Guidelines for Pathogen Log Reduction Credit Assignment

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Ministry of Health

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1. Objective

To provide guidance on pathogen log reduction credit[1] assignment for the production of microbiologically safe[2] drinking water based on the type of treatment processes used and the applicable pathogen log reduction credit assignment criteria being met.

2. Background and Regulatory Framework

The *Drinking Water Protection Act* (DWPA) (2001) and Drinking Water Protection Regulation (DWPR) (2003) specify water quality standards[3], monitoring schedules and recommended treatment aimed at reducing the risks from pathogens in drinking water. There are three main types of pathogens in drinking water that pose risks to human health in BC: viruses, protozoa, and bacteria. The ingestion of these pathogens can result in short term illness and in some instances, serious long-lasting illnesses or even death.

To ensure the provision of clean, safe, and reliable drinking water in British Columbia, the multi-barrier approach is used. The multi-barrier approach is a system of procedures, processes and tools that collectively prevents or reduces the risk of contamination of drinking water from source-to-tap to reduce risks to human health[4]. Drinking water treatment is one component of the multi-barrier approach. Other components include source protection, operator training, water system maintenance, water quality monitoring and emergency response planning.

Section 5 of the DWPR requires that drinking water from a water supply system must be disinfected if the water originates from surface water, or groundwater that in the opinion of a Drinking Water Officer is at risk of containing pathogens. As "disinfection" is not defined in the DWPA or DWPR, technical guidance on disinfection is provided in this document, the Design Guidelines for Drinking Water Systems in British Columbia (anticipated release date in 2022), the Guidelines for Ultraviolet Disinfection of Drinking Water (2022) and in provincial drinking water treatment objectives.

Provincial drinking water treatment objectives are set out in the following guidance documents, which are included in Part B to the Drinking Water Officers' Guide:

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[1] A pathogen log reduction credit is a value assigned to a specific drinking water treatment process, expressed in log units, for the removal or inactivation of a specific microorganism or a group of microorganisms. A 1-log credit equals 90% reduction, a 2-log credit equals 99% reduction, a 3-log credit equals 99.9% reduction, and a 4-log credit equals 99.99% reduction.

[2] Health risks posed from chemical, physical, or radiological parameters are beyond the scope of this document. Secondary disinfection to maintain a chemical residual in the distribution system is also beyond the scope of this document. Information on secondary disinfection can be found in the British Columbia Guidelines (Microbiological) on Maintaining Water Quality in Distribution Systems.

[3] Schedule A of the Drinking Water Protection Regulation.

[4] B.C. Office of the Provincial Health Officer (2019). Clean, Safe, and Reliable Drinking Water.

- Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia which provides a general overview of microbiological drinking water treatment objectives for surface water supplies; and

- Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia which specifies guidance on the treatment necessary to address microbiological contamination of groundwater sources and the assignment of subsurface filtration treatment credits.

Provincial drinking water treatment objectives for harvested rainwater are set out in the following guidance document, which supplements the existing provincial treatment objectives for surface water supplies:

- Guidance for Treatment of Rainwater Harvested for Potable Use in British Columbia which provides a general overview of assessing the risks and treatment of rainwater for potable use.

All surface water supplies require disinfection; however, the requirement to disinfect groundwater supplies only applies to groundwater sources at risk of microbiological contamination. The Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP) was developed to assist Health Authorities and water suppliers determine if a particular groundwater source requires disinfection. Risk factors that are discussed in the guideline include well construction, well location, aquifer characteristics and water quality results.

Minimum performance targets for surface water and groundwater at risk of containing pathogens are set out in the provincial drinking water treatment objectives.

Surface Water

The provincial drinking water treatment objectives for surface water supplies establish a minimum performance target for water suppliers to treat water to produce microbiologically safe drinking water. These objectives are often referred to as the "4-3-2-1-0 objectives" and are as follows:

- 4-log (99.99 percent) reduction of enteric viruses.
- 3-log (99.9 percent) reduction of *Giardia* and *Cryptosporidium* (both protozoa).
- 2 forms of treatment for pathogen log reduction - *see next paragraph.*
- 1-Less than or equal to 1 nephelometric turbidity unit (NTU) of turbidity.
- 0 detectable *E. coli,* total coliform, and fecal coliform (bacteria indicative of fecal presence – this objective is prescribed in the Regulation).

The provincial treatment objectives for surface water call for two forms of treatment. Filtration (as described in Section 6 of this document) followed by disinfection are the two forms of treatment recommended by Health Canada[5].

Groundwater

The provincial drinking water treatment objectives for groundwater supplies specify treatment objectives for groundwater at risk of containing pathogens (GARP), groundwater at risk of containing viruses only ('GARP-viruses only') and groundwater at low risk of containing pathogens.

Drinking water systems that draw water from sources determined to be GARP or 'GARP-viruses only' must employ disinfection. As a minimum, GARP water sources require disinfection by treatment methods that are equivalent to surface water supplies (i.e. 4-log reduction of enteric viruses, 3-log reduction of *Giardia* and *Cryptosporidium*, 2 forms of treatment for pathogen log reduction, less than 1 NTU turbidity, and 0 detectable *E. coli,* total coliform, and fecal coliform in delivered water). Water sources that are determined to be 'GARP-viruses only', require treatment for virus reduction only. Two forms of treatment are not required for 'GARP-viruses only' raw water sources.

Groundwater sources determined to be at low risk of containing pathogens do not require disinfection unless specified by a Drinking Water Officer per the DWPA.

3. Purpose and Scope

Under the DWPA, water suppliers are responsible for providing potable water to all users of their systems. This guideline provides provincial guidance[6] on the assignment of pathogen log reduction credits for drinking water systems using filtration, chemical disinfection and/or ultraviolet (UV) disinfection. The information in this document should be used by issuing officials during the approvals process, particularly with respect to the issuance of construction permits and operating permits under the *Drinking Water Protection Act* and the Drinking Water Protection Regulation. The information in this document can also be used by water suppliers, designers, and any other person or persons responsible for the planning and design of new water supply systems and when considering changes to existing systems.

[5] Provincial treatment objectives allow a surface water or GARP water supply system to operate without filtration if conditions for filtration exemption are met, or a timetable to implement filtration has been agreed to by a Drinking Water Officer (see Section 6.11). The filtration exemption should be supported by a continuous assessment of water supply conditions to ensure that source water quality does not deteriorate due to changes in the surrounding watershed.

[6] The guidance in this document is not legally binding. In the event of an inconsistency between the guidance in this document and the DWPA, DWPR, a drinking water operating permit or construction permit, or any direction of a Drinking Water Officer, the guidance in this document gives way to legally binding requirements.

More detailed information on the design and operation of filtration, chemical disinfection and/or UV disinfection systems can be found in the Design Guidelines for Drinking Water Systems in British Columbia and the Guidelines for Ultraviolet Disinfection of Drinking Water.

4. Standards and Treatment Objectives

One of the goals of drinking water treatment is to reduce the presence of pathogens (disease-causing organisms) and associated health risks to an acceptable or tolerable level. Bacterial indicator water quality standards for potable water are specified in Schedule A to the DWPR as:

- No detectable fecal coliform bacteria per 100 mL of water.
- No detectable *Escherichia coli (E. coli)* per 100 mL of water.
- No detectable total coliform bacteria per 100 mL of water when 1 sample is collected in a 30 day period. Where more than 1 sample is collected in a 30 day period, at least 90% of samples have no detectable total coliform bacteria per 100 mL of water and no sample has more than 10 total coliform bacteria per 100 mL of water.

Provincial drinking water treatment objectives recommend minimum pathogen log reduction for protozoa and viruses based on source water type (see Table 1).

Table 1: Recommended Minimum Pathogen Log Reduction for Different Source Water Types

Source Water Type	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Surface Water	3	3	4
Rainwater	4	4	4
GARP	3	3	4
GARP – viruses only	0	0	4
Groundwater at low risk of containing pathogens	0	0	0

Depending upon site-specific considerations, the actual amount of treatment required will depend on the risks identified and may require higher levels of pathogen log reduction and therefore greater levels of treatment. Pathogen log reduction requirements should be determined by an issuing official in consultation with the water supply system owner based on the type of source water and any site-specific considerations.

5. Pathogen Log Reduction Credits

There are many different treatment technologies available to produce microbiologically safe drinking water. These technologies are assigned pathogen log reduction credits by issuing officials for *Cryptosporidium*, *Giardia,* and viruses.

Recommended pathogen log reduction credit assignment is based on the following guidance documents:

- Health Canada Guidelines for Canadian Drinking Water Quality (GCDWQ)
    1. Guideline Technical Document – Enteric Protozoa: *Giardia* and *Cryptosporidium* (2019)
    2. Guideline Technical Document – Enteric Viruses (2019)
    3. Guideline Technical Document – Turbidity (2012)

- United States Environmental Protection Agency
    4. Membrane Filtration Guidance Manual (2005)
    5. Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule (2006)

- British Columbia Ministry of Health
    6. Design Guidelines for Drinking Water Systems in British Columbia (anticipated release date in 2022)
    7. Guidelines for Ultraviolet Disinfection of Drinking Water (2022)

By combining the pathogen log reduction credits assigned for each treatment technology in a treatment train, the combined total can be used to meet the recommended minimum pathogen log reduction listed in Table 1 for the specified source water type and specified pathogen. Pathogen log reduction credit assignment is based on the treatment processes being fully operational and the applicable recommended pathogen log reduction credit assignment criteria being met. The recommended pathogen log reduction credit assignment criteria are specific to each treatment technology, and include design, operational, and monitoring criteria which are important for treatment performance. The Drinking Water Officer may include additional operational and monitoring requirements in terms and conditions to an operating permit.

Sections 6, 7 and 8 of this guidance document discuss the treatment technologies that are available for producing microbiologically safe drinking water and include the recommended pathogen log reduction credits that should be assigned based on treatment process type, and the criteria that should be met for credit assignment. Filtration technologies are discussed in Section 6, UV disinfection is discussed in Section 7 and chemical disinfection is discussed in Section 8. It should be noted that pathogen log reduction capabilities vary depending upon the type of filtration or disinfection technology being applied.

