CT Calculations

Determining Virus and Giardia Inactivation with Chlorine

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What We Will Cover

- Basic Concepts
- Regulatory Requirements under the Safe Drinking Water Act
- How and When You Must Determine CT (Logs Inactivation)
- Documentation Requirements for Sanitary Surveys and WY DEQ Permits

The Surface Water Treatment Rule Treatment Technique:

"At least 99.9% (3-logs) removal and/or inactivation of *Giardia lamblia* and 99.99% (4-logs) removal and/or inactivation of viruses"

- Applies to all public water systems using Surface Water or Groundwater Under the Direct Influence of Surface Water
- Because C*ryptosporidium* is very resistant to chlorine, it must be removed or inactivated by other methods. This presentation does not address C*ryptosporidium.*

The Groundwater Rule Treatment Technique:

"At least 99.99% (4-logs) removal and/or inactivation of viruses"

- *This treatment is NOT required for all GW systems; it only applies in certain situations.*

The Groundwater Rule Treatment Technique:

- More discussion of the GroundWater Rule, chlorination and CT calculations for viruses, can be found in the "Sanitary Survey Guidance Manual for Ground Water Systems"
- On the EPA website @

http://www.epa.gov/safewater/disinfection/gwr/compliancehelp.html

Removal vs. Inactivation

REMOVAL = physically removing the organism from the water (by filtration or settling)

INACTIVATION (disinfection) = modifying the organism so that it is no longer is pathogenic (by chemical treatment to destroy the cell's walls, or UV disinfection which affects genetic material (RNA or DNA) so the organism cannot reproduce)

What does "LOG" Mean?

- "x" log removal means x = - log (1- % removal/100)
- e.g. 0.5 = - log (1-68/100)

"x" LOG	% Removal
0.5	68
1	90
2	99
3	99.9
4	99.99

Why Use Logs?

You can add logs to find the total reduction from multiple barriers applied in series:

2-logs filtration (99% removal)

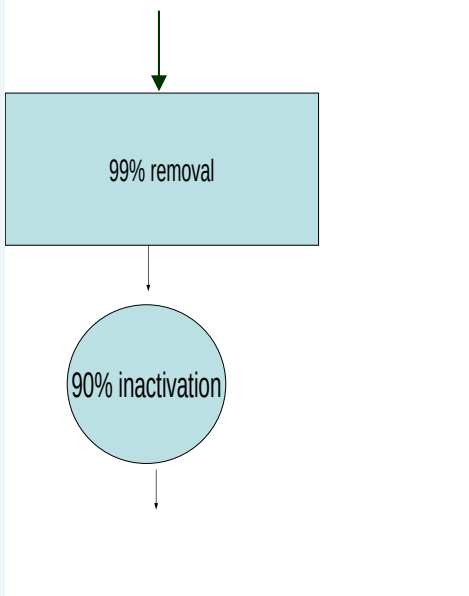
+

1- log inactivation (90% disinfection) =

3- logs total reduction

Since 3 logs = 99.9%, you know the overall reduction is 99.9%

10,000 organisms



100 after filters

10 after chlorination

How Many Logs of Inactivation are Needed?

- Total logs of reduction for each micro-organism are specified by the rule (Surface Water Treatment Rule or GW Rule)
- Filtration (removal) credits depend upon the type of filtration
- Logs inactivation required = Total logs reduction – logs achieved by Filtration

The Surface Water Treatment Rule Treatment Technique:

At least 99.9% (3-logs) reduction (removal and/or inactivation) of *Giardia lamblia* and

At least 99.99% (4-logs) reduction (removal and/or inactivation) of viruses

.

FILTRATION CREDITS FOR MICROBIAL REMOVAL, TO MEET SWTR, IESWTR and LT1ESWTR**

(systems consistently meeting the CFE turbidity limits in the table below, and the operational and design requirements outlined in this policy, are granted the Logs removal credit in the table below.)

