form that demands more intensive user involvement. It can be used to monitor compliance month to month or over an extended time period. Contact volume, baffling factor, water treatment, and source water quality details from the CDID can be input into a locked spreadsheet by the ENVC or input directly by users.

Users can then input the following instantaneous data points:
- Chlorine residual at the end of the contact volume (usually the tap at the first user);
- Instantaneous flow;
- Temperature; and
- pH.

The contact volume calculator allows the user to input various simple parameters such as pipe diameter (ID) and length to calculate the total volume available for chlorine disinfection.

Detailed explanations of and instructions for the contact volume, instantaneous CT, and log reduction calculators can be found in Appendix H.

### *4.4.3 GIS Layer*

Four GIS shapefiles have been developed that link data collected during the field portion of the study with points on the map. The locations and the data associated with them are summarized in Table 4.3.

**Table 4.3 Contents of GIS shapefiles**

| Location | Data Included |
|---|---|
| Point of disinfection | Disinfectant type, decay rate, average flow, peak flow, contact tank volume and configuration (where applicable) |
| First user | Chlorine residual, pH, water temperature, distance to first user, effective contact time, CT |
| Storage | Volume, baffling factor |
| Approximate 20 minute contact time point | None |

The shape files have been provided on the data CD that accompanies this report.

# CHAPTER 5 RESULTS

## 5.1 Desktop Study

### *5.1.1 Raw Water Quality*

The ENVC collects water samples from each water system in the province approximately twice a year. The raw water quality data provided by the ENVC for the 55 participating communities was compiled into a single database during the desktop portion of the study. Five parameters relevant to chlorine disinfection and decay were analyzed in greater detail. The mean values for pH, turbidity, DOC, and colour are provided in Figures 5.1 to 5.4. Error bars represent one standard deviation from the mean.

As shown in Figure 5.1, the average pH in the raw water of 27 of the 55 participating communities falls within the Health Canada guideline range, that is, between 6.5 and 8.0. The average pH in the remaining raw water sources ranges from 5.0 to 6.5. The error bars show that the raw water pH is variable in many communities, which may contribute to variable disinfection efficiency, changing DBP levels, and operational challenges within the distribution system in communities that lack pH control and/or formal water treatment.

The source waters used in most of the participating communities have average turbidity levels below 1.0 NTU (Figure 5.2). A few communities, however, have high and variable turbidity levels. Most of these use surface water sources, but two are served by GUDI wells. The high variability noted in the turbidity measurements reported for these communities likely reflects the fact that GUDI water sources (and some surface water sources) are very susceptible to changes in water quality during periods of high precipitation or runoff.

The graph in Figure 5.3 presents the average DOC levels measured in the various source waters. These vary from less than 1 mg/L (for some of the groundwater sources) to over 11 mg/L. The majority of the communities have average DOC levels between 4 mg/L and 8 mg/L. In communities without water treatment processes specifically aimed at removing organic carbon, DOC in this range is likely to result in the formation of significant levels of DBPs. Many of the source waters with high average DOC levels also have a large amount of variation amongst individual measurements. This suggests that the concentration of DOC in some of the communities may vary by 3 or 4 mg/L over the course of the year, possibly due to seasonal changes (precipitation, run-off, etc.).

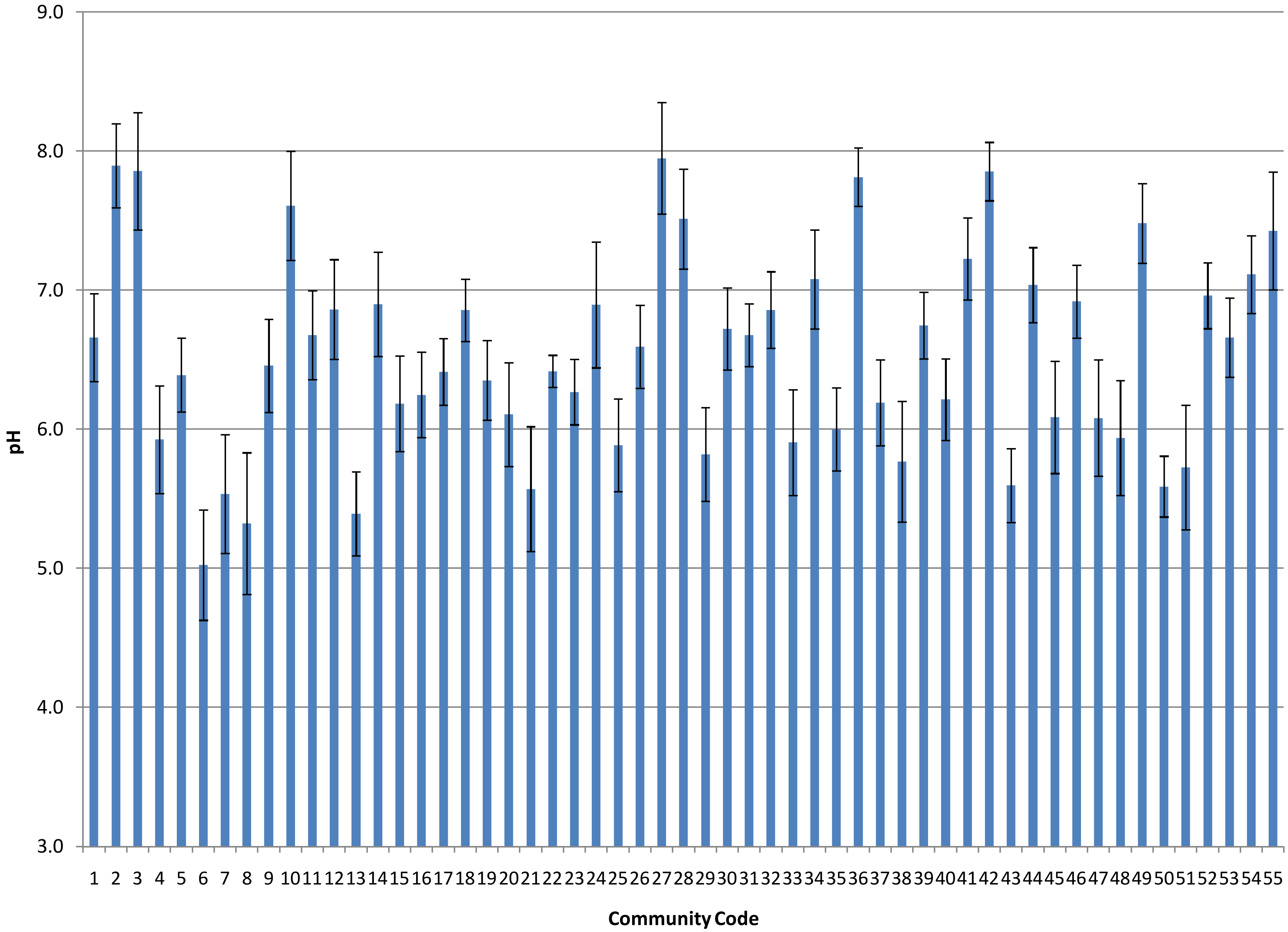


**Figure 5.1** Mean pH in the raw water from participating communities (ENVC, 2000 to 2010)

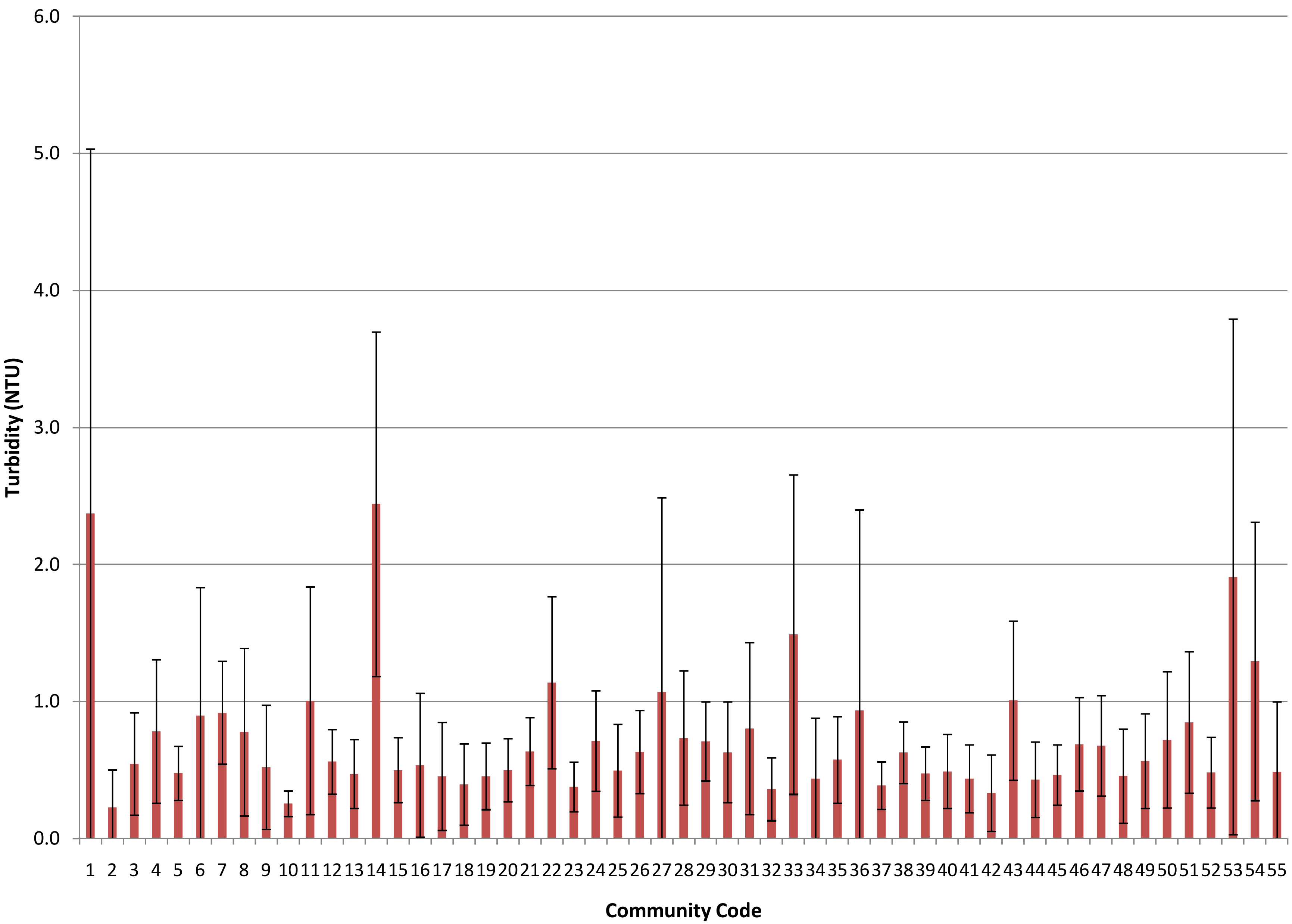


**Figure 5.2** **Turbidity measured in the raw water from participating communities (ENVC, 2000 to 2010)**

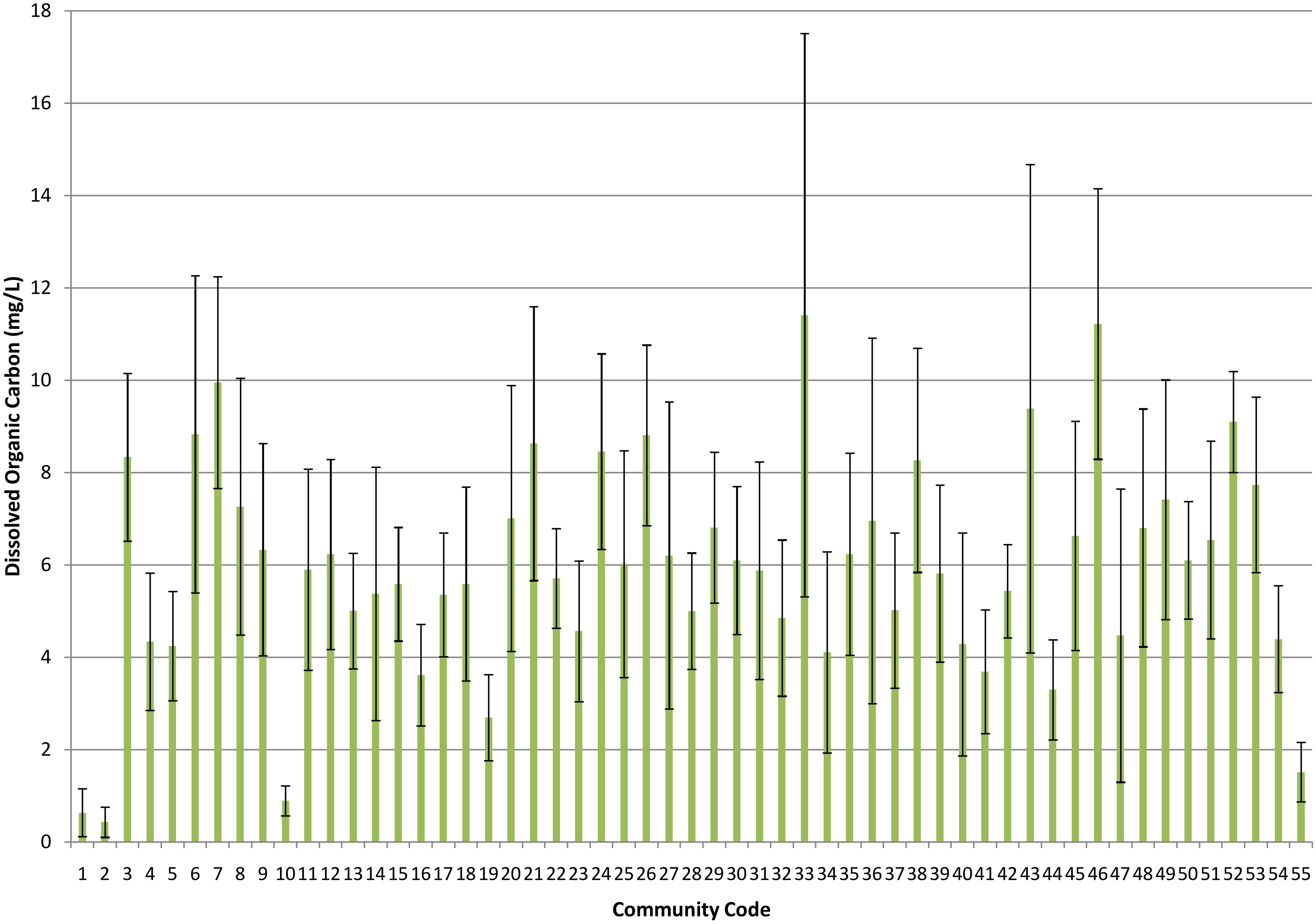


**Figure 5.3** Mean DOC measured in the raw water from participating communities (ENVC, 2000 to 2010)

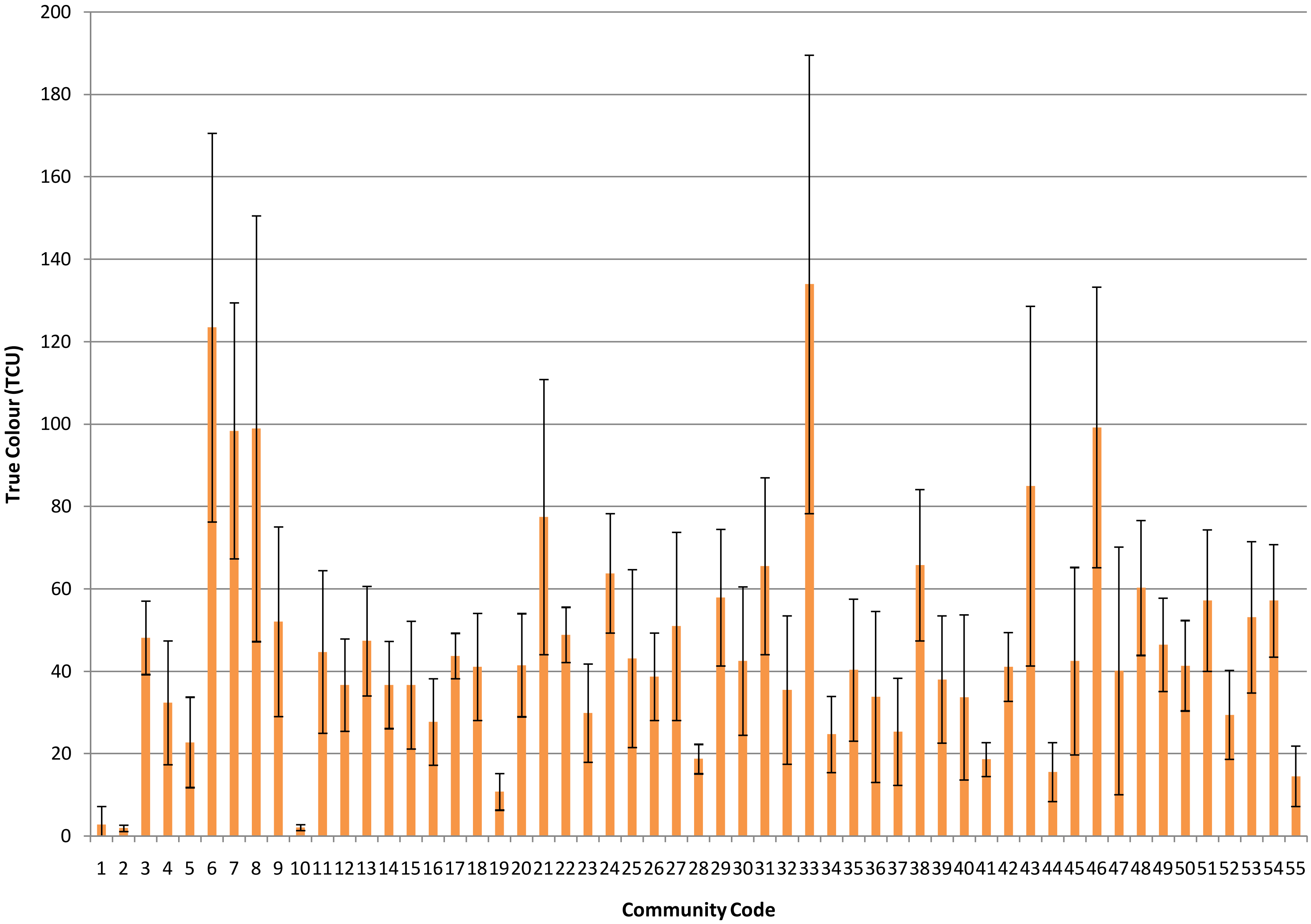


**Figure 5.4** True colour measured in the raw water used by participating communities (ENVC, 2000 to 2010)

Finally, Figure 5.4 presents the average colour measured in the source water for each community. Like DOC, colour is usually used as an indicator of the amount of organic matter present in a water sample. This relationship is not exact, however, as other parameters such as iron can also impact the colour of the water. Particles can interfere with the colour measurement, making colour an even less effective measure of organic matter in turbid samples. True colour, which is reported here, is a more exact measure of the dissolved colour-causing components of the water because it is read after the sample is passed through a 0.45 µm filter. Despite its lack of specificity, colour continues to be measured because it is one of the most important aesthetic concerns for water system users. The Health Canada guideline for colour in drinking water is 15 TCU but the human eye is able to detect 5 TCU. Most of the source waters examined in the study have average true colour levels that range from 20 to 60 TCU. Some groundwater is nearly colourless while some of the surface waters have average true colour levels above 120 TCU.

Table 5.1 summarizes the average raw water quality found in the water sources examined in this study.

**Table 5.1 Summary of average raw water quality measured in participating communities**

| Parameter | Units | All | Surface Water | GUDI | True Groundwater |
|---|---|---|---|---|---|
| pH | | 6.5 | 6.5 | 7.2 | 7.8 |
| DOC | mg/L | 5.9 | 6.0 | 4.0 | 0.7 |
| Colour | TCU | 46 | 47 | 31 | 2 |
| Turbidity | NTU | 0.7 | 0.7 | 1.5 | 0.2 |
| Iron | mg/L | 0.21 | 0.18 | 0.90 | 0.03 |
| Manganese | mg/L | 0.05 | 0.04 | 0.28 | 0.00 |
| Bromide | mg/L | 0.03 | 0.03 | 0.04 | 0.05 |
| TDS | mg/L | 51 | 43 | 145 | 158 |
| Hardness | mg/L as $CaCO_3$ | 23 | 19 | 78 | 57 |
| Ammonia | mg/L | 0.03 | 0.03 | 0.05 | 0.03 |

Surface water in Newfoundland and Labrador is generally low in pH, turbidity, and total dissolved solids (TDS) but high in organics. The average water quality in the 50 surface water sources examined in this study is typical for the province as a whole. The true groundwater sources have higher pH, lower DOC and colour, and higher TDS and hardness than the surface water sources. The water from the GUDI sources, which would be expected to have characteristics of both surface and groundwater, does indeed seem to fall somewhere between these two extremes. The pH in these sources tends to be neutral and colour and DOC levels are moderate to high.

### *5.1.2 Tap Water Quality*

Tap water quality data from each of the 55 participating communities was also provided to CBCL Limited by the ENVC. In addition to the common water quality parameters measured in the raw water in each community, disinfection by-products are measured quarterly. Figures 5.5 to 5.10 present the average values of pH, turbidity, DOC, colour, total trihalomethanes, and total haloacetic acids. The error bars in each figure represent one standard deviation from the mean.