6. Filtration

Table 2 sets out maximum pathogen log reduction credit assignment for filtration systems. Pathogen log reduction credit assignment is based on filtration systems meeting operational and design criteria and consistently meeting filter effluent turbidity objectives.

Table 2: Maximum Pathogen Log Reduction Credit Assignment for Filtration Systems

Maximum Pathogen Log Reduction Credits Assigned [a]	***Cryptosporidium* Oocysts**	***Giardia* Cysts**	**Viruses**
Conventional Filtration	3	3	2
Direct Filtration	2.5	2.5	1
Slow Sand Filtration	3	3	2
Diatomaceous Earth Filtration	3	3	1
Microfiltration	4 [b]	4 [b]	0 [c]
Ultrafiltration	4 [b]	4 [b]	0 [c]
Nanofiltration	4 [b]	4 [b]	0 [c]
Reverse Osmosis	4 [b]	4 [b]	0 [c]
Cartridge Filtration, single unit (1 micron absolute)	2 [d]	2 [d]	0
Cartridge Filtration, two units in series (1 micron absolute)	2.5 [d]	2.5 [d]	0
Subsurface Filtration [e] (Well/Surface Water Separation)	1	1	0
Subsurface Filtration [e] (Subsurface Filtration Study)	3	3	0
Subsurface Filtration [e] (Demonstration of Performance)	3	3	4
Filtration Exemption	0	0	0

[a] Pathogen log reduction credit assignment is based on the specified filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Removal efficiency is demonstrated using challenge testing and verified by daily direct integrity testing in accordance with the guidance set out in the Membrane Filtration Guidance Manual (USEPA, 2005), or another method deemed acceptable by an issuing official.

[c] Pathogen log reduction credits for viruses are not assigned for membranes as direct integrity tests to verify virus-sized leaks are not commercially available.

[d] Challenge testing should demonstrate at least 3-log reduction of *Cryptosporidium* oocysts and *Giardia* cysts for each unit. However, the recommended maximum pathogen log reduction credit assignment for each protozoa is 2-log for a single unit and 2.5-log (total) for two units in series, providing a safety factor to account for the lack of daily direct integrity testing.

[e] Subsurface filtration is only considered as one of the two required treatment processes if it has been awarded greater than 1-log removal credit each for *Cryptosporidium* oocysts and *Giardia* cysts and the second treatment process achieves the remainder of the recommended minimum pathogen log reduction.

Filtration Overview

Filtration systems remove particulate matter from water by passage through porous or non-porous media. The Guidelines for Canadian Drinking Water Quality state that the combination of physical removal (e.g. filtration) and inactivation barriers is the most effective way to reduce protozoa in drinking water[7].

Filtration systems should be designed, operated, and appropriately optimized to reduce turbidity levels as low as reasonably achievable. Turbidity objectives are specified in the recommended pathogen log reduction credit assignment criteria for different filtration types (see Sections 6.1 – 6.9); however, all filtration systems should strive to achieve a treated water turbidity target from individual filters of < 0.1 NTU at all times[8].

Filtration that is considered to be 'pre-treatment' is not eligible for pathogen log reduction credit assignment. This includes:

- pressure filtration
- media filtration for chemical-specific removal (ion exchange resin, greensand, and engineered media e.g. for iron/manganese removal) and
- conventional or direct filtration without chemically-assisted coagulation.

Bag filters are also not eligible for pathogen log reduction credits because they have shown variable performance for turbidity reduction (especially when raw water turbidity exceeds 1 NTU) and poor *Cryptosporidium* oocyst removal. Bag filters have also been known to fail due to:

- improper installation
- filter leaks or tears due to the fragility of the filter material
- bursting due to clogging and subsequent over-pressurizing and
- pressure transients causing damage to filter seams (Hung *et al.*, 2007).

[7] Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Protozoa: *Giardia* and *Cryptosporidium*.

[8] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

Clarification (sedimentation or DAF) without subsequent filtration is not eligible for pathogen log reduction credits. Without filtration, clarification may not provide adequate protection or process flexibility to manage adverse water quality events and may cause downstream issues with treatment or water chemistry.

6.1 Conventional Filtration

Conventional Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Conventional Filtration	3	3	2

[a] Pathogen log reduction credit assignment is based on the conventional filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Recommended Pathogen Log Reduction Credit Assignment Criteria
1. A chemical coagulant is used at all times when the treatment process is in operation. 2. Chemical dosages are monitored and adjusted in response to variations in raw water quality. 3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure during filter ripening to ensure that filter effluent turbidity objectives are met at all times. 4. Filter effluent turbidity is continuously monitored and recorded from each filter[9] and from combined filter effluent where there are multiple filters[10]. 5. For each filter, filter effluent turbidity is less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95% of the measurements either per filter cycle or per month. 6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[9] Continuous monitoring of filter effluent turbidity from each individual filter is necessary to (1) ensure that each filter is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual filters should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[10] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

Conventional Filtration Overview

Conventional filtration uses chemical coagulation, rapid mixing, flocculation, solids separation and rapid rate gravity filtration to remove pathogens, dissolved organic carbon and particulate matter from the raw water supply.

Chemical coagulation involves the addition of chemical coagulants to promote the aggregation of dissolved and suspended particles in water into larger particles called floc, initiating faster settling and water clarification. Rapid mixing is used to introduce and uniformly disperse chemical coagulants into the raw water supply. The coagulant chemicals typically used for water treatment include aluminum salts (e.g. aluminum sulphate), iron salts, and organic and inorganic polymers.

Following coagulation, flocculation is used to facilitate larger floc formation by using gentle mixing to bring floc into contact with each other. Larger floc can then be removed by a sedimentation process in which floc settle out of solution, or by dissolved air flotation (DAF) where tiny air bubbles are used to float contaminants to the water surface where they can be removed by mechanical skimming. Rapid rate gravity filtration is used to physically remove additional particulate matter and pathogens from the raw water supply by passing the water through porous media (e.g. sand, anthracite and/or granular activated carbon).

Conventional filtration is primarily used for the treatment of raw water supplies (or influent water after pre-treatment) with turbidity values of less than 3,000 NTU, total coliform counts of less than 20,000 per 100 mL, and colour measurements of less than 75 true colour units (TCU)[11].

[11] Washington State Department of Health (2019). Water System Design Manual.

6.2 Direct Filtration

Direct Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Direct Filtration	2.5	2.5	1

[a] Pathogen log reduction credit assignment is based on the direct filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. A chemical coagulant is used at all times when the treatment process is in operation.
2. Chemical dosages are monitored and adjusted in response to variations in raw water quality.
3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure during filter ripening to ensure that filter effluent turbidity objectives are met at all times.
4. Filter effluent turbidity is continuously monitored and recorded from each filter[12] and from combined filter effluent where there are multiple filters[13].
5. For each filter, filter effluent turbidity is less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95% of the measurements either per filter cycle or per month.
6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[12] Continuous monitoring of filter effluent turbidity from each individual filter is necessary to (1) ensure that each filter is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual filters should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[13] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

Direct Filtration Overview

Direct filtration uses chemical coagulation, rapid mixing, flocculation, and rapid rate gravity filtration. It is very similar to conventional filtration (see Section 6.1) but without the solids separation step prior to the filtration process. Direct filtration is primarily used for the treatment of raw water supplies (or influent water after pre-treatment) with turbidity values of less than 15 NTU, total coliform counts of less than 500 per 100 mL, colour measurements of less than 40 true colour units (TCU)[14], and low concentrations of algae, iron, and manganese. Pre-treatment processes can allow for greater levels of raw water turbidity, total coliform, or colour to be managed by direct filtration, and pilot testing may demonstrate that a direct filtration system has the ability to process higher levels of influent turbidity based on the system design parameters.

In-line filtration – coagulation with in-line mixing but no dedicated flocculation stage – may be acceptable for high quality raw water supplies (i.e. turbidity values of less than 5 NTU, total coliform counts of less than 500 per 100 mL, and colour measurements of less than 5 TCU) at the discretion of the Drinking Water Officer.

Compared to conventional filtration, the advantages of direct filtration include lower capital costs because there is no solids separation step, lower operating and maintenance costs, and potentially lower chemical costs due to lower coagulant usage. The disadvantages include shorter response times to address changes in raw water quality and a shorter detention time for controlling seasonal taste and odour problems.

[14] Washington State Department of Health (2019). Water System Design Manual.

6.3 Slow Sand Filtration

Slow Sand Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Slow Sand Filtration	3	3	2

[a] Pathogen log reduction credit assignment is based on the slow sand filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. An active biological layer is maintained.
2. Effective filter cleaning procedures are regularly carried out.
3. Filter-to-waste or an equivalent procedure is used during filter ripening periods.
4. Filter effluent turbidity is continuously monitored and recorded from each filter[15] and from combined filter effluent where there are multiple filters[16].
5. For each filter, filter effluent turbidity is less than or equal to 1.0 nephelometric turbidity unit (NTU) in at least 95% of the measurements either per filter cycle or per month.
6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 3.0 NTU.

[15] Continuous monitoring of filter effluent turbidity from each individual filter is necessary to (1) ensure that each filter is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual filters should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity). For facilities needing monitoring equipment upgrades, daily grab samples for turbidity monitoring may be considered an acceptable interim measure at the discretion of the Drinking Water Officer.

[16] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

Slow Sand Filtration Overview

Slow sand filtration is a process involving the passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms[17]. Filter effectiveness depends on the formation of the schmutzdecke — a layer of bacteria, algae, and other microorganisms on the surface of the sand — and the formation of a biological population within the sand bed[18].

Slow sand filtration is generally limited to raw water supplies (or influent water after pre-treatment) with applied filter turbidity values of less than 10 NTU, total coliform counts of less than 800 per 100 mL, and colour measurements of less than 5 true colour units (TCU). The treatment process can handle higher source water turbidity, coliforms, and colour if additional pre-treatment is provided[19]. Process efficiency depends upon water turbidity, nutrient levels, and temperature.

[17] 40 CFR Ch. 1, s 141.2.

[18] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

[19] Washington State Department of Health (2019). Water System Design Manual.

