THE CT METHOD: A REFERENCE GUIDE

Developed by the North Carolina Area Wide Optimization Program Team

April 21, 2020

Disclaimer: The purpose of this reference guide is to provide technical information. This reference guide is not a substitute for applicable legal requirements, nor is it a regulation itself.

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What is CT

According to the EPA's Surface Water Treatment Rule (SWTR), all public water systems which use a surface water source must achieve a minimum of 99.9% (3-log) removal and/or inactivation of *Giardia lamblia* cysts and a minimum of 99.99% (4-log) removal and/or inactivation of viruses. The CT method was developed to determine the level of inactivation of *Giardia lamblia* cysts and viruses based on water treatment plant operational data and disinfection conditions. CT stands for concentration (C) times contact time (T) and is the concentration of the disinfectant multiplied by the time that the disinfectant is in contact with the water. The SWTR established CT values for chlorine, chlorine dioxide, ozone, and chloramines which will achieve at least a 99.9% (3-log) inactivation of *Giardia lamblia* cysts and at least a 99.99% (4-log) inactivation of viruses.

Terminology of CT

Regulations and guidance documents often differ in terminology regarding components of the CT method, which lends to some of the confusion surrounding CT compliance. Particularly, there is a considerable amount of terminology used in regulations and in guidance documents concerning the CT method that is interchangeable. CT_{actual} is equivalent to $CT_{calculated}$ and to CT_{calc}. $CT_{99.9}$ is equivalent to $CT_{3\text{-log, Giardia}}$ and to $CT_{required}$. The terms 3-log and 99.9% removal and/or inactivation can be used interchangeably, as can the terms 4-log and 99.99% removal and/or inactivation. As we review how contact time is determined, the concept of the baffling factor will be introduced. The baffling factor is also known as the short-circuiting factor and can be represented by F_{SC} or by T_{10}/T.

Log Removal and Log Inactivation

The reduction of microorganisms that is achieved by treatment at a water treatment plant is measured on a logarithmic scale (i.e., order of magnitude scale) and is referred to in terms of log reduction. For example, a 2-log reduction of *Giardia lamblia* cysts corresponds to a 99% reduction of *Giardia lamblia* cysts, and a 3-log reduction of *Giardia lamblia* cysts corresponds to a 99.9% reduction of *Giardia lamblia* cysts.

The phrases log removal, log inactivation, and log reduction are not interchangeable, and care should be taken to differentiate these to avoid confusion. Log removal refers to the percentage of microorganisms that are removed by physical treatment processes. Log inactivation refers to the percentage of microorganisms that are inactivated (killed or rendered unable to replicate) by disinfection. Log reduction is the total log removal and log inactivation and refers to the percentage of microorganisms that are removed by physically treatment processes and that are inactivated by disinfection. Log inactivation is used to measure the effectiveness of disinfection, so this document will focus on the concept of log inactivation and how it relates to measuring compliance with CT requirements.

CT in the Rules and Regulations

Subpart H of 40 CFR §141 contains regulatory requirements for disinfection and filtration, which are two key water treatment processes that inactivate and physically remove microorganisms and the particulate matter that they readily grow on. The regulations in Subpart H are divided into two categories: (1) regulations that apply to systems with filtration treatment and (2) regulations that apply to systems without filtration treatment. All of North Carolina's surface water plants utilize filtration treatment, so the regulations that apply to systems with filtration treatment will be discussed.

40 CFR §141.70(a)(1) and 40 CFR §141.70(a)(2) state that at least 99.9% (3-log) removal and/or inactivation of *Giardia lamblia* cysts and at least 99.99% (4-log) removal and/or inactivation or viruses must occur between a point where the raw water is not subject to recontamination by surface water runoff and a point downstream at or before the first customer. The regulations within 40 CFR §141.72 reiterate that the total treatment processes of a system must be sufficient to achieve 99.9% (3-log) removal and/or inactivation of *Giardia lamblia* cysts and 99.99% (4-log) removal and/or inactivation of viruses for systems with filtration treatment. The EPA states that conventional treatment plants that are meeting the minimum performance criteria are achieving at least a 2.5-log removal of *Giardia lamblia* cysts and at least a 2-log removal of viruses prior to disinfection. The EPA recommends that a conventional water treatment plant provide sufficient disinfection to achieve a minimum of 0.5-log inactivation of *Giardia lamblia* cysts and a 2-log inactivation of viruses. 15A NCAC 18C .2002 also requires that all surface water treatment facilities include chemical disinfection to achieve a minimum of 0.5-log inactivation of *Giardia lamblia* cysts. On December 2, 2014, North Carolina's Public Water Supply Section issued a letter allowing a 2.5-log removal credit for *Giardia lamblia* cysts and a 2-log removal credit for viruses for systems operating conventional filtration treatment. A copy of this letter is provided in Appendix A. For water systems that are not utilizing conventional treatment, such as water systems that utilize direct filtration, Table 7-2 in the *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual* can be referenced to determine the log removal credits that are allowed for *Giardia lamblia* cysts and for viruses.

