Procedure for Disinfection of Drinking Water in Ontario

(As adopted by reference by Ontario Regulation 170/03 under the *Safe Drinking Water Act)*

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PREAMBLE

This procedure is a supporting document for Ontario legislation and regulations related to drinking water and specific to water disinfection and any pre-disinfection processes that may be necessary to ensure effectiveness of disinfection. (Note: Provisions of Ontario Regulation 170/03, "Drinking-Water Systems", ("Regulation") a regulation under the *Safe Drinking Water Act, 2002* ("SDWA"), adopt this Procedure by reference. For instance, the Procedure is adopted by reference in the provisions in Schedules 1 and 2 to the Regulation that deal with requirements for primary and secondary disinfection.) This procedure supersedes the MOE Procedure B13-3, "Chlorination of Potable Water Supplies in Ontario, January 2001."

The specific requirements in the Regulation to which this procedure pertains are as follows:

- all municipal drinking-water systems and regulated non-municipal drinking-water systems that are required to provide a minimum level of treatment must have a treatment process that consists of disinfection as a minimum, if the system obtains water from a raw water supply which is ground water;
- all regulated drinking-water systems that obtain water from a raw water supply which is surface water or ground water under the direct influence of surface water, must provide a minimum level of treatment consisting of chemically assisted filtration and disinfection or other treatment capable of producing water of equal or better quality;
- all drinking water entering a distribution system that has been treated and is otherwise ready for consumption must contain a disinfectant residual that persists throughout the distribution system unless a point of entry treatment approach is used as permitted by the Regulation; and,
- effectiveness of the provided treatment must be adequately monitored.

The underlying reasons for these requirements are: to ensure an adequate level of removal or inactivation of pathogenic organisms that may be present in the raw water; to prevent re-contamination of drinking water within the distribution system; and, to maintain drinking water quality throughout the distribution system.

Disinfection is the key element to the achievement of these goals, and any need for pre- or post-disinfection treatment related to the achievement of these goals derives from the limitations of the disinfection process. For this reason, although it also addresses these pre- or post-disinfection processes, this procedure is referred to as a disinfection procedure.

The intent of this Procedure is to ensure that new microbiological challenges and new developments in treatment technologies and practices are addressed both in the design of new drinking-water systems and in the upgrading, expansion, and maintenance of existing systems.

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1. DISINFECTION OF DRINKING WATER

1.1 Introduction

This Procedure provides guidance for:

- disinfection (primary disinfection), including any pre-disinfection treatment necessary to achieve the required level of removal or inactivation of pathogens potentially present in the source water;
- the maintenance of a disinfectant residual in a distribution system (secondary disinfection);
- control of disinfection by-products; and,
- disinfection following drinking-water system construction or repair.

A clear distinction is made between primary disinfection and secondary disinfection, which are often completely separate treatment processes and provide different outcomes. The former is intended to provide disinfection before the water is delivered to the first consumer and the latter ensures maintenance of a disinfectant residual throughout the distribution system.

1.2 Design and Construction of Disinfection Facilities

The design and construction of both primary and secondary disinfection facilities should normally conform to the criteria set out in the Recommended Standards for Water Works ("Ten State Standards") published by the Great Lakes - Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (of which Ontario is a member) or, when a site-specific application of an alternative design has been approved by the Ministry, to the construction, operation, and performance requirements criteria stipulated in the approval.

The design recommendations in the Ten State Standards should be considered as representing sound principles of good engineering practice. Variance from the detailed design recommendations may be appropriate, depending on site-specific circumstances associated with an individual drinking-water system. In this context, the Ten State Standards document should be considered as a guideline in the Ontario regulatory framework.

In assessing an application for approval of a drinking-water system, the Ministry's review team will also be regarding the design recommendations in the Ten State Standards as representative of sound engineering principles and a proponent may be required to demonstrate that any submitted design addresses the issues otherwise addressed by a 'Ten State' recommendation.

The Ten State Standards also include administrative procedures, policy statements, and reporting requirements (including Engineers' Reports) as recommendations. It is important to note that while these may also represent sound principles and good practices, the specific requirements of Ontario legislation, regulations, policies, processes and procedures will prevail over these recommendations.

It is further recognized that the Ten State Standards document focuses on public water supplies which include larger systems; however, many principles and recommended standards contained within the document will also have relevance to even the smallest of drinking-water systems. The designer of a drinking-water system that does not require an approval, and the Professional Engineer undertaking an Engineering Evaluation Report for the system in accordance with regulatory requirements, should have regard to the design recommendations of the Ten State Standards, but also use professional expertise to determine the site-specific relevancy and appropriateness of any single requirement in the context of the drinking-water system being designed or assessed.

The requirements contained elsewhere in this procedure are critical to the design or assessment of treatment processes for all drinking-water systems.

2. PATHOGEN REMOVAL/DISINFECTION REQUIREMENTS

Drinking water disinfection and any pre-disinfection treatment requirements in Ontario are specific to the type of raw water supply a drinking-water system will be relying upon. Design of the treatment processes should consider the characterization, variability and vulnerability of the raw water supply. All water supplies should be individually assessed by measuring relevant water quality parameters and utilizing, where chemical disinfection is used, the CT tables[1] provided to determine the appropriate disinfectant dosage. This section outlines the disinfection (primary disinfection) requirements by the type or raw water supply, with variations based on vulnerability of the raw water supply, and includes any applicable pre-disinfection treatment (filtration) requirements.

2.1 Ground Water

For the purpose of this document, a raw water supply which is ground water means water located in subsurface aquifer(s) where the aquifer overburden and soil act as an effective filter that removes micro-organisms and other particles by straining and antagonistic effect, to a level where the water supply may already be potable but disinfection is required as an additional health risk barrier, unless the Director has granted a drinking-water system relief, or requirements for exemption have been met in accordance with Ontario Regulation170/03, “Drinking-Water Systems”.

Where the drinking-water system obtains water from a raw water supply which is ground water, the treatment process must, as a minimum, consist of disinfection and must be credited with achieving an overall performance that provides, at a minimum 2-log (99%) removal or inactivation of viruses before the water is delivered to the first consumer.

For example, with ground water of pH 7-8 and temperature 7-10 degrees Celsius (ºC), this requirement can be met by a minimum chlorine residual of 0.2 mg/L, measured as free chlorine, after 15 minutes of contact time determined as T_{10} at maximum flow rate. For ground water

[1] The definition of the T_{10} contact time and explanation of the CT value concept are provided in subsection 3.1.1 (CT Disinfection Concept).

whose conditions are outside this range of pH or temperature, higher CT values may be needed to achieve the required minimum virus inactivation.

2.2 Surface Water and Ground Water under Direct Influence of Surface Water

Surface water[2] means water bodies (lakes, wetlands, ponds - including dug-outs), water courses (rivers, streams, water-filled drainage ditches), infiltration trenches, and areas of seasonal wetlands.

Ground water under the direct influence of surface water means ground water having incomplete or undependable subsurface filtration of surface water and infiltrating precipitation. The following drinking-water systems are deemed by the Drinking-Water Systems Regulation, to be drinking-water systems that obtain water from a raw water supply that is ground water under the direct influence of surface water:

- A drinking-water system that obtains water from a well that is not a drilled well or that does not have a watertight casing that extends to a depth of at least 6 metres below ground level.
- A drinking-water system that obtains water from an infiltration gallery.
- A drinking-water system that is not capable of producing 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.
- A drinking-water system that is capable of producing 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.
- A drinking-water system that is capable of producing 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.
- A drinking-water system that exhibits evidence of contamination by surface water.
- A drinking-water system in respect of which a written report has been prepared by a professional engineer or professional hydrogeologist that concludes that the system's raw water supply is ground water under the direct influence of surface water and that includes a statement of his or her reasons for reaching that conclusion.