6.4 Diatomaceous Earth Filtration

Diatomaceous Earth Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Diatomaceous Earth Filtration	3	3	1

[a] Pathogen log reduction credit assignment is based on the diatomaceous earth filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. A minimum 3.175 mm (1/8") thickness of pre-coat is maintained.
2. Effective filter cleaning procedures are maintained.
3. Full recycle or partial discharge to waste of water flow during filter pre-coat is maintained until recycle stream turbidity falls below 1.0 nephelometric turbidity unit (NTU)[20].
4. Filter effluent turbidity is continuously monitored and recorded from each filter[21] and from combined filter effluent where there are multiple filters[22].
5. For each filter, filter effluent turbidity is less than or equal to 1.0 NTU in at least 95% of the measurements either per filter cycle or per month.
6. The diatomaceous earth filtration process is specifically tested and confirmed by an independent testing agency for the removal of *Cryptosporidium* oocysts or removal of surrogate particles.
7. For each filter, the maximum level of filter effluent turbidity is less than or equal to 3.0 NTU.

[20] Recycle stream turbidity can be monitored continuously or via grab sampling.

[21] Continuous monitoring of filter effluent turbidity from each individual filter is necessary to (1) ensure that each filter is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual filters should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[22] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

Diatomaceous Earth Filtration Overview

Diatomaceous earth filtration is a process resulting in substantial particulate removal in which (1) a pre-coat cake of diatomaceous earth filter media is deposited on a support membrane (septum), and (2) while the water is filtered by passing through the cake on the septum, additional filter media known as body feed is continuously added to the feed water to maintain the permeability of the filter cake[23].

Diatomaceous earth filtration is generally limited to raw water supplies (or influent water after pre-treatment) with turbidity values of less than 5 NTU, total coliform counts of less than 50 per 100 mL, and colour measurements of less than 5 true colour units (TCU)[24].

[23] 40 CFR Ch. 1, s 141.2.

[24] Washington State Department of Health (2019). Water System Design Manual.

6.5 Microfiltration

Microfiltration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Microfiltration	4 [b]	4 [b]	0 [c]

[a] Pathogen log reduction credit assignment is based on the microfiltration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Removal efficiency is demonstrated using challenge testing and verified by direct integrity testing.

[c] Pathogen log reduction credits for viruses are not assigned for membranes as direct integrity tests to verify virus-sized leaks are not commercially available.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. *Cryptosporidium* and *Giardia* removal efficiency is demonstrated using challenge testing and verified by daily direct integrity testing in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005) or ANSI/NSF Standard 419.
2. Membrane integrity is monitored using continuous indirect integrity monitoring in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure to ensure that filter effluent turbidity objectives are met at all times.
4. Filter effluent turbidity is continuously monitored and recorded from individual membrane units in each filter[25] and from combined filter effluent where there are multiple filters[26].
5. For each filter, filter effluent turbidity is less than or equal to 0.1 nephelometric turbidity units (NTU) in at least 99% of the measurements per operational filter period or per month[27].
6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[25] Continuous monitoring of filter effluent turbidity from individual membrane units is necessary to (1) ensure that each unit is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual membrane units should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[26] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

[27] Measurements greater than 0.1 NTU for a period of greater than 15 minutes from an individual membrane unit should immediately trigger an investigation of the membrane unit integrity.

Microfiltration Overview

Microfiltration is a low operating pressure membrane process with a relatively low feed water operating pressure of approximately 100 to 400 kPa that is used to remove particles, sediment, algae, protozoa, and bacteria. Microfiltration membranes typically have a pore size range of 0.1 to 10 µm. Water is filtered through a thin wall of porous material.

The main mechanism for removal of particulate matter is through straining or size exclusion, and the types of contaminants that are removed depend partially on the pore size or molecular weight cut-off of the membrane[28]. Pre-treatment with coagulation can be applied to improve contaminant removal; however, fouling may affect membrane performance.

[28] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

6.6 Ultrafiltration

Ultrafiltration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Ultrafiltration	4 [b]	4 [b]	0 [c]

[a] Pathogen log reduction credit assignment is based on the ultrafiltration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Removal efficiency is demonstrated using challenge testing and verified by direct integrity testing.

[c] Pathogen log reduction credits for viruses are not assigned for membranes as direct integrity tests to verify virus-sized leaks are not commercially available.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. *Cryptosporidium* and *Giardia* removal efficiency is demonstrated using challenge testing and verified by daily direct integrity testing in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005) or ANSI/NSF Standard 419.
2. Membrane integrity is monitored using continuous indirect integrity monitoring in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure to ensure that filter effluent turbidity objectives are met at all times.
4. Filter effluent turbidity is continuously monitored and recorded from individual membrane units in each filter[29] and from combined filter effluent where there are multiple filters[30].
5. For each filter, filter effluent turbidity is less than or equal to 0.1 nephelometric turbidity units (NTU) in at least 99% of the measurements per operational period or per month[31].
6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[29] Continuous monitoring of filter effluent turbidity from individual membrane units is necessary to (1) ensure that each unit is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual membrane units should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[30] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

[31] Measurements greater than 0.1 NTU for a period of greater than 15 minutes from an individual membrane unit should immediately trigger an investigation of the membrane unit integrity.

Ultrafiltration Overview

Ultrafiltration is a lower pressure membrane process characterized by a wide band of molecular weight cut-off and pore sizes for the removal of small colloids, particulates and, in some cases, viruses. Ultrafiltration membranes typically have a pore size range of 0.01 to 0.1 µm. Similar to microfiltration, water is filtered through a thin wall of porous material.

The main mechanism for removal of particulate matter is through straining or size exclusion, and the types of contaminants that are removed depend partially on the pore size or molecular weight cut-off of the membrane[32]. Pre-treatment with coagulation can be applied to improve contaminant removal; however, fouling may affect membrane performance.

It is recognized that challenge testing has demonstrated that ultrafiltration membranes are capable of providing significant virus reduction. However, given the lack of viable direct integrity tests to detect virus-sized fiber breaks, virus log reduction credit assignment is not recommended.

[32] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

6.7 Nanofiltration

Nanofiltration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Nanofiltration	4 [b]	4 [b]	0 [c]

[a] Pathogen log reduction credit assignment is based on the nanofiltration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Removal efficiency is demonstrated using challenge testing and verified by direct integrity testing.

[c] Pathogen log reduction credits for viruses are not assigned for membranes as direct integrity tests to verify virus-sized leaks are not commercially available.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. *Cryptosporidium* and *Giardia* removal efficiency is demonstrated using challenge testing and verified by daily direct integrity testing in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
2. Membrane integrity is monitored using continuous indirect integrity monitoring in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
3. Filter effluent turbidity is continuously monitored and recorded from individual membrane units in each filter[33] and from combined filter effluent where there are multiple filters[34].
4. For each filter, filter effluent turbidity is less than or equal to 0.1 nephelometric turbidity units (NTU) in at least 99% of the measurements per operational filter period or per month[35].
5. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[33] Continuous monitoring of filter effluent turbidity from individual membrane units is necessary to (1) ensure that each unit is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual membrane units should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[34] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

[35] Measurements greater than 0.1 NTU for a period of greater than 15 minutes from an individual membrane unit should immediately trigger an investigation of the membrane unit integrity.

Nanofiltration Overview

Nanofiltration is a low-pressure reverse osmosis process for the removal of larger cations (e.g., calcium and magnesium ions) and organic molecules. Nanofiltration membranes are typically considered non-porous and are reported to reject particles in the size range of 0.5-2 nm. Nanofiltration is based on preferential diffusion to achieve separation of dissolved solutes from water. Nanofiltration can also remove particulate matter, although it is not intended specifically for this purpose as high particulate loadings can cause the membrane to foul rapidly[36].

[36] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

6.8 Reverse Osmosis

Reverse Osmosis Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Reverse Osmosis	4 [b]	4 [b]	0 [c]

[a] Pathogen log reduction credit assignment is based on the reverse osmosis treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Removal efficiency is demonstrated using challenge testing and verified by direct integrity testing.

[c] Pathogen log reduction credits for viruses are not assigned for membranes as direct integrity tests to verify virus-sized leaks are not commercially available.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. *Cryptosporidium* and *Giardia* removal efficiency is demonstrated using challenge testing and verified by daily direct integrity testing in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
2. Membrane integrity is monitored using continuous indirect integrity monitoring in accordance with the guidance set out in the Membrane Filtration Guidance Manual (2005).
3. Filter effluent turbidity is continuously monitored and recorded from individual membrane units in each filter[37] and from combined filter effluent where there are multiple filters[38].
4. For each filter, filter effluent turbidity is less than or equal to 0.1 nephelometric turbidity units (NTU) in at least 99% of the measurements per operational filter period or per month[39].
5. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[37] Continuous monitoring of filter effluent turbidity from individual membrane units is necessary to (1) ensure that each unit is functioning properly; (2) help determine when to end filter runs; and (3) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual membrane units should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity).

[38] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

[39] Measurements greater than 0.1 NTU for a period of greater than 15 minutes from an individual membrane unit should immediately trigger an investigation of the membrane unit integrity.

Reverse Osmosis Overview

Reverse osmosis is a high-pressure membrane process based on diffusion of water through a semi-permeable membrane as a result of a concentration gradient. Reverse osmosis membranes are considered to be non-porous and are used to remove dissolved solids, such as sodium, chloride, and nitrate, from water. Similar to nanofiltration, reverse osmosis is based on preferential diffusion to achieve separation of dissolved solutes from water. Reverse osmosis can also remove particulate matter, although it is not intended specifically for this purpose as high particulate loadings can cause the membrane to foul rapidly[40].

[40] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

6.9 Cartridge Filtration

Cartridge Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Cartridge Filtration, one unit [1 micron absolute pore size]	2 [b]	2 [b]	0
Cartridge Filtration, two units in series [1 micron absolute pore size]	2.5 [b]	2.5 [b]	0

[a] Pathogen log reduction credit assignment is based on the cartridge filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[b] Challenge testing should demonstrate at least 3-log reduction of *Cryptosporidium* oocysts and *Giardia* cysts for each unit. However, the recommended maximum pathogen log reduction credit assignment for each protozoa is 2-log for a single unit and 2.5-log (total) for two units in series, providing a safety factor to account for the lack of daily direct integrity testing.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. Materials coming into contact with water conform to ANSI/NSF Standard 61.
2. The cartridge filtration process is specifically tested and confirmed by an independent testing agency for at least 3-log removal of *Cryptosporidium* oocysts or surrogate particles (e.g. conforming to ANSI/NSF Standard 53 would satisfy this criterion for low flow systems)
3. Differential pressure across the filter medium is continuously measured and does not exceed the manufacturer's rating.
4. Filter effluent turbidity is continuously monitored and recorded[41] from each filter and from combined filter effluent where there are multiple filters[42].
5. For each filter, filter effluent turbidity is less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95% of the measurements per month.
6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.