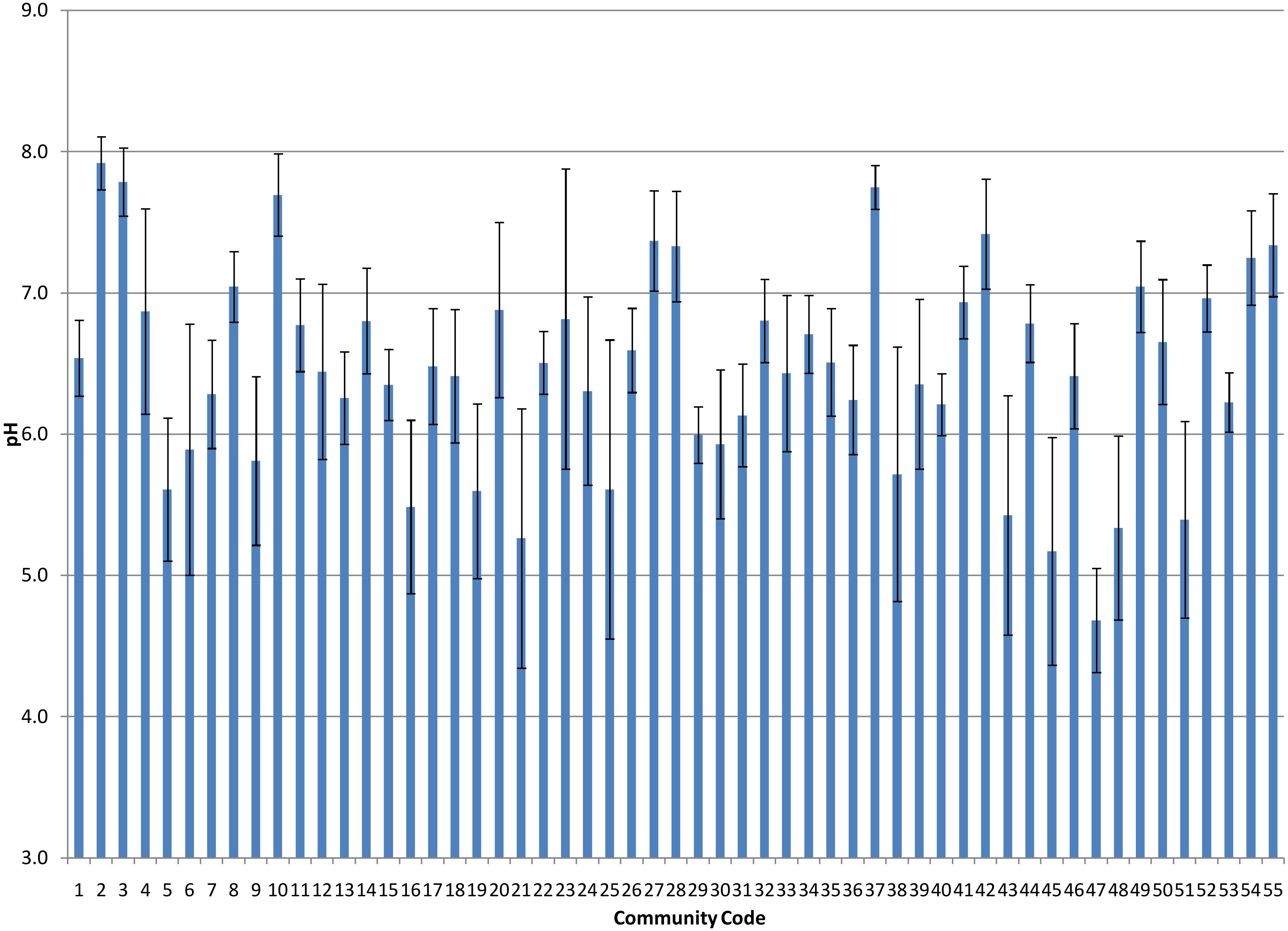


**Figure 5.5** pH measured in the tap water of participating communities (ENVC, 2000 to 2010)

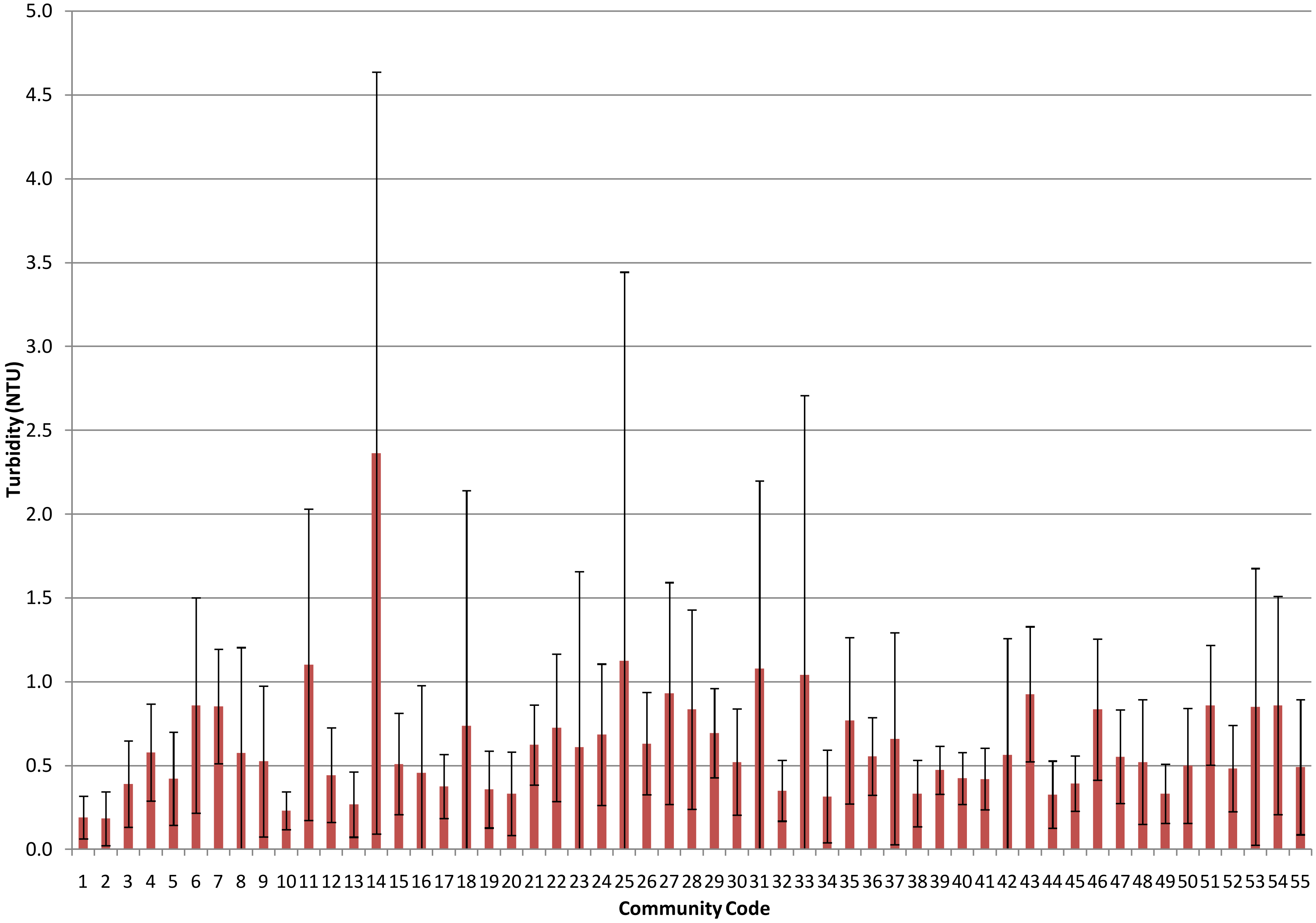


**Figure 5.6** **Turbidity measured in the tap water of participating communities (ENVC, 2000 to 2010)**

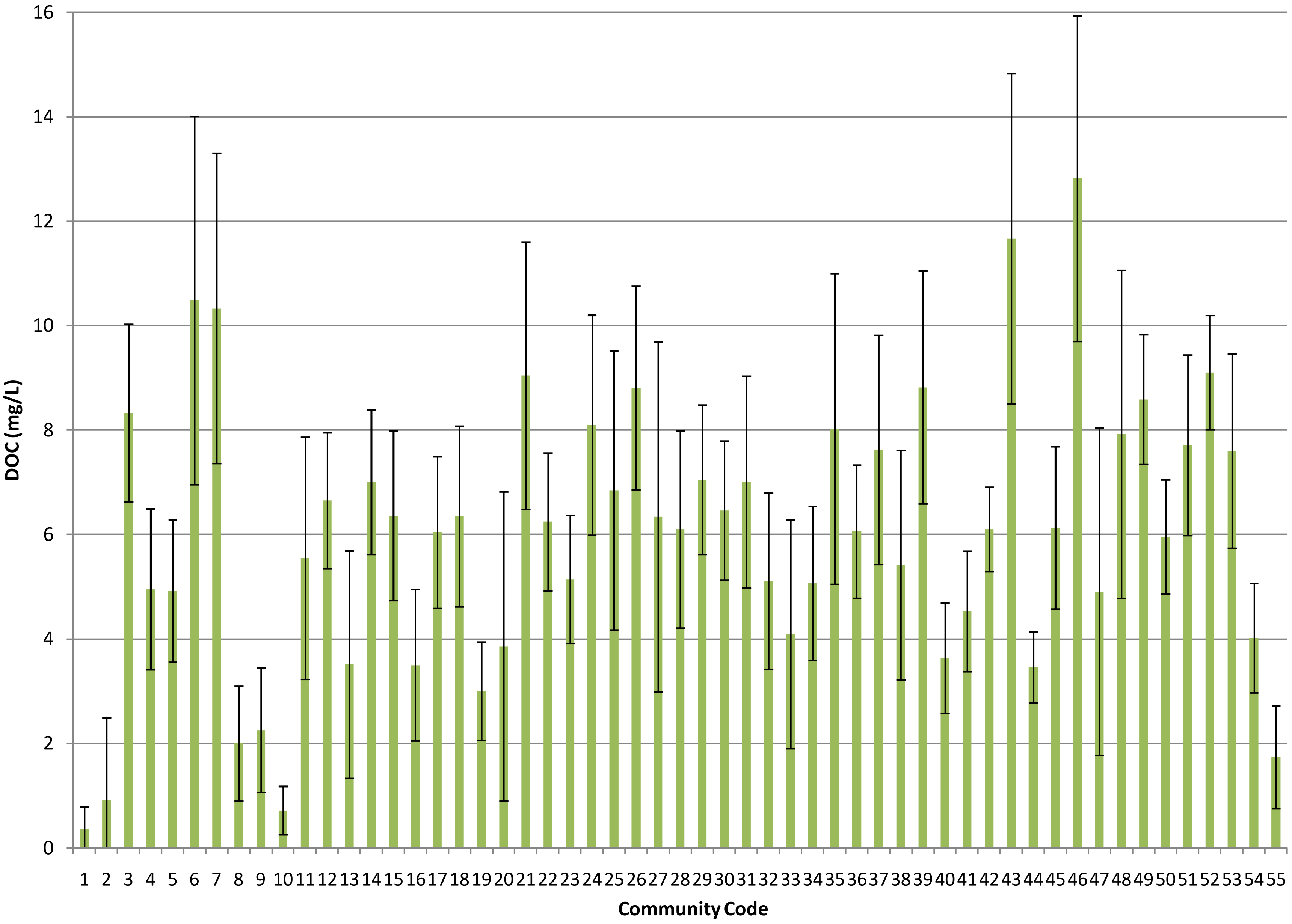


**Figure 5.7** DOC measured in the tap water of participating communities (ENVC, 2000 to 2010)

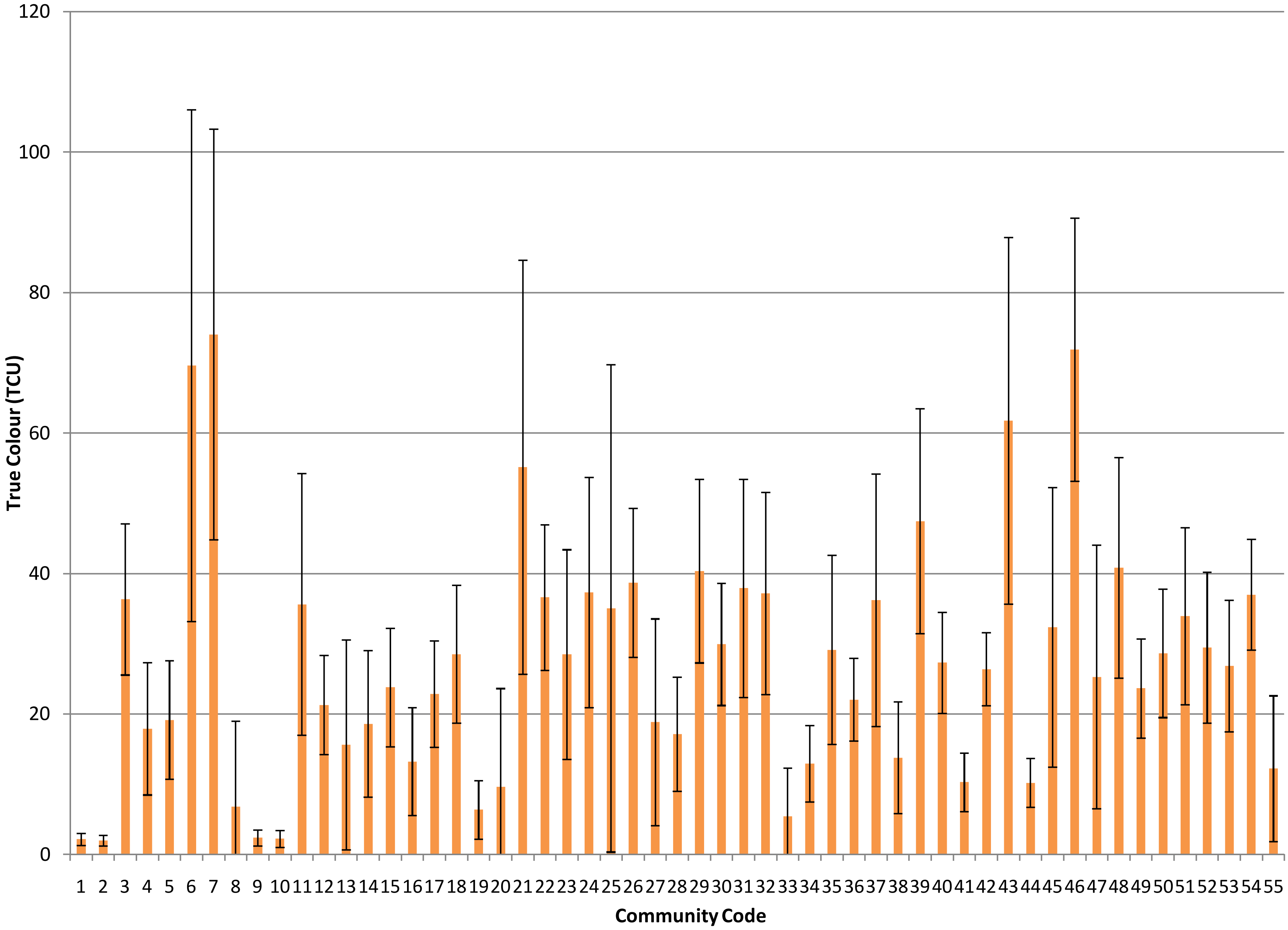


**Figure 5.8** True colour measured in the tap water of participating communities (ENVC, 2000 to 2010)

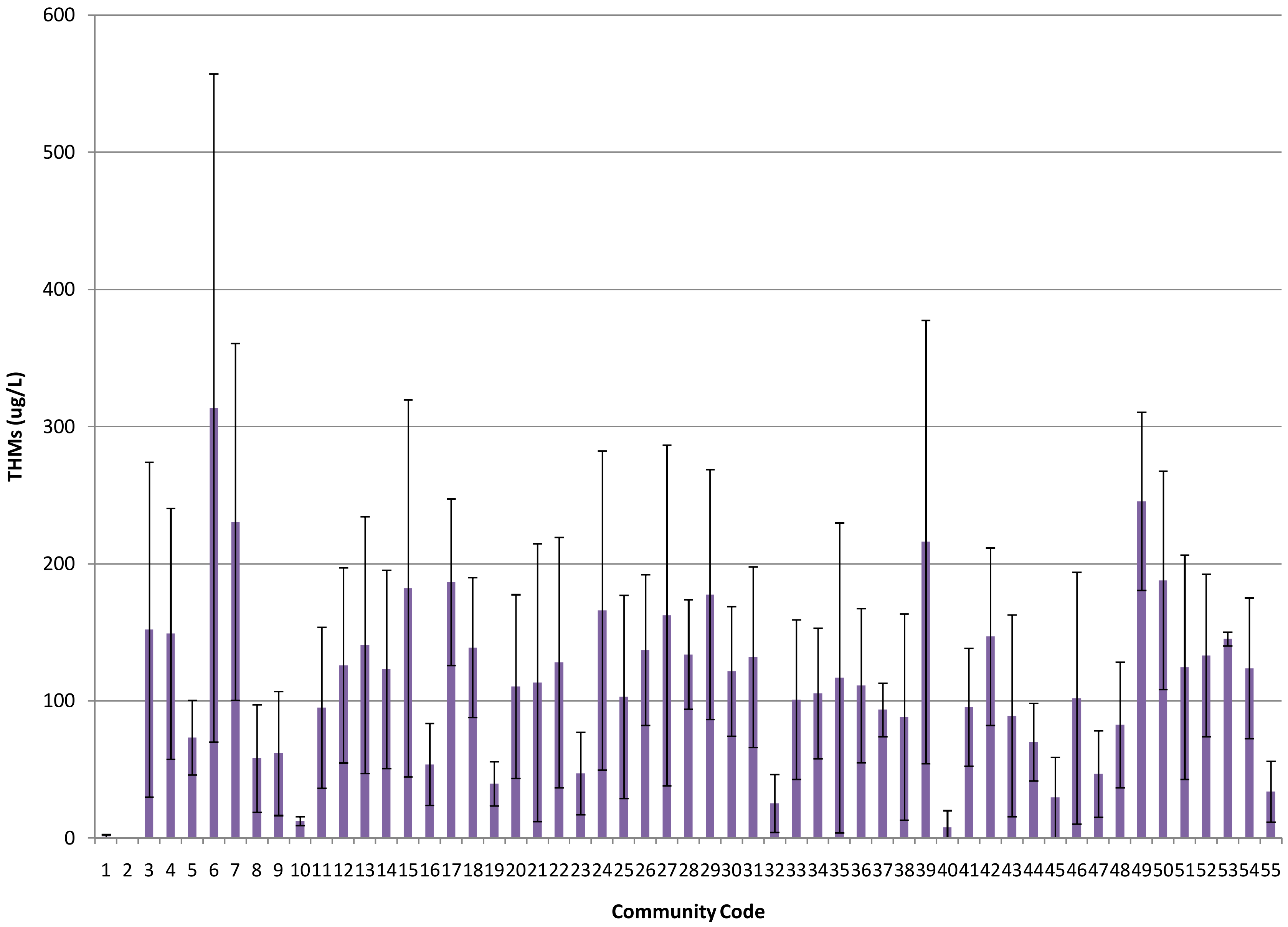


**Figure 5.9** Total trihalomethanes measured in the tap water of participating communities (ENVC, 1987 to 2010)

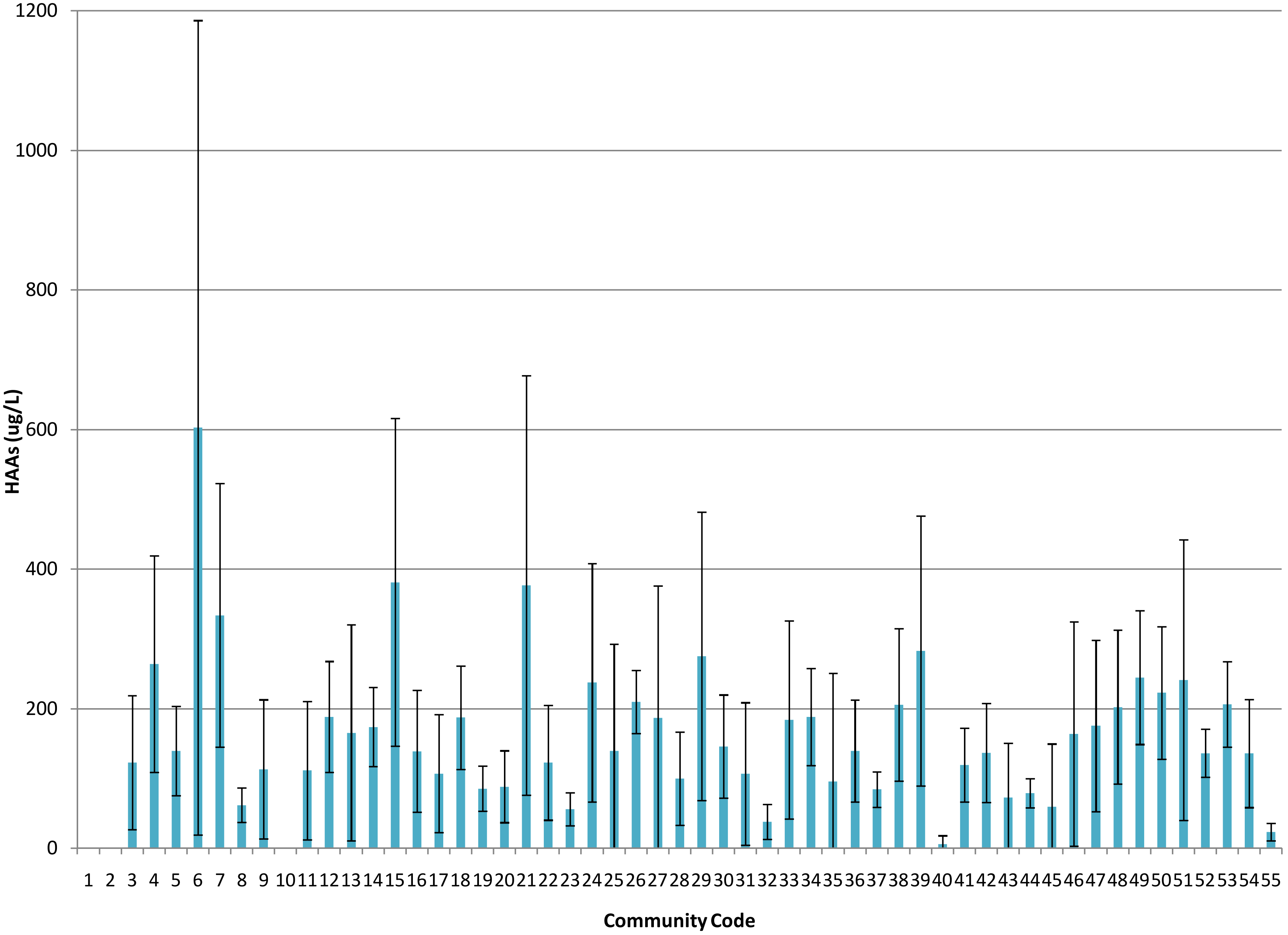


**Figure 5.10** Total haloacetic acids measured in the tap water of participating communities (ENVC, 2000 to 2010)

Figure 5.5 shows the average pH measured in the tap water from each community. The results suggest that many of the participating communities are not able to maintain the pH of their tap water within the operational guideline range (6.5 to 8) recommended by Health Canada. All of those who fall outside this range have an average pH that is below, rather than above, the guidelines. Low pH can positively impact disinfection processes but it can also contribute to the deterioration of the distribution system over time through corrosion. Some of the communities with low average pH in the tap water already have pH adjustment equipment, which should be evaluated and repaired as required. Those communities who do not currently employ pH adjustment technology might consider investing in such a system to protect the health of their distribution systems.

Turbidity is a parameter used to estimate the amount of suspended matter in a water sample. This suspended matter may include organic or inorganic particles and microorganisms. Current NL guidelines require that turbidity remain below 1.0 NTU throughout the distribution system. This is unlike the turbidity guidelines in most other jurisdictions, including the GCDWQ, which tend to limit the amount of turbidity permitted in the treatment plant effluent, where it acts as an indicator of filter integrity. As most of the participating communities have low levels of turbidity in their tap water (Figure 5.6), few of them require significant treatment upgrades in order to meet the existing guideline. Turbidity removal should, however, be installed in those communities where the average turbidity level currently exceeds the guideline as excessive turbidity can interfere with disinfection processes and/or indicate the presence of microorganisms.

Most of the communities participating in this study do not employ water treatment equipment optimized for organic removal. Therefore, it comes as no surprise that average DOC levels in the tap water used in most of them are not noticeably different than those measured in the raw water. The same can be said for colour levels. Notable exceptions include communities 8, 9, and 33, all of which have water treatment plants that include coagulation for organic removal. High DOC and colour measurements are indicative of elevated levels of organic carbon in the tap water. Organic carbon molecules exert a chlorine demand, which can hinder the primary disinfection process and contribute to difficulties in maintaining a residual throughout the distribution system. It can also result in the formation of DBPs.

As described in Chapter 2, DBPs such as THMs and HAAs form when organic carbon molecules react with chlorine, which is usually added for disinfection. Not all organic carbon molecules react with chlorine to form DBPs, but many do. Excessive chlorination and water age can also increase the total concentration of DBPs in the distribution system, however, in most cases high DBP levels can be directly tied to the level of organic carbon present in the water. This appears to have historically been the case in the 55 communities that participated in this study. THM and HAA levels above those recommended in the GCDWQ (100 µg/L and 80 µg/L respectively) have been measured in the majority of the communities. Linear regressions performed on the average THM and HAA values against the average DOC levels measured in each community resulted in weak ($r^2 = 0.4$ and 0.3, respectively) but significant ($P < 0.05$) relationships in both cases. This suggests that the presence of organic carbon in the water being disinfected with chlorine may be the main reason for high DBP levels in these communities.

Table 5.2 provides a summary of the results presented in Figures 5.5 to 5.10.

**Table 5.2 Summary of tap water quality in 55 participating communities**

| Parameter | Units | All | Surface Water | GUDI* | True Groundwater |
|---|---|---|---|---|---|
| TTHMs | ug/L | 113 | 119 | 73 | 6 |
| THAAs | ug/L | 158 | 169 | 73 | 0 |
| pH | | 6.4 | 6.3 | 7.2 | 7.8 |
| DOC | mg/L | 6.0 | 6.3 | 4.0 | 0.8 |
| Colour | TCU | 27 | 29 | 25 | 2 |
| Turbidity | NTU | 0.6 | 0.6 | 0.6 | 0.2 |
| Iron | mg/L | 0.19 | 0.18 | 0.48 | 0.02 |
| Manganese | mg/L | 0.02 | 0.02 | 0.07 | 0.00 |
| Bromide | mg/L | 0.03 | 0.03 | 0.03 | 0.03 |
| TDS | mg/L | 57 | 48 | 141 | 158 |
| Hardness | mg/L as $CaCO_3$ | 25 | 20 | 79 | 62 |
| Ammonia | mg/L | 0.04 | 0.04 | 0.03 | 0.03 |

Overall, the tap water in the participating communities can be characterized as having neutral to low pH, low turbidity, and low to moderate hardness. THM and HAA levels tend to be above Health Canada guidelines (100 µg/L and 80 µg/L), which is likely related to the high levels of organic carbon present in the raw water and the lack of access to organic removal technologies in smaller communities throughout the province.

As described previously, five of the communities that participated in the study use a groundwater source to supply their residents with drinking water. The average tap water quality in these five communities differs noticeably from that found in communities that use surface water sources, as shown in Table 5.2. For example, communities using true groundwater sources were less likely to struggle with high THM and HAA levels but more likely to face challenges related to elevated TDS. GUDI wells are known to share characteristics of both surface water and groundwater sources. Oftentimes, the water quality in GUDI wells will be similar to true groundwater sources under normal weather conditions. During high precipitation events, however, the wells may begin to exhibit surface water characteristics such as turbidity, colour, and elevated concentrations of pathogens.

The water quality profiles found in each type of source water suggest a need for disinfection and DBP mitigation strategies tailored to meet the distinct needs of each. In particular, three of the five groundwater supplies have been designated GUDI and consequently may require a higher level of treatment to minimize microbial and DBP risks associated with periods of high precipitation. Appropriate mitigation strategies will be described in detail in Chapter 6 of this report.

## 5.2 Boil Water Advisories

Minimizing public exposure to pathogens in drinking water is a major priority for the province, but despite their efforts, nine communities have experienced pathogen outbreaks within the past twenty years. Five of these have been included in the CT study. In all but one case, the outbreak was traced to *Giardia* in the source water. The remaining outbreak was related to *Escherichia coli*.

As described in Chapter 3, most jurisdictions in Canada regulate the disinfection of drinking water based on specific levels of reduction of pathogenic organisms. When a water system is unable to provide the degree of disinfection required by the regulating body, a BWA is issued for the community to encourage residents to boil their water before consumption to destroy any pathogens that may enter their taps as a result of the compromised treatment or distribution system.

The ENVC maintains a database of all BWAs issued in the province. Each entry includes the name of the community, the population served, the date of issuance, and the reason for the advisory. Each incident is labeled with a 'reason code' that indicates the general cause of the advisory. The accumulated data can then be used to pinpoint general areas of improvement for the province.

The majority of the reason codes correspond to the factors that may prompt a BWA listed in the Health Canada guidance document for BWAs (2009). The remaining reason codes refer to disinfection challenges that have historically plagued the province, including a lack of disinfection equipment or aesthetic concerns about chlorine among residents. Reason codes are listed in Table 3.3 in Chapter 3 of this report.

For simplicity, these 22 reason codes can be broken into nine major categories, which are summarized in Table 5.3.

**Table 5.3 Simplified BWA categories**

| Category | Reason |
|---|---|
| A | No disinfection system |
| B | Disinfection system turned off by operator for financial, regulatory, or aesthetic reasons |
| C | Disinfection system offline for operation and maintenance or due to lack of supplies |
| D | Distribution system is compromised or undergoing repairs |
| E | Inadequate disinfection / non-compliance with Bacteriological Standard |
| F | Detection of microorganisms in the distribution system |
| G | Disaster |
| H | Waterborne disease outbreak |

As shown in Figure 5.11, the total number of BWAs issued in the province has risen steadily since 2001. This overall increase may reflect an increasing focus on improvements in drinking water quality monitoring within the province. These BWAs have ranged in length from a day to multiple years.

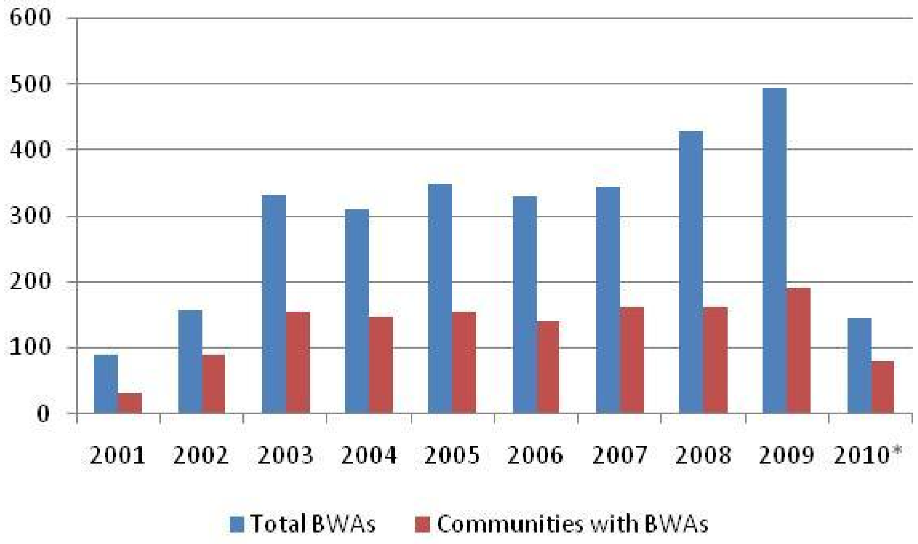
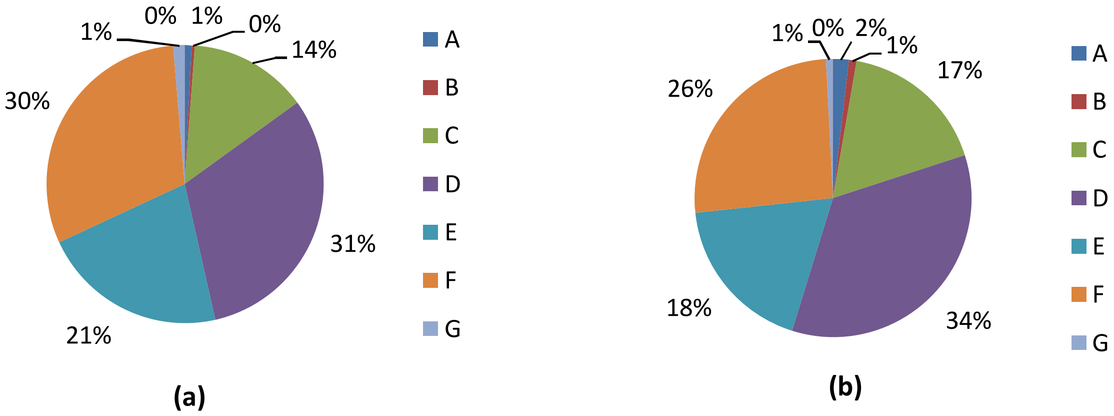


**Figure 5.11** BWAs issued in Newfoundland and Labrador (2001 to 2010)
*only five months of data available for 2010

The total number of communities where BWAs were issued also increased between 2001 and 2003 but remained relatively stable from 2003 until 2008. Larger communities (> 5,000) account for a disproportionate number of BWAs, though most of these are related to the maintenance and/or repair of the treatment equipment or distribution system rather than non-compliance with the *Standards for the Bacteriological Quality of Drinking Water*.