Drinking-water systems that obtain water from a raw water supply which is surface water or ground water under the direct influence of surface water must have a treatment process that is capable of producing water of equal or better quality than a combination of well-operated chemically assisted filtration and disinfection processes would provide. This treatment process must achieve an overall performance that provides at a minimum a 2-log (99%) removal or

[2] In a multi-barrier system for providing safe drinking water, the selection and protection of a reliable, high-quality drinking water source is the first barrier. In this context, many locations described as surface water would be unsuitable as a source water supply but are included in the description for full consideration as they may impact ground water.

inactivation of *Cryptosporidium* oocysts, a 3-log (99.9%) removal or inactivation of *Giardia* cysts and a 4-log (99.99%) removal or inactivation of viruses before the water is delivered to the first consumer.

At least 0.5-log removal or inactivation of *Giardia* cysts and 2-log removal or inactivation of viruses must be provided through the disinfection portion of the overall water treatment process.

Chemically assisted direct or conventional filtration and disinfection, and slow sand filtration and disinfection processes operating in accordance with performance criteria provided in subsections 3.4.1, 3.4.2 and 3.4.3 that have been credited with a 3-log (99.9%) removal or inactivation of *Giardia* cysts, will also be credited with 2-log (99%) removal or inactivation of *Cryptosporidium* oocysts. Where chlorination is used for primary disinfection, the 2-log removal credit for *Cryptosporidium* oocysts is considered to be attributed to these filtration processes because chlorine at reasonable doses and contact times is considered to be essentially ineffective in inactivating *Cryptosporidium* oocysts.

In the case of membrane and cartridge filtration or other filtration processes that only rely on physical characteristics of the filtration medium, the 2-log removal or inactivation of *Cryptosporidium* oocysts can only be assigned to the process specifically tested and confirmed by an independent testing agency or the approving Director for this removal or inactivation of *Cryptosporidium* oocysts or removal of surrogate particles.

Higher log removal or inactivation may be needed for a raw water supply where there is a presence of sewage effluent or other sources of microbial contamination - runoff from livestock operation, manure storage, handling or spreading, etc.

The determination of any additional log removal or inactivation required may also be based upon pathogen monitoring of raw water. This process may be subject to errors, however, when carefully planned, applied and interpreted, it may represent a useful tool in making process design decisions[3]. Where drinking-water systems are required to have an approval, these considerations should be further discussed during pre-submission consultation to determine the sources of microbial contamination.

For drinking-water systems that are subject to an approval and that rely on a raw water supply which is ground water under the direct influence of surface water, the approving Director may accept that disinfection alone is capable of producing water of equal quality if:

– a hydrogeologist report, prepared in accordance with the Ministry's "Terms of Reference for Hydrogeological Study to Examine Ground Water Sources Potentially Under Direct Influence of Surface Water. October 2001" concludes that adequate in-situ filtration is provided by the aquifer overburden, and,

[3] Reference should be made to US EPA's guidance manuals (Long Term 1 Enhanced Surface Water Treatment Rule and Long Term 2 Enhanced Surface Water Treatment Rule)

– wellhead protection measures are being, or will be, implemented in accordance with conditions imposed in the approval.

Should the approving Director concur that it is acceptable that the required treatment is achieved through disinfection alone, the disinfection process or combination of disinfection processes used in these circumstances must be capable of providing an effective inactivation of oocysts, cysts, and viruses. In this context, primary disinfection may need to use both ultraviolet disinfection and chemical disinfection. In this connection, the reader's attention is directed to section 3.2 of this procedure, Ultraviolet (UV) Disinfection.

3. DISINFECTION (PRIMARY DISINFECTION)

Disinfection (primary disinfection) is a process or a series of processes intended to inactivate human pathogens such as viruses, bacteria and protozoa, potentially present in influent water before the water is delivered to the first consumer.

The entire process of primary disinfection must be completed within the water treatment component of the system, which may include a dedicated part of the piping upstream of the first consumer connection. Where point of entry treatment units are permitted by the Regulation, primary disinfection must be completed within the point of entry treatment unit. Be aware that if point of entry treatment units are to be used at a drinking-water system, the Regulation imposes specific requirements in relation to such units, and these requirements should be carefully reviewed.

Effective disinfection of adequately filtered influent water or raw water of suitable quality can be accomplished by either chemical or physical means such as the use of chlorine, chlorine dioxide, ozone or ultraviolet light. However, the disinfection processes will not be as effective on influent waters of inferior quality.

Because of this limitation in the effectiveness of disinfection processes, in order to achieve the required level of inactivation of pathogens potentially present in a particular raw water supply, depending on the quality of the raw water as well as certain other site-specific conditions, it may be necessary to introduce some additional contamination barriers and/or treatment processes ahead of the primary disinfection stage. These additional requirements will be addressed as part of the Ministry approval or as part of the Engineer's consideration during the preparation of the Engineering Evaluation Report for systems that do not require an approval.

The following subsections identify specific requirements related to the use of different disinfection processes; the need for and use of different pre-disinfection treatment processes; as well as the pathogen removal or inactivation credits given to these processes and the criteria the processes must meet to qualify for these credits.

3.1 Chemical Disinfection

The selection of an appropriate disinfection process depends upon site-specific conditions and raw water characterization that is unique to each drinking-water system. Process selection decisions must consider and balance the need to inactivate human pathogens while minimizing

the production of disinfection by-products. Commonly accepted chemical disinfectants are free chlorine, monochloramine, chlorine dioxide and ozone.

Free chlorine residual disinfection ("Chlorination") is the application of chlorine to water to produce a free chlorine residual[4] (directly or through oxidation of any naturally present ammonia and/or other nitrogenous substances).

Free chlorine, in the form of hypochlorous acid, is considered a powerful disinfectant that is effective against a very broad range of pathogens. The free chlorine residual from primary disinfection may also be used to maintain a persistent residual within the water distribution system (secondary disinfection). In this case, where ammonia and other nitrogenous substances are present in the influent water, the application of chlorine should be such that the resulting free chlorine residual, at the end of the primary disinfection process, comprises more than 80% of the total chlorine residual[5] as only the free chlorine residual is considered a disinfectant for the purpose of secondary disinfection. In situations where breakpoint chlorination is being practiced (to oxidize natural raw water ammonia by the break-point chemistry), it will be effectively complete before the water leaves the disinfection equipment. If this provision were not in place, it is possible that the residual required to protect the water in the distribution system might be prematurely and rapidly lost through continuing break point chemistry.

Free residual chlorination may be achieved through the use of chlorine gas, sodium hypochlorite, calcium hypochlorite or free chlorine producing electrochemical process.

Combined chlorine residual disinfection ("Chloramination") is the application of ammonia and chlorine, with the ammonia addition downstream of the application of chlorine at the mass ratio of chlorine to ammonia of approximately 4.5:1 to produce a combined chlorine residual[6] predominantly in the form of monochloramine. Table 14 presents CT values for the inactivation of viruses by chloramines during primary disinfection. This table is only applicable for indicating virus inactivation efficiencies if chlorine is added prior to ammonia.