[41] Continuous monitoring of filter effluent turbidity from each individual filter is necessary to (1) ensure that each filter is functioning properly and (2) detect any short-term or rapid increases in turbidity that represent a process failure and a potential health risk. Filter effluent turbidity levels from individual filters should be continuously measured (with an online turbidimeter) and recorded at intervals no longer than five minutes apart at a point in each individual filter effluent line (see the Health Canada Guideline Technical Document for Turbidity). For facilities needing monitoring equipment upgrades, daily grab samples for turbidity monitoring may be considered an acceptable approach at the discretion of the Drinking Water Officer.

[42] The combined filter effluent should also be monitored at some point downstream of the combined filter effluent line or the clearwell or tank. Continuous monitoring of combined filter effluent turbidity will help ensure that the quality of water entering the distribution system has not deteriorated following filtration (see the Health Canada Guideline Technical Document for Turbidity).

Cartridge Filtration Overview

Cartridge filtration is a pressure-driven physical separation process that removes particles greater than 1 µm using a porous filtration medium. Cartridge filters are typically made of a semi-rigid or rigid wound filament that is housed in a pressure vessel in which water flows from the outside of the cartridge to the inside. Cartridge filtration systems can be constructed with either single or multiple filters within one pressure vessel[43].

Cartridge filters effectively remove particles from water in the size range of *Cryptosporidium* oocysts (2-5 microns) and *Giardia* cysts (5-10 microns). Cartridge filters do not significantly remove viruses[44]. Challenge testing should demonstrate at least 3-log reduction of *Cryptosporidium* and *Giardia* for individual cartridge filters; however, credit assignment for each protozoa should be 2-log reduction as cartridge filters lack daily direct integrity tests to confirm ongoing performance. For two cartridge filters in series, the total credit assignment for each protozoa should be 2.5-log reduction.

Cartridge filtration is generally limited to raw water supplies with applied filter turbidity values of less than 5 NTU. Cartridge filters can handle higher source water turbidity if additional pre-treatment is provided. Special studies are required to determine equipment-specific total coliform and colour limitations[45]. To reduce the frequency of filter replacement, cartridge filters are typically used in series with decreasing pore sizes.

Cartridge filters with filters and/or housings that are not certified by an approved testing agency are not eligible for pathogen log reduction credit assignment.

[43] Health Canada (2012). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Turbidity.

[44] Government of Ontario (2006). Procedure for Disinfection of Drinking Water in Ontario.

[45] Washington State Department of Health (2019). Water System Design Manual.

6.10 Subsurface Filtration

Subsurface Filtration Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Subsurface Filtration (Well/Surface Water Separation)	1	1	0
Subsurface Filtration (Subsurface Filtration Study)	3	3	0
Subsurface Filtration (Demonstration of Performance)	3	3	4

[a] Subsurface filtration is only considered as one of the two required treatment processes if it has been awarded greater than 1-log removal credit each for *Cryptosporidium* oocysts and *Giardia* cysts and the second treatment process achieves the remainder of the recommended minimum pathogen log reduction.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. Groundwater wells are properly constructed, have a satisfactory well protection plan in place, and draw from an unconsolidated and granular aquifer (e.g., sand and gravel). Aquifers have interconnected pores without substantial cementation which might indicate preferential flow pathways.
2. Subsurface filtration effectiveness is demonstrated by either well/surface water separation, a subsurface filtration study or by demonstration of performance.
3. If Microscopic Particulate Analysis (MPA) testing has been conducted, the groundwater source is not considered 'high risk'. Wells drawing from MPA high risk sources are ineligible for subsurface filtration credits.
4. Well water turbidity is monitored and recorded for each groundwater well at equal intervals (at least every four hours) immediately prior to where disinfection occurs. Different sampling requirements and intervals may be specified by a DWO.
5. For each well, well water turbidity is around 1.0 nephelometric turbidity unit (NTU)[46] in at least 95% of the measurements per month.
6. For each well, the maximum level of well water turbidity is less than or equal to 3.0 NTU.

[46] To ensure effectiveness of disinfection and for good operation of the distribution system, it is recommended that water entering the distribution system have turbidity levels of 1.0 NTU or less. For systems that use groundwater, turbidity should generally be below 1.0 NTU (Health Canada (2020). Guidelines for Canadian Drinking Water Quality – Summary Table).

Subsurface Filtration Overview

Subsurface filtration (also called riverbank filtration) is a naturally occurring process that filters surface water as it passes through river or lakebed sediments, lake/riverbank substrate, and into an aquifer before being drawn up by a well. Engineered filtration structures, such as infiltration galleries, are not naturally occurring and therefore are not considered equivalent to subsurface filtration treatment[47].

The effectiveness of subsurface filtration is site-specific and can depend on many factors such as surface water quality, water temperature, groundwater flow conditions, dilution rates, surface water-groundwater interface characteristics (such as pH, specific surface area of substrate particles, and organic matter content), and aquifer material (Wang et al., 2002). Further, subsurface filtration can vary seasonally and in response to extreme climatic events (Hrudey and Hrudey, 2004).

Subsurface filtration effectiveness should be demonstrated by either well/surface water separation, a subsurface filtration study or by demonstration of performance. Groundwater wells drawing from groundwater sources identified as 'high risk' by Microscopic Particulate Analysis (MPA) testing are ineligible for any subsurface filtration credits.

Subsurface Filtration Demonstration Methods

Well/Surface Water Separation

For well/surface water separation, wells that meet the following criteria are eligible for a 1-log credit for *Cryptosporidium* and *Giardia*:

- The wells are located at least 15 m from a surface water source (i.e., high water mark for horizontal separation, riverbed for vertical separation) through the shortest flow path.
- The wells have core samples collected along at least 85% of the well screen depth with composite samples that:
    - are collected at intervals of no greater than 60 cm (2 feet) in length and have more than 10% of particles passing through a 1.5 mm screen; or
    - in the absence of continuous core samples, a DWO may consider wells screened in sand with a grain size of 1 mm[48] or finer where well log information is provided, supplemented by field review and aquifer mapping (if available).

A 1-log credit based on well/surface water separation cannot be assigned **in addition to** log credits associated with other subsurface treatment credit demonstration methods (i.e. subsurface filtration study or demonstration of performance).

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[47] B.C. Ministry of Health (2017). Drinking Water Officers' Guide.

[48] Sand with a diameter of 1 mm is considered medium sand according to the Unified Soil Classification System (ASTM, 2006) and coarse sand according to the Canadian System of Soil Classification (SCWG, 1998).

Subsurface Filtration Study

Treatment credits for subsurface filtration may also be obtained through the completion of a subsurface filtration study. Hydrogeological conditions should be determined by a qualified professional[49] to characterize the subsurface filtration in question and should include the collection of a minimum of two paired (surface water and groundwater) MPA samples; one MPA sample pair must be collected annually under or close to worst-case conditions to establish and maintain this treatment credit. Alternatives to MPA testing (including analysis of surrogates for *Cryptosporidium* and *Giardia*) may be considered at the discretion of the DWO. The scope of the subsurface filtration study, including water quality sample timing and proposed analyses, should be established by the qualified professional, and submitted to the DWO for consideration prior to the start of the study, and should consider the following factors[50]:

Surface Water Conditions

- Historic flow patterns
- Seasonal variations
- 50, 100, and 200-year flood levels (considering diking, where applicable)
- High water mark
- Likelihood of extreme precipitation events and the impact on surface water quality
- Assessment of potential for riverbank or lakebed scour and flow rates that may cause scour
- Expected flooding frequency
- Clogging potential

Aquifer Conditions

- British Columbia Aquifer Classification System ranking
- Grain size and porosity
- Aquifer stratigraphy and lithology
- Hydraulic conductivity
- Storativity and transmissivity (in confined aquifers)
- Groundwater dilution rate (related to the pumping rate)
- Groundwater flow directions and gradients (under both natural and pumping conditions)
- Groundwater flow rate or velocity

Well Conditions

- The location and construction of a well should be consistent with legislated construction standards
- Time of travel from high water mark to well under various pumping and water level conditions

[49] A qualified professional is an individual who is registered with Engineers and Geoscientists BC with competency in the field of hydrogeology and experience in evaluating sources of groundwater supply.

[50] Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia (2015).

- Water level readings to capture seasonal fluctuations and recharge events (monthly readings should be completed at a minimum, however, continuous monitoring is ideal); sampling frequency can be reduced if aquifer does not show significant variation
- Pumping test data
- Well capture zone
- Summary of hydrogeological cross sections showing stratigraphy, aquifers, confining layers, well capture zones under high pumping and high surface water stage conditions

Groundwater and Surface Water Quality

- Paired MPA sampling results
- Total coliforms, *E. coli*, level and nature (organic vs inorganic) of turbidity
- Field measurements of temperature, pH, electrical conductivity
- Observed variations between groundwater and surface water quality with time
- Correlation between variations in surface water and groundwater quality employing statistical methods

Demonstration of Performance

Demonstration of Performance is based on the completion of a Subsurface Filtration Study but with a far more rigorous testing protocol. For an eligible well drawing from a GARP source, subsurface filtration may be considered for up to 3-log removal credit for *Cryptosporidium* oocysts and *Giardia* cysts and, in some cases, up to 4-log removal credit for viruses where proven by a Demonstration of Performance Study.

To maintain a treatment credit obtained as a result of a subsurface filtration study or demonstration of performance, water suppliers should collect and submit for analysis at least one pair (groundwater and surface water) of MPA samples (and virus surrogate samples, if virus credit was obtained) annually or at a frequency agreed upon by the Drinking Water Officer. The timing of the sample should coincide with the reasonable worst-case conditions, as identified during the initial MPA sampling[51].