The graphs in Figure 5.12 provide summaries of the BWAs (broken down by category) issued in: (a) the communities participating in this study and (b) all communities in the province.



(a)

(b)

**Figure 5.12** BWAs issued in Newfoundland and Labrador (2001 to 2010)
(a) Communities participating in the CT Study and (b) All communities

The most common categories of BWA issued, for the communities participating in this study as well as for the province as a whole, are C, D, E, and F. These correspond to:

- Disinfection system operation and maintenance;
- Distribution system compromised or undergoing repairs;
- Inadequate disinfection (CT or residual); and
- Detection of microorganisms.

The overrepresentation of these four categories provides an opportunity for reflection on past policies and initiatives and a path for future projects. For example, very few of the BWAs issued in the past ten years have been caused by operators turning off the disinfection system for financial or aesthetic reasons. This suggests that public opinion on the acceptability of chlorine tastes or smells in the water has shifted in some areas. Redundant treatment and/or disinfection equipment may have helped to minimize new BWAs that result from disinfection system operation and maintenance activities. The large number of BWAs resulting from inadequate disinfection, however, suggests that the province should focus future efforts on improving the ability of communities to operate, maintain, and monitor their disinfection systems.

These trends are presented in Figure 5.13.

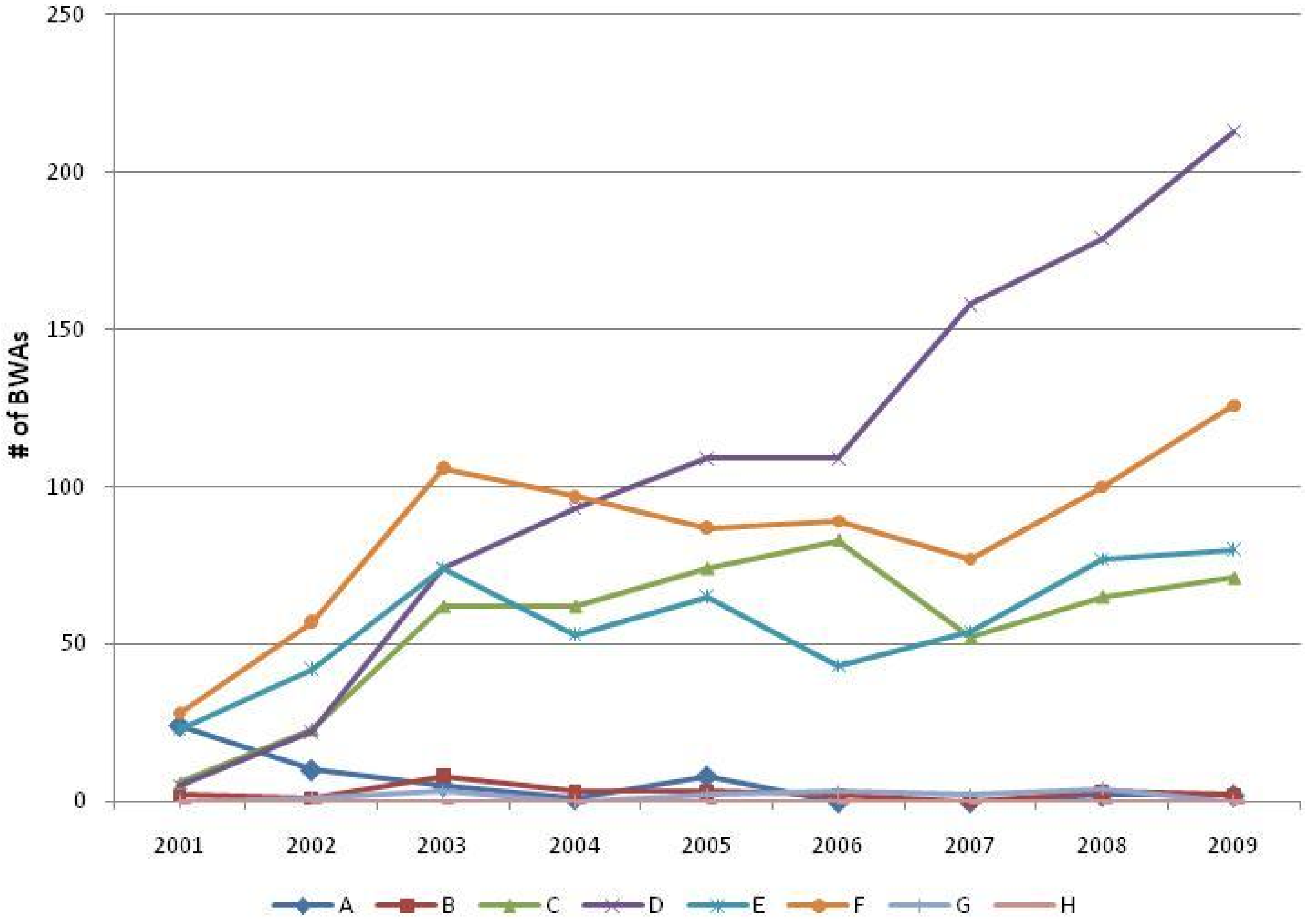


**Figure 5.13** **BWAs issued in Newfoundland and Labrador by category (2001 to 2009)**

The graph in Figure 5.13 shows that the total number of BWAs issued annually in the province has increased steadily over time.

As disinfection priorities have shifted over time, so too have the types of BWAs issued. For example, the provincial push to establish basic CT requirements over the past 10 years has resulted in a decrease in the number of communities under BWA because they lack a disinfection system (A). The number of communities fitting this description decreased from 24 in 2001 to two in 2009. Increased operator training may be reflected in the leveling off of the number of BWAs issued due to operation and maintenance activities (C) and inadequate CT/chlorine residual (E).

Please note that the results presented in this section represent the total number of BWAs issued in each of the past ten years. This number does not account for long-standing BWAs (i.e., each BWA is only counted once). Thus, the results of this section do not correspond to those presented in the annual Drinking Water Safety Reports prepared by the ENVC or with the total number of BWAs that active in any given year.

The BWA results presented in the annual Drinking Water Safety Reports are based on snapshots taken on the last day of each fiscal year. The 2009 Drinking Water Safety Report presents results from 2001 to 2009 that show that the total number of BWAs active at the end of the fiscal year has decreased from 322 to 211. The number of communities affected has also decreased – from 223 to 145. This same report noted that the majority of these were related to problems with chlorine residual maintenance (ENVC, 2009).

The total number of BWAs active during a given year can be determined by adding up the following:

- BWAs issued in a previous year that were lifted the current year;
- BWAs issued in the current year and lifted during the current year;
- BWAs issued in the current year and lifted in a subsequent year (or not at all); and
- BWAs issued in a previous year and lifted in a subsequent year (or not at all).

A quick assessment of records from the 2009-2010 fiscal year shows that the total number of active BWAs was above 800. 30% of these were related to distribution system repairs or disturbances (D). Difficulties with chlorine residual maintenance (E) were responsible for another 23% while the detection of microorganisms (F) accounted for 20%. Over 500 BWAs were resolved during the 2009-2010 fiscal year. Those most likely to be resolved were in categories D and F while those in categories A and B were least likely to be resolved. The results of this assessment are provided in Appendix E.

## 5.3 Field Results

The free and total chlorine residuals measured at the first user by CBCL technical staff during the site visits are presented in Figure 5.14. All but four communities had a measurable chlorine residual at the first user, and were therefore in compliance with the *Standards for the Bacteriological Quality of Drinking Water*. Many of the communities had chlorine residual measurements well above the minimum required by the standards, some of which were above 2 mg/L. Design standards in Ontario recommend an optimum chlorine residual of 0.2 mg/L throughout the distribution system, which is below those measured in the communities who participated in the study. Care should be taken, however, in encouraging these communities to lower their initial chlorine dose as most of these communities have significant chlorine demand in the bulk water. Any reduction in the amount of chlorine added may result in undetectable chlorine residuals at the end of the distribution system due to the chlorine decay resulting from this high chlorine demand.

The total and free chlorine measurements taken during the site visits line up relatively well for most communities, indicating that most of the chlorine present in the bulk water is in the form of free chlorine. This is a desirable result because free chlorine is a more effective disinfectant than the various species that are collectively referred to as combined chlorine. The total chlorine residual was at least twice the free chlorine residual in at least eight communities. This is an indication of the formation of combined chlorine species, which may be organic or inorganic. These communities should be encouraged to work towards removing the parameters that are known to combine with free chlorine to form combined chlorine, namely NOM and ammonia. One community was found to have a free chlorine residual higher than the total chlorine residual. As total chlorine is defined as the sum of free chlorine and combined chlorine, this result can be ascribed to operator/technician error.

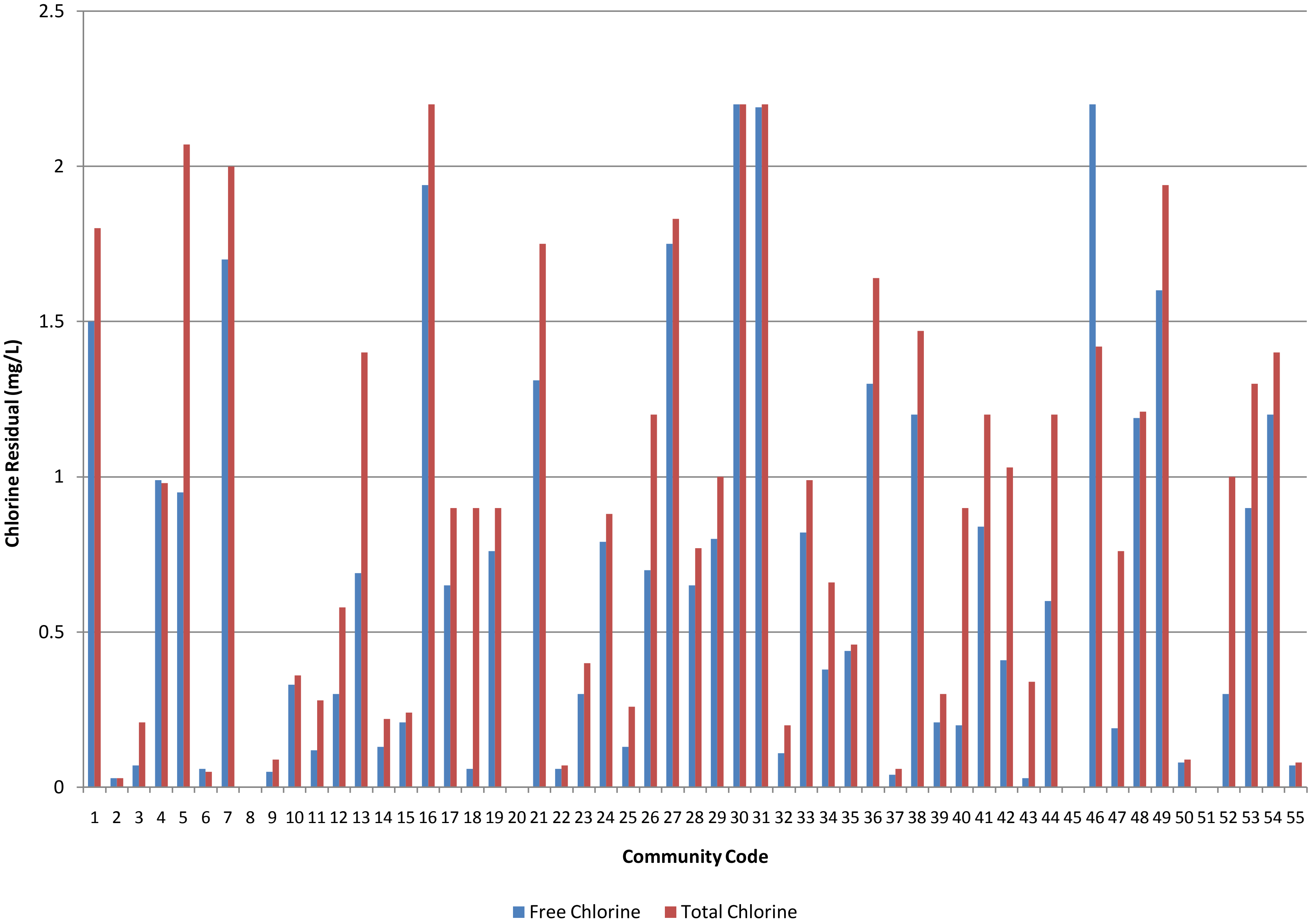


**Figure 5.14** Free and total chlorine measurements at the first user from the field program

## 5.4 Laboratory Results

Bulk chlorine decay tests were conducted on the water samples collected by CBCL technical staff during the site visits. The goal of these tests was to determine the coefficient of chlorine decay (k) for each water sample. This is accomplished by measuring the concentration of chlorine over time in a water sample that has been spiked with a known amount of chlorine. The natural log of the measured concentrations divided by the original concentration is plotted against time. This represents the first order chlorine decay model discussed in Chapter 2 of this report. The $r^2$ value of this linear relationship indicates how well the data matches the first order reaction model. The slope of the line of best fit is the k value. Higher values of k indicate that chlorine decays quickly in the water, usually due to the presence of chlorine demanding substances such as DOC, iron, and manganese. High k values are expected in communities who do not have formal water treatment systems and whose raw water is characterized by high concentrations of these chlorine demanding substances. Low k values are expected for water that is free of these substances, such as groundwater or effluent from formal water treatment processes optimized for organic removal.

This difference is illustrated in Figure 5.15, which compares the average decay coefficients and r2 values obtained from groundwater and surface water sources.

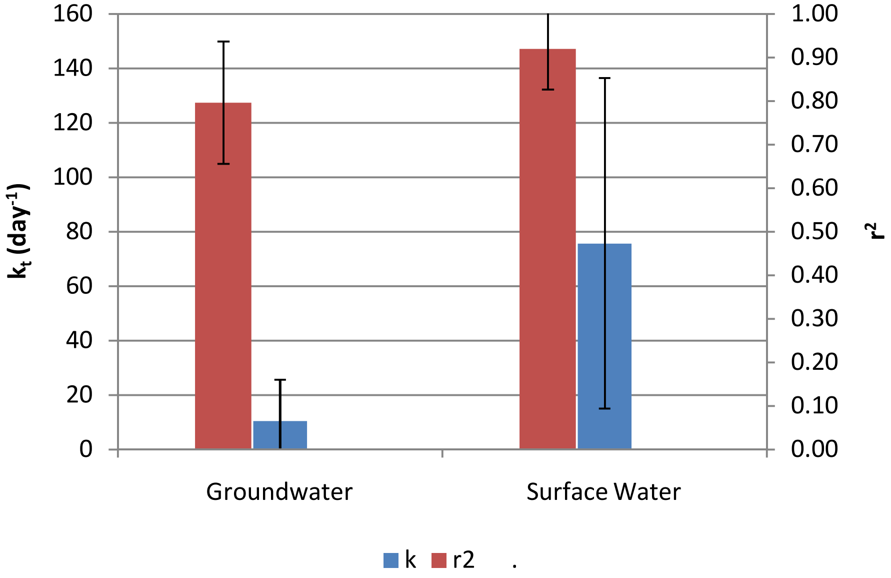


**Figure 5.15** **Average decay coefficients and $r^2$ values obtained during the study for groundwater and surface water sources**

Samples from communities served by groundwater tended to have lower decay coefficients and to have chlorine decay profiles that did not match the first order decay model. The inverse was true for communities served by surface water sources. A student t-test conducted on the k and $r^2$ values calculated during the study suggested that these differences were significant ($p < 0.05$). It should be noted that the graph and calculations did not take into account the fact that some of the groundwater wells are GUDI and that some of the communities that use surface water provide water treatment that includes organic and/or iron and manganese removal.

As mentioned previously, chlorine decay in the bulk water is often driven by the presence of chlorine demanding substances. Figure 5.16 shows the results from two communities with similar initial chlorine doses but different concentrations of TOC.

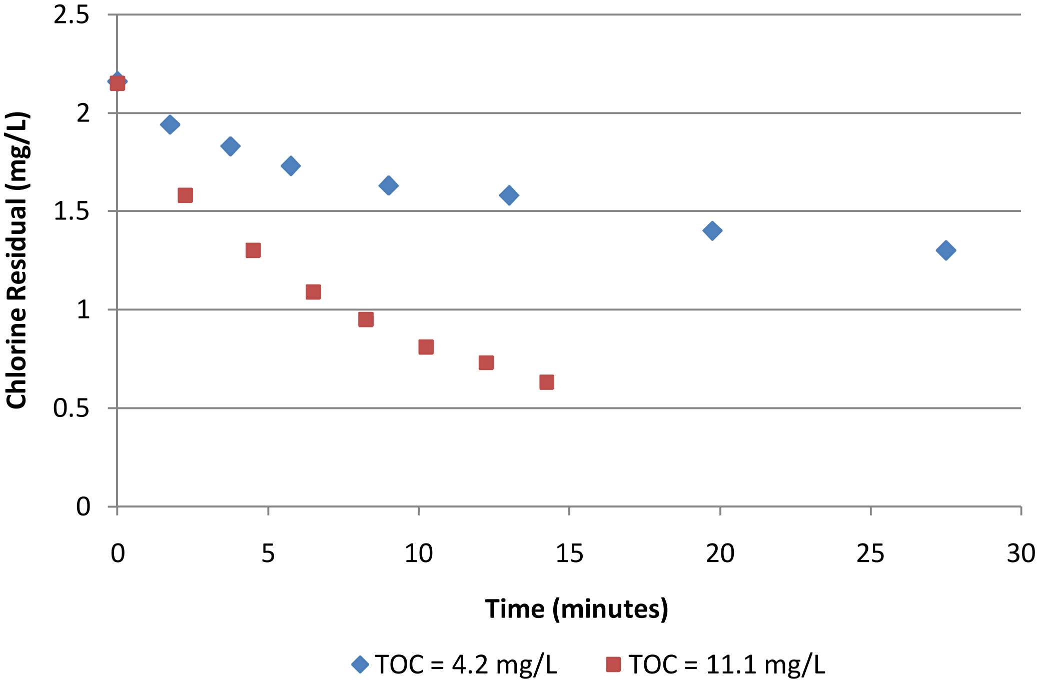


**Figure 5.16** **Chlorine decay in water samples with different concentrations of TOC**

It is unlikely that the decay patterns shown in Figure 5.16 are exclusively a function of TOC, however, the results demonstrate that chlorine residual decay occurs more quickly when the TOC concentration is elevated. Other water quality parameters such as pH, iron, manganese, and temperature can also impact the rate of chlorine decay.

When the results from all of the communities are considered, a weak but significant ($p < 0.05$) relationship was found between the historical average DOC in the raw water and the decay coefficient measured during this study. The relationship is shown in Figure 5.17.

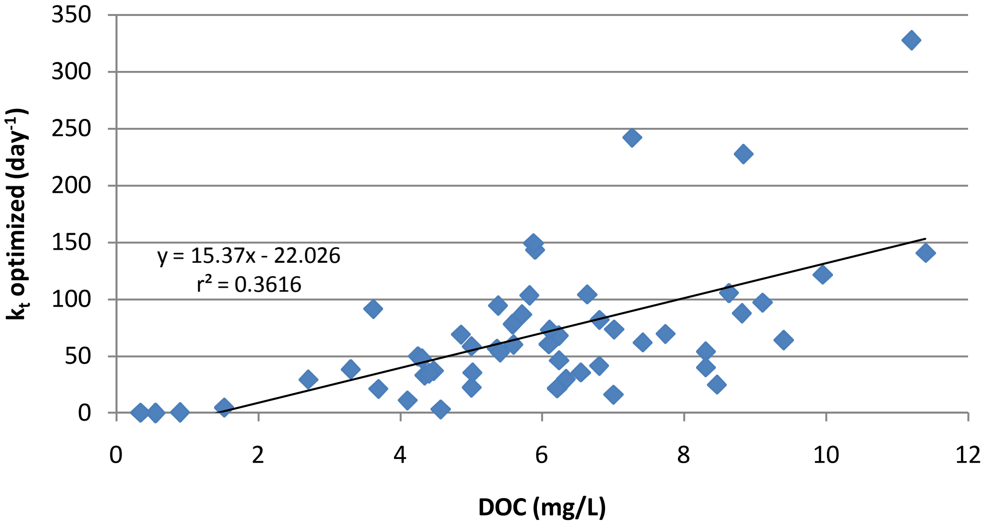


**Figure 5.17** **Average historical DOC vs. the measured chlorine decay coefficient**

No significant relationships were found between historical average iron or manganese concentrations in the raw water and the chlorine decay coefficient measured during this study. This is somewhat surprising, but likely explained by the fact that most of the chlorine consuming reactions that include metal reactants occur on the walls of the pipes in the distribution system.

The reaction between chlorine and NOM to form THMs and HAAs can be an important component of the total chlorine decay observed in the bulk water. The historical THM and HAA data represents water that has been chlorinated and spent time within the distribution system. Therefore, it was not expected that there would be a strong positive correlation between these and the chlorine decay coefficient, which was determined using raw water. A linear regression performed using average historical THMs measured in the tap water vs. the chlorine decay coefficient did not find a significant relationship between the two. A weak but significant ($p < 0.05$) positive relationship was found between average historical HAAs in the tap water and the measured chlorine decay coefficient. Many of the participating communities do not remove organic material from the raw water however, so in these places, a correlation may exist between the chlorine decay constant and the historical average THM and HAA values. When the analysis was restricted to the 87% of the participating communities that do not provide water treatment that includes organic removal, significant positive relationships were found between the chlorine decay coefficients measured in the lab and historical average THM and HAA values.

Finally, the chlorine dose applied during the test can also influence the rate of decay. Figure 5.18 shows the decay measured over time for two samples with different initial doses of chlorine.

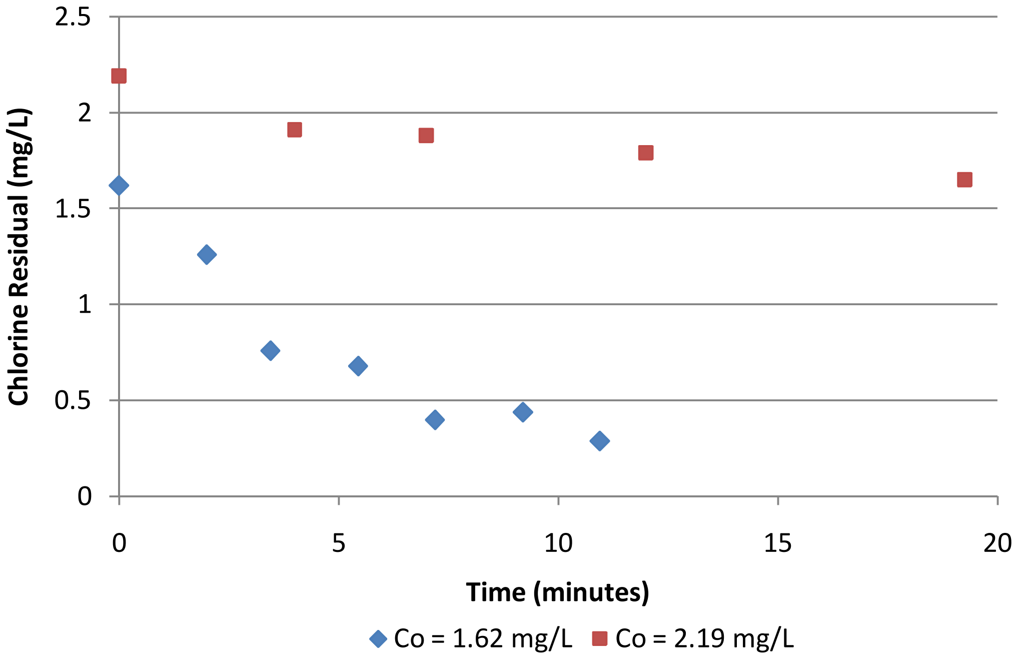


**Figure 5.18** **Chlorine decay in two water samples with different initial chlorine doses**

A full listing of the chlorine decay coefficients and $r^2$ values obtained in this study can be found in Appendix D of the report.

# CHAPTER 6 RECOMMENDATIONS

## 6.1 Introduction

The province of Newfoundland and Labrador has implemented the *Multi-Barrier Strategic Action Plan* (MBSAP) to begin to address the multitude of water-related challenges faced by the over 500 communities distributed throughout the province. The MBSAP includes source water protection, water treatment, distribution system maintenance, infrastructure improvement, water quality monitoring and reporting, inspection, ongoing research and development and interdepartmental collaborations.

At present, however, many communities in Newfoundland and Labrador, particularly those classified as ‘small’ or ‘very small’ lack formal water treatment. Instead, they rely exclusively on watershed protection and disinfection with free chlorine to remove and/or inactivate pathogens. A lack of formal water treatment, that is, treatment beyond simple chlorine disinfection, has been implicated in the occurrence of waterborne illness outbreaks (Wilson et al., 2009). It can also result in undesirable side effects like the formation of DBPs. Depending on the specific circumstances in each community, this higher risk might be mitigated by adding formal water treatment or by adjusting the disinfection strategy.

## 6.2 General Recommendations

### *6.2.1 Pathogen Reduction Requirements*

Water supply and pathogen reduction are often approached using the ‘multi-barrier’ concept. This is a nationally and internationally accepted water treatment and disinfection approach that encompasses source water protection, pathogen removal through formal water treatment and pathogen inactivation using disinfection processes such as chlorination, UV, ozone, chlorine dioxide or chloramines. A multi-barrier pathogen removal system helps to ensure that residents are provided with water that is consistently free of pathogenic organisms.

In determining the level of pathogen reduction that utilities will have to achieve, the province must balance the need for adequate disinfection with the challenges associated with achieving it in the small, rural communities that are struggling to comply with the provincial bacteriological standard and DBP guidelines.

Health Canada and all of other jurisdictions with disinfection regulations discussed in Chapter 3 of this report use log reduction, rather than CT, to quantify pathogen removal and/or inactivation. This approach has been adopted by public health agencies in many other parts of the world and has numerous advantages. For example, it encourages the use of filtration and/or alternative disinfectants for pathogen reduction.

A single CT value is not in and of itself sufficient to quantify pathogen reduction in all water treatment and disinfection processes. This is because the values in the CT tables describe the disinfectant contact required to remove a set amount of one type of pathogen using a specific disinfectant at a given temperature and pH. This means that one specific CT value means different things under different conditions. For example, a CT of 6 corresponds to 2.0-log inactivation of viruses using free chlorine at a temperature of 0.5$^{o}$C and a pH between 6 and 9. The same CT would provide 4.0-log inactivation at 10$^{o}$C. If ozone were used for disinfection, a CT of 6 would provide 4.0-log inactivation of both viruses and *Giardia*. UV inactivation of any pathogen is not accurately described by the CT concept.

A switch to use of log reduction will allow communities that employ engineered filtration systems to claim log removal credits for the pathogen removal taking place in the treatment train. This will reduce the amount of chlorination (ozonation, UV, etc) required to achieve adequate disinfection, which may in turn minimize the formation of DBPs within the distribution system. This will be of particular help to communities that achieve only partial organic removal in the treatment system and/or have long retention times within their distribution system.

Finally, by switching from CT to log reduction, the province will be in a better position to take advantage of the most recent innovations in disinfection technology and the guidance documents developed by federal and provincial regulators throughout North America.

Required or recommended log reduction levels for *Giardia*, *Cryptosporidium*, and viruses should be established by the ENVC. The levels chosen should reflect:

- The importance of adequate disinfection;
- Source water type and quality;
- The need to minimize DBP formation; and
- The challenges associated with major infrastructure upgrades in small and rural communities in the province.

It is suggested that the province consider setting the minimum disinfection requirement for all utilities using surface water or GUDI water sources at 4.0-log removal of viruses. This corresponds to a CT of 12 using free chlorine at a temperature of 0.5$^{o}$C and a pH between 6 and 9 or a UV dose of 186 mJ/c$^{2}$.