Monochloramine is a weak disinfectant and it is rarely suitable for use as a primary disinfectant, because at the normally used concentrations it requires very long contact time to achieve adequate disinfection. Because of its high persistence characteristics, monochloramine is more commonly used as a secondary disinfectant to maintain chlorine residual in the water distribution system. In the secondary disinfection process, the sequence of addition of chlorine and ammonia does not affect the efficiency or effectiveness of the formation of combined chlorine residual. In

[4] **Free (available) chlorine residual:** The amount of chlorine available as dissolved gas (Cl_2), hypochlorous acid (HOCl), and hypochlorite ion (OCl^-), that is not combined with ammonia (NH_3) or other compounds in water.

[5] **Total chlorine residual:** The total amount of chlorine residual present after a given contact time in a water sample, regardless of the form of chlorine.

[6] **Combined (available) residual chlorine:** The concentration of residual chlorine that is combined with ammonia (NH_3), organic nitrogen, or both in water as chloramine (or other chloroderivative), yet is still available to oxidize organic matter and act as a disinfectant.
Combined chlorine can be accurately estimated as the difference between the measured total chlorine and measure or known free chlorine residual.

fact, the chemicals can be added in any sequence, or simultaneously, provided proportioning is correctly balanced and a rapid mixing occurs immediately subsequent to the addition.

Chlorine dioxide disinfection involves on-site generation of chlorine dioxide through the reaction of sodium chlorite with chlorine gas, hypochlorous acid or hydrochloric acid, or through the use of an electrochemical process. Chlorine dioxide is a powerful disinfectant that is generally more rapidly effective than chlorine, but less than ozone. The chlorine dioxide residual from primary disinfection may also be used to maintain a residual through part or all of the water distribution system.

Ozone disinfection involves on-site generation of ozone through electrical treatment of oxygen or dry air. Although ozone is a highly effective disinfectant, it does not produce a persistent residual, and is not suitable for the purpose of the maintenance of disinfectant residual in the water distribution system. There is a potential for distribution system biofilm proliferation unless a biofiltration step is included downstream of ozone application.

Note: Where primary chemical disinfectants other than free chlorine are selected, the suitability and effectiveness of these processes must be established on a site-specific basis and the rationale for the selection should be documented by the designer of the drinking-water system or the professional engineer who is responsible for preparing a report on the system.

3.1.1 CT Disinfection Concept

The CT disinfection concept uses the combination of a disinfectant residual concentration (in mg/L) and the effective disinfectant contact time (in minutes), to quantify the capability of a chemical disinfection system to provide effective pathogen inactivation to the required level. The use of this concept involves determining the CT values required at the actual, often variable, operating conditions (flow, temperature, and pH) and ensuring that the employed disinfection process achieves these values at all times.

Chemical disinfection CT values are calculated by multiplying the disinfectant residual concentration (in mg/L) by the disinfectant contact time (in minutes).

$$CT = \text{Concentration (mg/L)} \times \text{Time (minutes)}$$

The chemical disinfectant residual is measured at the end of each treatment step (e.g., clarification, if a portion of the overall disinfection process is accomplished before filtration) and the contact time used is T_{10} - the length of time during which not more than 10% of the influent water would pass through that process. The use of T_{10} ensures that 90% of the water will therefore have a longer contact time.

Actual T_{10} values can be significantly different from calculated hydraulic detention times (T) and should be determined by a tracer study, mathematical modeling or by calculations using typical baffle conditions. The following table summarizes factors applicable to typical baffle conditions.

TYPICAL BAFFLE CONDITIONS

Baffle Condition	T_{10}/T Ratio	Baffle Description
Unbaffled (mixed flow) separate inlet/outlet	0.1	No baffles, agitated basin, very low length to width ratio, high inlet and outlet flow velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1	Very high length to width ratio (pipeline flow)

CT values can be determined for each process step of the treatment train and summed, where the pH level and chlorine residual remain constant. Calculations should be based on the disinfectant residual concentration as continuously measured at the end of, or at intermediate points within, each process step. Disinfectant concentrations will be assumed to be constant upstream of any monitoring station, at all upstream points up to the next upstream monitoring location or the disinfectant addition point.

The summed total (calculated) CT value is then compared to the required CT value, which is determined from the CT tables appended to this procedure. The tables[7] identify the free chlorine and other chemical disinfectants CT values required for specific values of log inactivation of *Giardia* cysts and target viruses (hepatitis A) at specific temperatures and pH levels.

The calculated CT value should, at all times during plant operation, be equal to or greater than the required overall CT value.

Where pH and chlorine levels change significantly in different sections of the disinfectant exposed treatment, a more accurate estimate of the overall treatment is obtainable by adding log inactivation values for each type of microbial threat in each section.

Where appropriate, the Integrated Disinfection Design Framework (IDDF)[8] method for accounting disinfection decay and true process hydraulic should be used for determining the CT values and associated logs of microbial inactivation in the interest of maximizing pathogen control while minimizing disinfection by-product formation.

[7] US EPA "Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources", and Long Term 2 Enhanced Surface Water Treatment Rule for the table providing the CT values for inactivation of *Cryptosporidium* by ozone.

[8] IDDF method is published by Awwa Research Foundation and American Water Works Association, 1998.

3.2 Ultraviolet (UV) Disinfection

The application of ultraviolet (UV) light is an acceptable primary disinfection process. A particular type and design of UV reactor may be considered acceptable if it has been shown to achieve the required level of disinfection through reactor biodosimetry testing using MS-2 bacteriophage and/or *Bacillus subtilis* spores to establish the flow maxima that the equipment can deliver under different UV transmittances and still achieve the target design dose. Where the considered technology uses UV light source providing radiation at wavelengths different from continuous monochromatic 254nm wavelength light that is close to the maximally effective germicidal wavelengths of 260-265nm, the dose delivered by the considered technology must be validated also by empirical biodosimetry testing and the dose must be expressed as a 254nm-equivalent UV dose.

For drinking-water systems that do not require an approval, as a consideration during the preparation of the Engineering Evaluation Reports, the Engineer should refer to published standards for the UV equipment being considered in order to demonstrate that the required level of disinfection is met for the use of the equipment in question. For point of entry treatment units, ANSI / NSF Standard 55A or equivalent can be referred to for the purposes of the report.

UV facilities should be designed taking into account appropriate reliability and redundancy measures, and the light transmission and scale formation/fouling potential in the UV reactor specific to the quality of the raw water supply. Particular attention is drawn to the recommendations contained with the 'Ten State Standards' for UV systems.

While the use of UV light may be acceptable for the purpose of primary disinfection, it does not provide a disinfectant residual. Where the regulation requires the provision of secondary disinfection for a drinking-water system, primary disinfection must be followed by another process, normally chlorination, which introduces and maintains a persistent disinfectant residual throughout the distribution system.

3.2.1 Ground Water

For ground water which is not under the direct influence of surface water, UV light is acceptable as a primary disinfection process, provided that the UV reactor's 254nm-equivalent UV pass through dose of at least 40 mJ/cm^2 is maintained throughout the life time of the lamp.