Subsurface filtration should only be considered as one of the two required treatment processes if it has been awarded greater than 1-log removal credit each for *Cryptosporidium* oocysts and *Giardia* cysts and the second treatment process achieves the remainder of the recommended minimum pathogen log reduction.

Detailed information on subsurface filtration including pathogen log reduction credit maintenance can be found in Appendix A to the Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia.

[51] Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia (2015).

6.11 Filtration Exemption

Filtration Exemption Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Filtration Exemption	0	0	0

Recommended Filtration Exemption Criteria

1. Overall pathogen inactivation is met using a minimum of two types of disinfection providing at a minimum 3-log reduction of *Cryptosporidium* and *Giardia*, and 4-log reduction of viruses.
2. The number of *E. coli* in raw water does not exceed 20/100 mL (or if *E. coli* data are not available, less than 100/100 mL of total coliform) in at least 90% of the weekly samples from the previous six months[52].
3. For all water systems, treated water is to contain no detectable *E. coli* or fecal coliform per 100 mL. Total coliform objectives are also zero based on one sample in a 30-day period. For more than one sample in a 30-day period, at least 90% of samples have no detectable total coliform bacteria per 100 mL and no sample has more than 10 total coliform bacteria per 100 mL.

   For Surface Water Supplies:
4. Average daily turbidity levels measured at equal intervals (at least every four hours) immediately before the disinfectant is applied are around 1 nephelometric turbidity unit (NTU)[53] and do not exceed 5 NTU for more than two days in a 12-month period.
5. A watershed control program[54] is maintained that minimizes the potential for fecal contamination in the source water.

   For Groundwater Supplies:
6. Average daily turbidity levels measured at equal intervals (every four hours or at an interval acceptable to the Drinking Water Officer) immediately prior to any disinfection process are around 1 NTU[53] and do not exceed 5 NTU for more than two days in a 12-month period.

[52] A longer monitoring period may be required at the discretion of the DWO to capture seasonal variations and annual trends in raw water quality. For UV equipment design, two years of data (including UVT) is recommended (B.C. Guidelines for Ultraviolet Disinfection of Drinking Water, 2022).

[53] To ensure the effectiveness of disinfection and for good operation of the distribution system, it is recommended that water entering the distribution system have turbidity levels of 1.0 NTU or less. (Health Canada (2020). Guidelines for Canadian Drinking Water Quality – Summary Table).

[54] Watershed control program requirements are not set out in the Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia (2012). The Comprehensive Drinking Water Source-to-Tap Assessment Guideline, Modules 1, 2, 7 & 8 could be considered for this purpose or another method deemed acceptable by a DWO.

Recommended Filtration Exemption Criteria
7. The well is properly constructed and protected to minimize the potential for fecal or other pathogenic-related contamination in the source water, and a Well Protection Plan (or equivalent satisfactory to the DWO) is in place.

Filtration Exemption Overview

Provincial treatment objectives allow a surface water or GARP water supply system to operate without filtration if conditions for filtration exemption are met, or a timetable to implement filtration has been agreed to by a Drinking Water Officer. To assist in the filtration exemption process, the Drinking Water Officer has the discretion to rely on additional sample types to account for local water quality influences and contaminants that could affect treatment. Even though there are no pathogen log reduction credits assigned, the filtration exemption should be recorded pursuant to Section 10 of these guidelines to facilitate open and transparent communication on how the drinking water system is meeting the provincial drinking water treatment objectives.

If a water supply system is permitted to operate without filtration, it does not mean that filtration will not be required in the future. Changes in raw water source quality and increased threats to the watershed or aquifer might necessitate the installation of a filtration system.

7. Ultraviolet Disinfection

Ultraviolet Disinfection Pathogen Log Reduction Credits and Assignment Criteria

Validation Protocol or Certification Standard	Minimum UV Dosage [a]	Maximum Pathogen Log Reduction Credits Assigned [b, c]		
		Cryptosporidium Oocysts	*Giardia* Cysts	Viruses [d]
DVGW W294	RED = 40 mJ/cm^2	3	3	0.5 or 2
NSF Standard 55 (Class A Systems only)	40 mJ/cm^2	3	3	0.5 or 2
ÖNORM M 5873	RED = 40 mJ/cm^2	3	3	0.5 or 2
UVDGM	Validated dose ≥ required dose for target pathogen log inactivation	Determined on a case by case basis	Determined on a case by case basis	Determined on a case by case basis

RED = Reduction Equivalent Dose. May also be called the REF (Reduction Equivalent Fluence).

[a] Validated reactors establish a RED for a specific organism (e.g. an MS2 RED or a *B. subtilis* RED). Similarly, NSF Standard 55 Class A certified systems are designed to deliver a UV dose that is at least equivalent to the MS2 bacteriophage dose-response at 40 mJ/cm^2 when the systems are tested in accordance with the Standard.

[b] Pathogen log reduction credit assignment is based on post-filter applications of UV equipment, or application of UV equipment to drinking water systems that use a groundwater source at low risk of containing pathogens; a 'GARP-viruses only' water source; or a water source that has been granted a filtration exemption by a Drinking Water Officer.

[c] Pathogen log reduction credit assignment is based on UV equipment being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

[d] For drinking water sources that a Drinking Water Officer considers to be at risk from human fecal contamination, a 0.5-log reduction credit should be assigned because of the high level of resistance of adenovirus to UV treatment. For drinking water sources that a Drinking Water Officer does not consider to be at risk from human fecal contamination[55], a 2-log reduction credit should be assigned based on rotavirus inactivation.

[55] The DWO may use their discretion to determine whether a drinking water source is at risk of fecal contamination, based on a source water assessment from the water supplier, or other studies conducted by the water supplier and provided to the DWO. Key considerations could include hydraulic connection to a known human sewage source and elevated presence of fecal indicators (i.e. *E. coli* > 20 colony forming units/100 mL).

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. UV equipment is validated or certified based on a validation protocol or certification standard recognized by the Province of British Columbia.
2. UV equipment is operated within its validated or certified operating conditions.
3. UV equipment is operated such that a continuous UV dose is maintained throughout the lifetime of the UV lamp(s) that is at least the minimum continuous UV dose used in the validation protocol or certification standard for the targeted pathogen log reduction credit.
4. For UV equipment using the UV intensity set point control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours:
    - Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated or certified operating conditions)
    - Lamp status
    - UV intensity
5. For UV equipment using the calculated dose control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours:
    - Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated operating conditions)
    - Lamp status
    - UV intensity
    - UV transmittance (UVT)[56]
6. When UV equipment components are installed or replaced, they are the same as the components used for equipment validation and/or certification unless the UV equipment was revalidated or recertified.
7. Within 30 days following the end of a calendar month, a monthly summary report is prepared which sets out the time, date, and duration of each major or critical UV equipment alarm that occurred during the month, the reason for the alarm, the volume of water treated during each alarm period and the actions taken by the water supplier to correct the alarm situation.

[56] UVT may not be required for some calculated dose monitoring approaches. See USEPA (2020) "Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems".

Ultraviolet Disinfection Overview

UV disinfection is an effective treatment process for the inactivation of protozoa, bacteria, and viruses, depending on the UV dose applied. UV light inactivates pathogens by damaging their nucleic acids (DNA and RNA) so that they cannot replicate and infect humans. One of the advantages of using UV disinfection is that the disinfection by-products typically associated with the use of chemical disinfectants are not formed. Unlike chlorine which can be used for both primary and residual disinfection, UV light can only be used for primary disinfection because it does not have any residual disinfection capability.

Provincial guidance on the reduction of pathogenic microorganisms in drinking water using UV disinfection is set out in the Guidelines for Ultraviolet Disinfection of Drinking Water.

8. Chemical Disinfection

Chemical Disinfection Pathogen Log Reduction Credits and Assignment Criteria

Maximum Pathogen Log Reduction Credits Assigned [a]	***Cryptosporidium* Oocysts**	***Giardia* Cysts**	**Viruses**
Chemical disinfection	Determined through CT calculations	Determined through CT calculations	Determined through CT calculations

[a] Pathogen log reduction credit assignment is based on the chemical disinfection process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Recommended Pathogen Log Reduction Credit Assignment Criteria

1. Chemical disinfectant dosages are adjusted in response to variations in raw water quality.

2. At all times, $CT_{Calculated}$ is greater than or equal to the $CT_{Required}$ to achieve the pathogen log reduction credits assigned.

For Large Water Systems

3. Sampling and testing for disinfectant residual are carried out by continuous monitoring equipment at or near a location where the intended contact time has been achieved.

For Small Water Systems

4. Sampling and testing for disinfectant residual are carried out:
    a. at a minimum frequency of once every 24 hours or on a more frequent basis at the discretion of the Drinking Water Officer;
    b. at or near a location where the intended contact time has been achieved.

Chemical Disinfection Overview

Chemical disinfection is used to inactivate pathogens in water by direct contact with chlorine, chloramine, chlorine dioxide or ozone.

The selection of an appropriate disinfectant should consider the efficacy of the chemical and the potential for the generation of disinfection by-products (DBPs). DBPs are formed when chemical disinfectants react with natural organic matter in source water or a drinking water distribution system. There are several factors that influence the formation of disinfection by-products including the presence of organic and inorganic precursors, the disinfectant type and dose, water temperature, pH, and water age. Disinfection is typically applied after filtration so that the formation of DBPs is

minimized because of the removal of organic and inorganic matter[57]. The health risks from disinfection by-products are generally much lower than the risks from consuming water that has not been disinfected[58].

Disinfection chemicals are discussed below.

Chlorine

Chlorination is the process of adding chlorine or chlorine-containing compounds (e.g. sodium hypochlorite or calcium hypochlorite) to water. Chlorine is the most common chemical used for drinking water disinfection because it is widely available, relatively inexpensive and produces a free chlorine residual[59] that can be used to maintain water quality in the distribution system[60]. Chlorine effectively inactivates enteric viruses, but the inactivation of protozoa is less effective due to their resistance to chlorine (*Cryptosporidium* is more resistant to chlorine than *Giardia*). Chlorine may form undesirable DBPs in water, including trihalomethanes (THMs) and haloacetic acids (HAAs).