Communities that have experienced outbreaks of disease related to *Giardia* or *Cryptosporidium*, or whose water sources are known or suspected to be impacted by faecal contamination, should be encouraged or required to provide additional treatment. The GCDWQ recommendation of 3.0-log reduction of protozoa would be in line with other Canadian jurisdictions and should be considered as a reasonable option.

In practice, it should be noted that all surface water and GUDI water sources are likely exposed to faecal contamination from human, agricultural, or wildlife wastes. Wallis et al. (1996) detected *Giardia* cysts in over 30% of raw and treated water samples collected in the province. In that same study, approximately 10% of the samples collected in Newfoundland and Labrador were found to contain *Cryptosporidium*.

#### 6.2.1.1 EVALUATION OF PROPOSED DISINFECTION REQUIREMENTS

As discussed in Chapter 4, the original CBCL Limited proposal suggested that the participating communities be divided into bins based on their compliance with provincial disinfection requirements and DBP recommendations. Each of these bins has been assigned a letter in the CDID as shown in Figure 6.1.

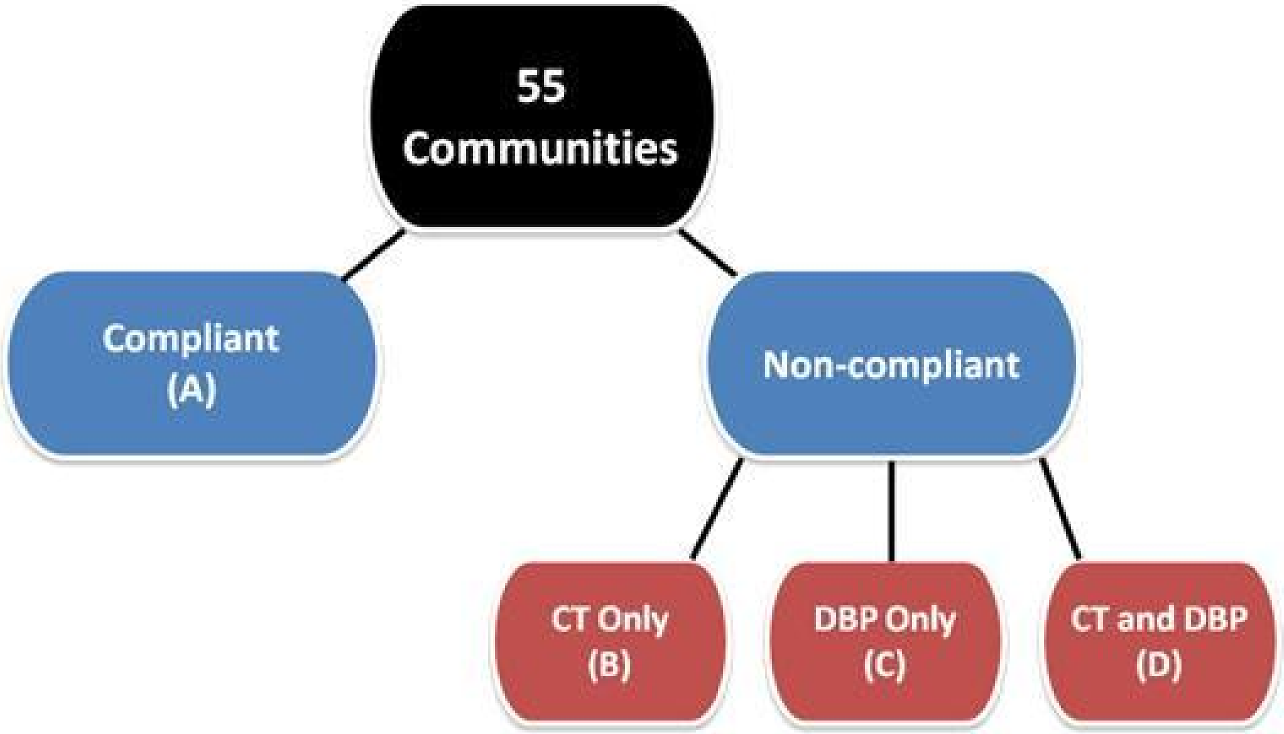


**Figure 6.1** **Division of communities into bins representing compliance with provincial disinfection requirements and DBP recommendations**

The CDID was initially used to assess whether each of the 55 participating communities was in compliance with the existing provincial disinfection requirements and DBP recommendations. The database was then used to assess whether changing disinfection requirements from a CT of 6 to 4.0-log reduction of viruses (+ 3.0-log reduction of *Giardia* and *Cryptosporidium* in communities where protozoa have been detected in the water supply) would impact the distribution of communities in the bins. The impacts of changing the disinfection requirements were assessed using the pH, temperature, and chlorine residual results obtained during the field program as well as at worst case conditions (temperature = 0.5°C, chlorine residual = 0.3 mg/L, pH = 8.5).

The results of the assessment are summarized in Table 6.1. Note that bins A and C represent communities that are in compliance with existing and/or proposed disinfection requirements, while B and D represent communities that are not.

**Table 6.1** **Number of communities in compliance with existing and proposed disinfection requirements and DBP recommendations**

| Scenario | A | B | C | D |
|---|---|---|---|---|
| *Standards for the Bacteriological Quality of Drinking Water* | 1 | 10 | 34 | 10 |
| Proposed Standard (field data)* | 2 | 9 | 31 | 13 |
| Proposed Standard (worst case conditions)* | 1 | 10 | 29 | 15 |

*3.0-log reduction of *Giardia* and *Cryptosporidium* only applied in communities where protozoa have been documented in the water supply

Only one community was found to be in compliance with both the provincial disinfection requirements and DBP recommendations. Ten communities were in compliance with DBP recommendations but not with CT requirements. Conversely, 34 communities were in compliance with CT requirements but not with DBP recommendations. Finally, 10 communities were out of compliance with both the CT requirements and the DBP recommendations. These results suggest that DBP non-compliance is more common than CT non-compliance, and that few communities are achieving compliance with both the current disinfection requirements and the DBP recommendations.

The results in Table 6.1 also suggest that, assuming that field conditions are relatively constant, instituting the proposed disinfection requirements will have only a minimal effect on the distribution of participating communities into the four designated bins.

Figure 6.2 shows how updating the regulations will affect the total number of communities in compliance with disinfection requirements (only participating communities were considered).

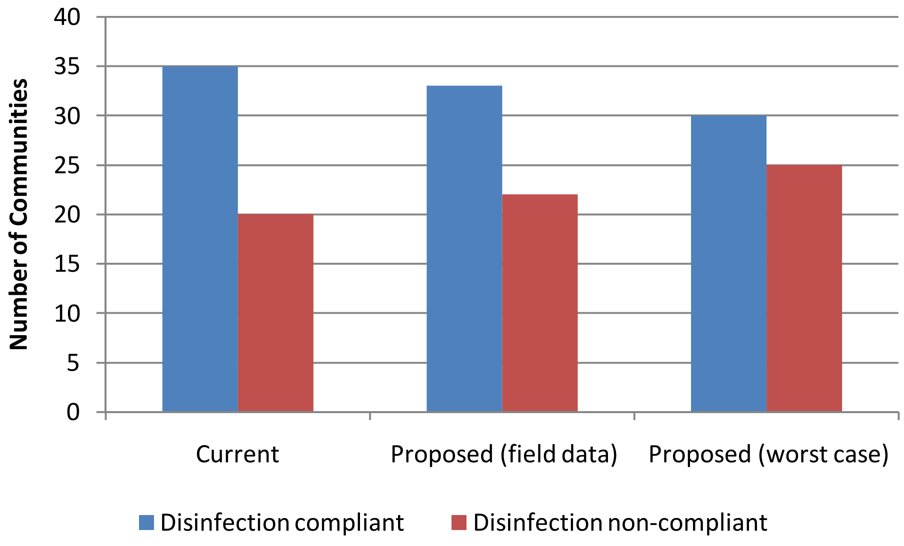


**Figure 6.2** **Total number of disinfection compliant and non-compliant participating communities**

Applying the proposed disinfection requirements to the communities in the CDID decreased the total number of disinfection compliant participating communities by two and solving the equations at worst case conditions decreased it by five. Based on these results, it is suggested that moving to the proposed disinfection requirements will not impact the compliance of most communities under normal conditions.

### *6.2.2 Recommendations for Achieving the Proposed Disinfection Requirements*

Recommended improvements for communities falling into the four CDID bins are shown in Table 6.2.

**Table 6.2 Recommended short and long-term solutions for communities in Newfoundland and Labrador assessed in the CDID**

| Bin | Description | Short Term | Long Term |
|---|---|---|---|
| A | CT and DBP compliant | No changes required | Continue monitoring the system to ensure compliance. |
| B | CT non-compliant<br>DBP compliant | Increase chlorine | Install filtration for pathogen removal, optimize disinfection system to increase contact time, install a booster station(s), provide a separate industrial water supply, and/or provide users with a potable water dispensing unit (PWDU). |
| C | CT compliant<br>DBP non-compliant | Decrease chlorine | Shorten contact time, install treatment equipment for organic removal or use alternative disinfectants to minimize the formation of DBPs, switch to a new water source, provide a separate industrial water supply, provide users with a potable water dispensing unit (PWDU), and/or use the decision making framework for selecting DBP corrective measures. |
| D | CT non-compliant<br>DBP non-compliant | BWA | Provide a separate industrial supply, install a water treatment system to remove pathogens and/or organics, provide users with a potable water dispensing unit (PWDU), use the decision making framework for selecting DBP corrective measures, and/or conduct an IDDF study. |

Many of the recommendations in Table 6.2 have been implemented in Newfoundland and Labrador. Other jurisdictions have also encountered difficulties attempting to balance the risks associated with disinfection non-compliance with those of DBP formation, particularly in small communities. As discussed in Chapter 3 of this report, Saskatchewan has permitted some small communities to apply to be designated ‘hygienic water systems’. These are mostly limited to communities with fewer than 100 residents who are experiencing population decline or whose water treatment systems are nearing the end of their useful life. Hygienic water systems must still be chlorinated and monitored and an alternate potable water source that does meet provincial disinfection requirements must be provided (SME, 2006).

This arrangement is somewhat analogous to the situation in some communities in Newfoundland and Labrador that have installed potable water dispensing systems. A designation system similar to that in Saskatchewan could allow some very small communities in this province to provide their residents with safe drinking water without shouldering the cost of extensive system upgrades if or when new disinfection regulations are introduced by the provincial government. Such a system may also encourage the adoption of potable water dispensing units (PWDUs) in the province.

### *6.2.3 Source Water Protection and Monitoring*

Newfoundland and Labrador has a well-established source water protection program. Many communities in the province draw their water from protected water sources. Upcoming federal disinfection guidelines encourage municipalities and system designers to take into account the characteristics and quality of the raw water source when determining the level of treatment required for a given community. Individual provinces have chosen to interpret these recommendations in different ways.

In some, such as Alberta and Nova Scotia, existing or proposed regulations require that even pristine surface water sources achieve 3.0-log removal of protozoa and 4.0-log removal of viruses. Source waters that are impacted by seasonal changes in water quality, human development, agriculture, and/or wastewater discharges will be required to provide even higher levels of disinfection.

Other jurisdictions, including the US EPA, make exceptions for systems that meet very specific requirements. For example, the *Surface Water Treatment Rule* recommends that all water systems served by surface water or GUDI sources be required to filter unless they conform to all of the following criteria:

- Disinfection reliably achieves at least a 99% (2.0-log) reduction of *Cryptosporidium* oocysts, a 99.9% (3.0-log) reduction of *Giardia lamblia* cysts and a 99.99% (4.0-log) reduction of viruses. Overall inactivation must be met using a minimum of two disinfectants. More than a 99% (2.0-log) reduction of *Cryptosporidium* oocysts and more than a 99.9% (3.0-log) reduction of *Giardia lamblia* cysts must be achieved if source water cyst/oocyst levels are greater than 1/100 L. Background levels for *Giardia lamblia* cysts and *Cryptosporidium* oocysts in the source water must be established by monitoring every quarter or more frequently during the periods of expected highest levels (e.g., during spring runoff or after heavy rainfall).
- Prior to the point where the disinfectant is applied, the source water *E.coli* concentration does not exceed 20/100 mL, or the total coliform concentration does not exceed 100/100 mL, in at least 90% of the weekly samples from the previous six months.
- Average daily source water turbidity levels measured at equal intervals (at least every four hours) immediately prior to where the disinfectant is applied do not exceed 5.0 NTU for more than two days in a 12-month period.
- A watershed/aquifer control program (e.g., protected watershed/aquifer, controlled discharges, etc.) is maintained that minimizes the potential for faecal contamination in the source water.

(US EPA, 1989)

The US EPA's LT2ESWTR is focused on establishing pathogen levels in surface water supplies to determine what levels of treatment and disinfection are required to meet disinfection requirements. Larger communities are required to take monthly *Cryptosporidium* samples while smaller communities must measure *E.coli* levels. In both cases the aim is to establish the levels of enteric pathogens present in the water supply. Communities are sorted into bins according to the results of their monitoring program and assigned log reduction requirements accordingly.

The province of Newfoundland and Labrador may want to consider developing a monitoring program similar to that described in the LT2ESWTR from the US EPA. Larger communities in particular could be required to take monthly samples of their raw water to establish the presence and baseline number of *Giardia* cysts and/or *Cryptosporidium* ooscysts in their source water. The province may also opt to conduct monitoring programs in a selection of representative communities with smaller population. The City of Corner Brook has already undertaken *Giardia* and *Cryptosporidium* monitoring programs and may be able to provide templates for the implementation of such programs in other parts of the province.

It should be noted that as the tests required to detect and enumerate *Cryptosporidium* are complex and expensive, the LT2ESWTR recommends that small utilities (< 10,000 users) monitor their source water for *E.coli* instead. Recent findings, however, suggest that *E.coli* is a poor indicator organism for Cryptosporidium (Nieminski et al., 2010). It is therefore not recommended that the province of Newfoundland and Labrador ask small utilities to monitor for *E.coli* in their source water in an attempt to quantify the risk posed by *Cryptosporidium* in each community.

Alternatively, the province may want to consider the Irish approach. In 2008, all Irish utilities were required to perform a risk assessment to determine the likelihood of *Cryptosporidium* exposure through the municipal drinking water system (EPA, 2008). The Office of Environmental Enforcement at the Irish EPA developed a guidebook to help communities sort through the complex requirements of the assessment. It includes a detailed questionnaire that helps the user calculate a 'risk assessment score', which can be used to classify the system as low risk, moderate risk, high risk, or very high risk. Details can be found in the *Drinking Water Regulations Guidance Booklet No.4 – Risk Screening Methodology for Cryptosporidium*, which is included in the recommended reading list in Appendix A. A somewhat similar program was described in the initial draft of the proposed *Municipal Drinking Water Standard* (2010 - Draft) in Nova Scotia.

If the Irish approach is chosen, care should be taken to ensure that communities are provided with the resources required to complete their assessment. This may take the form of site visits from trained government staff who can guide operators and community representatives through the questionnaires and address any remaining unknowns while on site. Site visits might be timed to coincide with scheduled water quality sampling or operator training visits.

### *6.2.4 Primary Disinfection*

Primary disinfection, or pathogen reduction, is distinct from secondary disinfection, which refers to the maintenance of a disinfectant residual throughout the distribution system. To improve the operation of both stages, the province might choose to encourage utilities to separate primary disinfection from secondary disinfection by establishing, monitoring, and enforcing specific requirements for each stage of the disinfection system. Most jurisdictions define primary disinfection as pathogen removal and/or inactivation (usually within a treatment plant), while secondary disinfection usually involves the addition of chlorine or chloramines to the finished water to prevent pathogen re-growth and provide a simple, easy to measure indicator of microbiological water quality throughout the distribution system. The primary disinfection system may include engineered filtration, chemical disinfectants such as free chlorine or ozone, or physical disinfection processes such as UV radiation. Some systems will rely on only one or two of these, while others will include all three.

#### 6.2.4.1 CHLORINE CONTACT

Many communities in Newfoundland and Labrador rely exclusively on free chlorine for pathogen inactivation. These communities should be encouraged to establish a designated chlorine contact volume with a set flow rate paired with separate storage volume to buffer variations in water demand. This will help to ensure that all the water used by the community receives adequate disinfection and will allow the community to calculate CT based on the flow rate through the contact volume. This is of particular importance in communities with large differences between summer and winter flows and those with large industrial users.

Additional recommendations for communities relying on free chlorine for disinfection include:

- The chlorine residual at the outlet of the chlorine contact volume should be monitored regularly (ideally on a continuous basis) and used to calculate the CT achieved;
- Utilities should be encouraged to include baffling in the contact volume to encourage more effective chlorine mixing; and
- Communities that rely on a transmission main for chlorine contact should be able to achieve adequate log removal rates at peak flow before the first user. This may mean changing the size or configuration of the transmission main.

#### 6.2.4.2 FILTRATION AND ALTERNATIVE DISINFECTANTS

Communities may also choose to use filtration or alternative disinfectants to achieve primary disinfection requirements. Filtration is generally preferred for *Cryptosporidium* and *Giardia* removal because of the onerous CT requirements associated with their inactivation by free chlorine. Engineered filtration is generally required in provinces where water treatment facilities are required to meet specific *Cryptosporidium* reduction requirements. The use of filtration for pathogen removal can also minimize the amount of chemical required for primary disinfection purposes. Various jurisdictions have assigned log removal credits, ranging from 0.5 to 3.0-log, to different ‘engineered’ filtration processes. Traditional (or conventional) water treatment systems include coagulation, clarification, and filtration steps. Other engineered filtration processes include direct filtration, slow sand filtration, and membrane filtration.

An advantageous side-effect of some engineered filtration systems is the removal of natural organic matter. This reduces the likelihood of DBPs in the treated water distributed to users. Engineered filtration systems that can be optimized to achieve significant removal of NOM are usually those that include coagulation:

- Conventional treatment (coagulation, flocculation, sedimentation, and filtration);
- Direct filtration (coagulation, flocculation, and filtration); and
- Dissolved air flotation (coagulation, flocculation, flotation, and filtration).

Other treatment processes, including low pressure membrane filtration with coagulation pre-treatment, nanofiltration (NF) , reverse osmosis (RO), activated carbon (granular or powdered), and certain resins can also be used to remove organic matter. Some of these are only assigned log removal credits by some jurisdictions, however, either because they are difficult to monitor (membrane filtration processes) or because they do not provide an adequate physical barrier to microorganisms (activated carbon, resins). Where feasible, communities that choose to incorporate water treatment for pathogen removal should be encouraged to choose processes that reduce the potential for DBP formation (and vice versa).

Alternative disinfectants can reduce the potential for the formation of the DBPs commonly associated with chlorination, namely THMs and HAAs. Unfortunately, they often carry other DBP risks. For example, ozone can react with bromine in the raw water to form bromate, a non-organic DBP.

#### 6.2.4.3 POTABLE WATER DISPENSING UNITS

Seven communities in Newfoundland and Labrador have constructed small scale potable water dispensing units (PWDUs) to provide high quality drinking water to residents. These systems are designed to provide enough water to fulfill the water consumption needs of the community, that is, all of the water required for drinking, cooking, and tooth brushing. Chlorinated water continues to be provided through the existing distribution system for showering, toilets, and other household uses. Four of the existing PWDUs rely on RO membranes to remove turbidity and colour from the water while the remaining three employ ozone and filtration. Many of the systems also include UV disinfection units.

The province has since undertaken an initiative to install PWDUs in more communities in the province. The new PWDUs will incorporate design elements from both types of existing PWDUs. First, water will be screened to remove excessive turbidity and ozone will be added. The ozone will oxidize dissolved metals and organic matter in the water and cause them to precipitate. These precipitates will be removed through multi-media and granular activated carbon filtration. Next, the water will undergo RO filtration and be disinfected with UV light. The clean, disinfected water will then be dispensed through taps located in a separate room.

The existing PWDUs are usually connected to the distribution system in each community, meaning that the influent water is pre-treated and/or pre-chlorinated and thus should not require any additional disinfection to meet provincial requirements. This will also be the case for most of the PWDUs that are slated for construction in the coming years. Some, however, may be connected to non-disinfected water sources. As well, if and/or when more stringent disinfection requirements are adopted by the provincial government the pre-treatment and pre-chlorination received upstream of the PWDU may no longer be sufficient. Additional pathogen reduction will be required within the PWDU treatment process to ensure that the water being dispensed to users is in compliance with disinfection regulations.

The new PWDU design is able to provide at least 3.0-log reduction of *Giardia* and *Cryptosporidium* (through ozone and UV) as well as 4.0-log reduction of viruses (ozone). It is also anticipated that the RO will provide an effective barrier against pathogens. Thus, the new PWDUs may represent a reasonable option for small communities who cannot otherwise afford to provide users with drinking water that meets provincial disinfection requirements.

If and/or when new disinfection requirements are implemented in the province, the ENVC and the Department of Municipal Affairs (DMA) should develop a program similar to that in Saskatchewan where communities could apply to be designated ‘hygienic water systems’. Communities with such designations could then be permitted to rely on PWDUs or other alternative water sources to meet disinfection requirements. This would allow them to avoid the need to incorporate expensive upgrades into their existing water systems. As in Saskatchewan, the designation should be limited to small communities with stagnant or declining populations who lack the operational and financial resources to comply fully with provincial disinfection requirements. Note that the program in Saskatchewan requires that communities continue to chlorinate and monitor the chlorine residual in the hygienic water supply.

#### 6.2.4.4 SYSTEM MONITORING

Continuous monitoring of all processes used for pathogen removal or inactivation is recommended because in addition to ensuring that pathogen reduction requirements are met consistently, it will improve the operator’s ability to manage and optimize the quality of water delivered to customers.

The following parameters could be monitored to quantify pathogen reduction in the primary disinfection system:

- The turbidity of the effluent from a filter used for pathogen removal;
- The disinfectant residual at the outlet of the disinfectant contact volume; and/or
- The transmittance of the water flowing through a UV system.

#### 6.2.4.5 REDUNDANCY

Equipment redundancy will also help to ensure that users are provided with adequately disinfected water at all times. That is, communities should be required to install two copies of each piece of essential disinfection equipment. For example:

- Filters used for pathogen removal;
- Chlorine dosing pumps; and
- UV disinfection lamps.

Redundant equipment should be connected to the system such that it is easy to switch between the primary and secondary versions of each process.

Some jurisdictions also require that water treatment systems provide multiple pathogen reduction steps. For example, in Nova Scotia utilities are required to provide 4.0-log reduction of viruses and 3.0-log reduction of *Giardia*, 0.5-log of which must be accomplished using a designated disinfection step (chemical addition or UV). This ensures that a minimum level of disinfection is provided even if a filter used for pathogen removal breaks down.

Equipment and process redundancy helps to minimize the risk of exposure to pathogens from drinking water. A requirement for one or both might be appropriate for large systems in Newfoundland and Labrador (at minimum).

### 6.2.5 Secondary Disinfection

The monitoring requirements listed in the *Standards for Bacteriological Drinking Water Quality* and in place throughout the province are comparable to those in other jurisdictions and appear to be working adequately. Operators should continue to monitor chlorine residuals at multiple locations on the distribution system.

The current design guidelines in Newfoundland and Labrador require that a detectable chlorine residual be maintained throughout the distribution system (ENVC, 2005). The detection limit for free chlorine using a common Hach handheld chlorine meter has been estimated by the manufacturer to be 0.02 mg/L, making this the de facto minimum residual for the province. Meters from other manufacturers may have different detection limits.

In Nova Scotia, a minimum residual of 0.2 mg/L of free chlorine must be present in the distribution system (NSE, 2002). The draft version of the proposed guidelines for that province suggest a minimum combined chlorine residual of 1.0 mg/L when chloramines are being used for secondary disinfection (NSE, 2010 – Draft). The Ten States Standards for Water Works also recommends a minimum residual of 0.2 mg/L for free chlorine and 1.0 mg/L for chloramines, depending on the disinfectant employed (SPPHEM, 2007). The province of Newfoundland and Labrador may consider adopting these values as guidelines at some point in the future, though it will be necessary to balance the risks of bacterial regrowth with those of increased DBP formation.

The province may also consider entering monthly bacteria and chlorine residual results from water samples taken by the Department of Government Services into the disinfection database and/or use them to evaluate compliance with the pathogen reduction requirements of the *Standards for Bacteriological Drinking Water Quality* using the pathogen reduction calculator.

### 6.2.6 Boil Water Advisories

The majority of the BWA categories used by the ENVC are in line with the requirements of other jurisdictions and will continue to be widely applicable as the province moves forward with the MBSAP.

The total number of BWAs might eventually be reduced by:

- Increasing pathogen reduction requirements;
- Removal of chlorine consuming parameters such as iron, manganese, and DOC from the raw water before chlorination/disinfection;
- Redundant equipment;
- More effective operator education; and/or
- Continuously monitoring the disinfection system.

Counter-intuitively, some of these improvements may result in an initial increase in BWAs as weaknesses are discovered in the design and operation of water systems in some communities. Despite this, in the long term the identification of these weaknesses will allow operators and regulators to judge if and when the disinfection system is not operating as intended, which will result in more effective operation and maintenance of the system and fewer BWAs.

Continuous monitoring, in particular, will help regulators pinpoint the cause of non-compliance with the bacteriological standard once a BWA has been called – minimizing its length and impact on the community. For example, the source of the coliforms detected at a monthly sampling point in the distribution system might be traced to carryover from the raw water if the continuous chlorine monitoring system indicates that the system is not achieving adequate pathogen removal. If the primary disinfection system is found to be operating normally, the operator can investigate other parts of the water system.

## 6.3 Updates to Existing Documents

### 6.3.1 Standards for Bacteriological Quality of Drinking Water

Disinfection guidelines and regulations in various North American jurisdictions were compared in Chapter 3. The majority of these rely on the log reduction concept to quantify the reduction of specific pathogens such as *Cryptosporidium*, *Giardia*, and viruses. For example, the GCDWQ recommends that utilities achieve 3.0-log removal of *Cryptosporidium* and *Giardia* and 4.0-log of viruses. Complying with these recommendations can have significant impacts on the design of water systems.

The *Standards for Bacteriological Quality of Drinking Water* in Newfoundland and Labrador currently require that utilities achieve 20 minutes of chlorine contact time and that the chlorine residual at the first user be at or above 0.3 mg/L, or failing this, that the equivalent CT (6) be met. Note that a CT of 6 provides 2.0-log inactivation of viruses at 0.5°C and a pH between 6 and 9. It does not provide any appreciable inactivation of *Giardia* or *Cryptosporidium*.

The standard also notes the maximum acceptable concentration of 0 for total coliforms and faecal coliforms recommended in the GCDWQ, but sets the following province-specific requirements:

- No sample should contain *Escherichia coli* (*E.coli*); and
- No consecutive samples from the same site or no more than 10% of the samples from each distribution system in a given sample set should show the presence of total coliforms.

The ENVC has expressed interest in updating these requirements, and might choose to look to the pathogen reduction recommendations and requirements in other Canadian provinces and the United States as guides. As an initial step, the standard should be re-written such that log reduction is emphasized as opposed to CT. This will mean that instead of a CT of 6, utilities will be required to provide 2.0-log removal of viruses. Short sections explaining how log reduction can be achieved using filtration, chlorine, and alternative disinfectants should be included in the standard and the CT tables should be appended. If disinfection requirements are made more stringent, the standard will have to be updated to reflect this. As the revised standard will address virus and protozoa reduction in addition to monitoring and inactivation of bacteria, the title of the document should be changed from the *Standards for Bacteriological Quality of Drinking Water* to the *Drinking Water Disinfection Standard* (or something similar) to more accurately describe its rationale and contents.

