Disinfection: CT and Microbial Log Inactivation Calculations

Drinking Water Reference Guide: Colorado Department of Public Health and Environment Water Quality Control Division - Engineering Section http://www.cdphe.state.co.us/wg/ 303-692-3500 May 2009

What do I need to know before I start calculating?

- Peak Hourly Flow, Q (gpm)
- Residual Disinfectant Concentration, C (mg/L)
- Temperature (°C)
- pH (standard units, s.u.)
- Basin Geometry
- Baffle Configuration
- Disinfectant type

Log Inactivation

- I log: 90% inactivation
- 2 log: 99% inactivation
- 3 log: 99.9% inactivation
- 4 log: 99.99% inactivation

Equation Summary

- I. Giardia Log Inactivation = 3 log × (CT_{CALC} / CT_{99.9})
- 2. Virus Log Inactivation = 4 log × (CT_{CALC} / CT_{99.99})
- 3. $CT_{CALC} = C \times T$
- 4. $T = TDT \times BF$
- 5. TDT = V/Q

Source and for more information:

U.S. Environmental Protection Agency. 2003. LTIESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual. EPA 816-R-03-004 http://www.epa.gov/safewater/mdbp/pdf/profile/ltlprofiling.pdf

This reference guide takes you step by step through the CT and log inactivation calculation procedure, through an example calculation, and presents the disinfection segment concept.

What is Log Inactivation?

"Log inactivation" is a convenient way to express the number or percent of microorganisms inactivated (killed or unable to replicate) through the disinfection process. For example, a 3 log inactivation value means that 99.9% of microorganisms of interest have been inactivated. (See box at left.) Log inactivation measures the effectiveness of the disinfection process, which is influenced by variables including disinfectant concentration, temperature, pH and disinfectant type (e.g., lower temperature results in less inactivation since the reactions slow down as temperature decreases).

What is CT?

"CT" (minutes•mg/L) in the context of water treatment is defined as the product of: C, for "residual disinfectant concentration" in mg/L (determined before or at the first customer) and T, for the corresponding "disinfectant contact time" in minutes. CT is a measure of the disinfection process reaction time, but CT is only one of several variables that control the effectiveness of the disinfection process.

CT and Log Inactivation Calculation Overview

Basically, log inactivation is a measurement of how effective a disinfection process is at killing microorganisms in a specific environment. Operationally, directly measuring log inactivation is not practical, but determining the microbial inactivation for an individual water treatment plant (WTP) can be achieved using the log inactivation calculations. The log inactivation calculation adjusts the WTP's CT value to account for the disinfection chemical reaction process variables that influence the disinfection process efficiency. The log inactivation calculations (Equations I and 2 in the left-hand bottom box) use the WTP's CT (CT_{CALC}) and the EPA-developed CT log inactivation tables ($CT_{99.9}$ for Giardia lamblia and CT_{99,99} for viruses). (See box on Page 3 for the basis of CT log inactivation tables.) The flowchart below illustrates the log inactivation calculation process.



T = Detention Time

 CT_{CALC} = Concentration Time Calculated Value for WTP

CT_{99.9} = Concentration Time to inactivate 3 log of *Giardia* (from table)

 $CT_{99,99}$ = Concentration Time to inactivate 4 log of virus (from table)

CT and Log Inactivation Calculation Steps

Step 1: Calculate Detention Time

Step 1-A: Calculate Theoretical Detention Time (TDT)

TDT = V/Q TDT = Theoretical Detention Time (minutes) V = Volume, based on low water level (gallons) Q = Peak hourly flow (gpm)

Step 1-B: Calculate Actual Detention Time (T)

- $T = TDT \times BF$
- T = Actual Detention Time (minutes)* TDT = Theoretical Detention Time (minutes) BF = Baffling Factor (measure of short circuiting)



* The Actual Detention Time also may be available from site-specific tracer tests conducted at all possible flowrates.