Monitoring and Reporting Requirements

40 CFR §141.74 contains monitoring requirements, such as those for pH, temperature, and residual disinfectant concentration, that are used in determining compliance with CT requirements. This rule also provides the methodology for the conversion of plant operational data to log inactivation values for *Giardia lamblia* cysts and for viruses.

Per 40 CFR §141.75(a)(2), disinfection information must be reported to the State within 10 days after the end of each month. The Public Water Supply Section requires that an electronic monthly operating report (eMOR) be submitted by each surface water treatment plant, and the following information must be included in the eMOR:

1. For each day, the lowest measurement of residual disinfectant concentration (in mg/l) at the distribution entry point.

2. The date and duration of any period in which the residual disinfectant concentration of water entering distribution fell below 0.2 mg/l and when the State was notified of the occurrence.

3. The daily residual disinfectant concentration(s) (in mg/l) and disinfectant contact time(s) (in minutes) used for calculating the CT value(s).

4. If chlorine is used, the daily measurement(s) of pH of disinfected water following each point of chlorine disinfection.

5. The daily measurement(s) of water temperature in °C following each point of disinfection.

6. The daily CT_{actual} and inactivation ratio for each disinfectant measurement or segment, and the sum of all inactivation ratio before or at the first customer.

7. The daily determination of whether disinfection achieves adequate *Giardia lamblia* cyst and virus inactivation, i.e., whether the inactivation ratio is at least 1.0 or, where disinfectants other than chlorine are used, other indicator conditions that the State determines are appropriate are met.

Determining CT Compliance Using Free Chlorine

The SWTR establishes CT values for systems using free chlorine, chlorine dioxide, ozone, and chloramines for primary disinfection. The majority of surface water systems in North Carolina use free chlorine for primary disinfection, so the focus of this section will be on determining CT compliance for systems with conventional treatment that use free chlorine as the primary disinfectant. It is recommended that the EPA's *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual* be consulted prior to determining CT compliance for a system using a primary disinfectant other than free chlorine. This section will also focus on CT compliance determination specifically for *Giardia lamblia* cysts because compliance with inactivation requirements for viruses is achieved if a system uses free chlorine for primary disinfection and has met the inactivation requirements for *Giardia lamblia* cysts.

CT inactivation requirements are achieved when the ratio of the CT that has been achieved, CT_{actual}, to the CT that is required, $CT_{required}$, is greater than or equal to 1.0. In order to determine if CT inactivation requirements have been achieved, three steps must be completed:

1. The minimum CT value that has been achieved at current operating conditions, which is also known as CT_{actual}, must be calculated once each day.

2. The minimum CT value that is required in order to meet the required log inactivation of *Giardia lamblia* cysts, which is also known as $CT_{required}$, must be determined once each day.

3. The ratio of CT_{actual} to $CT_{required}$, which is also known as the CT ratio or the inactivation ratio, must be calculated once each day. In order to be compliant, the ratio of CT_{actual} to $CT_{required}$ must be greater than or equal to one ($\frac{CT_{actual}}{CT_{required}} \geq 1$).

Additional information about how to complete the above steps is provided in the following sections. A spreadsheet to assist with determining CT_{actual}, $CT_{required}$, and the CT ratio is provided in Appendix B, and examples for determining CT_{actual}, $CT_{required}$, and the CT ratio are provided in Appendix C.

Determining CT_{actual}

The minimum CT value that has been achieved during current operating conditions, CT_{actual}, must be calculated once each day to determine the CT ratio. The free chlorine residual concentration, which is the “C” in CT, should be the minimum free chlorine residual measured during that day for each disinfection segment. The contact time, which is the “T” in CT, is measured from the point of disinfectant application to the point of residual measurement for each disinfection segment and is a measure of the detention time corresponding to the time for which 90% of the water has been in contact with at least the minimum free chlorine residual concentration, C. This contact time is designated as T_{10}. An explanation of disinfection segments can be found in the following section, and a discussion of how T_{10} is determined can be provided in the subsequent section.

CT_{actual} for a particular disinfection segment is calculated by multiplying the minimum free chlorine residual measured during the day in the disinfection segment times the contact time for that disinfection segment. If there are multiple disinfection segments, the CT_{actual} values for each disinfection segment are summed to determine the total CT_{actual}.