3.2.2 Surface Water and Ground Water under Direct Influence of Surface Water

Drinking-water systems that obtain water from a raw water supply which is surface water or ground water under the direct influence of surface water must have a treatment process that is capable of producing water of equal or better quality than a combination of well-operated chemically assisted filtration and disinfection. The use of UV light may only be acceptable as a primary disinfection process in combination with chemically assisted filtration (or an equivalent treatment process). UV light on its own is not an acceptable substitute for the chemically assisted filtration step. Where there is a presence of sewage effluent, a primary disinfection process (following chemically assisted filtration) using UV light alone may not be adequate to inactivate certain viruses (e.g., adenovirus). In such cases, a two-stage primary disinfection process

consisting of UV light and chemical disinfection, with a proper contact time may be needed. When monochromatic 254nm wavelength UV light is used in combination with chlorine it does not interfere significantly with the chlorine based disinfection process.

For some drinking-water systems that are subject to an approval and that rely on a raw water supply which is ground water under the direct influence of surface water, the approving Director may accept that disinfection without chemically assisted filtration is capable of producing water of equal quality if:

– a hydrogeologist report, prepared in accordance with the Ministry's "Terms of Reference for Hydrogeological Study to Examine Ground Water Sources Potentially Under Direct Influence of Surface Water, October 2001", concludes that adequate in-situ filtration is provided by the aquifer overburden, and,

– wellhead protection measures are being implemented in accordance with conditions imposed by the approval.

For drinking-water systems meeting the above criteria, the approving Director may concur that the required treatment performance can be achieved through disinfection alone, a two stage primary disinfection process consisting of UV light (UV reactor's 254nm-equivalent UV pass through dose of at least 20 mJ/cm^2) combined with chemical disinfection so as to provide an overall 4.0 log inactivation of viruses.

3.3 Other Disinfectants

In the case of other disinfectants or a combination of disinfectants other than those discussed in this procedure it must be demonstrated and documented that the disinfection process in conjunction with filtration (where required) achieves the required level of pathogen removal or inactivation.

3.4 Filtration Process Pathogen Removal Credits

This subsection identifies various filtration technologies and the associated specific pathogen removal credits. These credits only apply when a professional engineer, exercising his or her professional judgement, concludes that the technology design satisfies the Recommended Standards for Water Works ("Ten State Standards") or when a site-specific application of the alternative design has been approved by the Ministry and the operation meets the required performance criteria as discussed in the following subsections. Where possible, the filtration system should be designed and operated to reduce turbidity levels as low as possible, with a goal of treated water turbidity of less than 0.1 NTU at all times. The credits in the following table represent the minimum log removal efficiencies as opposed to average removal efficiencies.

PATHOGEN REMOVAL CREDITS

Treatment Technology	Log Removal Credit		
	Giardia Cysts	Viruses	*Cryptosporidium* Oocysts
Conventional Filtration	2.5	2	2
Direct Filtration	2	1	2
Slow Sand Filtration	2	2	2
Diatomaceous Earth Filtration	2	1	2*
Membrane Filtration	3.0 +	0.0 to 2.0 +	2*
Cartridge/Bag Filters	2.0 +	0	2*
* applies only when the process has been specifically tested and confirmed for this removal/inactivation or *cryptosporidium* cysts or removal of surrogate particles.			

3.4.1 Conventional Filtration

Conventional filtration is the most common treatment process currently used by drinking-water systems that rely on raw water supplies which are surface water. This treatment process consists of chemical coagulation, rapid mixing, flocculation, and sedimentation followed by rapid sand filtration.

In order to be considered conventional filtration and meet or exceed the 2.5 log *Giardia* cyst removal, the 2.0 log *Cryptosporidium* oocyst removal and 2.0 log virus removal credits, the filtration process must meet the following criteria:

- use a chemical coagulant at all times when the treatment plant is in operation;
- monitor and adjust chemical dosages in response to variations in raw water quality;
- maintain effective backwash procedures, including filter-to-waste or an equivalent procedure during filter ripening to ensure that the effluent turbidity requirements are met at all times;
- continuously monitor filtrate turbidity from each filter; and,
- meet the performance criterion for filtered water turbidity of less than or equal to 0.3 NTU in 95% of the measurements each month.

3.4.2 Direct Filtration

Direct filtration process consists of chemical coagulation, rapid mixing and flocculation followed by rapid sand filtration. It is very similar to a conventional filtration process but without the

sedimentation step prior to filtration. Generally, the use of direct filtration process is limited to raw water supply sources with water turbidity of less than 20 NTU and colour less than 40 TCU. In order to meet or exceed the 2.0 log *Giardia* cyst removal, the 2.0 log *Cryptosporidium* oocyst removal and 1.0 log virus removal credit, the direct filtration process must meet the conventional filtration criteria above.

3.4.3 Slow Sand Filtration[9]

Slow sand filtration is a biological and physical process, equivalent to chemically assisted filtration, where the processes of adsorption and biological flocculation that take place in the gelatinous microbial growth formed in the upper sand layer eliminate the need for chemical coagulation and flocculation. Generally, the use of a slow sand filtration process is limited to raw water supply sources (or influent water after pretreatment) having turbidity of less than 10 NTU and colour less than 15 TCU.

In order to meet or exceed the 2.0 log *Giardia* cyst removal, the 2.0 log *Cryptosporidium* oocyst removal and 2.0 log virus removal credits, the slow sand filtration process must meet the following criteria:

- maintain an active biological layer;
- regularly carry out effective filter cleaning procedures;
- use filter-to-waste or an equivalent procedure during filter ripening periods;
- continuously monitor filtrate turbidity from each filter or take a daily grab sample; and,
- meet the performance criterion for filtered water turbidity of less than or equal to 1.0 NTU in 95% of the measurements each month.

3.4.4 Diatomaceous Earth Filtration (DE)

Filtration using diatomaceous earth involves the passage of water through a layer of diatomite media supported on a fine metal screen, a porous ceramic material or a synthetic fabric supported on a septum. The initial diatomite layer is usually supplemented by a continuous feed of diatomite. Generally, the use of a DE filtration process is limited to raw supply water sources (or influent water after pretreatment) having turbidity of less than 20 NTU and colour less than 15 TCU.

In order to meet or exceed the 2.0 log *Giardia* cyst removal, the 2.0 log *Cryptosporidium* oocyst removal and 1.0 log virus removal credit, the DE filtration process must meet the following criteria:

- maintain a minimum thickness of pre-coat;
- maintain effective filter cleaning procedures;

[9] Because of the selective mechanisms of slow sand and DE filtration processes, filtrate turbidity levels exceeding 1.0 NTU can occur as a result of passage of inorganic particles through the filter without influencing the effective removal of harmful organisms. Temporary filtrate turbidity levels of over 1.0 NTU therefore should not be interpreted as indicating an adverse water condition with these processes in the absence of additional supporting evidence.

– maintain full recycle or partial discharge to waste of water flow during filter precoat until the recycle stream turbidity falls to below 1.0 NTU;

– continuously monitor filtrate turbidity from each filter; and,

– meet the performance criterion for filtered water turbidity of less than or equal to 1.0 NTU in 95% of the measurements each month.

3.4.5 Cartridge/Bag Filters

This technology is designed to meet the low flow demands of small systems. These filters can effectively remove particles from water in the size range of *Giardia* cysts (5-10 microns) and *Cryptosporidium* oocysts (2-5 microns). Cartridge filters do not remove any significant proportion of influent viruses. Generally, the use of cartridge/bag filtration processes is limited to raw water supply sources (or influent water after pretreatment) having turbidity of less than 5 NTU and colour less than 5 TCU.