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 intrabasin baffles

Step 2: Calculate CT_{CALC}

 $CT_{CALC} = C \times T$

CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

C = Residual disinfectant concentration measured during peak flow (mg/L)

T = Actual Detention Time (minutes)

Conversion Factors:

- 1 cu-ft = 7.48 gallons
- 1 MGD = 694 gpm
- 1 gal water = 8.34 lbs
- °C = 5/9 x (°F 32)

Step 3: Calculate *Giardia lamblia* log inactivation

Step 3-A: Determine CT required for *Giardia lamblia* 3 log reduction (CT_{99.9}) using EPA tables and WTP information

The CT required for 3 log inactivation of *Giardia lamblia* (designated as $CT_{99,9}$) is available in tables for different disinfectants. (See Page 6, Table A for the free chlorine tables.) The $CT_{99,9}$ for *Giardia lamblia* depends on the residual disinfectant concentration (C), temperature, and pH. A section of "Table A: *Giardia lamblia* 3 log reduction ($CT_{99,9}$) for free chlorine" can be seen below.

Chlorine	Temperature <= 0.5°C												
Conc.				ρН									
(mg/L)	<=6.0	6.5	7	7.5	8	8.5	9						
<=0.4	137	163	195	237	277	329	390						
0.6	141	168	200	239	286	342	407						
0.8	145	172	205	246	295	354	422						
1.0	148	176	210	253	304	365	437						

Log reduction tables for other disinfectants (e.g., UV, chloramine, chlorine dioxide, ozone) are available in the 2003 EPA LT1ESWTR Guidance Manual.

Step 3-B: Calculate Giardia lamblia Log Inactivation

Giardia Log Inactivation = $3 \log \times (CT_{CALC} / CT_{999})$

CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

 CT_{999} = Concentration Time to inactivate 3 log of *Giardia* (minutes•mg/L) from table

Step 4: Calculate virus log inactivation

Step 4-A: Determine CT required for Virus 4 log reduction (CT_{99.99})

The CT required for 4 log inactivation of viruses (designated as CT_{99.99}) for free chlorine is presented in the table below. The virus $CT_{99,99}$ is dependent on temperature and pH.

Temperature	рН					
°C	6-9	10				
0.5	12	90				
5	8	60				
10	6	45				
15	4	30				
20	3	22				
25	2	15				

Step 4-B: Calculate Virus Log Inactivation

Virus Log Inactivation = $4 \log \times (CT_{CALC} / CT_{99,99})$

 CT_{CALC} = Concentration Time, Calculated Value (minutes•mg/L)

CT_{99,99} = Concentration Time to inactivate 4 log of virus (minutes•mg/L) from table

Example Log Inactivation Calculation

Measured at Peak Flow: Peak Flow, Q = 347 gpm Free chlorine residual, C = 0.8 mg/L

pH = 6 s.u.

Temperature = $0.5^{\circ}C$

Cylindrical basin Information:

Inner tank diameter, D = 40 ft Inner tank radius, r = 20 ft Minimum tank water level, d = 30 ft No baffling, BF = 0.1

Background - Calculate Basin Volume, V

V= $\pi \times d \times r^2$, Cylindrical Basin Volume Equation

 $V= 3.1416 \times 30 \text{ ft} \times (20 \text{ ft})^2 = 37,680 \text{ ft}^3$

V= 37,680 ft³ × 7.48 gallons/ft³

V= 282,000 gallons

Step 1: Calculate Detention Time

Step 1-A: Calculate Theoretical Detention Time

TDT = V / Q

TDT = V / QTDT = 282,000 gals / 347 gpm TDT = 813 minutes

Fluorescence image of Giardia lamblia cysts Photo Credit: H.D.A Lindquist, U.S. EPA

Where did the CT tables come from?

What is Giardia?

Giardia lamblia is a flagellated protozoan, which is shed during

its cyst-stage within the feces of

the protozoan causes a severe gastrointestinal disease called

giardiasis.

humans and animals. When water containing these cysts is ingested,

The CT_{99,9} and CT_{99,99} tables were developed by the EPA, based on experimental data, to account for the impact of major variables (e.g., temp, pH, concentration) on disinfection reaction efficiency. For example, the $CT_{99,9}$ value in the EPA table is the CT required to achieve a 3 log reduction of Giardia lamblia for a given disinfectant type and concentrations under various temperature and pH conditions.

r =20 ft



 $T = TDT \times BF$ T = 813 minutes $\times 0.1$ T = 81.3 minutes

Step 1-B: Calculate Actual Detention Time

Example Log Inactivation Calculation (continued)