FILTRATION TREATMENT TECHNOLOGY	COMBINED FILTER EFFLUENT (CFE) TURBIDITY (95% MNTHLY/MAX) ntu	MAXIMUM LOGS OF CREDIT FOR PHYSICAL REMOVAL			MINIMUM LOGS OF INACTIVATION NEEDED BY DISINFECTION	
		Cryptosporidium	*Giardia*	Viruses	*Giardia*	Viruses
Conventional	*** 0.3/1	>2	2.5	2.0	0.5	2.0
Direct	***0.3/1	>2	2.0	1.0	1.0	3.0
Slow Sand	1/5	>2	2.0	2.0	1.0	2.0
Diatomaceous Earth	1/5	>2	2.0	1.0	1.0	3.0
Reverse Osmosis	0.3/1	>2	>3.0	3.0	0	1.0
Nanofiltration	0.3/1	>2	>3.0	3.0	0	1.0
Ultrafiltration	0.3/1	>2	>3.0	0	0	4.0
Microfiltration	0.3/1	>2	>3.0	0	0	4.0
Pretreatment plus Bag or Cartridge (B/C) *	1/5	2	2.0	0	1.0	4.0
Conventional Filtration followed by (B/C)	0.5/5	2	2.5	2.0	0.5	2.0

* See policy for description of adequate pretreatment for SW and for GWUDISW using B/C Filtration

** Additional types of alternative filtration should be evaluated on a case-specific basis. 95th percentile and maximum turbidity values will be no more than 1 NTU and 5 NTU, respectively, for all alternative filtration technologies, unless different site specific values are assigned. All NTU rounding shall be in accordance with EPA established policy. Also, these filtration credits do not apply to point-of-use devices.

*** Conventional and direct filtration also have requirements for monitoring of individual filter effluent turbidity(IFE). See IESWTR and LT1ESWTR.

Calculating Logs Inactivation

- The most common chemical disinfectant used for microbial pathogens in drinking water is chlorine.
- The ability of chlorine to kill *Giardia* or viruses depends on

  -- the **free** chlorine concentration, mg/L (C)

  -- the time for chlorine contact, minutes (T)

  -- the water temperature and pH.

How is Inactivation Calculated, cont.

- We determine the inactivation with chlorine using "CT" calculations. (CT = C x T)
- C = mg/L free chlorine in the water where the inactivation is occurring (tanks, pipelines, etc)
- T = minutes of contact time with the disinfectant in each segment, prior to first consumer.

How is Inactivation Calculated, cont.

Contact time T depends upon the effective volume V_{eff} (e.g. volume of the tank holding liquid at a given time), the hydraulics of flow (use of a Baffling Factor BF), and the peak flow (gpm) through the segment.

**Region 8 does not give CT credit for pressure tanks or tanks which can be bypassed

Step 1 – Calculate Effective Volume

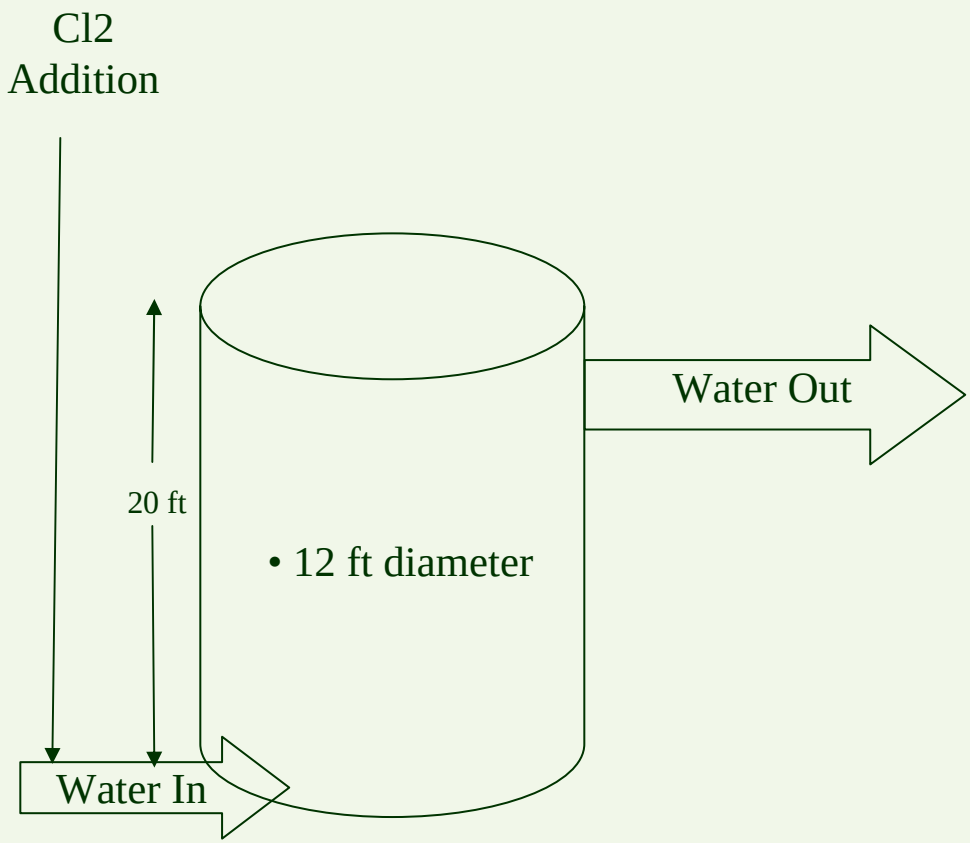
Formulas:

Cylindrical Tank: $V = 0.785 \times \text{diameter}^2 \times \text{height}$

Pipeline: $V = 0.785 \times \text{diameter}^2 \times \text{length}$

Rectangular Clearwell: $V = \text{length} \times \text{width} \times \text{depth}$

STEP 1 – Calculate Effective Volume V_{eff}



Outlet is @ 18 ft,
so top 2 ft is unused
(freeboard)

… 18 ft minimum operating height

V_{eff} = Effective tank volume = 0.785 x diameter^2 x min operating height =

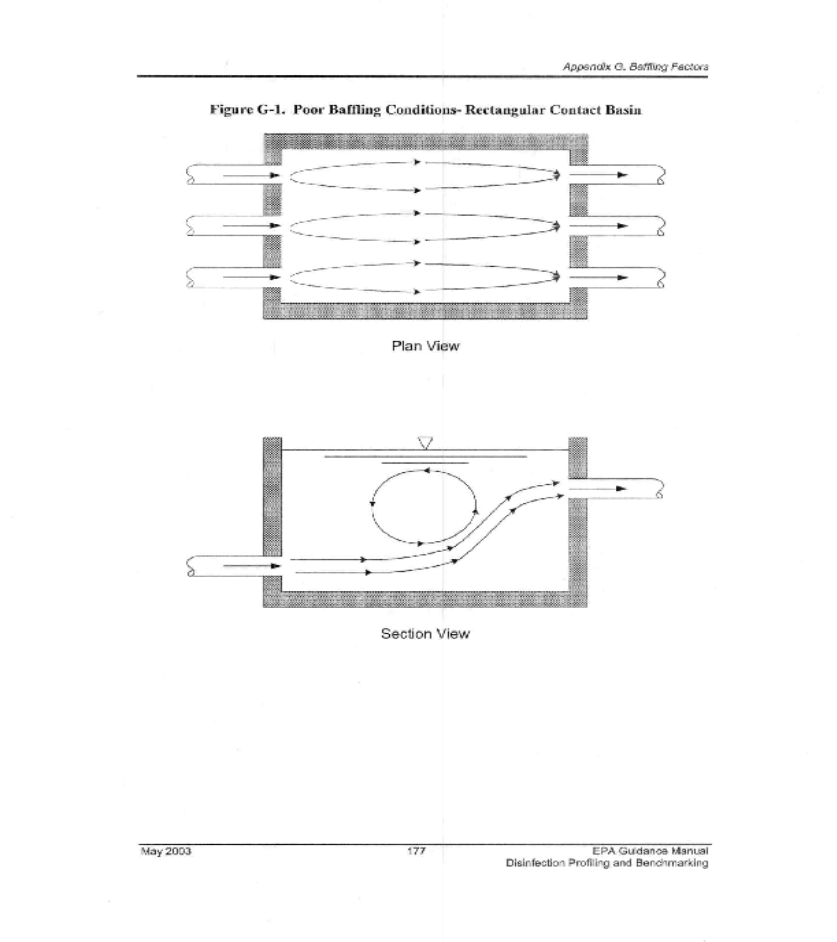
0.785 x (12 ft)^2 x 18 ft x 7.48 gallons/ft^3 = 15,200 gallons

Hydraulic Considerations

- Baffling factors (BF or T10/T) are adjustment factors or fractions usually less than 1 -- multipliers to get the actual detention or contact time
- BF are used because there may be “dead zones” where water bypasses part of the volume of the tank or chamber.