Cartridge and bag filters are made from fibre, and unlike membranes, have a broad range of pore/opening sizes which allow penetration of a few larger sized particles than the filter rating. This small penetration rate by oversized particles should be taken into consideration along with the quality of the raw water supply.

In order to claim the 2.0 log *Cryptosporidium* oocyst removal credit, the cartridge/bag filtration process must meet the following criteria:

– use filter elements and housing certified for surrogate particle removal evaluation in accordance with testing procedures and manufacturing quality control specified in ANSI/NSF Standard 53 or equivalent;

– continuously monitor filtrate turbidity from each filter or take a daily grab sample; and

– ensure that differential pressures across the filter medium do not exceed manufacturer's rating and materials coming in contact with water conform to ANSI/NSF Standard 61.

Normally, the filter should meet the performance criterion for filtered water turbidity of less than or equal to 0.2 NTU in 95% of the measurements each month. Where it can be shown that turbidity results from the presence of inorganic particles of a size less than 2 microns, higher turbidity may be acceptable.

3.4.6 Membrane Filtration

Membrane filtration processes involve passage of the water through a thin synthetic organic polymer film in a straining filtration step. Membranes that require moderate to low pressures for adequate flow (micro and ultra-filters) must have chemically formed and uniformly sized pores that are 1 micron or less in diameter. Higher pressure membrane filters (nano and reverse osmosis filters) have no pores but allow water to permeate or diffuse through the membrane. Virus removal capability will vary with type and manufacturer of a particular membrane.

In order to claim 2.0+ log *Cryptosporidium* oocyst removal credit, the membrane filtration process must meet the following criteria:

- maintain effective backwash procedures, including filter-to-waste or an equivalent procedure, to ensure that the effluent turbidity requirements are met at all times;
- monitor integrity of the membrane by continuous particle counting or equivalently effective means (e.g., intermittent pressure decay measurements);
- continuously monitor filtrate turbidity; and,
- meet the performance criterion for filtered water turbidity of less than or equal to 0.1 NTU in 99% of the measurements each month.

3.4.7 Other Filtration Technologies

In the case of the provision of a filtration technology other than those discussed in this procedure, before using the technology, it must be demonstrated and documented that the filtration technology in conjunction with disinfection achieves the required level of pathogen removal or inactivation.

4. DISINFECTANT RESIDUAL MAINTENANCE (SECONDARY DISINFECTION)

The maintenance of a disinfectant residual in the distribution system (secondary disinfection) is intended to maintain (or introduce and maintain) a persistent disinfectant residual to protect the water from microbiological re-contamination, reduce bacterial re-growth, control biofilm formation, and serve as an indicator of distribution system integrity (loss of disinfectant residual indicating that the system integrity has been compromised). Only chlorine, chlorine dioxide and monochloramine provide a persistent disinfectant residual and can be used for the maintenance of a residual in the distribution system.

Where the provision of secondary disinfection is required by the Regulation, the drinking-water system's distribution system must be operated such that at all times and at all locations within the distribution system, where there is a daily flow, there is at least a free chlorine residual of 0.05 mg/L at a pH 8.5 or lower[10], or chlorine dioxide residual of 0.05 mg/L, or where monochloramine is used, a combined chlorine residual of 0.25 mg/L.

The maximum chlorine residual at any time and at any location within the distribution system should not exceed 4.0 mg/L when measured as free chlorine, 0.8 mg/L when measured as chlorine dioxide, and 3.0 mg/L when measured as combined chlorine. (Note: A combined chlorine residual of 3.0 mg/L is equivalent to the maximum acceptable concentration of 3.0 mg/L for chloramines allowed by the Ontario Drinking-Water Quality Standards.)

[10] A maximum water pH of 8.5 is recommended for free chlorine residual maintenance for two reasons; the disinfecting power of free chlorine is rapidly and progressively reduced as pH levels rise over 7.0, and, pH levels tend to rise naturally in distribution systems as a result of biofilm activity.

The recommended optimum target for free chlorine residual concentration in a water distribution system is 0.2 mg/L at a pH 8.5 or less. The recommended optimum target for combined chlorine residual for systems designed to operate with chloramination is 1.0 mg/L at all locations within the distribution system to suppress bacterial activity that converts ammonia to nitrite and nitrate.

Drinking-water systems using only chloramination as a secondary disinfection, where addition of ammonia is properly adjusted as required, would not show any free chlorine residual in tests of distribution system samples. For such systems the measurement of total chlorine residual only would be adequate to represent the value of combined chlorine residual.

In larger water distribution systems, maintenance of the minimum required residual may not be possible without the operation of re-chlorination facilities at one or more points within the distribution system. Rapid decay of a disinfectant residual may occur as a result of a number of other causes such as heavy encrustation or sediment accumulation and biofilm activity and may require investigation and specific corrective action such as engineered flow velocity increases, and swabbing or pigging/lining and/or main replacement.

Note: The application of disinfectant for the maintenance of a residual does not require contact time.

5. DISINFECTION OF DRINKING- WATER SYSTEMS AFTER CONSTRUCTION OR REPAIRS

All parts of drinking-water systems in contact with drinking water which are taken out of service for inspection, repair or other activities that may lead to contamination before they are put back in service, must be disinfected in accordance with the provisions of the AWWA Standard for Disinfecting Water Mains (C651), AWWA Standard for Disinfection of Water Storage Facilities (C652), AWWA Standard for Disinfection of Water Treatment Plants (C653), and AWWA Standard for Disinfection of Wells (C654) or an equivalent procedure that ensures the safety of drinking water that is delivered to consumers.

6. MONITORING

6.1 Primary Disinfection

All systems providing primary disinfection must ensure that routine monitoring of the relevant parameters associated with the performance of the disinfection process is being carried out to ensure that water that is directed to consumers is being properly disinfected. Primary disinfection facilities for all municipal residential drinking-water systems must be equipped with continuous disinfection process monitoring and recording devices with alarms unless otherwise specified in the Regulation.

For drinking-water systems that are not required by the Regulation to have continuous monitoring equipment, it is strongly recommended that such systems consider installing such

equipment. Non-municipal systems that do not have continuous monitoring equipment[11] installed must analyze manual grab samples on a daily basis for the parameters specified in the Regulation.

Where appropriate instrumentation is available, consideration may be given to using continuous monitoring data to provide a real-time and recorded display of the relevant CT data and microbial inactivation/removal logs being achieved by the overall treatment process for all targeted microbial threats.

6.1.1 Free Chlorine Residual Disinfection

Except for situations identified below, the free chlorine residual analyzer(s) installed for the purpose of continuous monitoring of a primary disinfection process utilizing free chlorine residual, must take a continuous sample at the downstream end of the primary disinfection process. Where the complete primary disinfection is accomplished through a series of distinct disinfection processes/steps, a continuous sample must be taken at the downstream end of each such distinct process/step. In all cases, the location must be ahead of the point of addition of any post-disinfection chemicals, including those intended for the purpose of ensuring maintenance of disinfectant residual in the distribution system or preventing corrosion in the distribution system. For non-municipal or municipal non-residential systems where continuous monitoring devices are not installed, daily monitoring using manual grab samples at the same locations must be performed.

Where the chlorine contact time necessary to complete the process of primary disinfection is provided by a dedicated section of the piping upstream of the first consumer connection, the chlorine residual analyzer installed for the purpose of monitoring completion of the primary disinfection process may take a continuous sample at an intermediate location, between the point of the addition of chlorine and the down-stream end of the section of the piping used for the primary disinfection contact time, provided that the continuous sample adequately simulates the contact time.