Step 2: Calculate CT_{CALC}

 $CT_{CALC} = C \times T$

 $CT_{CALC} = C \times T$ $CT_{CALC} = 0.8 \text{ mg/L} \times 81.3 \text{ minutes}$ $CT_{CALC} = 65 \text{ minutes} \cdot \text{mg/L}$

Step 3: Calculate Giardia lamblia log inactivation

Step 3-A: Determine CT required for *Giardia lamblia* 3 log reduction

Determine Giardia CT_{99.9} from CT Table given Temperature = 0.5°C, pH = 6 s.u., Free chlorine residual = 0.8 mg/L

Chlorine	L		Temp	erature <=	0.5°C ┥		
Conc.				рΗ			
(mg/L)	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	137	163	195	237	277	329	390
0.6	141	168	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437

CT_{99.9} = 145 minutes•mg/L

Step 3-B: Calculate Giardia lamblia Log Inactivation

Giardia Log Inactivation = $3 \log \times (CT_{CALC} / CT_{99.9})$

Giardia Log Inactivation = 3 log × (CT_{CALC} / CT_{99.9}) Giardia Log Inactivation = 3 log × (65 minutes•mg/L / 145 minutes•mg/L)

Giardia Log Inactivation = 1.34 log

Step 4: Calculate virus inactivation

Step 4-A: Determine CT required for Virus 4 log reduction

Determine virus $CT_{99,99}$ from CT Table given Temperature = 0.5°C and pH = 6 s.u.

Temperature °	•	pН
С	6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

CT_{99.99} = 12 minutes•mg/L

General relationships:

- As C Iog inactivation
- As pH log inactivation
- As BF Iog inactivation
- As Peak Q log inactivation
- As Temp log inactivation
- As Contact Volume log inactivation

Step 4-B: Calculate Virus Log Inactivation

Virus Log Inactivation = $4 \log \times (CT_{CALC} / CT_{99,99})$

Virus Log Inactivation = 4 log× (CT_{CALC} / CT_{99.99}) Virus Log Inactivation = 4 log × (65 minutes•mg/L / 12 minutes•mg/L) Virus Log Inactivation = 21.67 log

Alternatively: What is the CT, *Giardia* and virus inactivation if the free chlorine residual concentration is 0.4 mg/L vs. 0.8 mg/L? Answer: $CT_{CALC} = C \times T = 0.4 \text{ mg/L} \times 81.3 \text{ minutes} = 32.5 \text{ minutes} \cdot \text{mg/L}$

Giardia Log Inactivation = 3 log × (CT_{CALC} / CT_{99.9}) = 3 × (32.5 minutes•mg/L / 137 minutes•mg/L) = 0.72 log

Virus Log Inactivation = $4 \log (CT_{CALC} / CT_{99,99}) = 4 \times (32.5 \text{ minutes} \cdot \text{mg/L} / 12 \text{ minutes} \cdot \text{mg/L}) = 10.83 \log (12 \text{ minutes} \cdot \text{mg/L}) = 10$

Disinfection Segments



Coagulation

Two Disinfection

Segments Example

Flocculation

of log inactivation is the sun disinfection segment (if the system has multiple disinfection segments).

Therefore, calculate log inactivation for each segment and add together to determine total system inactivation.

Disinfection Profile



Almost all community and non transient, non community public water systems that use Surface Water or Ground Water Under the Direct Influence of Surface Water sources are required to develop a disinfection profile. Systems are required to retain the disinfection profile in graphic form and it must be available for review by the state as part of a sanitary survey.

What is a Disinfection Profile and Benchmark?

Disinfection Segment 1

Monitoring Point

Cl₂ residual

Temperature

рН

Total inactivation = \sum log inactivation from each disinfection segment

- A disinfection profile is a graphical representation of a system's level of *Giardia lamblia* or virus inactivation measured, at least weekly, during the course of a year.
- A benchmark is the lowest monthly average microbial inactivation during the disinfection profile time period.

EPA Disinfection Profile Spreadsheet Calculator

The EPA has developed a disinfection profile spreadsheet calculator that calculates and graphs the disinfection profile for *Giardia* and viruses. The spreadsheet can be downloaded from: http://www.epa.gov/safewater/mdbp/ltleswtr.html.