Chloramine

Chloramination is the process of adding chlorine and ammonia to water to produce a combined chlorine residual predominantly in the form of monochloramine. A combined chlorine residual is defined as the concentration of residual chlorine that is combined with ammonia, organic nitrogen, or both in water that is available to oxidize organic matter and act as a disinfectant. Monochloramine is a weak disinfectant that is best suited for maintaining a more persistent chlorine residual in the water distribution system. Chloramine forms a significantly lower amount of most DBPs than chlorine but may produce more N-nitrosodimethylamine (NDMA).

Chlorine Dioxide

Chlorine dioxide is a highly effective disinfectant that is generally more rapidly effective than chlorine, but less so than ozone. Chlorine dioxide is explosive under pressure and is usually manufactured onsite. The use of chlorine dioxide can result in the formation of DBPs such as chlorite and chlorate.

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[57] To ensure the effectiveness of disinfection and for good operation of the distribution system, it is recommended that water entering the distribution system have turbidity levels of 1.0 NTU or less (Health Canada (2020). Guidelines for Canadian Drinking Water Quality – Summary Table).

[58] Health Canada (2006). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Trihalomethanes.

[59] A free chlorine residual is defined as the amount of chlorine available as dissolved gas (Cl_2), hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) that is not combined with ammonia or other compounds in water (see the Health Canada Guideline Technical Document for Chlorine).

[60] Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Viruses.

Ozone

Ozone is a strong oxidant and virucide. It is significantly more effective than chlorine at inactivating pathogens in water; however, it is more expensive than chlorine and does not produce a persistent residual that can be used for maintaining drinking water quality in the distribution system. The use of ozone results in the formation of fewer THMs and HAAs than chlorination but can also form other DBPs such as bromate.

The efficacy of chemical disinfectants can be predicted based on knowledge of the residual concentration of the disinfectant, temperature, pH, and contact time. This relationship is commonly referred to as the CT concept, where CT is the product of the residual concentration of the disinfectant (C) measured in mg/L and the disinfectant contact time (T) measured in minutes[61].

CT = C x T
= Concentration (mg/L) x Time (minutes)

To account for disinfectant decay, the residual concentration "C" is usually determined at the exit of the chemical contact chamber rather than using the applied dose or initial concentration. The contact time "T" is typically calculated using a T_{10} value, which is defined as the length of time during which 10% of the influent water passes through the contact chamber[62]. Using T_{10} in CT calculations ensures that 90% of the treated water meets or exceeds the contact time.

Ideally, hydraulic tracer tests can be used to determine the actual contact time under plant flow conditions[63]. However, it is often impractical or cost prohibitive to conduct tracer studies. Accordingly, the T_{10} value is usually estimated based on the geometry and flow conditions of the contact chamber or basin.

As ozone reactions occur quickly in water, T_{10} calculations are not always appropriate to assess contact time when ozone is used as the disinfectant. The U.S. EPA Long Term 2 Enhanced Surface Water Treatment Rule: Toolbox Guidance Manual (2010) describes the CSTR method, Extended T_{10} method and Extended CSTR method for calculating CT in an ozone contactor.

Other methods may be used to determine contact time with the approval of a DWO: for example, segregated flow analysis[64] (also referred to as segregated flow modelling) or partially segregated

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[61] Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Viruses.

[62] Government of Ontario (2006). Procedure for Disinfection of Drinking Water in Ontario.

[63] Health Canada (2019). Guidelines for Canadian Drinking Water Quality: Guideline Technical Document — Enteric Viruses.

[64] USEPA (1991). Guidance Manual for Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

modelling (also referred to as N-CSTR or tanks-in-series modelling)[65] of high-resolution tracer studies, or the use of site-specific computational fluid dynamics (CFD) modelling.

For the purpose of pathogen log reduction credit assignment, worst-case operating conditions should be considered when determining whether a drinking water treatment facility has the ability to achieve the recommended minimum pathogen log reduction for the chemical disinfection component of the larger drinking water treatment process.

Worst-case operating conditions reflect the most challenging conditions under which the drinking water treatment facility would operate and typically comprise minimum water depth or operating level in clearwells or reservoirs, minimum temperature, maximum pH, maximum flowrate, and minimum disinfectant residual.

Where appropriate, CT values can be calculated for each process step of the treatment train and the values summed. Calculations should be based on the residual concentration of disinfectant at the end of each process step.

Section 9 discusses the steps to calculate CT based on T_{10} and worst-case operating conditions.

9. Calculating CT based on T_{10} and Worst-Case Operating Conditions

Determining Contact Volume

The first step in calculating CT using T_{10} is to determine the volume of water (V) in the unit process, measured in cubic metres (m^3). Clearwells, reservoirs and contact pipes are typically used to provide disinfectant contact time and different formula are used to calculate contact volume depending upon the physical configuration of the contact chamber. For rectangular and cylindrical contact chambers, minimum water depth is based on the lowest allowable depth for the unit process (e.g. the low level alarm for finished water).

For rectangular contact chambers (e.g. a clearwell or reservoir), the volume of water (m^3) is calculated by multiplying together the chamber internal length (l) and width (w), and the minimum water depth (d).

Volume (V) = l x w x d
= length (m) x width (m) x minimum water depth (m)

For cylindrical contact chambers (e.g. a clearwell or reservoir), the volume of water (m^3) is calculated by multiplying together the constant pi (π), the square of the cylindrical contact chamber internal radius (r), and the minimum water depth (d).

[65] Pfeiffer and Barbeau (2014). Validation of a simple method for predicting disinfection performance in a flow-through contactor. Water Research 49: 144-156.

Volume (V) = π x r^2 x d
= pi x radius squared (m^2) x minimum water depth (m)

For contact pipes (e.g. designated contact piping or distribution pipes prior to the first customer), the volume of water (m^3) is calculated by multiplying together the constant Pi (π), the square of the contact pipe internal radius (r), and the length of the pipe (l).

Volume (V) = π x r^2 x l
= pi x radius squared (m^2) x length (m)

Determining T_{10}

T_{10} is estimated using the theoretical detention time (T) and a baffling factor. Baffling factors describe the degree of short circuiting that occurs within a contact chamber.

The theoretical detention time (T) measured in minutes, is calculated as the volume (V) of water in the contact chamber measured in m^3 divided by the flowrate (Q) of water through the chamber measured in m^3/minute. For the purpose of calculating CT under worst-case operating conditions, the peak hourly flowrate should be used.

T = V/Q
= Volume (m^3) / Flowrate (m^3/minute)

T_{10} is calculated as the theoretical detention time (T) of water in the contact chamber measured in minutes, multiplied by the baffling factor (T_{10}/T) based on the hydraulic characteristics of the chamber.

T_{10} = T x BF
= Theoretical Detention Time (minutes) x Baffling Factor (T_{10}/T)

The baffling factor for a particular contact chamber can be estimated based on the configuration of the chamber and the degree of short-circuiting. Typical baffling factors are set out in Table 3.

Table 3: Baffling Factors[66]

Baffling Factor (T_{10}/T)	Baffling Condition	Baffling Description
0.1	Unbaffled	No baffles, agitated basin, very low length-to-width ratio, high inlet and outlet flow velocities, inlet and outlet at the same level
0.2	Unbaffled	No baffles, agitated basin, very low length-to-width ratio, high inlet and outlet flow velocities, inlet high and outlet low or vice versa
0.3	Poor	Single or multiple unbaffled inlets and outlets, no intra-basin baffles, vertical perforated pipe for an inlet and/or outlet
0.5	Average	Baffled inlet or outlet, vertical perforated pipe for an inlet or outlet, with some intra-basin baffles
0.7	Superior	Perforated inlet baffle, perforated intra-basin baffles, outlet weirs or perforated launders
0.9	Excellent	Serpentine baffling throughout
1.0	Perfect	Pipeline flow, very high length-to-width ratio (≥160:1) with turbulent flow

Determining $CT_{Calculated}$

$CT_{Calculated}$ is used to estimate the CT that is being achieved with the use of the disinfectant. $CT_{Calculated}$ is measured in minutes·mg/L and is determined by multiplying together the disinfectant residual concentration (C) measured in mg/L and the contact time T_{10} measured in minutes.

$CT_{Calculated}$ = C x T
= Concentration (mg/L) x Time (minutes)

The disinfectant residual concentration is usually measured at the outlet of the contact chamber (clearwell, reservoir, or contact pipe) before the treated water reaches the first consumer. For the purposes of determining C, the minimum design disinfectant residual concentration (for example, the low chlorine alarm level) should be used for a conservative estimate.

If historical field data is available, the minimum recorded disinfectant concentration can be used as C. Alternative values for C, such as the C_{10} (the 10^{th} percentile of recorded disinfectant concentrations,

[66] Government of Ontario (2006). Procedure for Disinfection of Drinking Water in Ontario; Colorado Department of Public Health and Environment (2014). Baffling Factor Guidance Manual.

such that 90% of the treated water meets or exceeds that concentration) or estimates from models (see Section 8) may be used with the approval of a DWO.

In some cases, $CT_{Calculated}$ may be determined for multiple disinfection segments. This is often implemented for ozone, which has a short decay period in water. Refer to the U.S. EPA Guidance Manual for Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources (1991) for detailed guidance.

Determining $CT_{Required}$

$CT_{Required}$ is used to determine the level of disinfection that is required in the chemical disinfection part of the drinking water treatment process based on the CT tables that are included in the Appendix to this guidelines document. The Appendix comprises 14 CT tables:

- Tables A1 through A6 set out CT values for the inactivation of *Giardia* cysts by free chlorine.
- Table A7 sets out CT values for the inactivation of viruses by free chlorine.
- Tables A8 and A9 set out CT values for the inactivation of *Giardia* and viruses by chlorine dioxide.
- Tables A10, A11 and A12 set out CT values for the inactivation of *Cryptosporidium*, *Giardia,* and viruses by ozone.
- Tables A13 and A14 set out CT values for the inactivation of *Giardia* and viruses by chloramine.

Where applicable, the CT tables set out the $CT_{Required}$ values based on:

- Pathogen type (*Cryptosporidium*, *Giardia,* or viruses)
- Disinfectant type (free chlorine, chlorine dioxide, ozone, or chloramine)
- Water temperature (°C)
    - If water temperature falls between temperature values in Tables A1 through A14, the lower temperature value should be used.
- Water pH
    - If water pH falls between pH values in Tables A1 through A7, the higher pH value should be used.
- Target pathogen log inactivation
- Free chlorine concentration (mg/L)

If $CT_{Required}$ is less than $CT_{Calculated}$, then no additional disinfectant contact time is required.