Example of Poor Baffling

- Unbaffled inlet and outlet pipes
- Dead space in upper inlet and lower outlet corner
- Dead space along cross section



Appendix G. Baffling Factors

Figure G-1. Poor Baffling Conditions- Rectangular Contact Basin

Plan View

Section View

May 2003 177 EPA Guidance Manual
Disinfection Profiling and Benchmarking

Hydraulic Considerations

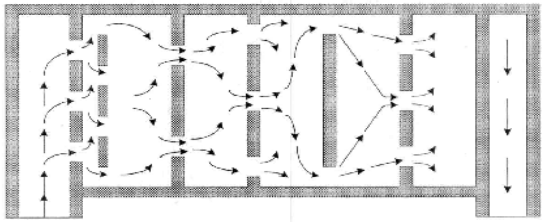
- Baffling is added to reduce inlet and outlet velocities, distribute water uniformly over the cross section of the basin, increase plug flow zone (increase the length to width ratio or create serpentine flow) and minimize short-circuiting.

Example of Superior Baffling

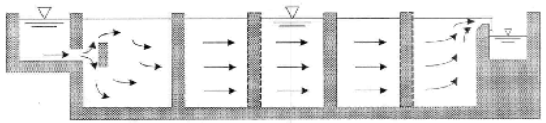
- Inlet with submerged, baffled ports reduces velocity of incoming water
- Outlet is sharp-crested weir extending entire width of basin
- Reduced short-circuiting
- Less dead space

Superior baffling conditions are exemplified by the flow pattern and physical characteristics of the basin shown in Figure G-3. The inlet to the basin consists of submerged, target-baffled ports. This inlet design serves to reduce the velocity of the incoming water and distribute it uniformly throughout the basin's cross-section. The outlet structure is a sharp-crested weir that extends for the entire width of the contact basin. This type of outlet structure will reduce short circuiting and decrease the dead space fraction of the basin, although the overflow weir does create some dead space at the lower corners of the effluent end.

Figure G-3. Superior Baffling Conditions- Rectangular Contact Basin



Plan View



Section View

Step 2 – Determine Baffling Factor

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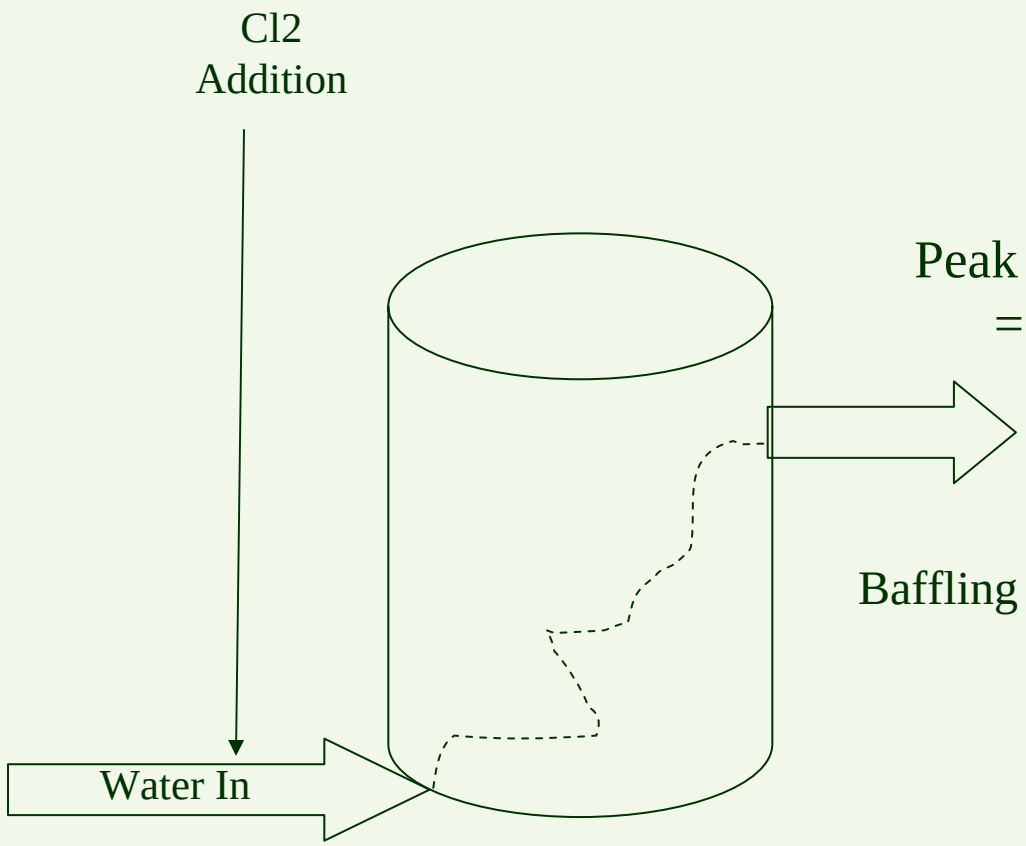
Baffling Condition	T10/T*	Baffling Description
Unbaffled	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities, unbaffled, inlet and outlet at the same levels.
Unbaffled	0.2	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities, unbaffled, inlet/high and outlet/low or visa versa.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles, vertical perforated pipe for an inlet and/or outlet.
Average	0.5	Baffled inlet or outlet, vertical perforated pipe for an inlet or outlet, with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, perforated intra-basin baffles, outlet weirs or perforated launders.
Excellent	0.9	Serpentine Baffling throughout
Perfect	1.0	Pipeline flow