$$CT_{actual} = C \times T_{10}$$

Where,

C = minimum daily measured free chlorine residual, mg/L

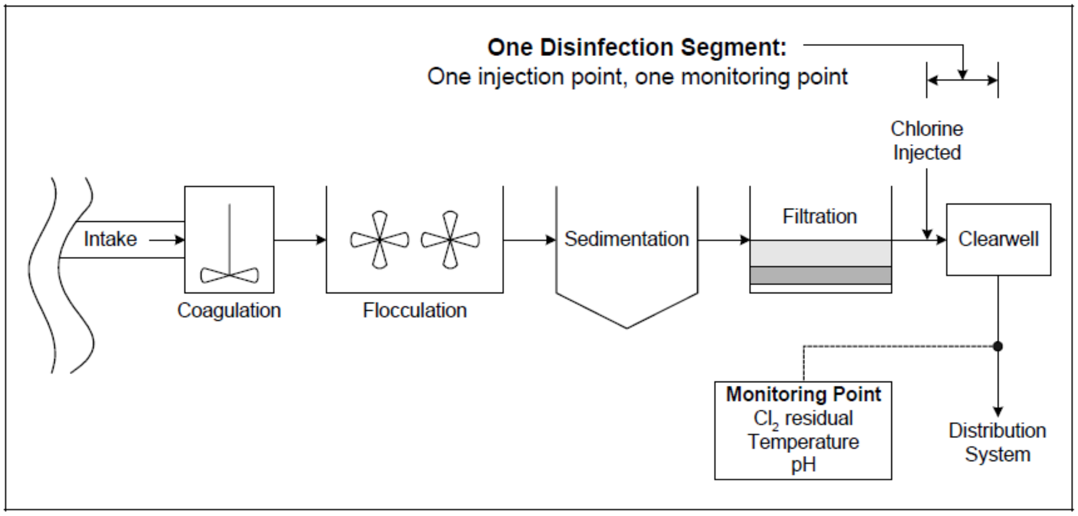
T_{10} = contact time, min

Detailed steps for calculating CT_{actual} may be helpful when performing these calculations for more complex water treatment plants, and additional information is provided in the *LT1ESTRW Disinfection Profiling and Benchmarking Technical Guidance Manual*.

Disinfection Segments

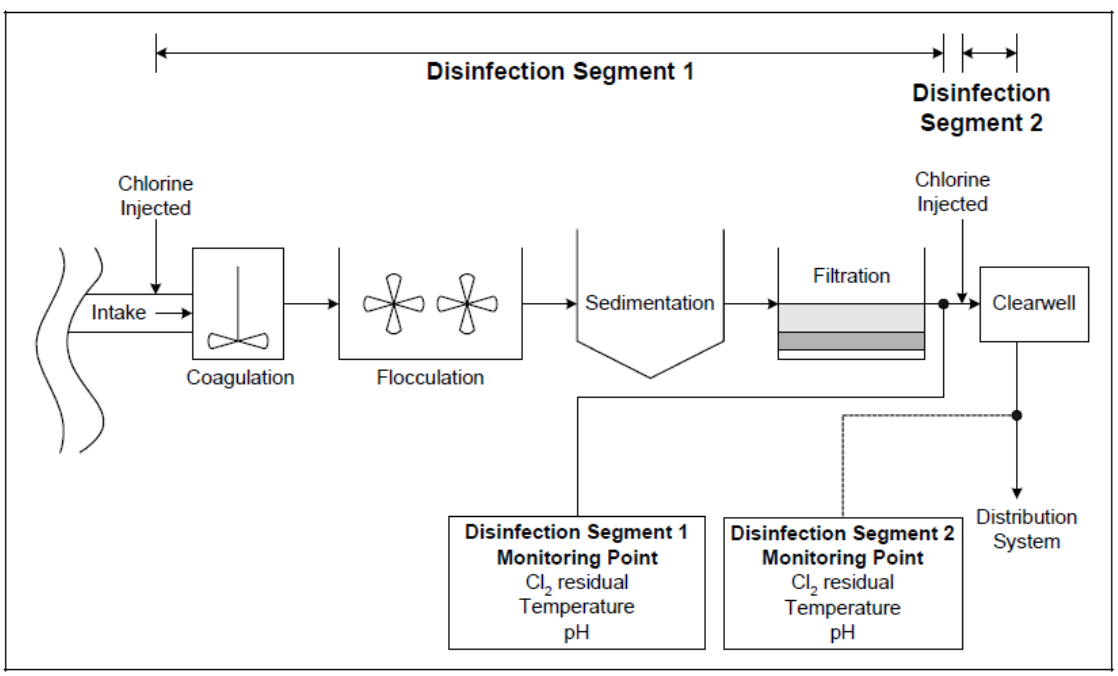
Disinfection segments are the treatment processes following a disinfectant injection point that provide detention time, and thus contact time, before reaching the monitoring point where the disinfectant residual is measured. CT values can be determined by using a single monitoring point or in segments based on multiple injection and monitoring points. Many systems utilize the single disinfection segment approach and rely primarily on contact time within the clearwell(s) to meet inactivation requirements. The following figure demonstrates how a system would typically utilize a single disinfection segment.

Figure 1: Plant Schematic Showing a Conventional Filtration Plan with One Disinfection Segment (Figure from *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*)



For systems with more than one disinfectant injection point, a multi-segment approach can be utilized if more than one monitoring point is provided. For each disinfection segment, an injection point will need an associated monitoring point at the end of the disinfection segment, and each disinfectant injection point will start a new disinfection segment. CT_{actual} for systems using multiple disinfection segments is calculated by summing the CT_{actual} values calculated for each disinfection segment. The following figure demonstrates how a system could use two disinfection segments.

Figure 2: Plant Schematic Showing Two Disinfection Segments (Figure from *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*)



Contact Time

Contact time, T_{10}, is a measure of the detention time corresponding to the time for which 90% of the water has been in contact with at least the minimum free chlorine residual concentration, C. Contact time in each basin, pipe, or unit process is a function of the configuration and the baffling, and contact time can be determined either by using theoretical detention time calculations (i.e. baffling factor methodology) or by performing a tracer study.