Distribution

System

Disinfection Segment 2

Monitoring Point

Cl, residual

Temperature

pН

Table A: 3 Log CT (CT_{99.9}) Values for *Giardia* Cysts by free chlorine

Chlorine	Temperature <= 0.5°C							Temperature = 5°C							Temperature = 10°C						
Conc.				pН							pН							pН			
(IIIg/L)	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9	<=6.0	6.5	7	7.5	8	8.5	9
<=0.4	137	163	195	237	277	329	390	97	117	139	166	198	236	279	73	88	104	125	149	177	209
0.6	141	168	200	239	286	342	407	100	120	143	171	204	244	291	75	90	107	128	153	183	218
0.8	145	172	205	246	295	354	422	103	122	146	175	210	252	301	78	92	110	131	158	189	226
1.0	148	176	210	253	304	365	437	105	125	149	179	216	260	312	79	94	112	134	162	195	234
1.2	152	180	215	259	313	376	45 I	107	127	152	183	221	267	320	80	95	114	137	166	200	240
I.4	155	184	221	266	321	387	464	109	130	155	187	227	274	329	82	98	116	140	170	206	247
1.6	157	189	226	273	329	397	477	111	132	158	192	232	281	337	83	99	119	144	174	211	253
1.8	162	193	231	279	338	407	489	114	135	162	196	238	287	345	86	101	122	147	179	215	259
2.0	165	197	236	286	346	417	500	116	138	165	200	243	294	353	87	104	124	150	182	221	265
2.2	169	201	242	297	353	426	511	118	140	169	204	248	300	361	89	105	127	153	186	225	271
2.4	172	205	247	298	361	435	522	120	143	172	209	253	306	368	90	107	129	157	190	230	276
2.6	175	209	252	304	368	444	533	122	146	175	213	258	312	375	92	110	131	160	194	234	281
2.8	178	213	257	310	375	452	543	124	148	178	217	263	318	382	93		134	163	197	239	287
3.0	181	217	261	316	382	460	552	126	151	182	221	268	324	389	95	113	137	166	201	243	292
	Temperature = 15°C						Temperature = 20°C						Temperature = 25°C								
Chlorine		Те	mper	ature	= 15°	°C			Те	mper	ature	= 20°	°C			Т	empe	rature	e = 25°	°C	
Chlorine Conc.		Те	mper	ature pH	= 15°	°C			Te	mper	ature pH	= 20°	Ċ			Т	empe	rature pH	e = 25°	°C	
Chlorine Conc. (mg/L)	<=6.0	Те 6.5	mper 7	ature pH 7.5	= 15° 8	°C 8.5	9	<=6.0	Те 6.5	mper 7	ature pH 7.5	= 20°	°C 8.5	9	<=6.0	Т 6.5	empe 7	raturo pH 7.5	e = 25° 8	°C 8.5	9
Chlorine Conc. (mg/L) <=0.4	< =6.0 49	Te 6.5 59	mper 7 70	ature pH 7.5 83	= 15° 8 99	°C 8.5	9 140	< =6.0 36	Те 6.5 44	mper 7 52	ature pH 7.5 62	= 20° 8 74	°C 8.5 89	9 105	<=6.0 24	6.5	empe 7 35	rature pH 7.5 42	e = 25° 8 50	°C 8.5 59	9 70
Chlorine Conc. (mg/L) <=0.4 0.6	< =6.0 49 50	Te 6.5 59 60	7 70 72	ature pH 7.5 83 86	= 15° 8 99 102	°C 8.5 118 122	9 140 146	< =6.0 36 38	Te 6.5 44 45	7 52 54	ature pH 7.5 62 64	= 20° 8 74 77	8.5 89 92	9 105 109	< =6.0 24 25	6.5 29 30	empe 7 35 36	rature pH 7.5 42 43	8 50 51	° C 8.5 59 61	9 70 73