*T10 = detention time at which 90% of the water passing through the unit is retained

Step 3 -Contact Time (T) Calculation

$$T\ (\text{min}) = \frac{V_{eff}\ (\text{gal}) \times BF}{\text{peak flow (gal/min)}}$$

STEP 3 – Calculate Contact Time T

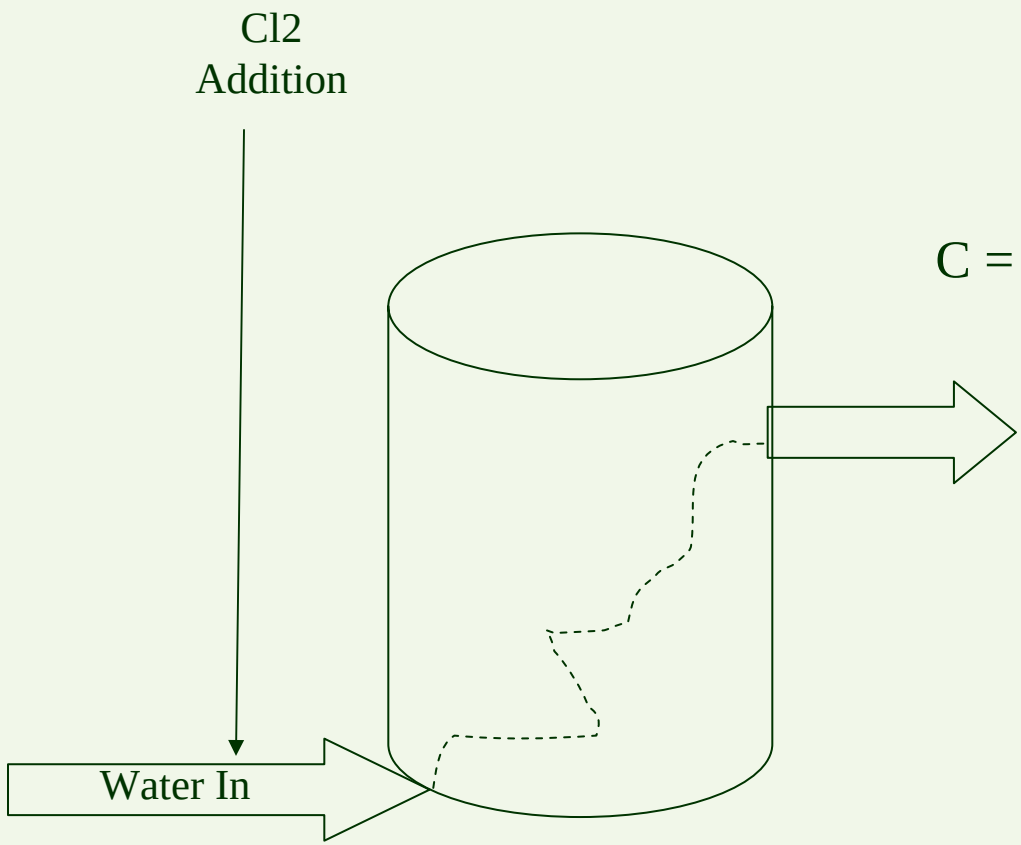


Peak Hourly Flow
= 100 gpm

Baffling Factor = 0.2 (no baffles, inlet low/outlet high)