Contact time should be determined when a new water treatment plant is placed into service or any time physical, operational, or disinfection modifications occur at a water treatment plant such that the previously determined contact time is no longer valid for the conditions at the water treatment plant. The Plan Review Unit of the Public Water Supply Section will identify projects that potentially impact contact time and will request either theoretical CT calculations or that a new tracer study be completed as a condition of the approval of the project. For instances where operational concerns regarding a water plant's contact time have been observed (often as a result of issues identified during compliance monitoring or routine sanitary surveys), Regional staff and Compliance staff of the Public Water Supply Section may also identify a need for a water system to reassess the contact times being utilized and recommend that either a revised theoretical determination or a tracer study be completed. Revised theoretical determinations and tracer studies should be submitted to the Regional Engineer at the applicable Regional Office, and it is the responsibility of the Regional Engineer, with the concurrence of the Operations Branch Head and the Surface Water Treatment Rule Manager, to approve the new contact time for use by the water system.

Tracer Studies

There is no regulatory requirement that a tracer study must be completed instead of using theoretical detention time calculations (i.e. baffling factor methodology) to determine contact time, T_{10}. However, tracer studies provide a more accurate contact time than baffling factors do as they provide a real measure of the contact time by evaluating the amount of time it takes for the tracer to flow through each segment in a treatment train. In some cases completion of a tracer study may be advised, as tracer studies provide a more accurate understanding of a plant's hydraulic conditions, and a tracer study may be able to identify field conditions that do not match the engineering plans and specifications on file for the water plant's current configuration (e.g. a failed baffle curtain or a closed valve). Additionally, tracer studies are especially important when the theoretical CT calculations are marginal or when a system is trying to optimize CT over multiple disinfection segments to address other compliance issues, such as disinfection-byproduct (DBP) formation. Should a tracer study be performed, Appendix D of the *EPA Disinfection and Profiling and Benchmarking Guidance Manual* provides a detailed explanation of how to perform a tracer study and how to determine the contact time from the data collected during the study. Worksheets to assist Public Water Supply Section personnel in reviewing a tracer study are included in Appendix D.

Baffling Factors

Baffling factors are numerical values that represent the degree of short-circuiting that is occurring within a treatment basin. It is important to note that baffling factors provide rough estimates of the actual contact time and should only be used on a limited basis. Contact time can be estimated based on the hydraulic characteristics of a basin, pipe, or unit process and the baffling factor for each with the following equation:

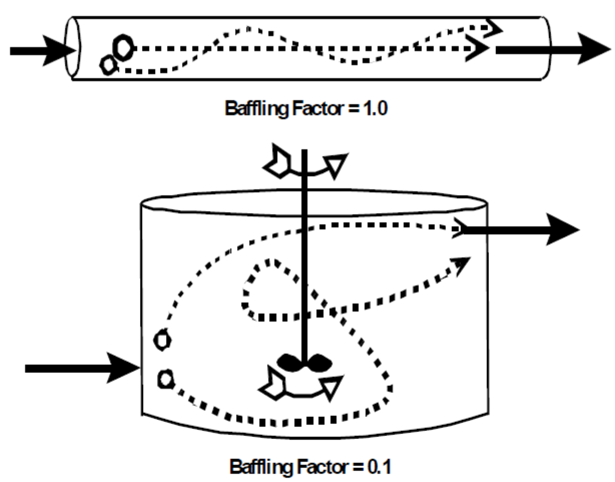
$$T_{10} = \text{TDT} \times \frac{T_{10}}{T}$$

Where,

T_{10} = contact time, min
TDT = theoretical detention time, min
T = hydraulic residence time, min
T_{10}/T = baffling factor

The values for a baffling factor can range from zero to one, and a higher baffling factor indicates that less short-circuiting is occurring. An example of the flow conditions with a baffling factor of 1.0 and with a baffling factor of 0.1 is provided in the figure below. Baffling factors have been developed that allow for the contact time to be estimated based on the volume and the flow rate through a basin, pipe, or unit process, and baffling factors for various baffling conditions and basins are provided in the table below. It is recommended that a conservative approach to calculating the contact time with baffling factors be used by selecting the lowest baffling condition that is applicable because the estimated contact time calculated using baffling factors may not accurately represent the actual contact time.

Figure 3: Baffling Factor Characteristics of a Pipe and a Clearwell (Figure from *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*)



Top: This pipe demonstrates a plug flow condition in which all of the material sent through the pipe discharges at the theoretical hydraulic detention time of the pipe.

Bottom: This unbaffled basin demonstrates short-circuiting in which some of the material entering the basin would come out almost immediately, while other material that enters at the same time will be detained for a longer period of time. Short-circuiting occurs in basins with poor baffling.

Table 2: Baffling Factors (Table from *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*)

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

Determining $CT_{required}$

The minimum CT value that is required in order to meet the required log inactivation of *Giardia lamblia* cysts, $CT_{required}$, must be determined once per day. $CT_{required}$ can either be determined from tables of CT values for inactivation of *Giardia lamblia* cysts by free chlorine, which are known as the CT tables, or $CT_{required}$ can be calculated using a regression equation. Plant operational data collected from the monitoring point for each disinfection segment are used to determine $CT_{required}$. The following is a list of the information that is needed for each disinfection segment:

1. The daily **minimum temperature** of the water at the monitoring point for each disinfection segment must be determined. Free chlorine's efficacy decreases as the water temperature decreases, so the minimum temperature measured during a day should be used when determining $CT_{required}$.