Chlorine Conc. (mg/L) <=0.4 0.6 0.8	<=6.0 49 50 52	Te 6.5 59 60 61	7 70 72 73	ature pH 7.5 83 86 88	= 15° 8 99 102 105	8.5 118 122	9 140 146 151	< =6.0 36 38 39	Te 6.5 44 45 46	7 52 54 55	ature pH 7.5 62 64 66	8 74 77 79	8.5 89 92 95	9 105 109	< =6.0 24 25 26	6.5 29 30 31	empe 7 35 36 37	rature pH 7.5 42 43 44	8 50 51 53	° C 8.5 59 61 63	9 70 73 75
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0	<=6.0 49 50 52 53	Te 6.5 59 60 61 63	70 70 72 73 75	ature pH 7.5 83 86 88 90	= 15° 8 99 102 105 108	8.5 118 122 126 130	9 140 146 151 156	<=6.0 36 38 39 39	Te 6.5 44 45 46 47	7 52 54 55 56	ature pH 7.5 62 64 66 67	8 74 77 79 81	8.5 89 92 95 98	9 105 109 113 117	< =6.0 24 25 26 26	6.5 29 30 31 31	7 35 36 37 37	rature pH 7.5 42 43 44 45	8 50 51 53 54	°C 8.5 59 61 63 65	9 70 73 75 78
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2	< =6.0 49 50 52 53 54	Te 6.5 59 60 61 63 64	7 70 72 73 75 76	ature pH 7.5 83 86 88 90 92	8 99 102 105 108	8.5 118 122 126 130 134	9 140 146 151 156 160	< =6.0 36 38 39 39 40	Te 6.5 44 45 46 47 48	7 52 54 55 56 57	ature pH 7.5 62 64 66 67 69	8 74 77 79 81 83	8.5 89 92 95 98 100	9 105 109 113 117 120	<=6.0 24 25 26 26 27	6.5 29 30 31 31 32	7 35 36 37 37 38	rature pH 7.5 42 43 44 45 46	8 8 50 51 53 54 55	°C 8.5 59 61 63 65 67	9 70 73 75 78 80
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4	< =6.0 49 50 52 53 54 55	Te 6.5 59 60 61 63 64 65	70 70 72 73 75 76 78	ature pH 7.5 83 86 88 90 92 92	8 99 102 105 108 111 114	8.5 118 122 126 130 134	9 140 146 151 156 160 165	< =6.0 36 38 39 39 40 41	Te 6.5 44 45 46 47 48 49	7 52 54 55 56 57 58	ature pH 7.5 62 64 66 67 69 70	8 74 77 79 81 83 85	8.5 89 92 95 98 100 103	9 105 109 113 117 120 123	< =6.0 24 25 26 26 27 27 27	6.5 29 30 31 31 32 33	7 35 36 37 37 38 39	rature pH 7.5 42 43 44 45 46 47	8 50 51 53 54 55 57	°C 8.5 59 61 63 65 67 69	9 70 73 75 78 80 82
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6	< =6.0 49505253545556	Te 6.5 59 60 61 63 64 65 66	70 70 72 73 75 76 78 79	ature pH 7.5 83 86 88 90 92 92 94 96	8 99 102 105 108 111 114 116	8.5 118 122 126 130 134 137 141	9 140 146 151 156 160 165 169	<=6.0 36 38 39 39 40 41 42	Te 6.5 44 45 46 47 48 49 50	7 52 54 55 56 57 58 59	ature pH 7.5 62 64 66 67 69 70 70	8 74 77 79 81 83 85 85	8.5 89 92 95 98 100 103	9 105 109 113 117 120 123 126	< =6.0 24 25 26 26 27 27 28	6.5 29 30 31 31 32 33 33	7 35 36 37 37 38 39 40	rature pH 7.5 42 43 44 45 46 45 46 47 48	8 50 51 53 54 55 57 58	°C 8.5 59 61 63 65 67 69 70	9 70 73 75 78 80 82 84
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8	<=6.0 49 50 52 53 54 55 56 57	Te 6.5 59 60 61 63 64 65 66 68	70 70 72 73 75 76 78 79 81	ature pH 7.5 83 86 88 90 92 92 94 96 98	<pre>= 15° 8 99 102 105 108 111 114 116 119</pre>	B.5 8.5 118 122 126 130 134 137 141 144	9 140 146 151 156 160 165 169 173	< =6.0 36 38 39 39 40 41 42 43	Te 6.5 44 45 46 47 48 49 50 51	7 52 54 55 56 57 58 59 61	ature pH 7.5 62 64 66 67 69 70 70 72 74	8 74 77 79 81 83 85 87 89	8.5 89 92 95 98 100 103 105	9 105 109 113 117 120 123 126 129	< =6.0 24 25 26 26 27 27 27 28 29	6.5 29 30 31 31 32 33 33 33 34	7 35 36 37 37 38 39 40 41	rature pH 7.5 42 43 44 45 46 45 46 47 48 49	8 50 51 53 54 55 57 58 60	°C 8.5 59 61 63 65 67 69 70 72	9 70 73 75 78 80 82 84 84