### *6.3.2 Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems*

The province currently has a detailed water treatment system design guidance document entitled *Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems*. If disinfection requirements are changed, this document will have to be updated accordingly. Sections discussing the use of filtration and other forms of water treatment for pathogen removal and inactivation should be included in the updated guidelines. These sections should include specific design requirements for system components but should nonetheless be kept concise to encourage use amongst designers.

A number of small corrections should also be made to Chapter 4 of the guidelines. For example, alternative disinfectants, including UV, chloramination, and ozone, should be mentioned and briefly explained at the beginning of Chapter 4. The existing log inactivation section should be removed and replaced by a section outlining how log reduction is to be applied to the design of water treatment and disinfection systems. This chapter should be shortened, made more concise, and updated with details from the most current versions of the *Ten State Standards*, *Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution, and Operation of Drinking Water Supply Systems*, and the various guidance documents prepared by Health Canada (available online).

### *6.3.3 Department of Municipal Affairs Design Requirements*

The DMA is in the process of developing a document entitled *Generic Terms of Reference* (GTR), which is to be used during the design and construction of new water treatment plants in the province. A preliminary version of this document was provided to the consultant for review. The GTR will require that all new water treatment facilities provide 3.0-log removal of *Giardia* in addition to 4.0-log removal of viruses. This does not match the requirements of the province's *Standards for Bacteriological Quality of Drinking Water* or the existing design guidelines, which may lead to confusion during the design and approval processes. It is, however, in line with the disinfection recommendations of the GCDWQ, which were discussed in Chapter 3 of this report.

The eventual implementation of the GTR should be viewed as one of many positive steps that the provincial government is taking towards improving disinfection effectiveness throughout the province. Care will have to be taken to ensure that consultants, operators, and municipal staff are not confused by conflicting requirements and/or recommendations. To simplify the overall process, it may be wise to combine the GTR with one of the existing documents (*Standards for Bacteriological Quality of Drinking Water* or design guidelines).

## 6.4 Implementation of New Disinfection Requirements in Newfoundland and Labrador

Changes to the existing drinking water disinfection requirements should be phased over a number of years to allow the ENVC time to assess existing systems and educate operators and for communities to line up the funding necessary to upgrade their water systems.

The province should consider implementing the following tasks over a four to six year period:

1. Negotiate required changes to provincial drinking water disinfection requirements internally and prepare necessary programs, documentation, and operator education modules.

2. Establish a timeline for disinfection compliance for communities in the province. This may be tiered based on population.
3. Require that all communities complete a surface water and/or system assessment to establish current levels of compliance and future disinfection requirements.
4. Determine what improvements will be required to bring non-compliant systems in line with proposed disinfection requirements.
5. Communicate the specifics of these improvements to communities.
6. Help communities plan for the necessary upgrades and source the required funding.
7. Oversee the implementation of upgrades and develop an approval process for water systems to ensure that disinfection compliance is achieved in new and upgraded systems.
8. Enforce disinfection requirements continuously by monitoring both primary and secondary disinfection effectiveness at both a municipal and provincial level.

Note that public and operator education will have to precede any major changes in drinking water disinfection practices in the province to ensure co-operation and compliance.

# CHAPTER 7 SUMMARY

## 7.1 Findings

A review of the disinfection requirements and recommendations in Canadian provinces and the United States revealed that all of these jurisdictions quantify disinfection using the log reduction model. That is, most specify levels of reduction for microorganisms that are associated with common waterborne diseases including *Giardia, Cryptosporidium*, and viruses. Many of these tie the level of reduction required to the quality of the source water. Once the reduction level is known, the utility/designer can then calculate or look up the CT required to achieve compliance.

Historical water quality records were provided to CBCL by the ENVC at the beginning of the project. Most of the communities who participated in the study are supplied by surface water that is characterized by high concentrations of NOM and low pH, alkalinity, and turbidity. Many of these communities have experienced difficulties due to the formation of DBPs such as THMs and HAAs in the tap water. Some have also had trouble maintaining a free chlorine residual.

The total number of BWAs issued each year that have been related to distribution system upgrades, coliform detection, and non-compliance with disinfection requirements have increased in recent years, while those associated with lack of chlorination equipment, malfunctioning equipment, or improper operation have levelled off. This suggests that improvements in equipment availability and operator education have reduced the number of new BWAs in many communities and that government programs designed to enforce the *Standards for the Bacteriological Quality of Drinking Water* have been successful at detecting areas of non-compliance.

Chlorine decay coefficients were calculated for water samples obtained during site visits conducted by CBCL technical staff. The decay coefficients ranged from less than zero to above 200 day$^{-1}$. Water samples from communities with a history of high NOM levels in the raw water and/or elevated levels of DBPs in the tap water had higher chlorine decay coefficients than those from communities with drinking water treatment systems optimized for organic removal or that are supplied by groundwater sources.

Of the 55 participating communities, 64% were found to be in compliance with the province’s CT requirements. Only one was in compliance with both the current CT requirements and DBP recommendations. When calculations were run using the proposed disinfection requirements and the pH, temperature, and chlorine residual data collected during the site visits, 60% of the communities

(33/55) were in compliance. The calculations were run again under worst case conditions (temperature of 0.5°C, pH of 8, chlorine residual of 0.3 mg/L) and 55% of communities (30/55) remained in compliance with the proposed disinfection requirements.

## 7.2 Deliverables

The deliverables for the study are included on the CD-ROM. They include:

- GIS shapefiles indicating the point of disinfection, the first user, water storage infrastructure, and the approximate 20 minute chlorine contact point;
- An updateable and filterable database of community disinfection infrastructure and minimum CT and log reduction levels; and
- A program designed to calculate instantaneous CT and log reduction based on measured pH, temperature, flow (L/min), and chlorine residual data.

## 7.3 Recommendations

**The province should consider adopting a log reduction based framework to replace the existing CT based disinfection framework.**

The simplest but most effective short-term improvement that the ENVC can make is to switch from the CT model to the log reduction model for disinfection to bring the province in line with the rest of the country. Depending on the log reduction levels chosen, this may not result in any need for changes in system design or operation in most communities. Instead, it will shift the focus of operators and system designers from chlorine contact time to pathogen reduction. This in turn is likely to encourage the adoption of filtration and/or alternative forms of disinfection, which may help some municipalities reduce the formation of DBPs.

**Disinfection requirements should appropriately reflect the need to manage and minimize public health risks associated with drinking water, particularly for communities with a history of outbreaks or known water quality risk factors.**

Specifically, communities are currently required to achieve 20 minutes of chlorine contact time with a minimum residual of 0.3 mg/L. This works out to a CT of 6 or 2.0-log reduction of viruses at a temperature of 0.5°C and pH between 6 and 9. This is less stringent than the disinfection requirements in most parts of Canada.

Future required or recommended log reduction levels will have to be established by the ENVC, possibly in consultation with other government departments. These should take into account the requirements established in other Canadian provinces while acknowledging the distinct challenges faced by small, rural communities in Newfoundland and Labrador. For example, the province might consider requiring a minimum of 4.0-log removal of viruses for all surface water and GUDI systems and 3.0-log removal of *Giardia* and/or *Cryptosporidium* in communities that have experienced outbreaks of these protozoa or whose water sources are known or suspected to be vulnerable to faecal contamination. A program that would allow smaller communities that lack the operational and/or financial resources required to upgrade their water systems to meet disinfection requirements using an alternative water source (i.e., PWDUs) could be implemented. Such should require that existing municipal systems continue to be disinfected and monitored to minimize the public health risk associated with pathogens in water used for personal hygiene.

**New disinfection requirements should be rolled out gradually over a four to six year time period.**
Most Canadian provinces have strengthened their disinfection requirements significantly over the past ten years in the wake of the Walkerton and North Battleford tragedies. These improvements have been implemented gradually to allow communities, operators, and regulators sufficient time to assess the extent of required changes and line up the funding required to implement them.

**Water supplies should be evaluated to determine the risks posed by enteric pathogens such as *Giardia* and *Cryptosporidium*.**
This may take the form of source water quality monitoring as proposed by the US EPA (12 months of *Giardia/Cryptosporidium* sampling) or site assessments similar to those used in Ireland. Should the latter be chosen efforts should be made to conduct a site visit to each community to complete the assessment instead of relying exclusively on the results of a survey-based study. The ENVC and DMA may consider running the program concurrently with Operator Education, Training, and Certification Section site visits.

It may also be possible to use a tiered approach to source water assessment. Larger communities could be required to collect monthly raw water samples for a full year while smaller communities would be required to complete a system assessment. The cut-off between large and small communities will have to be established by the ENVC and DMA.

Note that other jurisdictions that require source water monitoring to establish baseline levels of pathogens conduct this testing to increase the amount of pathogen reduction required. That is, all treatment and disinfection systems in these jurisdictions are required to achieve a minimum of 2.0 or 3.0-log reduction of *Giardia* and/or *Cryptosporidium* irrespective of the results of the source water monitoring program. If higher levels of pathogens are detected in the source water the community is required to provide additional reduction above and beyond the minimum requirements.

Alternatively, a blanket assumption could be made that all surface water and GUDI sources are contaminated with enteric pathogens and require that all water treatment systems using such sources achieve a certain level of pathogen reduction.

**Primary and secondary disinfection requirements should be clearly distinguished from one another in all government publications.**
The province should consider writing separate rules for primary and secondary disinfection. This will ensure that all the water used by the community receives adequate disinfection. For example:

Primary disinfection:
- Communities should be encouraged to install redundant equipment and/or disinfection steps such that pathogen reduction is not compromised when one portion of the system breaks down;
- Where possible, a defined chlorine contact volume should be included within the treatment plant;
- The chlorine residual at the outlet of the chlorine contact volume should be monitored regularly (ideally on a continuous basis);

- The effectiveness of filters or other treatment equipment used for pathogen removal or inactivation should also be monitored continuously (ex. turbidity at filter outlets);
- New chlorine reaction tanks and storage volumes should be required to include baffling to ensure effective chlorine mixing and prevent short-circuiting and water stagnation;
- Communities that rely on a transmission main for chlorine contact should be able to achieve adequate log removal rates at the peak hour flow before the first user - this may mean changing the size or configuration of the transmission main;
- Communities should be encouraged to install appropriately sized water storage between the point of chlorination and the first user in order to balance peak hour demands and fire flows. CT can then be calculated based on the maximum flow rate between the point of chlorination and the storage volume.

Secondary disinfection:
The province's secondary disinfection requirements are comparable to those in most other jurisdictions. The ENVC may want to consider setting a minimum chlorine residual (i.e., 0.2 mg/L) rather than requiring a 'detectable' chlorine residual. This will help to minimize inconsistency among different instruments. The province may also consider keeping the results of monthly chlorine residual and coliform testing in a centralized database.

**Standards, guidance documents, and operator education modules must be updated to reflect new disinfection requirements.**
This will include the:

- *Standards for Bacteriological Quality of Drinking Water* (ENVC);
- *Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems* (ENVC);
- *Proposed General Terms of Reference* (DMA);
- *Drinking Water Manual:* Parts 1-5 (Department of Health and Community Services); and
- *Chlorine Equipment Selection Guide* (ENVC, DMA).

The ENVC and DMA may want to consider amalgamating some of these documents. It is imperative that disinfection requirements be consistent in all government documentation to avoid confusion during the design of new and upgraded water treatment processes.

**Design requirements should be laid out in a concise matter such that system designers can easily conform to the expectations of the ENVC and the DMA.**
System designers are currently expected to conform to the disinfection requirements of the *Standards for Bacteriological Quality of Drinking Water*, the *Guidelines for the Design, Construction, and Operation of Water and Sewerage Systems*, and the internal requirements of the ENVC and DMA. Some of these requirements conflict with one another, making it difficult for designers to establish water quality priorities.

Disinfection regulations and design requirements should be presented in a clear and concise manner to simplify the design and approval processes. For example:

- All government documents relating to the design of drinking water disinfection systems should list the same disinfection requirements;

- Information about pathogen removal through filtration and pathogen inactivation using alternative disinfectants should be provided;
- Background information should be condensed and moved to appendices; and
- Specific design requirements (i.e., filtration, redundancy, continuous monitoring, log reduction using prescribed treatment processes) and water quality goals (turbidity, coliforms, DBPs) should be written clearly at the beginning of the design guidelines.

**The province should consider contacting officials in other jurisdictions to learn more about the disinfection programs they have implemented.**
The provincial government may find it useful to enter into dialogue with provincial/state and federal government departments in other jurisdictions that serve communities similar to those assessed in this study. For example, the Saskatchewan Ministry of the Environment has extensive experience implementing improved disinfection regulations in small communities. Ontario, Nova Scotia, and Alberta are continuously updating their disinfection requirements to take into account advances in the water industry and academia. Officials from Ireland, Scotland, and Alaska, all of which share many characteristics with Newfoundland and/or Labrador, may also be of help.

## 7.4 Opportunities for Future Study

### Proposed Study A – Monitoring of Protozoa in Surface Water Sources

A program to monitor the occurrence of protozoa such as *Giardia* and *Cryptosporidium* in surface and GUDI source waters would allow the ENVC to identify communities that should be held to a higher standard of pathogen reduction. At least two communities are known to have undertaken such studies already; Deer Lake (*Giardia*) and Corner Brook (*Giardia* and *Cryptosporidium*). Possible templates include the source water evaluation program delineated in the US EPA's LT2ESWTR or the Risk Screening Methodology for Cryptosporidium designed by the Irish EPA.

### Proposed Study B – Disinfection Profiling

A disinfection profiling study adapted from the IESWTR and LT1ESWTR could be conducted in a small number of communities to evaluate the effectiveness of existing disinfection procedures. Ideally, small communities with different treatment systems would be compared to one another and to (at least) one community without treatment to establish what treatment strategies are most effective at improving disinfection and DBP compliance in small communities.

- Confirm the configuration of the chlorine contact volume;
- Measure chlorine residual at the end of the contact volume for 12 months;
- Use the CT and log reduction calculator to determine CT inactivation ratio and log reduction;
- Measure influent water quality (i.e.. after any treatment, before disinfection):
    - DOC;
    - UV254;
    - pH;
    - Temperature;
    - Iron; and
    - Manganese.

- Measure DBPs at specific locations within the community to establish whether water quality variations are due to changes in water demand, raw water quality, or chlorination practices.

**Proposed Study C – Chlorine Dosage Optimization Using the Integrated Disinfection Design Framework**

The IDDF could be used to optimize the chlorine dose in some of the communities identified in this study as having both disinfection and DBP compliance issues (Bin D).

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APPENDIX A

# Recommended Reading

Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution, and Operation of Drinking Water Supply Systems (2004)

Guidance Manual for Conducting Sanitary Surveys of Public Water Systems; Surface Water and Ground Water Under the Direct Influence (GWUDI)
EPA 815-R-99-016, April 1999

Alternative Disinfectants and Oxidants Guidance Manual
EPA 815-R-99-014, April 1999

Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual
EPA-815-R-99-015, August 1999

Disinfection Profiling and Benchmarking Guidance Manual
EPA-815-R-99-013, August 1999

Low-pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues
EPA 815-C-01-001 April 2001

Membrane Filtration Guidance Manual
EPA 815-R-06-009, November 2005

Ultraviolet Disinfection Guidance Manual
EPA 815-R-06-007, November 2006

Drinking Water Regulations Guidance Booklet No.4 – Risk Screening Methodology for Cryptosporidium, Irish Environmental Protection Agency, January 2008

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Québec, Ministère Développment durable, Environment et Parcs (2006) Guide de conception des installations de productions d’eau potable (French)

APPENDIX B

# Information Collection Sheet

## Operator Questionnaire

This section to be filled out by the technician with input from the system operator.

### * 1. Community Name

### 2. Have you been certified as a water treatment or distribution operator?

○ Yes

○ No, but I am currently preparing to write the exam

○ No, but I have taken a number of courses

○ No

Courses taken:

### 3. Have you ever been visited by a Mobile Training Unit (MTU)?

○ Yes

○ No

### 4. Are as-built drawings available for the water system?

☐ Water supply system

☐ Water treatment system

☐ Water storage system

☐ Water distribution system

☐ No as-built drawings available

### 5. Describe any water treatment equipment used by the community.

| | |
|---|---|
| Type | |
| Make | |
| Model | |
| Date of installation | |
| Operational status | |
| Other | |

## 6. What type(s) of disinfection is (are) used in this community?

- ☐ Chlorine (gas)
- ☐ Chlorine (liquid)
- ☐ Chloramines
- ☐ Ozone
- ☐ UV
- ☐ Chlorine dioxide

Other (please specify)

## 7. If you add a chemical for disinfection (chlorine, ozone, etc), how much do you add?

Volume

Concentration

Weight

Other (please specify)

## 8. How do you measure the amount of chemical added to the water?

## 9. Describe the disinfection equipment.

Type

Make

Model

Date of installation

Operational status

## 10. Does your disinfection system include a clearwell or reaction tank?

- ○ Yes
- ○ No

Notes

## 11. If yes, what are its dimensions?

## 12. Is total water flow (use) monitored in this community?

○ Yes

○ No

○ Unknown

## 13. If yes, describe the following:

Flow measurement equipment

Flow measurement practices

Record-keeping practices

Record format

## 14. What is the distance between the point of chlorine (or other chemical) application and the first user in the distribution system?

## 15. What is(are) the diameter(s) of the pipe(s) between the point of chlorine (or other chemical) application and the first user in the distribution system?

## 16. Do you monitor the chlorine (or other chemical) residual at a specific location after the point of application?

☐ Yes, at the outflow of the clearwell

☐ Yes, at a designated location along the transmission main before the first customer

☐ Yes, at the first user's tap

☐ No

Other (please specify)

## 17. Does your distribution system include any type of water storage facility? (ex. water tower, underground storage tank, reservoir, etc.)

○ Yes

○ No

Notes

## 18. If yes, what are its dimensions?

## 19. Which of the following (if any) are monitored in your water treatment system?

☐ Influent pH

☐ Effluent pH

☐ Influent Temperature

☐ Effluent Temperature

☐ Influent Turbidity

☐ Effluent Turbidity

Other (please specify)

## 20. Are records maintained for any of the following?

☐ Maintenance activities

☐ Instantaneous flow rate (L/min, GPM, etc)

☐ pH

☐ Temperature

☐ Turbidity

☐ Biological testing results

☐ Chlorine (or other chemical) added

☐ Chlorine (or other chemical) residual

Other (please specify)

## 21. Are there bacteriological testing records available for this community?

○ Yes, at DMA

○ Yes, at the community office

○ No

○ Unknown

## 22. Is there a history of boil water advisories in this community?

○ Yes

○ No

○ Unknown

**23. If yes, what was (were) the cause(s)?**

**24. What actions, if any, have been taken to prevent the recurrence of boil water advisories in your community?**

**25. Is there anything else you would like to share about the water treatment and disinfection system in your community?**

## Site Conditions

This section to be filled out by the technician during the site visit.

### 1. Feed Water

pH

Temperature

Apparent colour

### 2. Point of Chlorine Application

pH

Temperature

Apparent colour

Free chlorine

Total chlorine

### 3. Clearwell Effluent

pH

Temperature

Apparent colour

Free chlorine

Total chlorine

### 4. First User's Tap

pH

Temperature

Apparent colour

Free chlorine

Total chlorine

### 5. Storage Tank Effluent

pH

Temperature

Apparent colour

Free chlorine

Total chlorine

## Photos

A list of photographs that technicians should try to obtain during the site visit.

**1. Did you manage to get photos of the following items?**
**(check all that apply - some items may only be present at a small number of sites)**

☐ Source water
☐ Intake
☐ Intake pump
☐ Treatment equipment
☐ Flow meter
☐ Flow totalizer
☐ Turbidimeter
☐ Disinfection system
☐ Disinfectant dispensing equipment
☐ Disinfectant monitoring equipment (chlorine monitor, etc)
☐ Clearwell
☐ Storage tank
☐ Tap at first user

Other pictures taken at this site include:

APPENDIX C

# Bulk Water Chlorine Decay Testing Procedure

# Annex A: Bulk Chlorine Decay Test

The following test can be used to measure bulk chlorine decay coefficients:

1. A 2.5 L brown glass bottle (Winchester style bottle) and eight 125 mL brown glass bottles with glass stoppers are required for this test.
2. Thoroughly clean and treat all glassware so that it is chlorine demand free:
    a. Fill freshly cleaned glassware with distilled water which has been dosed to 10 mg/L free chlorine using concentrated sodium hypochlorite solution.
    b. Leave to stand for 24 hours.
    c. Empty, rinse thoroughly with distilled water and leave to dry.
3. Fill 2.5 L bottle with the water sample and leave for 15 minutes to ensure homogeneity of the sample.
4. Decant sample into eight 125 mL brown glass bottles and seal with glass stoppers
5. Store in an incubator, set at the temperature of the sample water. If samples are taken and prepared on site then transfer the samples to the laboratory in a well insulated box.
6. Measure the chlorine concentration from one of the 125 mL bottles and note as the time (the "start time").
7. Measure chlorine concentrations at intervals from the remaining bottles in a similar manner. These intervals should ideally be set so that the chlorine concentration falls by approximately 10% of the initial reading between measurements.
8. Plot the chlorine concentration versus sample time to establish the decay curve.
9. The data can also be used to establish decay coefficients. For example the first order decay of a substance can be described by the equation: $C_t = C_0 \exp(-k_t t)$, where: $C_t$ = concentration of substance at any time, (mg/L), $C_0$ = initial concentration of chlorine, (mg/L), and $k_t$ = total decay rate, a function of bulk phase decay constant ($\text{day}^{-1}$).
    a. Plotting "$\ln(C/C_o)$" against "time", the decay coefficient is given by the gradient of the best fit line which should pass through the intercept.
    b. Alternatively, the data can be entered into a spreadsheet and a routine used which optimises the kinetic constants so as to minimize the sum of the squared errors between the modelled and observed chlorine concentrations. In Microsoft Excel, the Solver tool can be used to do this. In theory this is more accurate than fitting against a logarithmic curve if the chlorine measurement errors are of a fixed magnitude for all samples.

APPENDIX D

# Chlorine Decay Results and Related Historical Water Quality Data

Bulk Chlorine Decay Testing for Drinking Water Systems in Newfoundland AND Labrador

| Code | Average Raw DOC | Average TTHMs | UVA (Treated) | UVT (Treated) | $C_O$ | Final Time | $k_{t\ log}$ | $R^2$ | $k_{t\ optimized}$ | $k_{opt}$ - $kt_{log}$ |
|---|---|---|---|---|---|---|---|---|---|---|
|  | mg/L | ug/L | $cm^{-1}$ | % | mg/L | mins (adjusted) | $day^{-1}$ | c vs. t | $day^{-1}$ | $day^{-1}$ |
| 1 | 0.5 | 1 |  |  | 2.16 | 1668.0 | 0.08 | 0.77 | 0.08 | 0.003 |
| 2 | 0.3 | 0 |  |  | 1.82 | 298.0 | 0.34 | 0.93 | 0.34 | 0.003 |
| 3 | 8.3 | 152 | 0.289 | 51.3 | 1.91 | 17.5 | 53.78 | 0.98 | 54.05 | 0.269 |
| 4 | 4.3 | 149 | 0.110 | 75.8 | 2.16 | 29.0 | 31.01 | 0.81 | 33.26 | 2.251 |
| 5 | 4.2 | 73 | 0.200 | 61.8 | 2.06 | 11.5 | 49.21 | 0.97 | 49.97 | 0.764 |
| 6 | 8.8 | 314 |  |  | 1.38 | 12.6 | 232.77 | 0.99 | 227.69 | 5.083 |
| 7 | 9.95 | 231 | 0.567 | 27 | 1.88 | 14.8 | 116.82 | 0.98 | 121.59 | 4.771 |
| 8 | 7.3 | 62 |  |  | 1.62 | 11.0 | 232.43 | 0.94 | 242.18 | 9.749 |
| 9 | 6.3 | 58 |  |  | 2.02 | 29.8 | 28.91 | 0.94 | 29.79 | 0.882 |
| 10 | 0.9 | 12 | 0.000 | 98.4 | 1.8 | 376.5 | 0.58 | 0.58 | 0.59 | 0.009 |
| 11 | 5.9 | 95 |  |  | 2.16 | 12.3 | 136.30 | 0.96 | 143.50 | 7.204 |
| 12 | 6.2 | 126 | 0.224 | 59.6 | 1.94 | 16.0 | 64.88 | 0.9 | 68.06 | 3.176 |
| 13 | 5.0 | 141 |  |  | 1.86 | 17.5 | 57.08 | 0.97 | 58.72 | 1.642 |
| 14 | 5.4 | 123 | 0.227 | 59.2 | 1.85 | 13.5 | 84.98 | 0.46 | 94.54 | 9.555 |
| 15 | 5.6 | 182 | 0.227 | 59.2 | 1.81 | 14.6 | 74.91 | 0.93 | 78.23 | 3.325 |
| 16 | 3.6 | 54 | 0.360 | 43.5 | 1.96 | 15.5 | 88.16 | 0.98 | 91.44 | 3.284 |
| 17 | 5.4 | 187 |  |  | 2.2 | 18.0 | 54.26 | 0.91 | 56.57 | 2.305 |
| 18 | 5.6 | 139 |  |  | 2.14 | 17.6 | 58.24 | 0.97 | 60.18 | 1.937 |
| 19 | 2.7 | 40 | 0.080 | 82.9 | 2.02 | 30.9 | 27.59 | 0.76 | 29.46 | 1.867 |
| 20 | 7.0 | 111 |  |  | 1.87 | 17.8 | 70.46 | 0.96 | 73.47 | 3.007 |
| 21 | 8.6 | 113 | 0.387 | 40.9 | 2.03 | 13.8 | 102.00 | 0.98 | 105.59 | 3.586 |
| 22 | 5.7 | 128 |  |  | 2 | 18.3 | 84.41 | 0.92 | 86.66 | 2.254 |
| 23 | 4.6 | 47 |  |  | 1.78 | 157.2 | 3.19 | 0.91 | 3.25 | 0.063 |
| 24 | 8.5 | 166 | 0.244 | 56.9 | 1.85 | 29.0 | 24.31 | 0.78 | 24.88 | 0.568 |
| 26 | 8.8 | 137 | 0.441 | 36.1 | 1.42 | 16.5 | 82.94 | 0.94 | 87.66 | 4.722 |
| 27 | 6.2 | 162 | 0.053 | 88.4 | 1.94 | 38.0 | 21.40 | 0.98 | 21.69 | 0.287 |
| 28 | 5 | 134 | 0.165 | 68.3 | 2.18 | 39.8 | 21.34 | 0.87 | 22.49 | 1.145 |
| 29 | 6.8 | 178 | 0.389 | 40.7 | 1.98 | 12.8 | 41.15 | 0.99 | 41.45 | 0.299 |
| 30 | 6.1 | 122 | 0.480 | 32.7 | 2.02 | 20.0 | 60.55 | 0.99 | 60.44 | 0.108 |
| 31 | 5.9 | 132 | 0.164 | 68.4 | 1.67 | 12.5 | 141.81 | 0.97 | 149.25 | 7.442 |
| 32 | 4.9 | 25 |  |  | 1.98 | 15.6 | 66.45 | 0.95 | 69.05 | 2.603 |
| 33 | 11.4 | 101 |  |  | 2.15 | 14.3 | 132.99 | 0.97 | 140.74 | 7.746 |
| 34 | 4.1 | 106 |  |  | 2.2 | 83.7 | 10.60 | 0.9 | 11.04 | 0.442 |
| 35 | 6.2 | 117 |  |  | 2.18 | 21.3 | 45.48 | 0.99 | 46.26 | 0.778 |
| 36 | 5.8 | 111 | 0.223 | 59.8 | 1.87 | 13.5 | 96.97 | 0.89 | 103.39 | 6.419 |
| 37 | 7 | 94 | 0.129 | 74.2 | 2.19 | 50.5 | 15.26 | 0.79 | 16.13 | 0.875 |