2. The daily **maximum pH** of the water at the monitoring point for each disinfection segment must be determined. Free chlorine's efficacy decreases as the pH of the water increases, so the maximum pH measured during a day should be used when determining $CT_{required}$.

3. The daily **minimum free chlorine residual** measured at the monitoring point for each disinfection segment must be determined.

With this information, the CT tables that are provided in Appendix E can be used to determine the $CT_{required}$. To obtain a $CT_{required}$ value from the CT tables, the following steps should be performed:

1. Find the appropriate table based on the disinfectant used (free chlorine).

2. Find the appropriate table based on the microorganisms of concern (*Giardia lamblia* cysts).

3. Find the appropriate table based on the temperature.

4. Find the appropriate section based on the pH.

5. Find the appropriate column based on the required log inactivation.

6. Find the appropriate row based on the measured disinfectant residual.

7. Identify the CT value where the log inactivation column and disinfect residual row intersect.

Oftentimes, the exact values that were recorded for the minimum temperature, the maximum pH, and the minimum free chlorine residual are not in the CT tables. When this issue arises, it is recommended that the conservative values for temperature, pH, and the free chlorine residual are used to determine the $CT_{required}$ value. Linear interpolation may also be used to determine a $CT_{required}$ value that lies between two values.

As an alternative to using the CT tables, the *Disinfection Profiling and Benchmarking Guidance Manual* provides regression equations for calculating $CT_{required}$. The regression equations are as follows:

- For temperatures < 12.5 °C:

$$CT_{required} = (0.353 \times I)[12.006 + e^{(2.46 - 0.073 \times Temp + 0.125 \times C + 0.389 \times pH)}]$$

- For temperatures ≥ 12.5 °C:

$$CT_{required} = (0.361 \times I)[-2.261 + e^{(2.69 - 0.065 \times Temp + 0.111 \times C + 0.361 \times pH)}]$$

Where,

I = 0.5, the number of log inactivations required after the 2.5 log credit
Temp = Minimum temperature in the disinfection segment, °C
C = Minimum residual chlorine concentration at the disinfection segment monitoring point, mg/L
pH = Maximum measured pH in the disinfection segment
e = 2.7183, the base for the natural logarithm

Determining the CT Ratio

The CT ratio, which is the ratio of CT_{actual} to $CT_{required}$, must be calculated once per day. This is done with the following equation:

$$\frac{CT_{actual}}{CT_{required}}$$

If the ratio of CT_{actual} to $CT_{required}$ is greater than 1, then CT inactivation requirements have been achieved. If the ratio of CT_{actual} to $CT_{required}$ is less than 1, then CT inactivation requirements have not been achieved.

References

Brock Rush, M. Eng., P.Eng. (2002). *CT Disinfection Made Simple*. Alberta Environmental.

Unites States Environmental Protection Agency. (1991). *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water*.

United States Environmental Protection Agency. (1999). *Disinfection and Profiling and Benchmarking Guidance Manual*. EPA 815-R-99-013.

United States Environmental Protection Agency. (2003). *EPA LT1ESWTR Disinfection and Profiling Technical Guidance Manual*. EPA 816-R-03-004.

Appendices

Appendix A: Conventional Filtration Treatment Log Removal Credits Letter

Appendix B: Log Inactivation Ratio Determination for Surface Water Systems

Appendix C: CT Calculation Examples

Appendix D: CT Compliance Review Worksheets

Appendix E: CT Values for Inactivation of *Giardia lamblia* Cysts

Appendix A: Conventional Filtration Treatment Log Removal Credits Letter

NCDENR

North Carolina Department of Environment and Natural Resources

Pat McCrory
Governor

John E. Skvarla, III
Secretary

December 2, 2014

«TINLGENTNAME»
«TINLGENTADDR_LINE_ONE_TXT»
«TINLGENTADDRESS_CITY_NAME», «TINLGENTADDRESS_STATE_CODE»
«TINLGENTADDRESS_ZIP_CODE»

Re: Conventional Filtration Treatment Log Removal Credits

The purpose of this letter is to provide notice that the historic *N. C. Guideline - Treatment Facility Capabilities for C.T. Credit* rating form will no longer be used to determine the appropriate Giardia and virus log removal credits for conventional surface water treatment plants in North Carolina.

As defined in federal regulation 40 CFR 141.2 (adopted by reference in the North Carolina *Rules Governing Public Water Systems*), "Conventional filtration treatment means a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal."

The first of several federal surface water treatment rules adopted by reference in North Carolina became effective January 1, 1991 (*Surface Water Treatment Rule, adopted by reference in 15A NCAC 18 C .2001 - .2006*). This initial Surface Water Treatment Rule established that all public water systems treating surface water with filtration and disinfection must achieve a combined removal/inactivation of at least 3-log for Giardia and 4-log for viruses. It was also stated in the EPA *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources (March 1991)* that "The Primacy Agency can assume that conventional treatment plants that are meeting the minimum performance criteria are achieving a 2.5-log removal of Giardia cysts and at least a 2-log removal of viruses prior to disinfection."