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0	<=6.0 49 50 52 53 54 55 56 57 58	Te 6.5 59 60 61 63 64 65 66 68 68 69	7 70 72 73 75 76 78 79 81 83	ature pH 7.5 83 86 88 90 92 92 94 96 98 100	<pre>= 15° 8 99 102 105 108 111 114 116 119 122</pre>	8.5 118 122 126 130 134 137 141 144 147	9 140 151 156 160 165 169 173 177	< =6.0 36 38 39 39 40 41 42 43 44	Te 6.5 44 45 46 47 48 49 50 51 51	7 52 54 55 56 57 58 59 61 62	ature pH 7.5 62 64 66 67 69 70 72 72 74	8 74 77 79 81 83 85 87 89 91	8.5 89 92 95 98 100 103 105 108	9 105 109 113 117 120 123 126 129 132	< =6.0 24 25 26 26 27 27 28 29 29	6.5 29 30 31 31 32 33 33 34 35	7 35 36 37 37 38 39 40 41 41	rature pH 7.5 42 43 44 45 46 47 48 49 50	8 50 51 53 54 55 57 58 60 61	°C 8.5 59 61 63 65 67 69 70 70 72 74	9 70 73 75 78 80 82 84 84 88
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2	<=6.0 49 50 52 53 54 55 56 57 58 59	Te 6.5 59 60 61 63 64 65 66 68 68 69 70	7 70 72 73 75 76 78 79 81 83 85	ature pH 7.5 83 86 88 90 92 92 94 92 94 98 100 102	<pre>= 15° 8 99 102 105 108 111 114 116 119 122 124</pre>	8.5 118 122 126 130 134 137 141 144 147 150	9 140 146 151 156 160 165 169 173 177 181	<=6.0 36 38 39 39 40 41 42 43 44 44	Te 6.5 44 45 46 47 48 49 50 51 52 53	7 52 54 55 56 57 58 59 61 62 63	ature pH 7.5 62 64 66 67 69 70 72 74 75 77	8 74 77 79 81 83 85 87 89 91 93	8.5 89 92 95 98 100 103 105 108 110 113	9 105 109 113 117 120 123 126 129 132 135	< =6.0 24 25 26 27 27 28 29 30	T 6.5 29 30 31 32 33 34 35	7 35 36 37 37 38 39 40 41 41 41 42	rature pH 7.5 42 43 44 45 46 47 48 49 50 51	8 50 51 53 54 55 57 58 60 61 62	°C 8.5 59 61 63 65 67 69 70 72 74 74	9 70 73 75 78 80 82 84 84 86 88 90
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4	<=6.0 49 50 52 53 54 55 56 57 58 59 60	Te 6.5 59 60 61 63 64 65 66 68 69 70 72	7 70 72 73 75 76 78 78 79 81 83 85 86	ature pH 7.5 83 86 88 90 92 94 94 96 98 100 102 105	<pre>= 15° 8 99 102 105 108 111 114 116 119 122 124 127</pre>	8.5 118 122 126 130 134 137 141 144 147 150	9 140 146 151 156 160 165 169 173 177 181 184	< =6.0 36 38 39 40 41 42 43 44 44 45	Te 6.5 44 45 46 47 48 49 50 51 52 53 54	7 52 54 55 56 57 58 59 61 62 63 65	ature pH 7.5 62 64 66 67 69 70 72 74 75 77 77	8 74 77 79 81 83 85 87 89 91 93 95	8.5 89 92 95 98 100 103 105 108 110 113	9 105 109 113 117 120 123 126 129 132 135 138	< =6.0 242526272728293030	6.5 29 30 31 32 33 34 35 35 36	7 35 36 37 37 38 39 40 41 41 41 42 43	rature pH 7.5 42 43 44 45 46 47 48 49 50 51 51	8 8 50 51 53 54 55 57 58 60 61 62 63	°C 8.5 59 61 63 65 67 69 70 72 74 74 75 77	9 70 73 75 78 80 82 84 86 88 90 92