### Bulk Chlorine Decay Testing for Drinking Water Systems in Newfoundland AND Labrador

| Code | Average Raw DOC | Average TTHMs | UVA (Treated) | UVT (Treated) | $C_O$ | Final Time | $k_{t\ log}$ | $R^2$ | $k_{t\ optimized}$ | $k_{opt}$ - $kt_{log}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | mg/L | ug/L | $cm^{-1}$ | % | mg/L | mins (adjusted) | $day^{-1}$ | c vs. t | $day^{-1}$ | $day^{-1}$ |
| 38 | 5.0 | 88 | | | 2.01 | 26.3 | 33.79 | 0.91 | 35.61 | 1.817 |
| 39 | 8.3 | 216 | 0.425 | 37.5 | 1.81 | 18.0 | 39.13 | 0.91 | 40.18 | 1.049 |
| 40 | 4.3 | 8 | 0.225 | 59.5 | 1.99 | 19.5 | 46.66 | 0.96 | 47.74 | 1.076 |
| 41 | 3.7 | 95 | | | 2.01 | 34.8 | 20.48 | 0.91 | 21.24 | 0.763 |
| 42 | 5.4 | 147 | 0.239 | 57.6 | 1.7 | 21.8 | 52.15 | 0.98 | 53.43 | 1.284 |
| 43 | 9.4 | 89 | 0.529 | 29.5 | 1.67 | 17.3 | 88.46 | 0.95 | 64.06 | 24.401 |
| 44 | 3.3 | 70 | | | 1.72 | 20.7 | 36.59 | 0.82 | 38.41 | 1.815 |
| 45 | 6.6 | 29 | 0.337 | 45.9 | 1.66 | 14.8 | 103.70 | 0.99 | 104.18 | 0.482 |
| 46 | 4.5 | 47 | 0.360 | 43.3 | 1.71 | 23.3 | 36.60 | 0.97 | 37.10 | 0.501 |
| 47 | 11.2 | 102 | 0.529 | 29.5 | 1.42 | 8.0 | 302.34 | 0.99 | 327.68 | 25.340 |
| 48 | 6.8 | 83 | | | 2.02 | 16.3 | 72.01 | 0.99 | 82.00 | 9.985 |
| 49 | 7.4 | 246 | 0.313 | 48.6 | 2.15 | 16.5 | 59.46 | 0.91 | 61.95 | 2.488 |
| 50 | 6.1 | 188 | | | 1.87 | 14.1 | 70.44 | 0.93 | 73.20 | 2.756 |
| 51 | 6.5 | 125 | | | 2.01 | 26.3 | 33.79 | 0.93 | 35.61 | 1.817 |
| 52 | 9.1 | 133 | 0.339 | 45.7 | 1.72 | 14.6 | 91.37 | 0.91 | 97.12 | 5.748 |
| 53 | 7.7 | 145 | | | 2.06 | 15.5 | 65.76 | 0.85 | 69.61 | 3.846 |
| 54 | 4.4 | 124 | 0.169 | 67.6 | 1.93 | 25.5 | 34.45 | 0.91 | 34.91 | 0.458 |
| 55 | 1.5 | 34 | | | 1.8 | 107.8 | 4.57 | 0.69 | 4.82 | 0.249 |

APPENDIX E

# Total Number of Boil Water Advisories Active during the 2009 – 2010 Fiscal Year

Table E.1 Definition of codes used for analysis

| Code | Description |
|---|---|
| 1 | issued before - lifted during |
| 2 | issued during - lifted during |
| 3 | issued during - lifted after |
| 4 | issued before - lifted after |

Table E.2 Results of analysis

| | 1 | 2 | 3 | 4 | Total Active | Total Resolved | Total Remaining |
|---|---|---|---|---|---|---|---|
| A | 2 | 1 | 1 | 73 | 77 | 3 | 74 |
| B1 | 0 | 0 | 0 | 9 | 9 | 0 | 9 |
| B2 | 0 | 2 | 0 | 3 | 5 | 2 | 3 |
| B3 | 0 | 0 | 0 | 9 | 9 | 0 | 9 |
| B4 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| C1 | 11 | 55 | 9 | 38 | 113 | 66 | 47 |
| C2 | 0 | 2 | 0 | 1 | 3 | 2 | 1 |
| D1 | 9 | 172 | 19 | 11 | 211 | 181 | 30 |
| D2 | 1 | 0 | 0 | 2 | 3 | 1 | 2 |
| D3 | 1 | 30 | 2 | 8 | 41 | 31 | 10 |
| E1 | 8 | 50 | 4 | 31 | 93 | 58 | 35 |
| E2 | 6 | 33 | 5 | 51 | 95 | 39 | 56 |
| E3 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| F1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| F2 | 3 | 36 | 6 | 10 | 55 | 39 | 16 |
| F3 | 2 | 70 | 5 | 21 | 98 | 72 | 26 |
| F4 | 0 | 8 | 1 | 2 | 11 | 8 | 3 |
| F5 | 0 | 2 | 0 | 2 | 4 | 2 | 2 |
| G | 0 | 9 | 0 | 0 | 9 | 9 | 0 |
| TOTAL | 43 | 470 | 53 | 273 | 839 | 513 | 326 |

Table E.3 Summary of results

| | Active | Resolved | Remaining |
|---|---|---|---|
| A | 77 | 3 | 74 |
| B | 23 | 2 | 21 |
| C | 116 | 68 | 48 |
| D | 255 | 213 | 42 |
| E | 189 | 97 | 92 |
| F | 169 | 121 | 48 |
| G | 9 | 9 | 0 |
| TOTAL | 838 | 513 | 325 |

APPENDIX F

# Field Data

Table F.1 Summary of field water quality data

| Code | Feed Water | | | Point of Chlorine Application | | | | | Clearwell Effluent | | | | | First User's Tap | | | | | Storage Tank Effluent | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Temperature | Apparent colour | pH | Temperature | Apparent colour | Free chlorine | Total chlorine | pH | Temperature | Apparent colour | Free chlorine | Total chlorine | pH | Temperature | Apparent colour | Free chlorine | Total chlorine | pH | Temperature | Apparent colour | Free chlorine | Total chlorine |
| 1 | 5.37 | 11 | 0 | | | | | | | | | | | 5.42 | 11.7 | 34 | 1.5 | 1.8 | | | | | |
| 2 | 8.55 | 12.3 | 31 | 8.55 | 13.4 | 8 | 0.02 | 0.03 | | | | | | 8.47 | 17.7 | 18 | 0.03 | 0.03 | | | | | |
| 3 | 7.5 | 12.2 | 119 | | | | | | | | | | | 7.65 | 10.4 | 57 | 0.07 | 0.21 | | | | | |
| 4 | 6.77 | 19.8 | 54 | | | | | | | | | | | 4.98 | 18.2 | 41 | 0.99 | 0.98 | | | | | |
| 5 | 6 | 10 | 61 | 5.26 | 10.8 | 258 | 3.6 | 1.13 | | | | | | 5.78 | 12 | 77 | 0.95 | 2.07 | | | | | |
| 6 | 4.52 | 18.5 | 347 | 5.02 | 18.2 | 40 | 1.65 | 1.62 | | | | | | 6.47 | 22.2 | 51 | 0.06 | 0.05 | | | | | |
| 7 | 7.03 | 15.7 | 160 | | | | | | | | | | | 7 | 16.4 | 170 | 1.7 | 2 | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | 5.83 | 21.9 | 347 | | | | | | 6.86 | 22.2 | 0 | 1.23 | 1.4 | 7.11 | 20.9 | 98 | 0.05 | 0.09 | | | | | |
| 10 | 8.24 | 10.6 | 0 | 7.98 | 10.5 | 0 | 0.33 | 0.36 | | | | | | 7.77 | 10.7 | 0 | 0.33 | 0.36 | | | | | |
| 11 | 6.87 | 18.1 | 208 | | | | | | | | | | | 7.07 | 17.6 | 41 | 0.12 | 0.28 | | | | | |
| 12 | 7.06 | 16.8 | 23 | | | | | | | | | | | 6.79 | 16.1 | 0 | 0.3 | 0.58 | | | | | |
| 13 | 5.84 | 15.2 | 126 | | | | | | | | | | | 6.47 | 15 | 103 | 0.69 | 1.4 | | | | | |
| 14 | 7.55 | 24.6 | 106 | | | | | | | | | | | 6.56 | 22.3 | 100 | 0.13 | 0.22 | | | | | |
| 15 | 6.37 | 22.1 | 116 | | | | | | | | | | | 7.01 | 22.3 | 18 | 0.21 | 0.24 | | | | | |
| 16 | 4 | 20.3 | 0 | 4.95 | 18.7 | 4 | 1.42 | 1.93 | | | | | | 6.41 | 20.8 | 5 | 1.94 | 2.2 | | | | | |
| 17 | 7.24 | 19.3 | 101 | | | | | | | | | | | 7.11 | 19.3 | 21 | 0.65 | 0.9 | | | | | |
| 18 | 6.43 | 15.6 | 75 | 6.43 | 15.8 | 90 | 0.09 | 1.1 | | | | | | 6.72 | 16.5 | 106 | 0.06 | 0.9 | | | | | |
| 19 | 7.25 | 22.2 | 60 | | | | | | | | | | | 5.2 | 20.8 | 0 | 0.76 | 0.9 | | | | | |
| 20 | 6.82 | 20 | 40 | | | | | | | | | | | 5.56 | 19.9 | 50 | 0 | 0 | | | | | |
| 21 | 5.85 | 15.4 | 246 | 5.85 | 15.6 | 200 | 1.52 | 1.9 | | | | | | 5.52 | 16.3 | 169 | 1.31 | 1.75 | | | | | |
| 22 | 6.91 | 19.2 | 96 | | | | | | | | | | | 6.96 | 19 | 89 | 0.06 | 0.07 | 5.87 | 19.4 | 0 | 0 | 0.01 |
| 23 | 6.97 | 16.3 | 7 | | | | | | | | | | | 5.66 | 17 | 5 | 0.3 | 0.4 | | | | | |
| 24 | 7.06 | 20.4 | 33 | | | | | | | | | | | 7.17 | 21.3 | 24 | 0.79 | 0.88 | | | | | |
| 25 | | | | | | | | | | | | | | 4.92 | 20.6 | 18 | 0.13 | 0.26 | | | | | |
| 26 | 7.03 | 15.7 | 122 | | | | | | | | | | | 7.03 | 15.7 | 3 | 0.7 | 1.2 | | | | | |
| 27 | 7.9 | 22 | 44 | | | | | | | | | | | 7.4 | 20.6 | 0 | 1.75 | 1.83 | | | | | |
| 28 | 6.93 | 7.3 | 6 | | | | | | | | | | | 6.94 | 10.7 | 17 | 0.65 | 0.77 | 7.31 | 8.2 | 75 | 0.67 | 1.03 |
| 29 | 6.62 | 9.7 | 120 | | | | | | | | | | | 6.6 | 10.2 | 100 | 0.8 | 1 | | | | | |
| 30 | 6.6 | 23.6 | 53 | 4.41 | 19.6 | 92 | 2.2 | 2.2 | | | | | | 4 | 20.6 | 123 | 2.2 | 2.2 | 5.52 | 22.6 | 178 | | |
| 31 | 6.68 | 14.3 | 255 | | | | | | | | | | | 4.28 | 14.8 | 127 | 2.19 | 2.2 | | | | | |
| 32 | 6.46 | 13.7 | 112 | | | | | | | | | | | 7.04 | 13.8 | 95 | 0.11 | 0.2 | | | | | |
| 33 | 6.02 | 14.2 | 365 | | | | | | | | | | | 7.94 | 14.8 | 134 | 0.82 | 0.99 | | | | | |
| 34 | 2.18 | 14 | 32 | | | | | | | | | | | 6.99 | 14 | 0 | 0.38 | 0.66 | | | | | |
| 35 | 7.44 | 20.6 | 11 | | | | | | | | | | | 7.14 | 20.3 | 49 | 0.44 | 0.46 | | | | | |
| 36 | 5.56 | 13.7 | 60 | | | | | | | | | | | 5.13 | 14.1 | 69 | 1.3 | 1.64 | | | | | |
| 37 | 8.03 | 6.6 | 283 | | | | | | | | | | | 7.69 | 14.8 | 73 | 0.04 | 0.06 | | | | | |
| 38 | 6.06 | 20.4 | 96 | | | | | | | | | | | 7.02 | 18.2 | 111 | 1.2 | 1.47 | | | | | |
| 39 | 5.66 | 16.7 | 72 | | | | | | | | | | | 5.4 | 17 | 70 | 0.21 | 0.3 | | | | | |
| 40 | 6.06 | 14.5 | 100 | | | | | | | | | | | 6 | 15 | 80 | 0.2 | 0.9 | | | | | |
| 41 | 6.97 | 14.9 | 0 | | | | | | | | | | | 7.18 | 14.6 | 73 | 0.84 | 1.2 | | | | | |
| 42 | 7.65 | 8.7 | 59 | | | | | | | | | | | 7.16 | 14.2 | 141 | 0.41 | 1.03 | | | | | |
| 43 | 7.75 | 12.1 | 192 | | | | | | | | | | | 7.11 | 13.7 | 104 | 0.03 | 0.34 | | | | | |
| 44 | 7.21 | 14.8 | 26 | | | | | | | | | | | 7.02 | 14.9 | 57 | 0.6 | 1.2 | | | | | |
| 45 | 6.28 | 19.1 | 194 | | | | | | | | | | | 5.93 | 19 | 194 | | | | | | | |
| 46 | 6.4 | 19 | 127 | 4 | 18.7 | 110 | 2.2 | 1.87 | | | | | | 4 | 16.6 | 84 | 2.2 | 1.42 | | | | | |
| 47 | 7.02 | 11.5 | 204 | | | | | | | | | | | 6.9 | 12 | 180 | 0.19 | 0.76 | | | | | |
| 48 | 7.04 | 19 | 47 | 6.28 | 18.3 | 37 | 2.19 | 2.2 | | | | | | 4.93 | 19 | 9 | 1.19 | 1.21 | | | | | |
| 49 | 7.72 | 15.6 | 29 | | | | | | | | | | | 7.04 | 13.2 | 47 | 1.6 | 1.94 | | | | | |
| 50 | 6.19 | 18.1 | 6 | | | | | | | | | | | 6.39 | 18.6 | 7 | 0.08 | 0.09 | | | | | |
| 51 | 6.48 | 21.1 | 93 | | | | | | | | | | | 6 | 20 | 60 | 0 | 0 | | | | | |
| 52 | 7.64 | 17.4 | 42 | | | | | | | | | | | 5.94 | 15.9 | 20 | 0.3 | 1 | | | | | |
| 53 | 6.92 | 14 | 63 | | | | | | | | | | | 6.62 | 15.4 | 0 | 0.9 | 1.3 | | | | | |
| 54 | 6.9 | 11.9 | 102 | | | | | | | | | | | 6 | 12 | 80 | 1.2 | 1.4 | | | | | |
| 55 | 7.82 | 17.1 | 43 | | | | | | | | | | | 8.33 | 18.5 | 41 | 0.07 | 0.08 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | |
| Average | 6.7 | 16.0 | 100.3 | 5.9 | 16.0 | 83.9 | 1.5 | 1.4 | 6.9 | 22.2 | 0.0 | 1.2 | 1.4 | 6.5 | 16.6 | 63.8 | 0.7 | 0.9 | 6.2 | 16.7 | 84.3 | 0.3 | 0.5 |
| St. Dev. | 1.1 | 4.2 | 93.2 | 1.5 | 3.4 | 86.8 | 1.1 | 0.8 | n/a | n/a | n/a | n/a | n/a | 1.0 | 3.4 | 52.0 | 0.6 | 0.7 | 0.9 | 7.6 | 89.4 | 0.5 | 0.7 |
| Maximum | 8.6 | 24.6 | 365.0 | 8.6 | 19.6 | 258.0 | 3.6 | 2.2 | 6.9 | 22.2 | 0.0 | 1.2 | 1.4 | 8.5 | 22.3 | 194.0 | 2.2 | 2.2 | 7.3 | 22.6 | 178.0 | 0.7 | 1.0 |
| Minimum | 2.2 | 6.6 | 0.0 | 4.0 | 10.5 | 0.0 | 0.0 | 0.0 | 6.9 | 22.2 | 0.0 | 1.2 | 1.4 | 4.0 | 10.2 | 0.0 | 0.0 | 0.0 | 5.5 | 8.2 | 0.0 | 0.0 | 0.0 |
| Number | 53 | 51 | 53 | 10 | 10 | 10 | 10 | 10 | 1 | 1 | 1 | 1 | 1 | 54 | 54 | 54 | 53 | 53 | 3 | 3 | 3 | 2 | 2 |

APPENDIX G

# Community Disinfection Infrastructure Database (CDID) - User Guide

# Community Disinfection Infrastructure Database

## Introduction

The Community Disinfection Infrastructure Database (CDID) was designed to store information about disinfection infrastructure, water quality, and disinfection by-products (DBPs) in communities throughout the province. Currently it contains information gathered during the desk, field, and laboratory phases of the current study.

Based on the data input into the CDID, it is possible to calculate:

- Contact time achieved;
- CT achieved;
- CT required (ENVC and disinfection recommendations from report);
- Inactivation ratio (CT achieved/CT required); and
- Log reduction (*Giardia, Cryptosporidium,* and viruses).

Default values for average per capita water use, peak hour flow, pH, chlorine residual, and temperature are also included in the database. These are automatically substituted into calculations if no community-specific information is available.

The following default values will be applied to the contact time, CT, and log reduction calculations if they are not entered into the Data Entry Form:

- Per capita flow rate (population < 1,000, residential only) = 395 Lpcd;
- Per capita flow rate (population > 1,000 OR < 1,000 with industrial user) = 804 Lpcd;
- pH = 8;
- Temperature = 0.5$^{o}$C;
- Chlorine dose = 0.3 mg/L;
- Peaking factor – based on population and PRP-Gumbel calculation method;
- Baffling factor for pipe contactor = 1; and
- Baffling factor for chlorine reaction tank and storage volumes = 0.3.

Information from the 55 communities that participated in the current study has already been input into the CDID. Additional communities can be added using the Data Input Form. To ensure accurate results, the fields in Table G.1 should be filled out.

Table G.1 Information required to calculate an accurate CT

| Item | Definition | Units | Options |
|---|---|---|---|
| Community name | | | |
| Population serviced | Total population receiving disinfected water | | |
| Disinfectant type | Type of primary disinfectant used | | |
| Pipe diameter | Diameter of transmission main between point of chlorination and first user | m | |
| Pipe length | Length of transmission main between point of chlorination and first user | m | |
| RT volume | Volume of chlorine reaction tank | $m^3$ | |
| RT baffling factor | Baffling factor for chlorine reaction tank | | 0.1 to 1.0 |
| ST volume | Volume of treated water storage (clearwell, water tower, tank, etc.) | $m^3$ | |
| ST baffling factor | Baffling factor for treated water storage | | 0.1 to 1.0 |
| Storage between PoC and FU? | Is storage between point of chlorination and first user? | | Yes or No |
| AD residential | Average day residential water use | L/day | |
| AD industrial | Average day industrial water use | L/day | |
| Peak flow | Maximum flow through the chlorine contact volume OR the highest instantaneous flow expected during any hour of an average day (peak hour flow in minutes) | L/min | |
| pH RT | pH at outlet of chlorine reaction tank | | |
| Temp RT | Temperature at outlet of chlorine reaction tank | $^oC$ | |
| Cl Res RT | Chlorine residual at outlet of chlorine reaction tank | mg/L | |
| pH ST | pH at outlet of storage volume | | |
| Temp ST | Temperature at outlet of storage volume | $^oC$ | |
| Cl Res ST | Chlorine residual at outlet of storage volume | mg/L | |
| pH FU | pH at first user | | |
| Temp FU | Temperature at first user | $^oC$ | |
| Cl Res FU | Chlorine residual at first user | mg/L | |

*component volumes can be calculated using the Chlorine Contact Volume Calculator

Note that at least one form of chlorine contact volume must be specified (transmission main, chlorine reaction tank, storage). Additional information, including the region, water source type, historical average DOC, UV adsorption/transmittance, and the chlorine decay factor (k), can also be added for information storage purposes. Log reduction credits will be applied if the user indicates that the following treatment processes are used in the community:

- Conventional treatment (2.5-log *Giardia,* 2.0-log *Cryptosporidium*, 2.0-log viruses);
- Dissolved air flotation (2.5-log *Giardia*, 2.0-log *Cryptosporidium*, 2.0-log viruses);
- Direct filtration (2.0-log *Giardia* and *Cryptosporidium*, 1.0-log viruses); and
- Ozone (3.0-log *Giardia*, 1.0-log *Cryptosporidium*, 4.0-log viruses); and
- UV (3.0-log *Giardia* and *Cryptosporidium*).

## User Instructions

1. Open the CDID using Microsoft Access 2000
   a. Double click on the CDID icon on the desktop or choose it from the folder where it's saved.

   b. When the introductory screen appears click on the 'Data Input Form' or 'Search / Browse'.

   c. Alternatively, you can choose to work directly within the database using the default Microsoft Access navigation window (see Figure G.1).

2. Enter community-specific information on the Data Input Form
   a. To enter new data choose 'Data Input Form' on the introductory screen.

   b. Fill in the 'record number' field using the record number indicated at the bottom left of the form (see Figure G.2).

   c. The following fields must be filled in to calculate contact time, CT, and log reduction:
      - Community name;
      - SA#;
      - Population; and
      - Contact volume dimensions (transmission line, reaction tank, and/or storage).

   d. If the following fields are not filled out the CDID will use and/or calculate a default value:
      - Average day residential water use;
      - Average day industrial water use;
      - Peak hour flow (in minutes);
      - Temperature at first user;
      - pH at first user; and
      - Chlorine residual at first user.

   e. If no information is provided about the chlorine reaction tank(s) and storage volume(s) the database calculations will assume that they do not exist. If no baffling factor is provided for these components the CDID will assign a baffling factor of 0.3.

   f. Be sure to indicate whether the storage volume is located between the point of chlorination and the first user!

   g. Data does not need to be entered into some of the fields to run the calculations but can be included at the discretion of the ENVC in order to keep a record of relevant infrastructure and water quality information.

h. If one of the following treatment options is checked off a log reduction credit will be applied to the disinfection compliance calculations:
   - Conventional treatment (2.5-log *Giardia,* 2.0-log *Cryptosporidium*, 2.0-log viruses);
   - Dissolved air flotation (2.5-log *Giardia*, 2.0-log *Cryptosporidium*, 2.0-log viruses);
   - Direct filtration (2.0-log *Giardia* and *Cryptosporidium*, 1.0-log viruses);
   - Ozone (3.0-log *Giardia*, 1.0-log *Cryptosporidium*, 4.0-log viruses); and
   - UV (3.0-log *Giardia* and *Cryptosporidium*).

i. The record is saved automatically when you exit the form.

### 3. Filter records by community name or SA#

a. Click on the 'Browse / Search' button on the introductory screen.

b. This will open a search form that can be filtered by typing in the community name or SA# and clicking 'Search'.

c. Click 'Clear' to removed the filter.

### 4. Display results using pre-existing reports

Five 'reports' have been developed that allow the user to view and export information about:

- Total effective contact time;
- Total CT achieved;
- Log reduction (*Giardia* and viruses) achieved;
- Bin assignments: Existing ENVC disinfection requirements; and
- Bin assignments: Proposed disinfection requirements.

Please see the accompanying report for a detailed explanation of bins.

To view a report:

a. Choose 'Reports' in the Microsoft Access navigation window.

b. Double click on the report you wish to view (see Figure G.3).

c. A printable sheet will appear with the information arranged in the order in which the data was entered.

d. To print the report click on the printer icon in the top left corner of the screen or choose File: Print.

### 5. Exporting data

Data can be exported from the Data Input Form or the five preset reports.
When using the Data Entry Form, click on the 'Output to Excel' button in the top right corner of the form. This will export the data to a file location specified in the CDID's programming*.

To export data from the reports:

a. Choose File: Export.

b. A window will open and ask you what format you would like to export to.

c. Choose 'Microsoft Excel 97-2003'.

d. You may also name the file and choose where you want to save it.

e. When you have specified the file format and location click 'Export'.

## 6. Removing data from the CDID

To remove a record from the CDID:

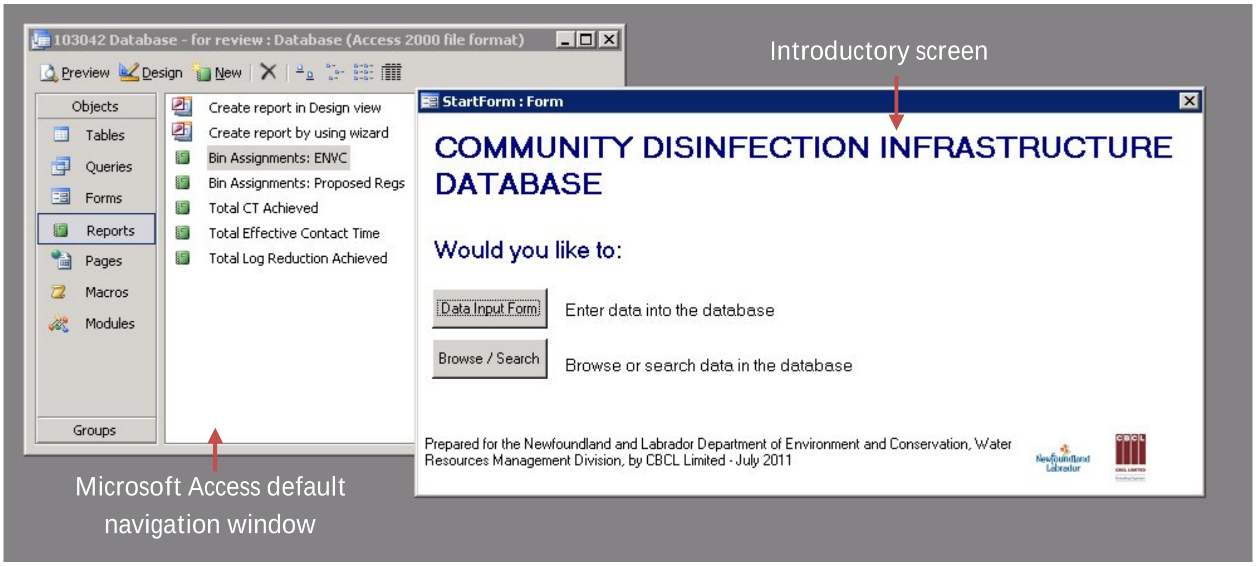
a. In the Microsoft Access navigation window (see Figure G.4) choose 'tbl_static_data'.

b. A data table will open.

c. Highlight the record that you would like to delete.

d. Right click and choose 'Delete Record'.

*Default export location must be set by the CDID administrator.