Due to concerns regarding the efficacy of physical treatment operations at that time, the Public Water Supply Section implemented use of the *N. C. Guideline - Treatment Facility Capabilities for C.T. Credit* rating form to score surface water treatment plants utilizing conventional filtration treatment and to determine the physical log removal credits for Giardia and viruses. Use of the rating form resulted in many surface water treatment plants receiving credit for less than 2.5-log removal of Giardia cysts and less than 2-log removal of viruses prior to disinfection. This necessitated a corresponding increase in log removal credit by disinfection. The use of the rating form, intended to ensure public health protection from waterborne pathogens, gained further support after an April 1993 outbreak of *Cryptosporidium* in Milwaukee, Wisconsin that caused more than 400,000 illnesses and more than 100 deaths in a population of 1.6 million.

Since that time, the following additional surface water treatment rules have been established and fully implemented:

- *Interim Enhanced Surface Water Treatment Rule (IESWTR) adopted by reference in 15A NCAC 18C .2007 (f), amended effective August 1, 2000;*
- *Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) adopted by reference in 15A NCAC 18C .2007(f) amended effective November 1, 2005;*
- *Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) adopted by reference in 15A NCAC 18C .2007(f) amended effective October 1, 2009.*

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Within the complete suite of Surface Water Treatment Rules, Nephelometric Turbidity Unit (NTU) is the primary measure to indicate the efficacy of conventional filtration treatment. The initial Surface Water Treatment Rule, in effect at the time the rating form was established, required a maximum combined filter effluent turbidity of 5 NTU and a combined filter turbidity less than or equal to 0.5 NTU 95 % of the time. The more stringent IESWTR and LT1ESWTR now in effect, require a maximum combined filter effluent turbidity of 1 NTU and a combined filter effluent turbidity less than or equal to 0.3 NTU 95 % of the time and require specific follow-up actions for turbidity excursions. In addition, these rules require continuous individual filter effluent monitoring (recorded turbidity levels every 15 minutes) in addition to combined filter effluent monitoring. (Note: Systems with a population of less than 10,000 and only two filters may continuously monitor combined filter effluent in lieu of individual filter effluent).

Considering: 1) the *N. C. Guideline - Treatment Facility Capabilities for C.T. Credit* rating form was drafted by PWS Section staff before the establishment and implementation of the entire suite of federal surface water treatment rules including the IESWTR, LT1ESWTR and LT2ESWTR; 2) the current significantly more stringent turbidity standards, monitoring, recording and reporting requirements and required follow-up actions for turbidity excursions; and 3) the simultaneous compliance objectives of the fully established and implemented Disinfectants and Disinfection Byproducts Rules; the PWS Section recognizes the need to cease use of the rating form for determining log credits for Giardia and viruses removed by conventional filtration treatment. Effective immediately, conventional filtration surface water treatment plants may use 2.5-log removal of Giardia and 2-log removal of viruses before disinfection rather than the log removal credit indicated on the historical *N. C. Guideline - Treatment Facility Capabilities for C.T. Credit* rating form to determine and report compliance data on monthly operating reports sent to the PWS Section.

If you have any questions, please contact the appropriate regional office indicated below.

Sincerely,

Jessica C. Godreau, P.E. BCEE, Chief

cc: «TINLGENT_2NAME»
R.W. (Bob) Midgette, P.E. Operations Branch Head
PWS Section «TINLGENT_1NAME»

Regional	Address	Phone
Asheville	2090 U.S. Highway 70, Swannanoa, NC 28778	(828) 296-4500
Fayetteville	225 Green Street, Suite 714, Fayetteville, NC 28301	(910) 433-3300
Mooresville	610 East Center Avenue, Suite 301, Mooresville, NC 28115	(704) 663-1699
Raleigh	3800 Barrett Drive, Raleigh, NC 27609	(919) 791-4200
Washington	943 Washington Square Mall, Washington, NC 27889	(252) 946-6481
Wilmington	127 Cardinal Drive Extension, Wilmington, NC 28405-3845	(910) 796-7215
Winston-Salem	450 W. Hanes Mill Road, Suite 300, Winston-Salem, NC 27105	(336) 776-9800

Appendix B: Log Inactivation Ratio Determination for Surface Water Systems

Log Inactivation Ratio Determination for Surface Water Systems									
	Log Removal Credit (Giardia):		Log Inactivation Required (Giardia):		Maximum Flow Rate During Tracer Study (MGD):		Minimum Clearwell Level During Tracer Study (ft):		
System Name:									
PWSS ID #:						Date (Month/Yr):			
Day	Peak Hourly Flow (MGD)	Minimum Daily Residual Disinfectant Concentration (C) (mg/L)	Maximun Daily pH	Minimum Daily Water Temperature (T) (°C)	Disinfectant Contact Time (T_{10}) (min)	$CT_{actual} = C \times T_{10}$ (min-mg/L)	$CT_{required}$ (min-mg/L)	CT Ratio = $CT_{actual}/CT_{required}$	
1									
2									
3									
4									
5									
6									
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31									

Disinfectant: ____________________ Level of Inactivation Required: **Giardia** 3

Treatment Segment: ____________________ **Viruses** 4

Prepared by: ______________________________ Date: ______________

(signature)

Adapted from: Worksheet #1, LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual, May 2003

Appendix C: CT Calculation Examples

Example 1:

Problem:

Determine CT_{actual} for a day at a water treatment plant with conventional treatment. The water treatment plant uses one disinfection segment, and the contact time (T_{10}) is 81.3 minutes. The lowest free chlorine residual recorded during the day is 0.8 mg/L.