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.4 2.6	<=6.0 49 50 52 53 54 55 56 57 58 59 60 61	Te 6.5 59 60 61 63 64 65 66 68 69 70 72 73	7 70 72 73 75 76 78 79 81 83 85 86 88	ature pH 7.5 83 86 88 90 92 92 94 96 98 100 102 105 107	 = 15° 8 99 102 105 108 111 114 116 119 122 124 127 129 	8.5 118 122 126 130 134 137 141 144 147 150 153	9 140 146 151 156 160 165 169 173 177 181 184 188	< =6.0 36 38 39 39 40 41 42 43 44 44 45 46	Te 6.5 44 45 46 47 48 49 50 51 52 53 54	7 52 54 55 56 57 58 59 61 62 63 65 66	ature pH 7.5 62 64 66 67 69 70 72 72 74 75 77 78 80	8 74 77 79 81 83 85 87 89 91 93 95 97	8.5 89 92 95 98 100 103 105 108 110 113 115 117	9 105 109 113 117 120 123 126 129 132 135 138 141	< =6.0 2425262727282929303031	6.5 29 30 31 32 33 34 35 36 37	7 35 36 37 37 38 39 40 41 41 41 42 43 44	rature pH 7.5 42 43 44 45 46 47 48 49 50 51 52 53	8 50 51 53 54 55 57 58 60 61 62 63 65	°C 8.5 59 61 63 65 67 69 70 72 74 75 77 78	9 70 73 75 78 80 82 84 86 88 90 92 94
Chlorine Conc. (mg/L) <=0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8	<=6.0 49 50 52 53 54 55 56 57 58 59 60 61 62	Te 6.5 59 60 61 63 64 65 66 68 69 70 72 73 73	7 70 72 73 75 76 78 78 79 81 83 85 86 88 88 88 88	ature pH 7.5 83 86 88 90 92 92 94 92 94 98 100 102 105 107 109	 8 99 102 105 108 111 114 116 119 122 124 127 129 132 	8.5 118 122 126 130 134 137 141 144 147 150 153 156 159	9 140 146 151 156 160 165 169 173 177 181 184 188 191	< =6.0 36 38 39 39 40 41 42 43 44 45 46 47	Te 6.5 44 45 46 47 48 49 50 51 52 53 54 55 56	7 52 54 55 56 57 58 59 61 62 63 65 66 66 67	ature pH 7.5 62 64 66 67 69 70 72 74 75 77 78 80 80 81	8 74 77 79 81 83 85 87 89 91 93 95 97 97	8.5 89 92 95 98 100 103 105 108 110 113 115 117 119	9 105 109 113 117 120 123 126 129 132 135 138 141 143	< =6.0 2425262727282930303131	T 6.5 29 30 31 32 33 34 35 36 37 37	7 35 36 37 37 38 39 40 41 41 41 41 41 42 43 44 45	rature pH 7.5 42 43 44 45 46 47 48 49 50 51 51 52 53 53	8 50 51 53 54 55 57 58 60 61 62 63 65 66	°C 8.5 59 61 63 65 67 69 70 72 74 72 74 75 77 78 80	9 70 73 75 78 80 82 84 86 88 90 92 94 96

Table B: 4 Log CT (CT_{99.99}) Values for viruses by free chlorine

Temperature	рН					
°	6-9	10				
0.5	12	90				
5	8	60				
10	6	45				
15	4	30				
20	3	22				
25	2	15				

Tables reproduced from

U.S. EPA. 2003. LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual. EPA 816-R-03-004, http://www.epa.gov/safewater/mdbp/pdf/profile/lt1profiling.pdf

For more information

EPA's LTIESWTR web site: http://www.epa.gov/safewater/mdbp/ltleswtr.html

CDPHE WQCD web site: http://www.cdphe.state.co.us/wq/