For a raw water supply which is ground water, where the chlorine consumption characteristics of the influent water is sufficiently stable to allow establishment of a reliable chlorine depletion algorithm, a grab sample or a continuous sample may be taken at a location other than the downstream end of the section of the piping used for the primary disinfection contact time. In such a case, based on the established chlorine depletion algorithm, a minimum chlorine residual concentration, necessary to maintain the residual at the end of the dedicated chlorine contact section of the piping must be maintained at the level required for complete primary disinfection.

Every free chlorine residual analyzer installed for the purpose of monitoring a primary disinfection process utilizing free chlorine residual, must be calibrated at a frequency necessary to ensure appropriate operation of the analyzer within a quality control band of plus/minus 0.05

[11] Continuous monitoring equipment is equipment that, at intervals appropriate for the process and parameter being monitored, automatically tests for the parameter directly in the stream (or in the case of UV disinfection, through the stream) of water being treated or distributed, or in a continuous sample taken from the stream of water being treated or distributed, where a continuous sample is a continuous stream of water flowing from the stream of water being treated or distributed to the continuous monitoring equipment.

mg/L at a chlorine concentration up to and including 1.0 mg/L or plus/minus 5.0% at a chlorine concentration greater than 1.0 mg/L.

6.1.2 Chlorine Dioxide Residual Disinfection

The location and installation of chlorine dioxide residual analyzer(s)[12] for continuous monitoring of a primary disinfection process utilizing chlorine dioxide residual should follow the recommendations provided in section 6.1.1. In addition, at frequencies appropriate for site-specific conditions (type of chlorine dioxide generator, water quality, etc.), grab samples should be taken from the same location and analyzed for chlorite and chlorate concentrations.

6.1.3 Monochloramine Residual Disinfection

The location and installation of total and free chlorine residual analyzer(s) for continuous monitoring of a primary disinfection process utilizing monochloramine chlorine residual should follow the recommendations provided in section 6.1.1. In addition, at frequencies appropriate for site-specific conditions and water quality, grab samples should be taken from the same location and analyzed for total chloramines and monochloramine concentrations.

6.1.4 Ultraviolet (UV) Light Disinfection

All UV disinfection facilities must continuously monitor such parameters that allow the operator to determine that the target design 254nm-equivalent UV pass through dose or higher is being delivered, and all systems must provide annunciated failure alarms when this design dose is not being delivered.

Equipment that records test results of the continuous monitoring equipment is strongly recommended for drinking-water systems using a surface water supply or a groundwater supply under the direct influence of surface water. All sensors that constitute part of the monitoring system must be calibrated at a frequency that maintains their necessary sensitivity and reliability in ensuring that the design UV dose is being achieved. Calibration frequencies are to be determined as part of the process of obtaining Ministry approval or should be provided to the owner by the Engineer in the Engineering Evaluation Report, with specific regard to the manufacturer’s instructions.

6.1.5 Turbidity

Regulated drinking-water systems that obtain their water from a raw water supply that is surface water or ground water under the direct influence of surface water, may be required by the Regulation to be equipped with continuous water turbidity monitoring and recording devices with alarms on each filter effluent line.

[12] In circumstances where chlorine dioxide generation and chlorine dioxide demand is stable, consideration may be given to an alternative to continuous chlorine dioxide monitoring using continuous redox potential monitoring supplemented by intermittent assay of disinfectant chemical components.

If a drinking-water system is not required by the Regulation to have continuous monitoring equipment to monitor turbidity, it is, nonetheless, strongly recommended. Systems not required to have continuous monitoring and which choose not to install such equipment must ensure that a water sample is taken at least once a day on each filter effluent line and is tested for turbidity.

Water turbidity analyzers installed at water treatment plants utilizing a raw water supply which is surface water or ground water under direct influence of surface water, should take a continuous sample upstream of the primary disinfection process. For systems where continuous monitoring equipment is not installed, the daily water sample should be taken from this same location.

Every water turbidity analyzer installed for the purpose of monitoring the effectiveness of the filtration process (usually ahead of the primary disinfection process) must be calibrated at a frequency necessary to ensure the appropriate operation of the analyzer.

6.2 Maintenance of disinfectant residual in a distribution system

Information obtained through the monitoring of disinfectant residual in the distribution system in accordance with the Regulation, should be used to assess the effectiveness of secondary disinfection throughout the distribution system, as well as to control the level of disinfectant in the water leaving the water treatment plant and any re-chlorination facilities located within the distribution system.

It is recommended that the facilities provided for the purpose of the introduction, change, or adjustment of disinfectant residual in the distribution system at re-chlorination facilities or at the water treatment plant, be provided with equipment for continuous monitoring of the operation of the facilities and an alarm system.

Where a treatment process that is operated downstream of natural or engineered filtration produces turbidity solely due to oxidation or chemical precipitation, the turbidity does not present a health hazard. For aesthetic reasons, however, it is recommended that turbidity levels be maintained below 5.0 NTU. In such cases, turbidity may be monitored with grab samples taken at the entrance to the distribution system.

7. DISINFECTION BY-PRODUCTS

Chemical disinfectants may be capable of producing by-products[13] in quantities that may present long-term health risks to the drinking water consumer. The concentrations of disinfection by-products (DBPs) produced are specific to the type of disinfectant, the chemical make-up of the naturally occurring organic precursors and their concentrations in water prior to chlorine (or other chemical disinfectant) addition, the concentration of the disinfectant in water, and the retention time in the drinking-water system before reaching the consumer's tap.

The claim for CT credits related to chemical disinfection should be supported by evidence that the treatment processes are designed and operated for efficient DBP precursor removal before the primary disinfection process. Chemical disinfectant addition should not take place upstream

[13] Unlike chemical disinfectants, UV light appears not to form detectable amounts of potentially toxic by-products.

of the precursor removal process(s), unless the use of prechlorination can be justified by the raw water source quality including active mussel veliger content, measurement of DBP formation potential, and other site specific conditions.

To control the formation of DBPs in the drinking-water systems, the following should be considered:

- source water protection, including nutrient and algal management;
- DBP precursor removal by optimization of chemical and physical treatment process prior to chemical disinfection; and,
- disinfection strategy selection involving adjusting, and where possible, delaying and reducing the usage of, and minimizing, active chemical disinfectant contact and treated water storage time. When there is evidence to suggest such adjustments may be insufficiently effective, consideration should be given to the use of one or more disinfectants or pre-disinfection process steps selected from the following: disinfection with UV light, alternative chemical disinfection with chlorine dioxide or ozone, optimization of pretreatment oxidation, if present, or, using monochloramine as the distribution system disinfectant. It should be noted that the use of ozone in a pre-disinfection process has a potential for greater disinfection by-product formation when chlorine is added downstream.

Notwithstanding the above, the treatment processes must be designed and always operated to achieve the required removal or inactivation of pathogens as a priority with the minimization of disinfection by products formation as a secondary objective.