Solution:

$$CT_{actual} = C \times T_{10} = 0.8 \times 81.3 = 65.0 \, mg \cdot min/l$$

Example 2:

Problem:

Determine the ratio of CT_{actual} to $CT_{required}$ for a day at a water treatment plant with conventional treatment using the CT tables method if 0.5-log inactivation of *Giardia lamblia* cysts is required. The water treatment plant uses one disinfection segment, and the contact time (T_{10}) is 135 minutes. The lowest free chlorine residual recorded during the day is 1.2 mg/l. The minimum water temperature recorded during the day is 5.0 °C. The highest pH recorded during the day is 7.5.

Solution:

First, CT_{actual} must be calculated:

$$CT_{actual} = C \times T_{10} = 1.2 \times 135 = 162 \, mg \cdot min/l$$

Second, $CT_{required}$ must be determined. Locate the CT table for a temperature of 5.0 °C. Read the CT value for a pH of 7.5, a free chlorine concentration of 1.2 mg/l, and a log inactivation of 0.5. The $CT_{required}$ value from the CT table is 31 mg·min/l.

Finally, the CT ratio must be calculated:

$$\frac{CT_{actual}}{CT_{required}} = \frac{162}{31} = 5.23$$

The CT ratio 5.23 > 1.0, therefore adequate *Giardia lamblia* cysts inactivation has been achieved.

Example 3:

Problem:

Determine the ratio of CT_{actual} to $CT_{required}$ for a day at a water treatment plant with conventional treatment using the CT tables and the approximation method if 0.5-log inactivation of *Giardia lamblia* cysts is required. The water treatment plant uses one disinfection segment, and the contact time (T_{10}) is 75 minutes. The lowest free chlorine residual recorded during the day is 0.9 mg/l. The minimum water temperature recorded during the day is 5.0 °C. The highest pH recorded during the day is 6.9.

Solution:

First, CT_{actual} must be calculated:

$$CT_{actual} = C \times T_{10} = 0.9 \times 75 = 67.5\, mg \cdot min/l$$

Second, $CT_{required}$ must be determined. Locate the CT table for 5.0 °C. A CT value for a pH of 6.9 and a free chlorine residual of 0.9 mg/l is not provided in the table, so the approximation method must be used to determine $CT_{required}$. To use the approximation method, conservative values for pH, temperature, and chlorine concentration must be used to select a CT value from the table; therefore, a pH of 7.0 and a free chlorine residual of 0.8 mg/l are used to read the table. Locate the CT table for a temperature of 5.0 °C. Read the CT value for a pH of 7.0, a free chlorine residual of 0.8 mg/l, and a log inactivation of 0.5. The $CT_{required}$ value from the CT table is 24 mg·min/l.

Finally, the CT ratio must be calculated:

$$\frac{CT_{actual}}{CT_{required}} = \frac{67.5}{24} = 2.81\, mg \cdot min/l$$

The CT ratio 2.81 > 1.0, therefore adequate *Giardia lamblia* cysts inactivation has been achieved.

Example 4:

Problem:

Determine the ratio of CT_{actual} to $CT_{required}$ for a day at a water treatment plant with conventional treatment using the regression method if 0.5-log inactivation of *Giardia lamblia* cysts is required. The water treatment plant uses one disinfection segment, and the contact time (T_{10}) is 25 minutes. The lowest free chlorine residual recorded during the day is 0.8 mg/l. The minimum water temperature recorded during the day is 10.3 °C. The highest pH recorded during the day is 7.4.

Solution

First, CT_{actual} must be calculated:

$$CT_{actual} = C \times T_{10} = 0.8 \times 25 = 20\, mg \cdot min/l$$

Second, $CT_{required}$ must be calculated with the regression method equation. The minimum water temperature is < 12.5 °C, so the appropriate equation for that temperature must be used:

$$
\begin{aligned}
CT_{required} &= (0.353 \times I)\left[12.006 + e^{(2.46\,-\,0.073\,\times\,Temp\,+\,0.125\,\times\,C\,+\,0.389\,\times\,pH)}\right] \\
&= (0.353 \times 0.5)\left[12.006 + e^{(2.46\,-\,0.073\,\times\,10.3\,+\,0.125\,\times\,0.8\,+\,0.389\,\times\,7.4)}\right] \\
&= 21.27\ mg \cdot min/l
\end{aligned}
$$

Finally, the CT ratio must be calculated:

$$
\frac{CT_{actual}}{CT_{required}} = \frac{20}{21.27} = 0.94\ mg \cdot min/l
$$

The CT ratio 0.94 < 1.0, therefore adequate *Giardia lamblia* cysts inactivation has **<u>NOT</u>** been achieved. The CT ratio of CT_{actual} to $CT_{required}$ must be greater than 1.0 in order for adequate inactivation to have been achieved.