Introductory screen

COMMUNITY DISINFECTION INFRASTRUCTURE DATABASE

Would you like to:

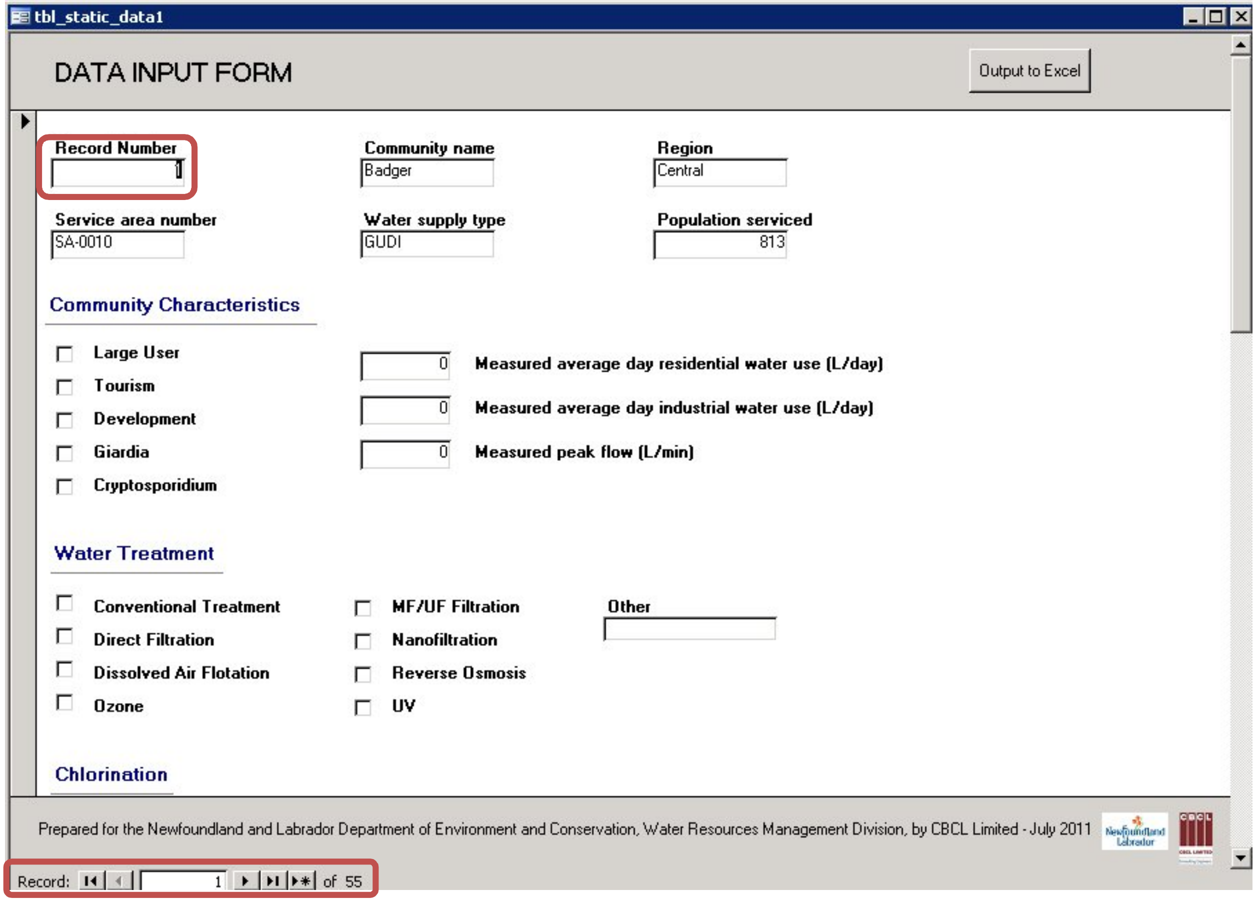
Data Input Form — Enter data into the database

Browse / Search — Browse or search data in the database

Prepared for the Newfoundland and Labrador Department of Environment and Conservation, Water Resources Management Division, by CBCL Limited - July 2011

Microsoft Access default navigation window

Figure G.1 Introductory screen and Microsoft Access default navigation window



DATA INPUT FORM

| | | |
|---|---|---|
| **Record Number** 1 | **Community name** Badger | **Region** Central |
| **Service area number** SA-0010 | **Water supply type** GUDI | **Population serviced** 813 |

**Community Characteristics**

☐ Large User
☐ Tourism
☐ Development
☐ Giardia
☐ Cryptosporidium

0 **Measured average day residential water use (L/day)**
0 **Measured average day industrial water use (L/day)**
0 **Measured peak flow (L/min)**

**Water Treatment**

☐ Conventional Treatment
☐ Direct Filtration
☐ Dissolved Air Flotation
☐ Ozone
☐ MF/UF Filtration
☐ Nanofiltration
☐ Reverse Osmosis
☐ UV

**Other**

**Chlorination**

Prepared for the Newfoundland and Labrador Department of Environment and Conservation, Water Resources Management Division, by CBCL Limited - July 2011

Record: 1 of 55

Figure G.2 Data Input Form

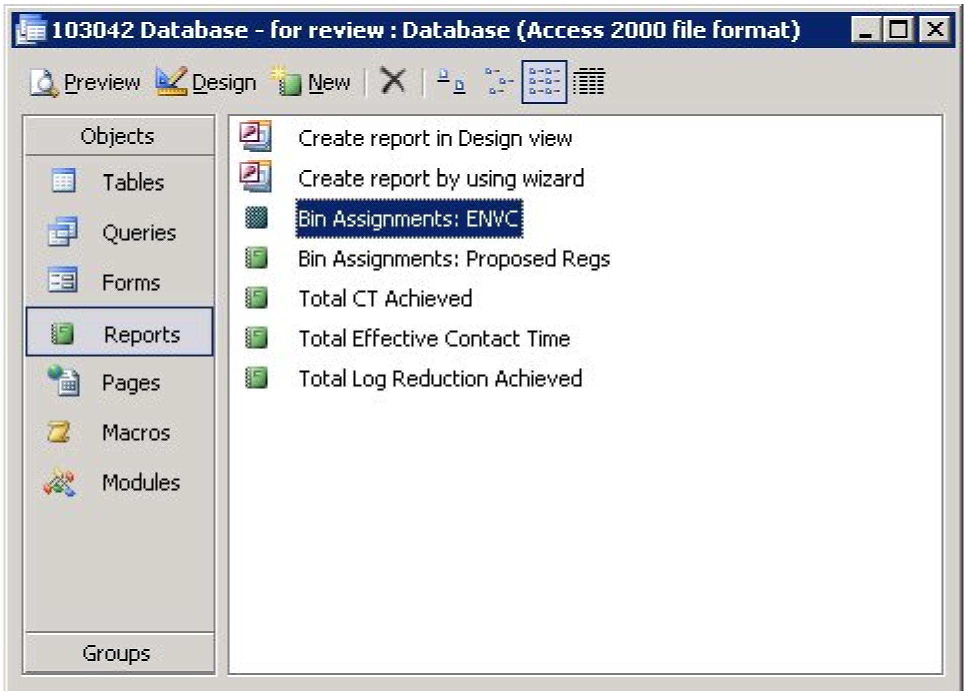


Figure G.3 Microsoft Access default navigation window – reports

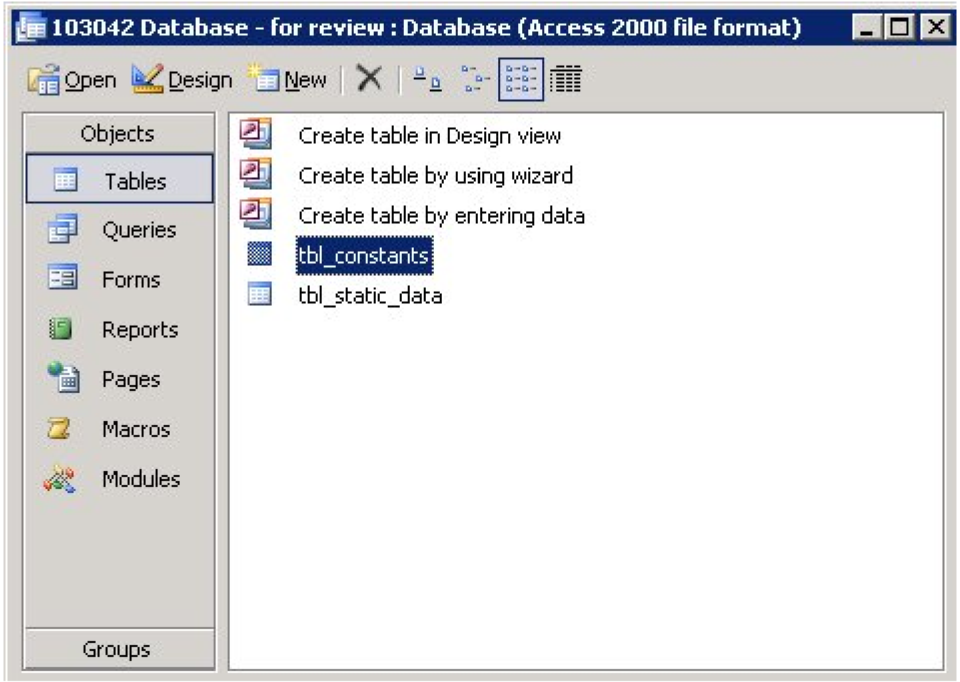


Figure G.4 Microsoft Access default navigation window – tables

APPENDIX H

# Contact Volume, CT, and Log Reduction Calculators - User Guide

# Disinfection Compliance Calculator Spreadsheet User Guide

The disinfection compliance calculator spreadsheet includes four separate tabs. The first is a CT-based calculator that can be used to determine whether a community is in compliance with existing CT-based disinfection requirements. The second is a similar calculator that can be used to calculate compliance with log reduction based disinfection requirements. The effective contact volume tab can be used to determine the total amount of volume available for chlorine contact. The results obtained on this tab can be then be used in the compliance calculators. The final tab contains a table that can be used to choose an appropriate baffling factor to describe the mixing characteristics of the chlorine contact volume. The spreadsheet also contains a conversion table that can be used to convert from Imperial and US units to metric units. This last is located on the effective contact time tab.

## Inputs

Throughout most of the spreadsheet input cells are indicated in white while output cells are dark blue. The calculators are designed to accept three types of inputs:

- General defaults;
- ENVC requirements; and
- User inputs.

The calculators use the values entered in these sections to compute the average day and peak hour flow, peaking factor, contact time, CT required, and CT achieved. The individual sections can be password protected such that the calculator can be distributed to staff at different levels.

## General Defaults

General default values will be chosen and entered by the ENVC prior to the calculator being provided to field staff and/or system operators. The current default values were chosen based on the findings and results of this study. These can be changed at the discretion of the ENVC.
The default variables are summarized in Table H.1.

Table H.1 Default values used in the Disinfection Compliance Calculator Spreadsheet

| Variable | Calculator(s) | Current Default | Source |
|---|---|---|---|
| Per capita water use | LR and CT based disinfection compliance calculators | 504 Lpcd | Environment Canada (2010) |
| Required log reduction of viruses | LR based disinfection compliance calculator | 4-log | Guidelines for Canadian Drinking Water Quality (2010) |
| Required log reduction of *Giardia* | LR based disinfection compliance calculator | 3-log | Guidelines for Canadian Drinking Water Quality (2010) |
| CT required in NL | CT based disinfection compliance calculator | 6 | Bacteriological Quality of Drinking Water (2008) |

ENVC Inputs

Variables such as population, known water use and flow rates, the amount of pathogen reduction achieved before chlorine application, and the volume available for chlorine contact are community specific and unlikely to change (quickly) over time. The ENVC can enter whatever information is available for a given community into the ‘ENVC Inputs’ section in each of the compliance calculators. If some information is missing, the calculators will default to the values described in Table H.1. If the effective chlorine contact volume is unknown it can be calculated using the ‘Effective Chlorine Contact Volume Calculator’.

Once all available information has been input into the calculators, they will provide the following outputs:

CT based calculator:

- Average day flow (L/day);
- Peaking factor;
- Peak flow (L/min); and
- Effective contact time.

Log reduction based calculator:

- Log inactivation required from chlorination (*Giardia* and viruses);
- Average day flow;
- Peaking factor;
- Peak flow; and
- Effective contact time.

*Contact Volume Calculator*

The effective chlorine contact volume can be calculated using the third tab of the spreadsheet. The user must enter the dimensions of the system components where chlorine contact is occurring. This may include the transmission main between the point of chlorination and the first user, a chlorine reaction tank within the water treatment plant, a clearwell storage within the water treatment plant, or a storage volume separate from the water treatment plant/disinfection system. Once the dimensions of each component are entered, the system component calculators will determine their volumes. Not every community will have all of these components. In locations where one to three of them are missing, the input fields in the individual system component calculators can be left empty.

In order to calculate the effective contact volume all system components except the transmission main must be assigned a baffling factor to account for the level of mixing within the chlorine contact volume. An appropriate baffling factor can be chosen by comparing the characteristics of the contact volume with the tank configurations described in the table in the ‘Baffling Factor’ tab of the spreadsheet. The transmission main does not require a baffling factor because it is assumed that it approximates the characteristics of a ‘plug-flow’ reactor, which has a baffling factor of 1.

Once an appropriate baffling factor has been entered into the individual component calculators, each will calculate an effective contact volume. This will appear in the ‘Total Effective Contact Volume’ calculator at the top of the page along with the effective contact volumes calculated for all of the other system components. This calculator will sum the individual volumes to determine the total effective volume available for chlorine contact, which can then be input into the disinfection compliance calculators.

If the individual system component calculators are insufficient to describe the chlorine contact volume in a community, the actual and/or additional contact volume can be added to the ‘other’ field on the ‘Total Effective Contact Volume’ calculator.

### Operator Inputs

Once all of the community-specific information described in the previous section has been input into the compliance calculators the actual day to day compliance of the system can be evaluated by inputting the temperature and pH of the water as well as the chlorine residual at the end of the total chlorine contact volume. Once these have been input, the calculator will provide a number of outputs including:

CT based calculator:

- CT achieved;
- Inactivation ratio;
- Log inactivation of *Giardia*;
- Log inactivation of viruses; and
- Compliance with ENVC disinfection requirements (yes or no).

Log reduction based calculator:

- CT required (*Giardia* and viruses);
- CT achieved; and
- Inactivation ratio (*Giardia* and viruses).

### Operator Instructions

1. Measure the pH, temperature, and chlorine residual at the end of your chlorine contact volume (this may be at the first users tap).
2. Input these values into the appropriate fields of the disinfection compliance calculator.
3. The calculator will indicate whether you are currently in or out of compliance with ENVC disinfection requirements.

APPENDIX I

# Community Codes

| Community Identification | |
|---|---|
| **Number** | Name |
| 1 | Badger |
| 2 | Barachois Brook |
| 3 | Bird Cove |
| 4 | Bonavista |
| 5 | Brigus |
| 6 | Burgeo |
| 7 | Cartwright |
| 8 | Channel Port-Aux-Basques |
| 9 | Clarenville |
| 10 | Colliers |
| 11 | Come-By- Chance |
| 12 | Comfort Cove Newstead |
| 13 | Conne River |
| 14 | Cow Head |
| 15 | Ferryland |
| 16 | Fortune |
| 17 | Gander |
| 18 | Harbour Breton |
| 19 | Harbour Grace |
| 20 | Heart's Delight- Islington |
| 21 | Hermitage |
| 22 | Howley |
| 23 | Indian Bay |
| 24 | Irishtown - Summerside |
| 25 | Joe Batt's Arm |
| 26 | Leading Tickles |
| 27 | Lourdes |
| 28 | Main Brook |
| 29 | Mary's Harbour |
| 30 | Marystown |
| 31 | Milltown |
| 32 | Morrisville |
| 33 | Musgrave Harbour |
| 34 | Pasadena |
| 35 | Placentia - Larkin's Pond |
| 36 | Point Leamington |
| 37 | Port Aux Choix |
| 38 | Port Blandford |
| 39 | Port Hope Simpson |
| 40 | Red Bay |
| 41 | Roberts Arm |
| 42 | Rocky Harbour |
| 43 | Seldom - Little Seldom |
| 44 | Springdale |
| 45 | St. Bernards and Jaques Fontaine |
| 46 | St. Lawrence |
| 47 | St. Lunaire- Criquet |
| 48 | Steady Brook |
| 49 | Summerford |
| 50 | Trinity |
| 51 | Trinity Bay North |
| 52 | Triton |
| 53 | Twillingate |
| 54 | West St. Modeste |
| 55 | Woody Point |

APPENDIX J

# Background Information on the Integrated Disinfection Design Framework

# Determining disinfection needs

*The integrated disinfection design framework can help utilities lower disinfectant dosages and costs and minimize formation of disinfection by-products.*

**William Bellamy, Kenneth Carlson, David Pier, Joel Ducoste, and Mark Carlson**

**The integrated disinfection design framework (IDDF) is a new approach for determining disinfection requirements for a water treatment facility. The framework may be applied in place of the procedures in the US Environmental Protection Agency's Surface Water Treatment Rule guidance manual. Potential benefits include lower disinfectant dosages, reduced disinfectant costs, and reduced formation of disinfection by-products. The feasibility of the IDDF was presented in an AWWA Research Foundation–sponsored project completed in 1998. A user-friendly model has been developed based on the original IDDF concepts; this model allows utility personnel, consultants, and regulators to determine site-specific disinfection requirements. The model has four components or modules: (1) hydraulic characteristics, (2) disinfectant demand–decay, (3) inactivation kinetics, and (4) disinfection by-product formation. Implementation of the IDDF at the Aurora (Colo.) Water Department is in progress with a chlorine dioxide dosage reduction of approximately 15 percent. Other IDDF implementation studies have indicated that primary disinfectant dosages can be reduced by 8–35 percent with a corresponding reduction in disinfection by-products.**

Design and operation of drinking water disinfection systems have been and will continue to be evolving processes. Significant disinfection research occurred during the twentieth century; however, current design criteria are based on the mathematical concepts described at the turn of the past century. As the water supply profession moves into the twenty-first century, disinfection design approaches will evolve in response to the need to more rigorously protect public health from the acute risk of pathogen infection, the chronic and acute risks of disinfection by-products (DBPs), and the need to conserve financial resources. This

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*A full report of this project, Integrated Disinfection Design Framework (90739), is available from AWWA Customer Service (1-800-926-7337). Reports are free to AWWA Research Foundation subscribers by calling (303) 347-6121.*

***For executive summary, see page 156.***

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***The integrated disinfection design framework is being implemented at the Aurora Water Department in Colorado, where construction is under way on the Kuiper contact basin.***

balance of disinfection benefit and risk will continue to cause the profession to evolve toward more encompassing regulations, informed design, and optimized operation.

This article presents some of the latest developments in disinfection technology with the intent of advancing the knowledge and application of disinfection in the drinking water profession. This is of significance to the profession because the use of inappropriate design relationships can lead to incorrectly sized and operated disinfection processes, which in turn can result in inappropriate disinfection, formation of unnecessary DBPs, and inefficient use of resources.

**As the water supply profession moves into the twenty-first century, disinfection design approaches will evolve in response to the need to more rigorously protect public health.**

The research described here builds on the integrated disinfection design framework (IDDF) project that was completed by Bellamy et al in 1998.[1] This follow-on project was intended to develop protocols that could take the framework from a theoretical exercise to implementation at an operating utility. This article describes the protocols that have been developed to implement the IDDF and discusses implementation at a utility that is designing a new primary disinfection process. The AWWA Research Foundation report and model that resulted from this project are currently in review and will be available later this year.[2]

## Graphical development of the IDDF model

The IDDF approach is presented in the following steps to provide a visual understanding of how it works.

**Step 1—determine the contactor hydraulics.** Figure 1 presents an example histogram of cysts emerging from a chlorine contactor after a pulse addition to the inlet of 1 million cysts. The residence time distribution (RTD) in this example represents cysts so that the disinfection model can be developed directly from the outcome of the test. Chemical tracer tests are the most common method for determining the RTD. They can be easily converted to represent the RTD of cysts.

**Step 2—determine the disinfectant characteristics.** Figure 2 presents a decay curve for chlorine ($Cl_2$) in water. This plot is characteristic of the type of residual decay expected with $Cl_2$, chlorine dioxide ($ClO_2$), and ozone ($O_3$) in natural water. The simplest interpretation of the Surface Water Treatment Rule (SWTR)[3] does not consider disinfectants with decaying concentrations. Instead it requires that the effluent concentration of the disinfection contactor be used. There are provisions for a segmented analysis that can approximate the disinfectant decay and hydraulic provisions of the IDDF. There are also provisions to allow for site-specific calculations if approved by the state regulator.

**Step 3—determine the inactivation kinetics.** Inactivation kinetics have typically been developed with oxidant demand–free water and a constant disinfectant concentration. In natural water, the disinfectant concentration is not constant; thus, the use of a single concentration at the end of the contactor for determining disinfection requirements will not result in the optimal process. Figure 3 shows results for $Cl_2$ inactivation of *Giardia* for fixed residuals of 1 and 2 mg/L. The dashed curve is a plot of the disinfectant effectiveness corrected for disinfectant decay assuming that the initial concentration is 2 mg/L and the contactor effluent concentration is 1 mg/L. The SWTR approach would assume that inactivation corresponds to the 1-mg/L line.

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**FIGURE 1** Example histogram of Giardia cysts in contactor effluent with pulse input

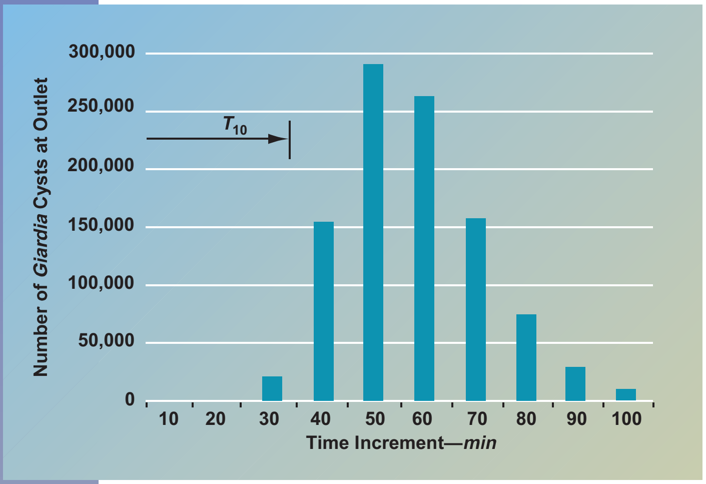


**FIGURE 2** Graph showing decay curve of chlorine disinfectant residual

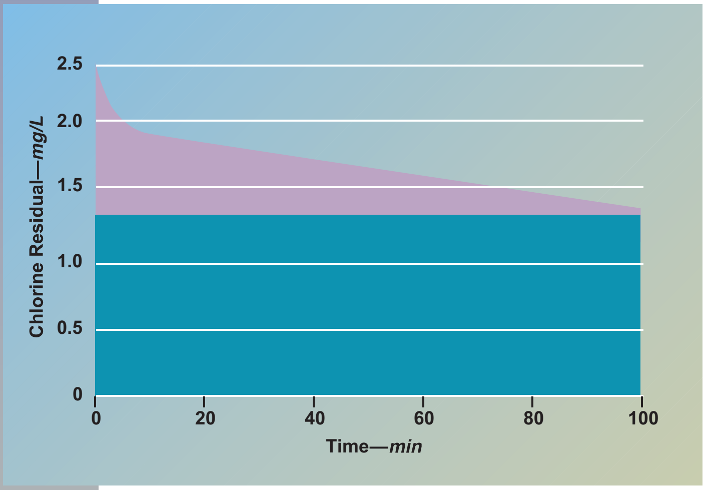
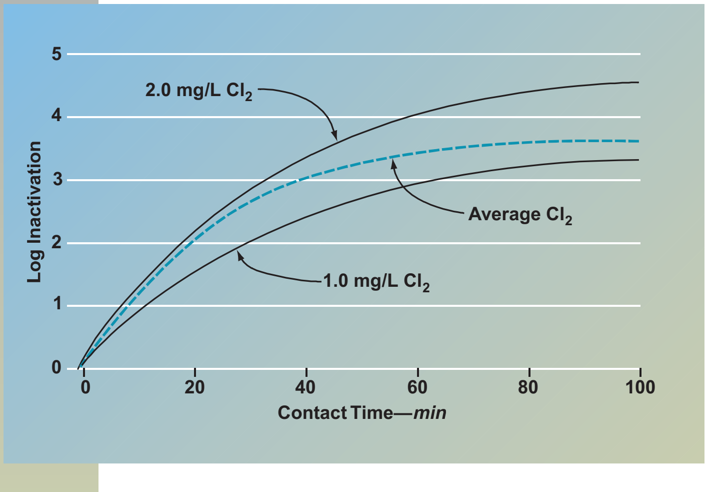


**FIGURE 3** Example inactivation curves for Giardia cysts



**Step 4—develop a disinfection model.** Table 1 shows an arithmetic model based on Figures 1–3. The example assumes that $10^6$ cysts are pulsed into a contactor. The hydraulic characteristics shown in Figure 1 are used to determine the fraction of cysts remaining in the contactor after a particular time (Table 1, column 3). Next the cysts passing through the contactor are determined (Table 1, column 4). Then the inactivation of cysts at each time interval can be found in Figure 3 (the dashed line) and is shown in Table 1, column 2. Finally, this information (Table 1, column 2) along with the number of cysts (Table 1, column 4) can be used to determine how many viable cysts make it through the contactor (Table 1, column 5). The resulting disinfection effectiveness is 3.27-log inactivation with $Cl_2$. Under the same conditions, the US Environmental Protection Agency (USEPA) concentration X time (*C* X *T*) tables would credit this disinfection system with 2.1-log inactivation.

## IDDF implementation protocols

The model developed for implementing the IDDF has four components or modules: (1) hydraulic characterization, (2) disinfectant demand–decay, (3) inactivation kinetics, and (4) DBP formation. A model (mechanistic or empirical) has been developed for each of these components. The output from each module provides an input to the IDDF model with which the user can interface. A conceptual representation of how the IDDF model is configured is shown in Figure 4. A software model* (IDDF model) is the central feature that provides the primary interface with the user. This model uses three modules—hydraulic characterization, disinfectant demand–decay, and inactivation kinetics—to calculate pathogen inactivation levels for a set of input parameters. The IDDF model established for this project has little flexibility for modification. However, the modules that support the IDDF model will have considerable flexibility, and the user can adapt the accuracy and complexity of the approach to the application. Specifically, each of the modules can be applied at three levels:

**Basic level.** This level offers the simplest use of the IDDF. It also allows development of the model input parameters without experimentation; e.g., USEPA val-

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*Visual Basic–Excel, Microsoft Corp., Redmond, Wash.

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ues from the guidance manual can be used.

**Standard level.** This level is anticipated to be the most common application of the IDDF. Development of model input parameters will require site-specific experimentation that can be mostly completed with water quality staff.

**Advanced level.** This approach is expected to be used by utilities that have shown a significant benefit potential by using the IDDF and are preparing for implementation. External expertise will likely be required to develop model input parameters.

**TABLE 1** **Summary of disinfection and hydraulic data**

| Time *min* | Log Inactivation (Figure 3) | Fraction of Cysts Remaining (Calculated) | Number of Cysts Passing Through Contactor (Figure 2) | Number of Viable *Giardia* Cysts Remaining (Calculated) |
|---|---|---|---|---|
| 0 | 0 | 1.00000 | 0 | 0 |
| 10 | 1.04 | 0.09120 | 0 | 0 |
| 20 | 1.94 | 0.01148 | 135 | 2 |
| 30 | 2.58 | 0.00263 | 20,871 | 55 |
| 40 | 3.01 | 0.00098 | 153,842 | 150 |
| 50 | 3.28 | 0.00052 | 288,309 | 151 |
| 60 | 3.44 | 0.00036 | 261,783 | 95 |
| 70 | 3.52 | 0.00030 | 157,321 | 48 |
| 80 | 3.53 | 0.00029 | 73,460 | 21 |
| 90 | 3.54 | 0.00029 | 29,114 | 8 |
| 100 | 3.55 | 0.00029 | 10,316 | 3 |
| Summation | | | 995,151 | 533 |
| Average log inactivation | | | 3.27 | |

Three levels can be applied for each module (Table 2). The different levels allow the IDDF to be applied for various purposes with different amounts of resources committed to develop the input parameters. For example, the user should always conduct a screening analysis to assess the potential benefits. This analysis would rely on the basic level of each module and thus would require a minimal investment of resources. If the potential benefits are significant and the utility is considering implementation, the standard or advanced levels should be used to develop more accurate input parameters. If these levels are used, external expertise may be required.