TABLE 1- CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 0.5ºC OR LOWER

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195	40	79	119	158	198	237
0.6	24	47	71	94	118	141	28	56	84	112	140	168	33	67	100	133	167	200	40	80	120	159	199	239
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205	41	82	123	164	205	246
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210	42	84	127	169	211	253
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215	43	86	130	173	216	259
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	201	44	89	133	177	222	266
1.6	26	52	79	105	131	157	32	63	95	126	158	189	38	75	113	151	188	226	46	91	137	182	228	273
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231	47	93	140	186	233	279
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236	48	95	143	191	238	286
2.2	28	56	85	113	141	169	34	67	101	134	168	201	40	81	121	161	202	242	50	99	149	198	248	297
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247	50	99	149	199	248	298
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252	51	101	152	203	253	304
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257	52	103	155	207	258	310
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261	53	105	158	211	263	316

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< = 0.4	46	92	139	185	231	277	55	110	165	219	274	329	65	130	195	260	325	390
0.6	48	95	143	191	238	286	57	114	171	228	285	342	68	136	204	271	339	407
0.8	49	98	148	197	246	295	59	118	177	236	295	354	70	141	211	281	352	422
1	51	101	152	203	253	304	61	122	183	243	304	365	73	146	219	291	364	437
1.2	52	104	157	209	261	313	63	125	188	251	313	376	75	150	226	301	376	451
1.4	54	107	161	214	268	321	65	129	194	258	323	387	77	155	232	309	387	464
1.6	55	110	165	219	274	329	66	132	199	265	331	397	80	159	239	318	398	477
1.8	56	113	169	225	282	338	68	136	204	271	339	407	82	163	245	326	408	489
2	58	115	173	231	288	346	70	139	209	278	348	417	83	167	250	333	417	500
2.2	59	118	177	235	294	353	71	142	213	284	355	426	85	170	256	341	426	511
2.4	60	120	181	241	301	361	73	145	218	290	363	435	87	174	261	348	435	522
2.6	61	123	184	245	307	368	74	148	222	296	370	444	89	178	267	355	444	533
2.8	63	125	188	250	313	375	75	151	226	301	377	452	91	181	272	362	453	543
3	64	127	191	255	318	382	77	153	230	307	383	460	92	184	276	368	460	552

TABLE 2 - CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 5ºC

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	16	32	49	65	81	97	20	39	59	78	98	117	23	46	70	93	116	139	28	55	83	111	138	166
0.6	17	33	50	67	83	100	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	114	143	171
0.8	17	34	52	69	86	103	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175
1	18	35	53	70	88	105	21	42	63	83	104	125	25	50	75	99	124	149	30	60	90	119	149	179
1.2	18	36	54	71	89	107	21	42	64	85	106	127	25	51	76	101	127	152	31	61	92	122	153	183
1.4	18	36	55	73	91	109	22	43	65	87	108	130	26	52	78	103	129	155	31	62	94	125	156	187
1.6	19	37	56	74	93	111	22	44	66	88	110	132	26	53	79	105	132	158	32	64	96	128	160	192
1.8	19	38	57	76	95	114	23	45	68	90	113	135	27	54	81	108	135	162	33	65	98	131	163	196
2	19	39	58	77	97	116	23	46	69	92	115	138	28	55	83	110	138	165	33	67	100	133	167	200
2.2	20	39	59	79	98	118	23	47	70	93	117	140	28	56	85	113	141	169	34	68	102	136	170	204
2.4	20	40	60	80	100	120	24	48	72	95	119	143	29	57	86	115	143	172	35	70	105	139	174	209
2.6	20	41	61	81	102	122	24	49	73	97	122	146	29	58	88	117	146	175	36	71	107	142	178	213
2.8	21	41	62	83	103	124	25	49	74	99	123	148	30	59	89	119	148	178	36	72	109	145	181	217
3	21	42	63	84	105	126	25	50	76	101	126	151	30	61	91	121	152	182	37	74	111	147	184	221

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	33	66	99	132	165	198	39	79	118	157	197	236	47	93	140	186	233	279
0.6	34	68	102	136	170	204	41	81	122	163	203	244	49	97	146	194	243	291
0.8	35	70	105	140	175	210	42	84	126	168	210	252	50	100	151	201	251	301
1	36	72	108	144	180	216	43	87	130	173	217	260	52	104	156	208	260	312
1.2	37	74	111	147	184	221	45	89	134	178	223	267	53	107	160	213	267	320
1.4	38	76	114	151	189	227	46	91	137	183	228	274	55	110	165	219	274	329
1.6	39	77	116	155	193	232	47	94	141	187	234	281	56	112	169	225	281	337
1.8	40	79	119	159	198	238	48	96	144	191	239	287	58	115	173	230	288	345
2	41	81	122	162	203	243	49	98	147	196	245	294	59	118	177	235	294	353
2.2	41	83	124	165	207	248	50	100	150	200	250	300	60	120	181	241	301	361
2.4	42	84	127	169	211	253	51	102	153	204	255	306	61	123	184	245	307	368
2.6	43	86	129	172	215	258	52	104	156	208	260	312	63	125	188	250	313	375
2.8	44	88	132	175	219	263	53	106	159	212	265	318	64	127	191	255	318	382
3	45	89	134	179	223	268	54	108	162	216	270	324	65	130	195	259	324	389

TABLE 3 - CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 10ºC

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

TABLE 4 - CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 15ºC

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	10	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	17	33	50	66	83	99	20	39	59	79	98	118	23	47	70	93	117	140
0.6	17	34	51	68	85	102	20	41	61	81	102	122	24	49	73	97	122	146
0.8	18	35	53	70	88	105	21	42	63	84	105	126	25	50	76	101	126	151
1	18	36	54	72	90	108	22	43	65	87	108	130	26	52	78	104	130	156
1.2	19	37	56	74	93	111	22	45	67	89	112	134	27	53	80	107	133	160
1.4	19	38	57	76	95	114	23	46	69	91	114	137	28	55	83	110	138	165
1.6	19	39	58	77	97	116	24	47	71	94	118	141	28	56	85	113	141	169
1.8	20	40	60	79	99	119	24	48	72	96	120	144	29	58	87	115	144	173
2	20	41	61	81	102	122	25	49	74	98	123	147	30	59	89	118	148	177
2.2	21	41	62	83	103	124	25	50	75	100	125	150	30	60	91	121	151	181
2.4	21	42	64	85	106	127	26	51	77	102	128	153	31	61	92	123	153	184
2.6	22	43	65	86	108	129	26	52	78	104	130	156	31	63	94	125	157	188
2.8	22	44	66	88	110	132	27	53	80	106	133	159	32	64	96	127	159	191
3	22	45	67	89	112	134	27	54	81	108	135	162	33	65	98	130	163	195