Appendix D: CT Compliance Review Worksheets

Plant Specifications Worksheet

Water System Name: ____PWS ID: ___________________
ORC or Responsible Party: ___________________________________
Date of Review: ________________________

Flow:
Treatment Plant Design Capacity: ________MGD
Maximum Historical Flow: _____ MGD
Average Flow: _______MGD

High Service Pumps:
Maximum Design Flow: ______MGD
Maximum Historical Flow: ______MGD
Average Flow: _______ MGD

Clearwell(s):
Clearwell 1:
Capacity: _______MG
Maximum Historical Depth: ___________ft
Minimum Historical Depth: ______ft
Basin / Clearwell Geometry_______ Length (ft), _______Width (ft), _______Height (ft)
Baffle Configuration (Describe): ____
____

Clearwell 2:
Capacity: _______MG
Maximum Historical Depth: ___________ft
Minimum Historical Depth: ______ft
Basin / Clearwell Geometry_______ Length (ft), _______Width (ft), _______Height (ft)
Baffle Configuration (Describe): ____
____

Clearwell 3:
Capacity: _______MG
Maximum Historical Depth: ___________ft
Minimum Historical Depth: ______ft
Basin / Clearwell Geometry_______ Length (ft), _______Width (ft), _______Height (ft)
Baffle Configuration (Describe): ____
____

Water Quality Data:
Disinfection Log Inactivation Required for *Giardia lamblia* cysts: _____ (typically 0.5-log)

Minimum Historical Temperature: ___ ^{o}C
Maximum Historical pH: ____
Minimum Historical Free Chlorine Residual: ____ mg/l
Describe the Disinfection Segments: ____
____
____
____
____
____

Segment 1:
Disinfectant Chemical: ____
Point of Application: ____
Temperature at End of Segment 1: _______^{o}C
pH at End of Segment 1: _______
Disinfectant Residual at End of Segment 1: ______mg/l

Segment 2:
Disinfectant Chemical: ____
Point of Application: ____
Temperature at End of Segment 2: _______^{o}C
pH at End of Segment 2: _______
Disinfectant Residual at End of Segment 2: ______mg/l

Segment 3:
Disinfectant Chemical: ____
Point of Application: ____
Temperature at End of Segment 3: _______^{o}C
pH at End of Segment 3: _______
Disinfectant Residual at End of Segment 3: ______mg/l

Segment 4:
Disinfectant Chemical: ____
Point of Application: ____
Temperature at End of Segment 4: _______^{o}C
pH at End of Segment 4: _______
Disinfectant Residual at End of Segment 4: ______mg/l

Tracer Study Worksheet

Tracer Study Performed By: ____

Date of Tracer Study: __________________________

Describe the tracer study segment(s) for which T_{10} was determined: ______________________________

____

____

____

Tracer Chemical Used:

Tracer Study Method: _________________________ (Slug dose, Step dose, other)

Type: ____ (i.e. Hydrofluorosilicic Acid)

Background Concentration (raw water concentration): ______mg/l

Dosage: ______mg/l

Net Concentration: ______mg/l (background concentration – dosage)

Sample Location: ____

Flow:

___ Yes ___ No Was a process flow diagram (PFD) included in the tracer study report?

Number of Flow Rates Tested: ______

Flow 1: ______ MGD

Flow 2: ______ MGD

Flow 3: ______ MGD

Flow 4: ______ MGD

___ Yes ___ No Was highest flow rate tested at least 91% of flow rate expected to ever occur?

Clearwell(s):

Clearwell 1:

Tracer Study Depth: _____ ft

___ Yes ___ No Was the minimum operating level used during the tracer study?

Clearwell 2:

Tracer Study Depth: _____ ft

___ Yes ___ No Was the minimum operating level used during the tracer study?

Clearwell 3:

Tracer Study Depth: _____ ft

___ Yes ___ No Was the minimum operating level used during the tracer study?

Tracer Study Results:

T_{10} _________ minutes

Appendix E: CT Values for Inactivation of *Giardia lamblia* Cysts

Table C-1. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5°C or Lower

CHLORINE CONCENTRATION	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	169	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	155	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	169	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

CHLORINE CONCENTRATION	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	113	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	55	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	369	460	552

Source: AWWA, 1991.

Table C-2. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 5°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	49	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	97	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	69	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

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	197	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	189	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

Source: AWWA, 1991.

Table C-3. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 10°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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

Source: AWWA, 1991.

Table C-4. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 15°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	9	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

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	59	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	109	135	162	33	65	98	130	163	195

Source: AWWA, 1991.

Table C-5. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 20°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	9	16	24	31	39	47	10	19	29	38	48	57	11	23	34	45	57	68	14	28	42	55	69	83

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	12	25	37	49	62	74	15	30	45	59	74	89	19	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	139
2.6	16	32	49	65	81	97	20	39	59	78	98	117	24	47	71	94	117	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

Source: AWWA, 1991.

Table C-6. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 25°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	13	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	19	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

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=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	19	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	89
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

Source: AWWA, 1991.