If $CT_{Required}$ is greater than $CT_{Calculated}$, then additional disinfectant contact time is needed to achieve the required pathogen log inactivation.

9.1 CT Calculation Examples

The following two examples set out CT calculations for a chlorine contact pipe and a chlorine contact chamber.

CT Calculation for a Chlorine Contact Pipe

The following example is for a drinking water treatment facility that has a design capacity of 1,090 m^3/day, and a 300 m long chlorine contact pipe (300 mm internal diameter) that is being used to provide chlorine contact time for 2-log inactivation of viruses. The treatment facility is targeting a minimum free chlorine residual of 0.4 mg/L (low residual alarm setting). The CT calculation is based on worst-case operating conditions (e.g., minimum water temperature, maximum pH, maximum flowrate, and minimum free chlorine residual).

For the ABC Water Treatment Plant, and for 2-log inactivation of viruses by free chlorine under worst-case operating conditions:

Minimum water temperature = 0.5 degrees Celsius
Maximum pH = 8.0
Minimum free chlorine residual = 0.4 mg/L (based on the low residual alarm setting for finished water)

$CT_{Required}$ = 6 min·mg/L (for 2-log inactivation of viruses by free chlorine based on the CT values in Table A7 of the British Columbia Guidelines for Pathogen Log Reduction Credit Assignment)

Maximum flow rate (Q) = 1,090 m^3/day = 0.757 m^3/min (based on plant design capacity)

Contact Pipe Length = 300 m
Contact Pipe (D) = 300 mm

Contact Pipe Radius = D/2 = 300 mm/2 = 150 mm = 0.15 m
Contact Pipe Volume (V) = $\pi \times r^2 \times l = \pi \times (0.15\ m)^2 \times 300\ m = 21.21\ m^3$

Theoretical Detention Time (T) = V/Q = (21.21 m^3) / (0.757 m^3/min) = 28 min
Baffle Factor (B.F.) = 1.0 (based on very high length to width ratio – pipeline flow)

T_{10} = T x B.F. = 28 min x 1.0 = 28 min

$CT_{Calculated}$ = Concentration X T_{10}
= 0.4 mg/L x 28 min
= 11.2 min·mg/L

Based on the above calculations, under worst-case operating conditions, $CT_{Calculated}$ is greater than $CT_{Required}$, and no additional chlorine contact time is required to achieve 2-log inactivation of viruses by free chlorine.

CT Calculation for a Chlorine Contact Chamber

The following example is for a drinking water treatment facility that has a design capacity of 30,000 m^3/day, and two rectangular clearwells in series that are being used to provide chlorine contact time for 0.5-log inactivation of *Giardia* cysts. Each clearwell is 30 metres long and 25 metres wide (internal dimensions). The minimum water depth in each clearwell is 1.5 metres based on the low water alarm setting. The facility is targeting a minimum free chlorine residual of 0.4 mg/L, based on the low residual alarm setting for finished water.

The CT calculation below is based on worst-case operating conditions (e.g., minimum water temperature, maximum pH, maximum flowrate, minimum clearwell volume, and minimum free chlorine residual).

For the ABC Water Treatment Plant under worst-case operating conditions:

Minimum water temperature = 0.5 degrees Celsius
Maximum pH = 8.5
Minimum free chlorine residual = 0.4 mg/L (based on the low residual alarm setting for finished water)

$CT_{Required}$ = 55 min·mg/L (for 0.5-log inactivation of *Giardia* cysts by free chlorine based on the CT values in Table A1 of the Guidelines for Pathogen Log Reduction Credit Assignment)

Maximum flow rate (Q) = 30,000 m^3/day = 20.83 m^3/min (based on plant design capacity)

Minimum Clearwell Level = 1.5 m (based on the low alarm)
Minimum Clearwell Volume (V) = l x w x d = (30 m x 25 m x 1.5 m) + (30 m x 25 m x 1.5 m) = 2,250 m^3

Theoretical Detention Time (T) = V/Q = (2,250 m^3) / (20.83 m^3/min) = 108 min
Baffle Factor (B.F.) = 0.5 (based on baffled inlet or outlet with some intra-basin baffles)

T_{10} = T x B.F. = 108 min x 0.5 = 54 min

$CT_{Calculated}$ = Concentration X T_{10}
= 0.4 mg/L x 54 min
= 21.6 min·mg/L

Based on the above calculations, under worst-case operating conditions at maximum flow rate with the low water alarm for the clearwells set at 1.5 m, $CT_{Calculated}$ is less than $CT_{Required}$. Additional chlorine contact time is required to achieve 0.5-log inactivation of *Giardia* cysts by free chlorine.

10. Pathogen Log Reduction Credit Assignment

Pathogen log reduction credit assignment can be used to determine whether drinking water treatment facilities have the necessary infrastructure in place to meet provincial drinking water treatment objectives and where necessary, to prioritize facilities for infrastructure improvements.

The pathogen log reduction credit assignment examples below illustrate how pathogen log reduction credits can be documented in a clear, succinct way that identifies how the credits are assigned based on source water type, the treatment processes used for disinfection, and the criteria that should be met for pathogen log reduction credit assignment. The pathogen log reduction credit assignment criteria are customized for each treatment facility based on the treatment processes used at the facility.

Where multiple raw water sources are combined and treated in a common treatment facility, recommended minimum pathogen log reduction would be based on the most demanding source water type: for example, for a surface water supply with supplemental groundwater supply (GARP – viruses only), the recommended minimum pathogen log reduction would be based on the surface water supply (i.e., 3-log reduction of both *Cryptosporidium* oocysts and *Giardia* cysts, and 4-log reduction of viruses).

The following examples set out pathogen log reduction credit assignment for:

a) One treatment facility with one raw water source
b) One treatment facility with multiple raw water sources
c) Two treatment facilities with multiple raw water sources and a common distribution system

Pathogen Log Reduction Credit Assignment Example #1

(One Treatment Facility with One Raw Water Source)

ABC Water Treatment Plant

Source Water Information			
Source Water Name	Source Water Type	Water Licence Number	Well Tag/ID Number (if applicable)
ABC Lake	Surface Water	*[Insert Number]*	N/A

Recommended Minimum Pathogen Log Reduction			
Treatment Facility Name	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
ABC Water Treatment Plant	3	3	4

Pathogen Log Reduction Credits Assigned			
Treatment Technology Applied [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Filtration Exemption	0	0	0
UV Disinfection	3	3	2
Chlorination	0	0	2
Total Pathogen Log Reduction Credits	**3**	**3**	**4**

[a] Pathogen log reduction credit assignment is based on each treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Pathogen Log Reduction Credit Assignment Criteria	
Filtration Exemption	1. Overall pathogen inactivation is met using a minimum of two types of disinfection providing at a minimum 3-log reduction of *Cryptosporidium* and *Giardia*, and 4-log reduction of viruses. 2. The number of *E. coli* in raw water does not exceed 20/100 mL (or if *E. coli* data are not available, less than 100/100 mL of total coliform) in at least 90% of the weekly samples from the previous six months. 3. For all water systems, treated water is to contain no detectable *E. coli* or fecal coliform per 100 mL. Total coliform objectives are also zero based on one sample in a 30-day period. For more than one sample in a 30-day period, at least 90% of samples have no detectable total coliform bacteria per 100 mL and no sample has more than 10 total coliform bacteria per 100 mL. 4. Average daily turbidity levels measured at equal intervals (at least every four hours) immediately before the disinfectant is applied are around 1 nephelometric turbidity unit (NTU) and do not exceed 5 NTU for more than two days in a 12-month period. 5. A watershed control program is maintained that minimizes the potential for fecal contamination in the source water.

UV Disinfection	1. UV equipment is validated or certified based on a validation protocol or certification standard recognized by the Province of British Columbia. 2. UV equipment is operated within its validated or certified operating conditions. 3. UV equipment is operated such that a continuous UV dose is maintained throughout the lifetime of the UV lamp(s) that is at least the minimum continuous UV dose used in the validation protocol or certification standard for the targeted pathogen log reduction credit. 4. For UV equipment using the UV intensity set point control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours: – Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated or certified operating conditions) – Lamp status – UV intensity 5. For UV equipment using the calculated dose control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours: – Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated operating conditions) – Lamp status – UV intensity – UV transmittance (UVT) 6. When UV equipment components are installed or replaced, they are the same as the components used for equipment validation and/or certification unless the UV equipment was revalidated or recertified. 7. Within 30 days following the end of a calendar month, a monthly summary report is prepared which sets out the time, date, and duration of each major or critical UV equipment alarm that occurred during the month, the reason for the alarm, the volume of water treated during each alarm period and the actions taken by the water supplier to correct the alarm situation.
Chlorination	1. Chemical disinfectant dosages are adjusted in response to variations in raw water quality. 2. At all times, $CT_{Calculated}$ is greater than or equal to the $CT_{Required}$ to achieve the pathogen log reduction credits assigned. 3. Sampling and testing for disinfectant residual are carried out by continuous monitoring equipment at or near a location where the intended contact time has been achieved.

Pathogen Log Reduction Credit Assignment Example #2

(Example for One Treatment Facility with Multiple Raw Water Sources)

ABC Water Treatment Plant

Source Water Information			
Source Water Name	Source Water Type	Water Licence Number	Well Tag/ID Number (if applicable)
ABC Lake	Surface Water	*[Insert Number]*	N/A
Well #1 (backup water supply)	GARP	*[Insert Number]*	*[Insert Number]*
Well #2 (backup water supply)	GARP-viruses only	*[Insert Number]*	*[Insert Number]*

Recommended Minimum Pathogen Log Reduction			
Treatment Facility Name	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
ABC Water Treatment Plant	3	3	4

Pathogen Log Reduction Credits Assigned			
Treatment Technology Applied [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Conventional Filtration	3	3	2
Chlorination	0	0	2
Total Pathogen Log Reduction Credits	**3**	**3**	**4**

[a] Pathogen log reduction credit assignment is based on each treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Pathogen Log Reduction Credit Assignment Criteria	
Conventional Filtration	1. A chemical coagulant is used at all times when the treatment process is in operation. 2. Chemical dosages are monitored and adjusted in response to variations in raw water quality. 3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure during filter ripening to ensure that filter effluent turbidity objectives are met at all times. 4. Filter effluent turbidity is continuously monitored and recorded from each filter and from combined filter effluent where there are multiple filters. 5. For each filter, filter effluent turbidity is less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95% of the measurements either per filter cycle or per month. 6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.
Chlorination	1. Chemical disinfectant dosages are adjusted in response to variations in raw water quality. 2. At all times, $CT_{Calculated}$ is greater than or equal to the $CT_{Required}$ to achieve the pathogen log reduction credits assigned. 3. Sampling and testing for disinfectant residual are carried out by continuous monitoring equipment at or near a location where the intended contact time has been achieved.