TABLE 5 - CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 20ºC

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	6	12	18	24	30	36	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62
0.6	6	13	19	25	32	38	8	15	23	30	38	45	9	18	27	36	45	54	11	21	32	43	53	64
0.8	7	13	20	26	33	39	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66
1	7	13	20	26	33	39	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67
1.2	7	13	20	27	33	40	8	16	24	32	40	48	10	19	29	38	48	57	12	23	35	46	58	69
1.4	7	14	21	27	34	41	8	16	25	33	41	49	10	19	29	39	48	58	12	23	35	47	58	70
1.6	7	14	21	28	35	42	8	17	25	33	42	50	10	20	30	39	49	59	12	24	36	48	60	72
1.8	7	14	22	29	36	43	9	17	26	34	43	51	10	20	31	41	51	61	12	25	37	49	62	74
2	7	15	22	29	37	44	9	17	26	35	43	52	10	21	31	41	52	62	13	25	38	50	63	75
2.2	7	15	22	29	37	44	9	18	27	35	44	53	11	21	32	42	53	63	13	26	39	51	64	77
2.4	8	15	23	30	38	45	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
2.6	8	15	23	31	38	46	9	18	28	37	46	55	11	22	33	44	55	66	13	27	40	53	67	80
2.8	8	16	24	31	39	47	9	19	28	37	47	56	11	22	34	45	56	67	14	27	41	54	68	81
3	8	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	12	25	37	49	62	74	15	30	45	59	74	89	18	35	53	70	88	105
0.6	13	26	39	51	64	77	15	31	46	61	77	92	18	36	55	73	91	109
0.8	13	26	40	53	66	79	16	32	48	63	79	95	19	38	57	75	94	113
1	14	27	41	54	68	81	16	33	49	65	82	98	20	39	59	78	98	117
1.2	14	28	42	55	69	83	17	33	50	67	83	100	20	40	60	80	100	120
1.4	14	28	43	57	71	85	17	34	52	69	86	103	21	41	62	82	103	123
1.6	15	29	44	58	73	87	18	35	53	70	88	105	21	42	63	84	105	126
1.8	15	30	45	59	74	89	18	36	54	72	90	108	22	43	65	86	108	129
2	15	30	46	61	76	91	18	37	55	73	92	110	22	44	66	88	110	132
2.2	16	31	47	62	78	93	19	38	57	75	94	113	23	45	68	90	113	135
2.4	16	32	48	63	79	95	19	38	58	77	96	115	23	46	69	92	115	138
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	118	141
2.8	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	95	119	143
3	17	34	51	67	84	101	20	41	61	81	102	122	24	49	73	97	122	146

TABLE 6 - CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY FREE CHLORINE AT 25ºC

Free Chlorine Concentration mg/L	pH < = 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	4	8	12	16	20	24	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	28	35	42
0.6	4	8	13	17	21	25	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43
0.8	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44
1	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45
1.2	5	9	14	18	23	27	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46
1.4	5	9	14	18	23	27	6	11	17	22	28	33	7	13	20	26	33	39	8	16	24	31	39	47
1.6	5	9	14	19	23	28	6	11	17	22	28	33	7	13	20	27	33	40	8	16	24	32	40	48
1.8	5	10	15	19	24	29	6	11	17	23	28	34	7	14	21	27	34	41	8	16	25	33	41	49
2	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	27	34	41	8	17	25	33	42	50
2.2	5	10	15	20	25	30	6	12	18	23	29	35	7	14	21	28	35	42	9	17	26	34	43	51
2.4	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43	9	17	26	35	43	52
2.6	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44	9	18	27	35	44	53
2.8	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45	9	18	27	36	45	54
3	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46	9	18	28	37	46	55

Free Chlorine Concentration mg/L	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH < = 9.0 Log Inactivations					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
< =0.4	8	17	25	33	42	50	10	20	30	39	49	59	12	23	35	47	58	70
0.6	9	17	26	34	43	51	10	20	31	41	51	61	12	24	37	49	61	73
0.8	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75
1	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78
1.2	9	18	28	37	46	55	11	22	34	45	56	67	13	27	40	53	67	80
1.4	10	19	29	38	48	57	12	23	35	46	58	69	14	27	41	55	68	82
1.6	10	19	29	39	48	58	12	23	35	47	58	70	14	28	42	56	70	84
1.8	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
2	10	20	31	41	51	61	12	25	37	49	62	74	15	29	44	59	73	88
2.2	10	21	31	41	52	62	13	25	38	50	63	75	15	30	45	60	75	90
2.4	11	21	32	42	53	63	13	26	39	51	64	77	15	31	46	61	77	92
2.6	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
2.8	11	22	33	44	55	66	13	27	40	53	67	80	16	32	48	64	80	96
3	11	22	34	45	56	67	14	27	41	54	68	81	16	32	49	65	81	97

TABLE 7 – CT VALUES FOR INACTIVATION OF VIRUSES BY FREE CHLORINE

	Log Inactivation					
	2		3		4	
	pH		pH		pH	
Temperature (ºC)	6 to 9	10	6 to 9	10	6 to 9	10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

TABLE 8 – CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY CHLORINE DIOXIDE

	Temperature (ºC)					
Inactivation	≤1	5	10	15	20	25
0.5 log	10	4.3	4	3.2	2.5	2
1.0-log	21	8.7	7.7	6.3	5	3.7
1.5-log	32	13	12	10	7.5	5.5
2.0-log	42	17	15	13	10	7.3
2.5-log	52	22	19	16	13	9
3.0-log	63	26	23	19	15	11

TABLE 9 – CT VALUES FOR INACTIVATION OF VIRUSES BY CHLORINE DIOXIDE

	Temperature (ºC)					
Inactivation	≤1	5	10	15	20	25
2-log	8.4	5.6	4.2	2.8	2.1	1.4
3-log	25.6	17.1	12.8	8.6	6.4	4.3
4-log	50.1	33.4	25.1	16.7	12.5	8.4

TABLE 10 – CT VALUES FOR INACTIVATION OF *CRYPTOSPORIDIUM* BY OZONE

Log credit	Temperature (ºC)								
	1	**2**	**3**	**5**	**7**	**10**	**15**	**20**	**25**
0.5	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2
1.0	23	21	19	16	13	9.9	6.2	3.9	2.5
1.5	35	31	29	24	20	15	9.3	5.9	3.7
2.0	46	42	38	32	26	20	12	7.8	4.9
2.5	58	52	48	40	33	25	16	9.8	6.2
3.0	69	63	57	47	39	30	19	12	7.4

TABLE 11 – CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY OZONE

Inactivation	Temperature (ºC)					
	≤1	**5**	**10**	**15**	**20**	**25**
0.5 log	0.48	0.32	0.23	0.16	0.12	0.08
1.0-log	0.97	0.63	0.48	0.32	0.24	0.16
1.5-log	1.5	0.95	0.72	0.48	0.36	0.24
2.0-log	1.9	1.3	0.95	0.63	0.48	0.32
2.5-log	2.4	1.6	1.2	0.79	0.6	0.4
3.0-log	2.9	1.9	1.43	0.95	0.72	0.48

TABLE 12 – CT VALUES FOR INACTIVATION OF VIRUSES BY OZONE

Inactivation	Temperature (ºC)					
	≤1	**5**	**10**	**15**	**20**	**25**
2-log	0.9	0.6	0.5	0.3	0.25	0.15
3-log	1.4	0.9	0.8	0.5	0.4	0.25
4-log	1.8	1.2	1	0.6	0.5	0.3

TABLE 13 – CT VALUES FOR INACTIVATION OF *GIARDIA* CYSTS BY CHLORAMINE AT PH 6-9

Inactivation	Temperature (ºC)					
	≤1	**5**	**10**	**15**	**20**	**25**
0.5 log	635	365	310	250	185	125
1.0-log	1270	735	615	500	370	250
1.5-log	1900	1100	930	750	550	375
2.0-log	2535	1470	1230	1000	735	500
2.5-log	3170	1830	1540	1250	915	625
3.0-log	3800	2200	1850	1500	1100	750

TABLE 14 – CT VALUES FOR INACTIVATION OF VIRUSES BY CHLORAMINE AT pH 6-9

Inactivation	Temperature (ºC)					
	≤1	**5**	**10**	**15**	**20**	**25**
2-log	1243	857	643	428	321	214
3-log	2063	1423	1067	712	534	356
4-log	2883	1988	1491	994	746	497