The user interface is an important part of the IDDF because it must provide a simple way to access the model for assessing the framework's benefits

**FIGURE 4** **Conceptual approach for implementing the integrated disinfection design framework (IDDF)**

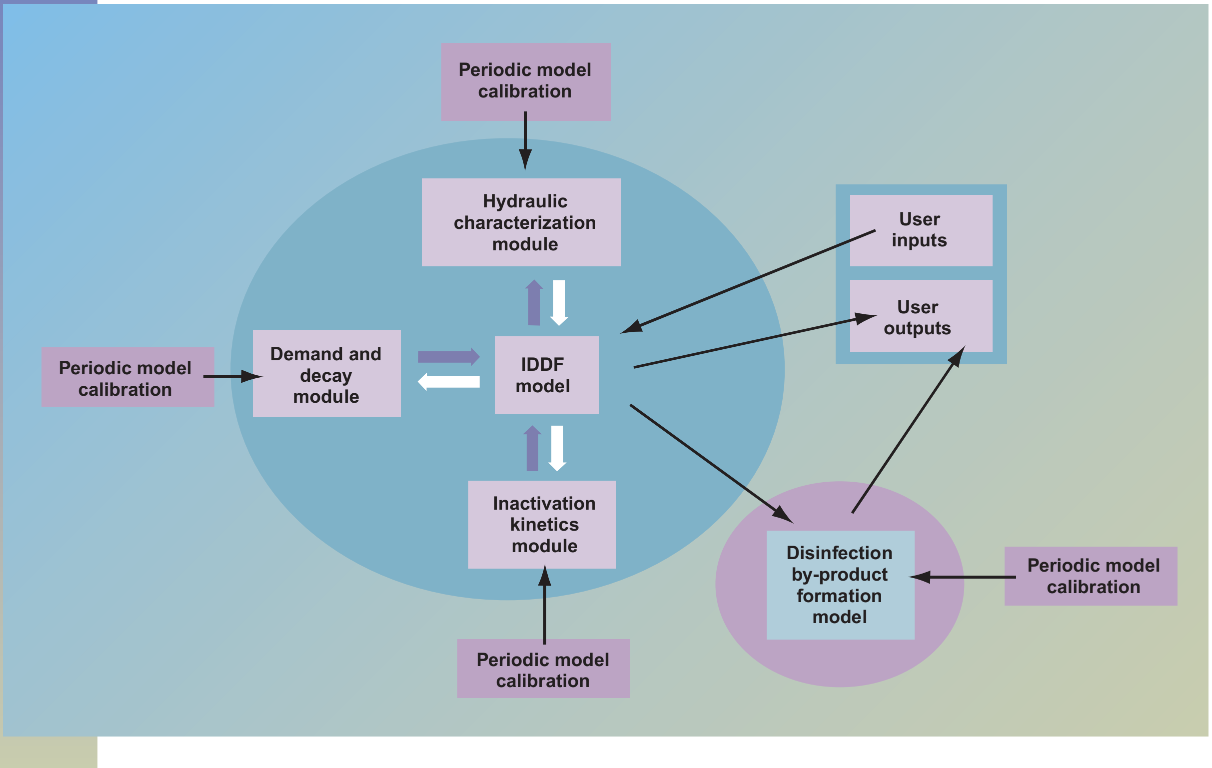

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**FIGURE 5** **Preliminary proposed user interface for the integrated disinfection design framework (IDDF)**

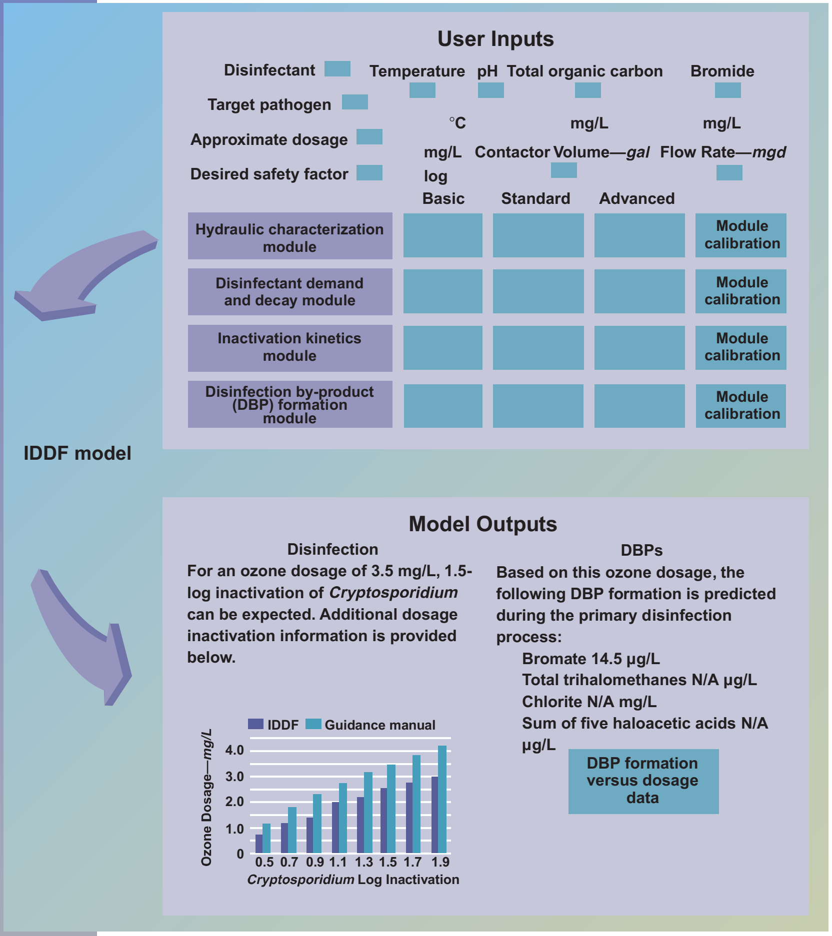
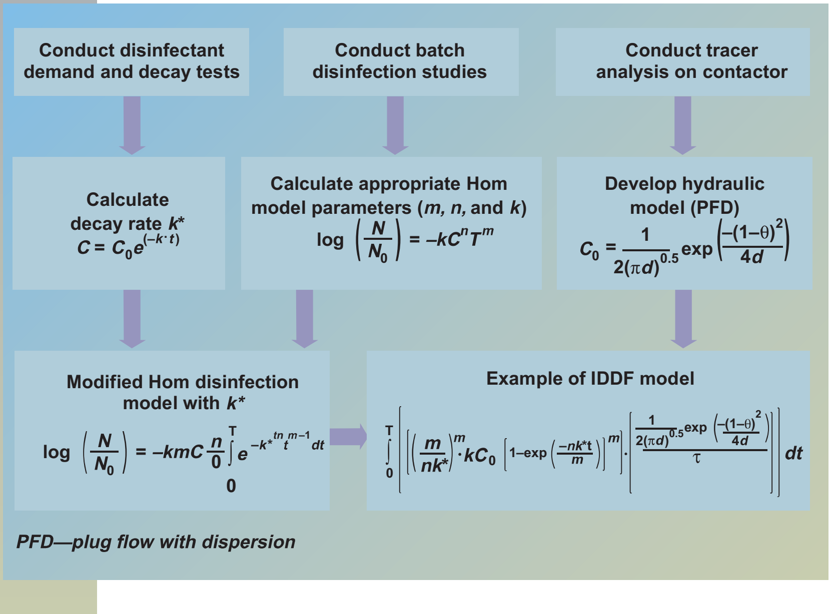


**FIGURE 6** **Integrated disinfection design framework (IDDF) modeling approach used in the original project**



*PFD—plug flow with dispersion*

(Figure 5). Inputs to the IDDF include the target pathogen, disinfectant, and the approximate dosage that will be applied. Water quality parameters such as temperature, pH, dissolved organic carbon, $UV_{254}$, and bromide concentrations are required to estimate DBP formation.

After the level of each module is selected, the user is asked to input the specific parameters shown in Table 2. For example, the user would need to input the site-specific RTD determined with tracer testing if the standard protocol was chosen for the hydraulic characterization module. If the basic level of this module was selected, a $T_{10}/T$ value, dispersion coefficient, or number of tanks in series would be input depending on which approach is used. The primary output of the IDDF is an estimation of the disinfectant dosage required for a given inactivation level. This information is provided in the form of a graph that shows a range of dosages and inactivation levels around the approximate dosage input by the user. This estimation is compared with the disinfectant dosage determined using the SWTR guidance manual.

A potentially important part of the IDDF presented here is the prediction of DBP formation based on the disinfectant dosages determined previously. DBP formation associated with the primary disinfection process is compared using both the IDDF and SWTR approaches for determining disinfection requirements. Additionally, concentrations of chlorination by-products (trihalomethanes [THMs] and haloacetic acids [HAAs]) formed during the secondary disinfection process are predicted.

## Development of the IDDF model

The original IDDF project used mathematical relation-

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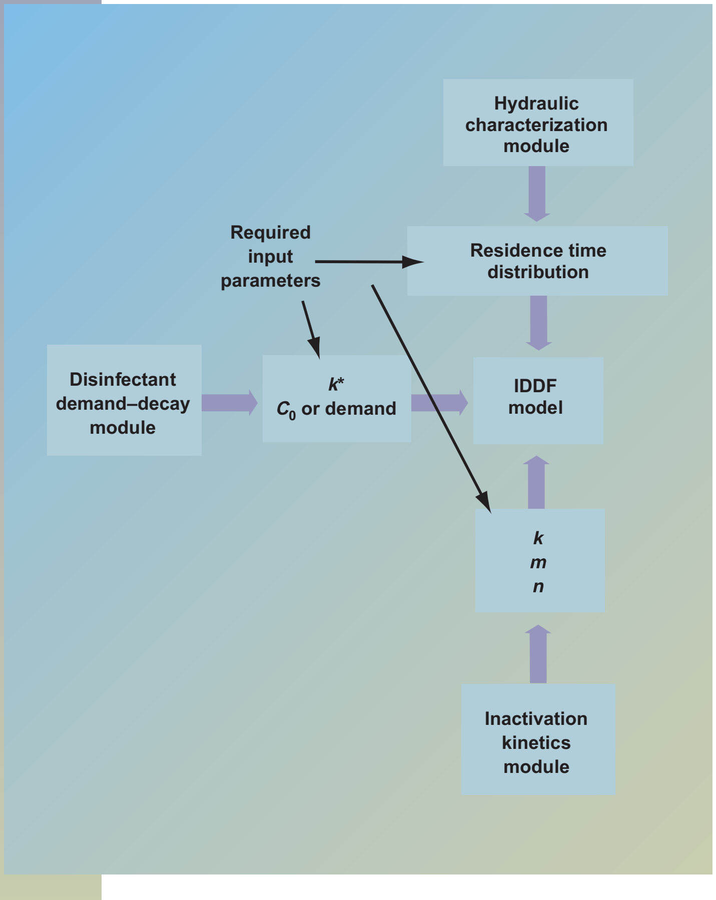
**TABLE 2** Integrated disinfection design inputs for different model levels and purposes

| Level | Type of Input | |
|---|---|---|
| | Existing Contactor | New Contactor |
| Hydraulic characterization alternatives | | |
| Basic | $D$* or $T_{10}$ | None |
| Standard | Tracer data | $D$ or $T_{10}$ |
| Advanced | Computational fluid dynamics (CFD)–derived residence time distribution (RTD) | CFD–derived RTD |
| Disinfectant demand–decay characterization alternatives | | |
| Basic | Model $k$* (decay constant), demand values | |
| Standard | Testing-derived $k$*, demand values for one dosage (assumes dosage independence) | |
| Advanced | Testing-derived $k$*, $C_0$ values for three dosages (develop dosage relationship) | |
| Inactivation kinetic parameter alternatives | | |
| Basic | Model $k$, $m$, and $n$† values | |
| Standard | Confirmation testing to determine $k$, $m$, and $n$ | |
| Advanced | Site-specific inactivation testing to determine $k$, $m$, and $n$ | |
| Disinfection by-product formation parameter alternatives | | |
| Basic | Literature empirical relationships | |
| Standard | Literature empirical relationship with site-specific dissolved organic carbon reactivity | |
| Advanced | Site-specific testing to determine empirical relationship | |

*Dispersion coefficient
†These values are the Horn model coefficients.

**FIGURE 7** Standard inputs for the integrated disinfection design framework (IDDF) model



ships for each of the components. This enabled the integrated model to be solved with the fairly complex integral shown in Figure 6. This approach works well if the hydraulic characterization of the disinfection contactor can be described by a mathematical relationship such as the plug flow with dispersion (PFD) model used in this case.

A limitation of this approach is the reliance on a curve-fitting model such as PFD or number of continuous stirred tank reactors (N-CSTRs) in series to represent the hydraulic characteristics of a contactor. These models attempt to curve-fit tracer data, but they often do not accurately predict the actual RTD, particularly in the critical $T_{10}$ region. Additionally, the PFD model is only applicable for contactors without significant deviations from plug flow. The model is not valid when $T_{10}/T$ is less than about 0.45. The integral approach shown in Figure 6 is also difficult to adapt to the use of computational fluid dynamics (CFD) for the hydraulic characterization of a contactor. In addition, this approach is mathematically complex and not user-friendly.

Based on this assessment of the original IDDF approach, goals were estab-

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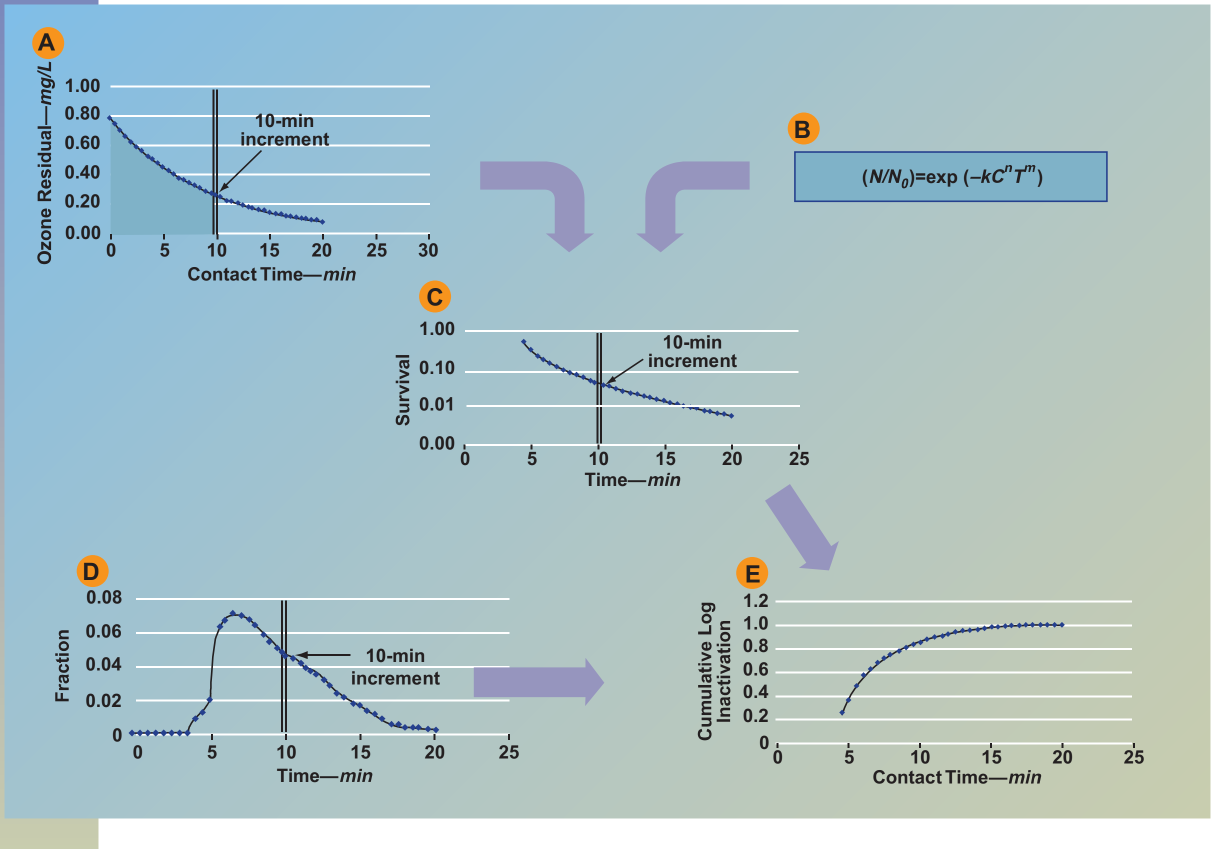
**FIGURE 8** Example of integrated disinfection design framework (IDDF) module inputs to the model: disinfectant demand–decay module (A), Hom model (B), inactivation kinetics model (C), hydraulic characterization module (D), and IDDF model output (E)



lished for the IDDF that may be proliferated and implemented at utilities. According to these goals, the modeling approach

- should be understandable as well as accessible by a range of academicians, consultants, and utility personnel;
- must be flexible enough to accept input from a range of alternative protocols (e.g., CFD);
- must not require data that are difficult to obtain; and
- must be as accurate as more mathematically complex methods.

To simplify the IDDF model without losing flexibility to accept data from different protocols, the input data format has been standardized (Figure 7). Flexibility resides with the modules that can use any protocol as long as the output conforms to the standard.

The IDDF is set up in this manner because of the need for the IDDF model to handle the essentially discrete data that will be input from the hydraulic module. The approach chosen uses a spreadsheet to analyze the disinfection process incrementally over a given period of time. Graphical examples of the inputs to this modeling approach are shown in Figure 8. The IDDF model integrates the three components sequentially by summing up finite slices of the disinfection process with respect to time. The finite slices are summed up over the hydraulic detention time (HDT) of the contactor being analyzed. For the example in Figure 8, the disinfectant is $O_3$, the pathogen is *Giardia,* and the contactor has an HDT of 8 min. The time interval is 0.5 min, and a disinfection element at 10 min is highlighted.

The disinfectant demand and decay profile ($C_0$ and $k^*$, the disinfectant decay term, for a first-order reaction) is a required output of the demand and decay module (Figure 8, part A). These data are a required input along with the Hom model (Figure 8, part B) to develop the inactivation kinetics module output—a survival versus contact time plot (Figure 8, part C). The modified Hom model[4] (which includes $k^*$) is used because the disinfectant concentration must be represented continuously up to the time element at which the disinfection is being calculated.

In the example shown, the disinfectant decay is represented by a first-order relationship. Thus, the incomplete gamma function solution developed by Haas and Joffe[5] is used. In Figure 8, the pathogen survival–contact time plot (part C) is used with the RTD (part D) that is derived from tracer tests, $T_{10}/T$ estimations, or CFD analysis to develop the IDDF model output, a disinfection effectiveness (log inactivation) versus contact time relationship (part E).

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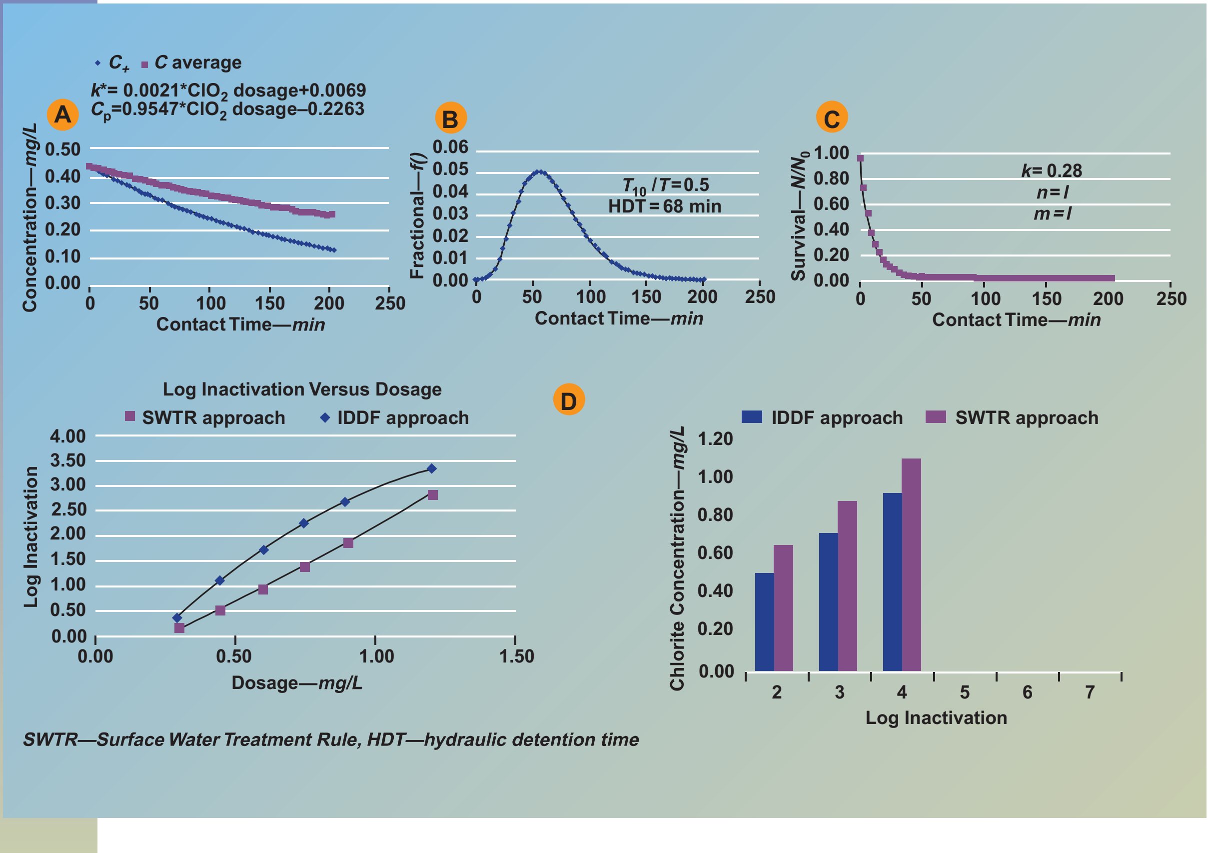
**FIGURE 9** Aurora, Colo., water utility output of integrated disinfection design framework (IDDF) for virus inactivation using chlorine dioxide ($ClO_2$): disinfectant demand–decay module (A), hydraulic characterization module (B), inactivation kinetics module (C), and IDDF model output (D)



*SWTR—Surface Water Treatment Rule, HDT—hydraulic detention time*

## IDDF implementation at a Colorado utility

The SWTR allows the use of site-specific disinfection calculations for $O_3$ and $ClO_2$, although no systems have taken full advantage of this provision. The IDDF is being implemented at the Aurora (Colo.) Water Department. This utility uses direct filtration and is implementing $ClO_2$ as its primary disinfectant. The IDDF was used to develop the design criteria for the $ClO_2$ process using the basic hydraulic characterization, the advanced demand–decay, and the basic inactivation modules. Disinfection requirements were based on 3-log virus inactivation. Because chloramines are used in the distribution system, THM and HAA formation is considered negligible.

**The use of inappropriate design relationships can lead to incorrectly sized and operated disinfection processes.**

Several of the output graphs from the IDDF model applied at the Aurora Water Department are shown in Figure 9. The RTD for the contact basin is determined by the hydraulics characterization module. The contact basin was designed to have a minimum $T_{10}/T$ of 0.5, and this value was used with an N-CSTRs in series modeling approach as the input parameter for the hydraulic characterization module. After the contactor is operational, tracer tests will be conducted and used in the standard level of this module instead of the $T_{10}/T$ assumption.

The predicted $ClO_2$ residual is shown as instantaneous and average concentrations. The average concentration represents the value used in the IDDF model, whereas the instantaneous concentration is the predicted concentration at the effluent of the contactor that would be used in a $C \times T$ calculation based on the SWTR.[2] When the contactor is operational, the module input data, the initial residual ($C_0$), and the first-order decay constant ($k^*$) will be determined periodically to adjust for changes in water quality. The inactiva-

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**TABLE 3** Summary of integrated disinfection design framework application studies at three utilities

| Primary Disinfectant Used | Target Pathogen | Target Disinfection Level *log* | Dosage Reduction Achieved *percent* |
|---|---|---|---|
| Aurora, Colo. | | | |
| Chlorine dioxide ($ClO_2$) | *Giardia* | 1 | 35 |
| $ClO_2$ | *Cryptosporidium* | 1 | 29 |
| $ClO_2$ | Viruses | 3 | 13 |
| Alameda County (Calif.) Water District | | | |
| Ozone ($O_3$) | *Giardia* | 0.5 | 8 |
| $O_3$ | *Cryptosporidium* | 1 | 28 |
| Denver (Colo.) Water Department | | | |
| Chlorine | *Giardia* | 0.5 | 27 |

tion kinetics module uses the Hom model input parameters of $k$, $m$, and $n$ (0.28, 1, and 1, respectively) along with the $ClO_2$ residual data to calculate the virus survival versus contact time assuming ideal hydraulic conditions.

The outputs from each of the modules were used to determine the overall virus inactivation. The virus inactivation determined with the IDDF was compared with that calculated using the $C$ X $T$ approach (contactor effluent concentration and $T_{10}$) described in the SWTR. For 3-log virus inactivation, the use of the IDDF will result in a $ClO_2$ dosage reduction of 13 percent with a corresponding 13 percent reduction in the formation of chlorite, a DBP.

When the $ClO_2$ contactor is operational, the Aurora Water Department will use the IDDF to determine its disinfectant dosage based on measured water quality conditions. Site-specific data such as oxidant demand and decay, temperature, and target pathogen inactivation will be used to optimize the disinfection process. An appropriate safety factor will be applied.

**IDDF case studies.** Several case studies have been conducted using the IDDF to determine the benefits in other water treatment systems.[6] Table 3 summarizes these case studies. The benefits of using the IDDF depend on the target pathogen and the required inactivation, with disinfectant dosage reductions ranging from 8 to 35 percent. A more rigorous sensitivity analysis will be conducted in the future to identify the disinfection process conditions that will result in the greatest benefits from using the IDDF to determine pathogen inactivation requirements.

## Conclusion

A computerized framework for determining site-specific drinking water disinfection requirements has been developed. The IDDF uses contactor hydraulic characteristics, disinfectant demand and decay data, and inactivation kinetics to determine disinfection requirements. DBP formation is then estimated based on these requirements and site-specific water quality data. Benefits to water utilities may include reduced disinfectant dosages and reduced formation of related by-products. In any case, the IDDF provides a more direct and accurate approach for determining disinfection requirements.

The IDDF provides a user-friendly technique for utilities, consultants, and regulators to use to optimize disinfection processes to inactivate microorganisms while minimizing cost and the formation of DBPs. The IDDF can be used for $O_3$ and $ClO_2$ within the current regulatory structure, and more widespread application of the technique may be considered in future regulations.

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**About the authors:** *William Bellamy is director of water supply and treatment at CH2M Hill, 100 Inverness Terrace E., Englewood, CO 80112. Kenneth Carlson is assistant professor at the Dept. of Civil Engineering, Colorado State University, Fort Collins, CO 80523. David Pier is a project engineer at Camp, Dresser & McKee, 1331 17th St., Ste. 1200, Denver, CO 80202. Joel Ducoste is assistant professor, Dept. of Civil Engineering, North Carolina State University, 208 Mann Hall, Campus Box 7908, Raleigh, NC 27695-7908, and Mark Carlson is a vice-president at CH2M Hill, 2300 N.W. Walnut Blvd., Corvallis, OR 97330.*

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