Pathogen Log Reduction Credit Assignment Example #3

(Two Treatment Facilities with Multiple Raw Water Sources and a Common Distribution System)

ABC Pump House

Source Water Information			
Source Water Name	Source Water Type	Water Licence Number	Well Tag/ID Number (if applicable)
Well #1	Groundwater at low risk of containing pathogens	*[Insert Number]*	*[Insert Number]*
Well #2	Groundwater at low risk of containing pathogens	*[Insert Number]*	*[Insert Number]*
Recommended Minimum Pathogen Log Reduction			
Treatment Facility Name	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
ABC Pump House	0	0	0
Pathogen Log Reduction Credits Assigned			
Treatment Technology Applied [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
No Treatment Required	0	0	0
[a] Pathogen log reduction credit assignment is based on each treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.			
Pathogen Log Reduction Credit Assignment Criteria			
Not Applicable	Not Applicable		

Continued on next page …

ABC Water Treatment Plant

Source Water Information			
Source Water Name	Source Water Type	Water Licence Number	Well Tag/ID Number (if applicable)
ABC Lake	Surface Water	*[Insert Number]*	N/A

Recommended Minimum Pathogen Log Reduction			
Treatment Facility Name	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
ABC Water Treatment Plant	3	3	4

Pathogen Log Reduction Credits Assigned			
Treatment Technology Applied [a]	*Cryptosporidium* Oocysts	*Giardia* Cysts	Viruses
Direct Filtration	2.5	2.5	1
UV Disinfection	3	3	2
Chlorination	0	0	1
Total Pathogen Log Reduction Credits	**5.5**	**5.5**	**4**

[a] Pathogen log reduction credit assignment is based on each treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met.

Pathogen Log Reduction Credit Assignment Criteria	
Direct Filtration	1. A chemical coagulant is used at all times when the treatment process is in operation. 2. Chemical dosages are monitored and adjusted in response to variations in raw water quality. 3. Effective backwash procedures are maintained including filter-to-waste or an equivalent procedure during filter ripening to ensure that filter effluent turbidity objectives are met at all times. 4. Filter effluent turbidity is continuously monitored and recorded from each filter and from combined filter effluent where there are multiple filters. 5. For each filter, filter effluent turbidity is less than or equal to 0.3 nephelometric turbidity units (NTU) in at least 95% of the measurements either per filter cycle or per month. 6. For each filter, the maximum level of filter effluent turbidity is less than or equal to 1.0 NTU.
UV Disinfection	1. UV equipment is validated or certified based on a validation protocol or certification standard recognized by the Province of British Columbia. 2. UV equipment is operated within its validated or certified operating conditions. 3. UV equipment is operated such that a continuous UV dose is maintained throughout the lifetime of the UV lamp(s) that is at least the minimum continuous UV dose used in the validation protocol or certification standard for the targeted pathogen log reduction credit. 4. For UV equipment using the UV intensity set point control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours:

	– Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated or certified operating conditions) – Lamp status – UV intensity 5. For UV equipment using the calculated dose control strategy, the following parameters are tested at a minimum frequency of once every five minutes and are recorded at a minimum frequency of once every four hours: – Flow rate (not needed for UV reactors that have a device that limits the maximum flow rate through the reactor based on the reactor's validated operating conditions) – Lamp status – UV intensity – UV transmittance (UVT) 6. When UV equipment components are installed or replaced, they are the same as the components used for equipment validation and/or certification unless the UV equipment was revalidated or recertified. 7. Within 30 days following the end of a calendar month, a monthly summary report is prepared which sets out the time, date, and duration of each major or critical UV equipment alarm that occurred during the month, the reason for the alarm, the volume of water treated during each alarm period and the actions taken by the water supplier to correct the alarm situation.
Chlorination	1. Chemical disinfectant dosages are adjusted in response to variations in raw water quality. 2. At all times, $CT_{Calculated}$ is greater than or equal to the $CT_{Required}$ to achieve the pathogen log reduction credits assigned. 3. Sampling and testing for disinfectant residual are carried out by continuous monitoring equipment at or near a location where the intended contact time has been achieved.

11. Conclusion

This guideline document provides provincial guidance on the assignment of pathogen log reduction credits for the production of microbiologically safe drinking water based on the types of treatment processes used for disinfection and the applicable pathogen log reduction credit assignment criteria being met. Additional guidance is set out in the Design Guidelines for Drinking Water Systems in British Columbia. In all cases, a Drinking Water Officer should be consulted when planning or considering upgrades to a drinking water supply system.

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13. Glossary

Cartridge Filtration – a pressure driven physical separation process that removes particles greater than 1 µm using an engineered porous filtration media.

Challenge Test – a study conducted to determine the removal efficiency or log removal value for the challenge test of a membrane module, or cartridge filter for a particular organism, particulate, or surrogate.

Direct Integrity Test – physical test applied to a membrane unit in order to identify and/or isolate integrity breaches.

Groundwater at Low Risk of Containing Pathogens – groundwater that is considered to be at low risk of containing pathogens as a result of a GARP assessment (i.e. no hazards were identified following a GARP Stage 1: Hazard Screening and Assessment, or the groundwater source was determined to be at low risk following a Stage 2: GARP Determination). Refer to the Guidance Document for Determining Groundwater At Risk of Containing Pathogens (GARP) when assessing the risk that groundwater may become contaminated with pathogens.

Groundwater at Risk of Containing Pathogens (GARP) – any groundwater supply likely to be contaminated from any source of pathogens, continuously or intermittently. Potential sources of pathogens include sewage discharge to land, leaking municipal sewage pipes (especially force mains), agricultural waste stockpiles, runoff intrusion into poorly constructed wells, and surface water.

GARP-Virus Only – any groundwater supply determined to be 'at risk' of containing viruses (i.e. if the DWO has reason to believe that the source is only at risk of containing viruses, and not other pathogens). This would include water supply system wells located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport or other conditions indicating possible viral contamination, therefore requiring treatment of viruses.

Membrane Filtration – a pressure- or vacuum-driven separation process in which particulate matter larger than 1 µm is rejected by an engineered barrier, primarily through a size-exclusion mechanism and which has a measurable removal efficiency of a target organism that can be verified through the application of a direct integrity test; includes common membrane classifications microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), as well as any "membrane cartridge filtration" (MCF) device that satisfies this definition.

Microfiltration (MF) – a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.2 µm (nominally 0.1 µm).

Nanofiltration (NF) – a pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water; typically applied for membrane softening or the removal of dissolved organic contaminants.

Rainwater – water collected from natural precipitation from a roof or similar structure.

Reverse Osmosis (RO) – 1) the reverse of the natural osmosis process – i.e., the passage of a solvent (e.g., water) through a semi-permeable membrane from a solution of higher concentration to a solution of lower concentration against the concentration gradient, achieved by applying pressure greater than the osmotic pressure to the more concentrated solution; also, 2) the pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water.

Surface Water – water from a source which is open to the atmosphere and includes steams, lakes, rivers, creeks, and springs.

Ultrafiltration (UF) – a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.01 – 0.05 µm (nominally 0.01 µm).

Appendices

Table A1: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5 °C or Lower

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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	221	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						pH = 8.5						pH ≤9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	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

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A2: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 5 °C

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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						pH = 8.5						pH ≤ 9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	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

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A3: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 10 °C

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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						pH = 8.5						pH ≤ 9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	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

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A4: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 15 °C

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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						pH = 8.5						pH ≤ 9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	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

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A5: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 20 °C

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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						pH = 8.5						pH ≤ 9.0					
	Log Inactivation						Log Inactivation						Log Inactivation					
	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

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A6: CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 25 °C

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	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						pH = 8.5						pH ≤ 9.0											
	Log Inactivation						Log Inactivation						Log Inactivation											
	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						

CT units = min·mg/L

Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A7: CT Values for Inactivation of Viruses by Free Chlorine

Temperature (°C)	Log Inactivation					
	2		3		4	
	pH		pH		pH	
	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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A8: CT Values for Inactivation of *Giardia* Cysts by Chlorine Dioxide

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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A9: CT Values for Inactivation of Viruses by Chlorine Dioxide

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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A10: CT Values for Inactivation of *Cryptosporidium* Oocysts by Ozone

Log Inactivation	Temperature (°C)									
	≤0.5	1	2	3	5	7	10	15	20	25
0.5	12	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2
1.0	24	23	21	19	16	13	9.9	6.2	3.9	2.5
1.5	36	35	31	29	24	20	15	9.3	5.9	3.7
2.0	48	46	42	38	32	26	20	12	7.8	4.9
2.5	60	58	52	48	40	33	25	16	9.8	6.2
3.0	72	69	63	57	47	39	30	19	12	7.4

CT units = min·mg/L
Source: (2006) Code of Federal Regulations, 40 CFR 141.720.

Table A11: CT Values for Inactivation of *Giardia* Cysts by Ozone

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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A12: CT Values for Inactivation of Viruses by Ozone

Log Inactivation	Temperature (°C)					
	≤1	5	10	15	20	25
2	0.9	0.6	0.5	0.3	0.25	0.15
3	1.4	0.9	0.8	0.5	0.4	0.25
4	1.8	1.2	1	0.6	0.5	0.3

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A13: CT Values for Inactivation of *Giardia* Cysts by Chloramine at pH 6-9

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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.

Table A14: CT Values for Inactivation of Viruses by Chloramine at pH 6-9

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

CT units = min·mg/L
Source: USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.