Contact Time $T = V_{eff} \times BF/\text{peak flow}$

= 15,200 gallons x 0.2/100 gpm = 30 minutes



STEP 4- Calculate CT

Measure at EXIT

C = 0.6 mg/L free chlorine

T = 5C

pH = 7

Contact Time T = 30 minutes

Free Chlorine concentration C = 0.6 mg/L

CT = 0.6 mg/L x 30 min =**18 mg/L - min**

STEP 5 – Determine the Logs Inactivation Provided by the Calculated CT

- Based upon research, tables have been developed for Giardia and virus inactivation by free chlorine.
- Logs of inactivation depend upon CT, temperature and pH

TABLE E-7

CT VALUES FOR
INACTIVATION OF VIRUSES BY FREE CHLORINE[1]

(mg/L) min

	Log Inactivation					
	2.0 pH		3.0 pH		4.0 pH	
Temperature (C)	6-9	10	6-9	10	6-9	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

Notes:

1. Basis for values given in Appendix F.

if CT = 18 $\left(\frac{mg}{L}\right)(min)$

this provides > 4.0 logs
virus inactivation

our CT of 18 mg/L · min provides < 0.5 logs

TABLE E 2
CT VALUES FOR INACTIVATION
OF GIARDIA CYSTS BY FREE CHLORINE
AT 5 C (1)

CHLORINE CONCENTRATION (mg/L)	pH <= 6 Log Inactivations						pH = 6.5 Log Inactivations						pH = 7.0 Log Inactivations						pH = 7.5 Log Inactivations					
	0.5	1.0	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	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

CHLORINE CONCENTRATION (mg/L)	pH = 8.0 Log Inactivations						pH = 8.5 Log Inactivations						pH <= 9.0 Log Inactivations					
	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	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	334	389

Notes:

(1) $CT_{99.9}$ = CT for 3-log inactivation

Good News – Easier Process!

- Excel spreadsheets were developed for the SWTRs based upon formulas for these inactivation tables.
- You can enter information for the system (peak flow, temp, pH, effective volumes, baffling factors, and free chlorine residuals) and they will calculate the logs inactivation for Giardia and viruses for you!

Weekly Disinfection Profile available at

www.epa.gov/safewater/mdbp/ltleswtr.html

Select the Start Date: March 24 2009

Enter Baffling Factor for Stage 1: 0.28

Sample Date	Week Number	Treatment Stage	Disinfectant	Residual Conc. (C) (mg/L)	pH	Temp. (Celsius)	Peak Flow (GPM)	Volume (gal)	TDT (min)	Contact Time (T) (min)	CT_{calc}	3-log CT_{req}	Log Inactivation (Giardia)	4-log CT_{req}	Log Inactivation (viruses)
March 24, 2009	1	tank	Free Chlorine	0.50	7.00	5.0	100	15,200	152.0	30.4	15.2	142.67	9.38	6.00	9.12
March 31, 2009	2	tank	Free Chlorine						0.0	0.0	0.0		check pH		check pH
April 7, 2009	3	tank	Free Chlorine						0.0	0.0	0.0		check pH		check pH

How and When Must Your System Calculate Logs Inactivation (CT)?

1. Disinfection Profiling - Daily or weekly calculations to document inactivation levels over at least one year.

   Required for all SW systems (excluding transient) that were not exempted because of low TTHM and HAA5 levels:

   - start daily profiling by April 1, 2000 (serving 10,000 or more)
   - start weekly profiling by July 1, 2003 (serving 500 – 9,999)
   - start weekly profiling by January 1, 2004 (serving <500)

   (Note: if significant changes to disinfection practices are made as a result of the new LT2 SWTR, this profiling may be required of previously-exempt systems.)

How and When Must Your System Calculate Logs Inactivation (CT), cont.

Even if your system was exempted, we strongly recommend that you develop and continue to profile daily or weekly. This documentation shows ongoing compliance with the CT requirements, and allows you to adjust chlorine dosages to ensure adequate inactivation without overdosing and causing excessive DBPs.

By regulation, these disinfection profiles (if required) must be available for review during Sanitary Surveys.

To Find Weekly Disinfection Profiling Spreadsheets:

http://www.epa.gov/safewater/mdbp/lt1eswtr.html

Guidance Documents **(ALL ABOUT PDF FILES)**

•Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) Implementation Guidance (EPA 816-R-04-008, August, 2004)

- •Implementation Guidance Document (544 K PDF FILE, 162 pgs)
- •Appendices (4.5 M PDF FILE, 210 pgs)

•Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) Implementation Turbidity Provisions - Technical Guidance Manual (EPA 816-R-04-007, August, 2004) (6.1 M PDF FILE, 254 pgs)

•Long Term 1 Enhanced Surface Water Treatment Rule: A Quick Reference Guide (EPA 816-F-02-001) (298 K PDF FILE 2 pgs)

•Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) Disinfection Profiling and Benchmarking Technical Guidance Manual (EPA 816-R-03-004, May 2003) (4 M PDF FILE, 210 pgs)

•Disinfection Profile Spreadsheet, April 25, 2006

- •Long Form (Microsoft Excel File 2.6 M)
- •Short Form (Microsoft Excel File 1.2M)

How and When Must Your System Calculate Logs Inactivation (CT), cont.

2. **Sanitary Surveys**:
   During sanitary surveys, EPA checks CT calculations to ensure adequate inactivation is being achieved, as required by a specific rule.

   Conservative CT calculations are made for summer and winter conditions, using lowest water temperature, highest pH, peak hourly flow, and lowest chlorine residual of the season.

How and When Must Your System Calculate Logs Inactivation (CT), cont.

3. **With Permit Application to WYDEQ**
   For new or modified construction of treatment and/or storage, where the SDWA requires levels of inactivation of microbials.

4. **With Change Form to EPA**
   Also notify EPA prior to changes in treatment or storage @
www.epa.gov/region8/waterops/reporting/forms.html

Documentation Requirements

1. <u>Drawing Of The Removal and Inactivation Process(es)</u>

   A sketch or Process Flow Diagram (PFD) showing drinking water treatment, storage, and piping up to the first water consumer (consider if this is at the water plant itself). PFD should also show:

   - pipe sizes and lengths
   - locations and description of chlorine injection equipment
   - locations and equipment description for measurement of water flow rate, chlorine residual, pH and temperature.

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Documentation Requirements, cont.

2. Tank or Clearwell Schematics to Justify Baffling Factor

Plan view (from the top) and a profile (elevation) view showing inlets and outlets, baffling, all tank dimensions, and expected water flow path in the tank. The schematic should depict the minimum water height (i.e. level of outlet, setting of automatic level controller, etc.)

Documentation Requirements, cont.

3. Either your ongoing daily or weekly disinfection profile, or else documentation from previous (or expected) operating conditions to allow conservative CT calculations. For summer and winter operations:
   - Peak hourly flow through the segment (tank)
   - Lowest water temperature leaving the segment (tank)
   - Highest water pH leaving the segment (tank)
   - Minimum FREE chlorine residual leaving the segment (tank)

Documentation Requirements, cont.

4. Discussion/listing of the logs reduction for each micro-organism credited to all other treatment processes (e.g. filtration)
5. Discussion/listing of the logs credited for each micro-organism by the inactivation process(es)
6. Table showing that the total logs reduction required by regulation is met for each micro-organism (based upon items 4 and 5 above).

Surface Water Treatment Rules - Minimum Requirements

Regulation	*Giardia*	Virus	*Cryptosporidium*
SWTR	3 log removal and/or inactivation	4 log removal and/or inactivation	Not Addressed
Interim Enhanced SWTR	No change from SWTR		2 log removal
Long Term 1 ESWTR	No change from SWTR or IESWTR		
Long Term 2 ESWTR	No change from SWTR, IESWTR, or LT1ESWTR		Additional removal and/or inactivation depends upon type of filtration and Bin #:

_____Filtration Plant: _____

Proposed Log Removal /Inactivation Credits

Process	*Giardia*	Virus	*Cryptosporidium*
Filtration (specify type)			
Disinfection/Inactivation			
Chlorine			
Chlorine Dioxide			
Ozone			
Ultraviolet			
Additional Treatment			

Total Logs Reduction: