What should Small Water Systems know about **CT** disinfection?

BC Small Water Systems Webinar

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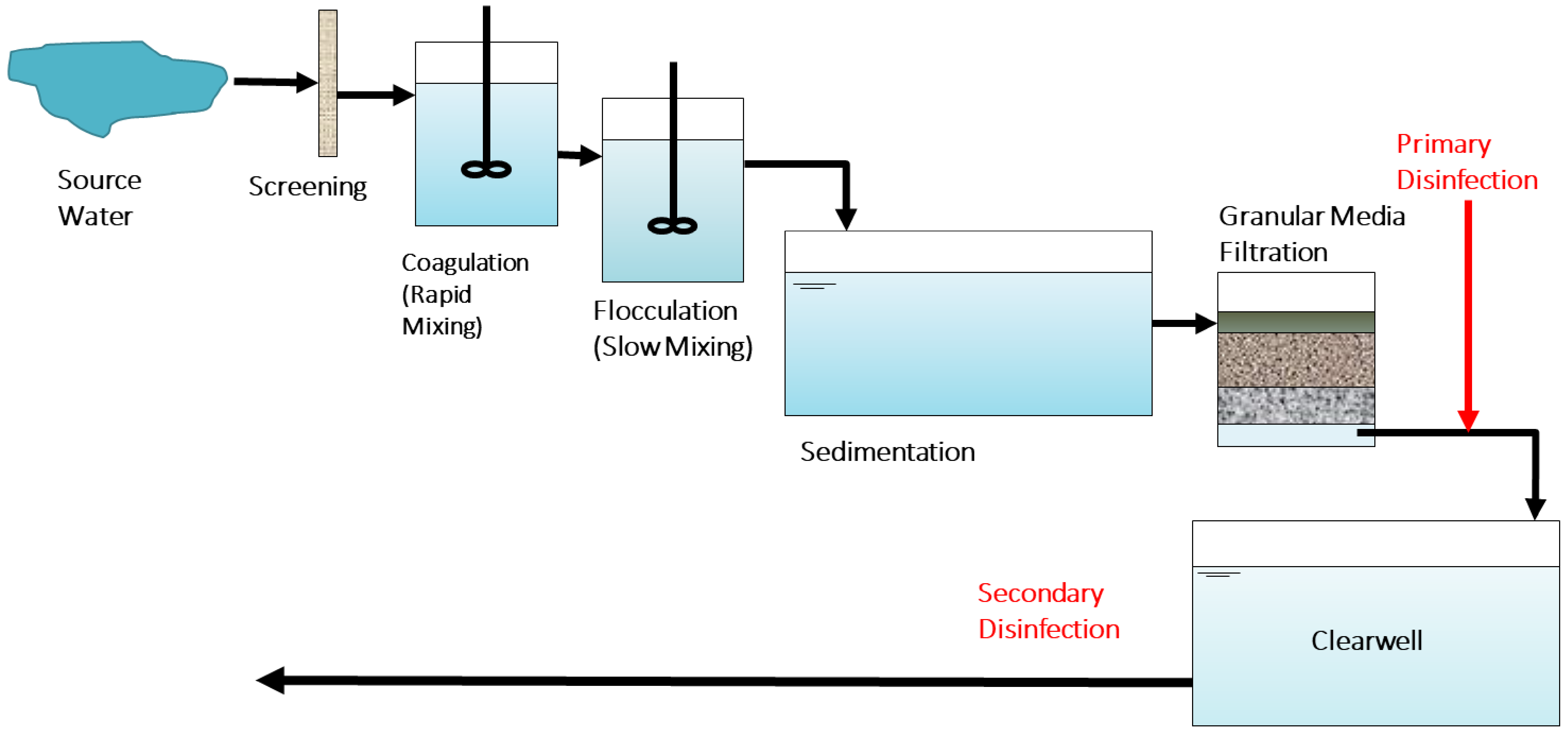
Outline

- Disinfection: the destruction of pathogens
- Guidelines for pathogen reduction
- What is CT?
- How do we get C?
- How do we get T?
    - Calculating volume of a reservoir
    - Calculating theoretical detention time (TDT)
    - Baffling Factors
- Log Credits
- Q&A


Source Water
Screening
Coagulation (Rapid Mixing)
Flocculation (Slow Mixing)
Sedimentation
Granular Media Filtration
Primary Disinfection
Clearwell
Secondary Disinfection

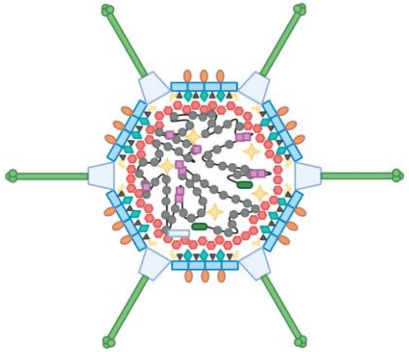
Primary and Secondary Disinfection

- Focused on destroying pathogens – the microorganisms that make people sick
  - Bacteria, Viruses, Protozoa (like Giardia and Cryptosporidium)

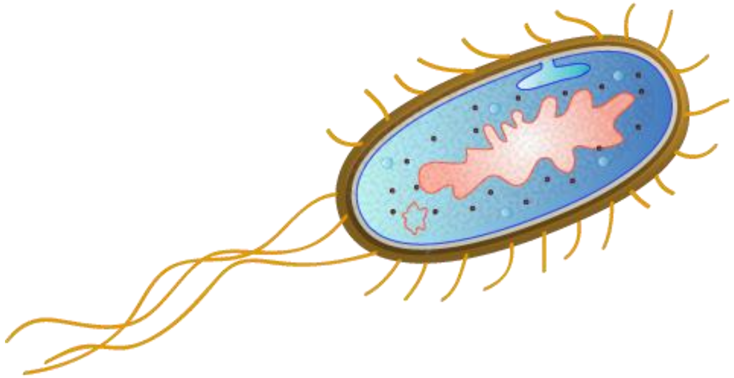
- **Primary Disinfection:** Treating all the pathogens in the water at the treatment facility
    - → Sometimes chlorine, sometimes UV, sometimes ozone

- **Secondary Disinfection:** Making sure pathogens don't regrow, and continue to treat the water in the pipes going to people's homes
    - → Maintaining a chlorine residual

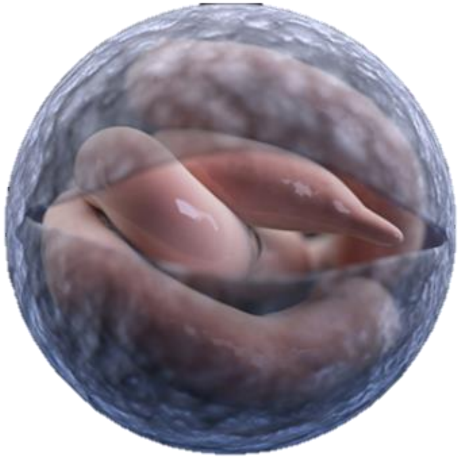
Target Pathogens



Viruses



Bacteria



Protozoa

Image References:
Virus: [Jennings and Parks (MDPI, 2022)]
Bacteria: [Database Centre for Life Science (DBCLS)]
Protozoa: [Centers for Disease Control and Prevention]

Guidelines for pathogen reduction

Surface Water*

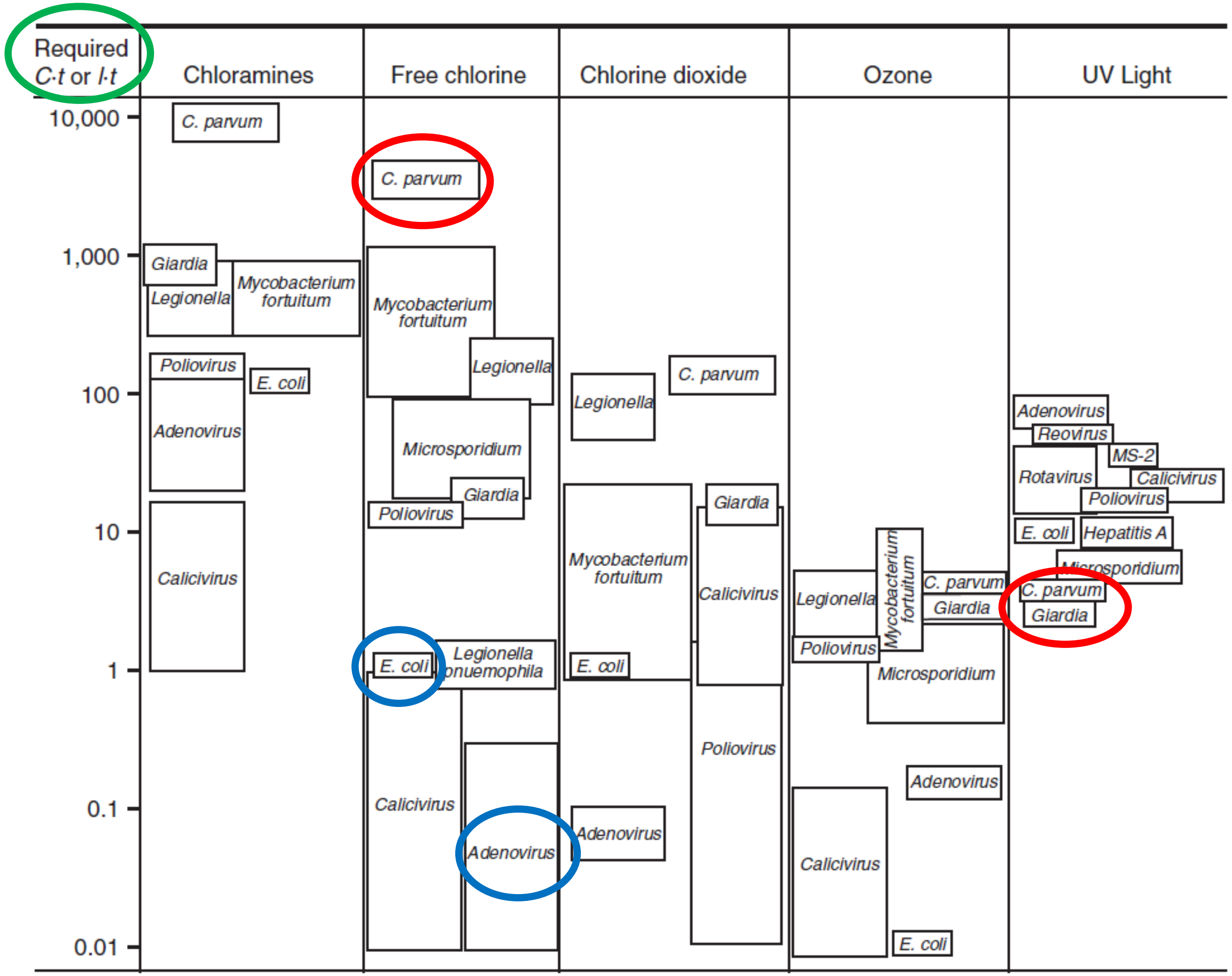
- 4-log (99.99%) reduction of viruses
- 3-log (99.9%) reduction of Giardia and Crypto (protozoa)
- 0 detectable E. coli, total coliform, and fecal coliform (bacteria)

Ground Water

- GARP**: 4-3-2-1-0 rule
- GARP-viruses only: 4-log reduction of viruses

*Also, 2 forms of treatment (e.g., filtration + disinfection) and <1 NTU of turbidity
**Ground Water At Risk of containing Pathogens

Effectiveness of Disinfectants



What is CT?

How effective a disinfectant is depends on both **the concentration of the disinfectant (C)** and **the amount of time it's in contact with the water (T):**

C = concentration of the disinfectant
T = contact time between the disinfectant and the water

$C \times T = CT$ = a constant value required to achieve a specific level of disinfection for a pathogen.

CT values are determined for a <u>specific</u> pathogen

- For example, the table below shows CT values for 3-log removal of Giardia:

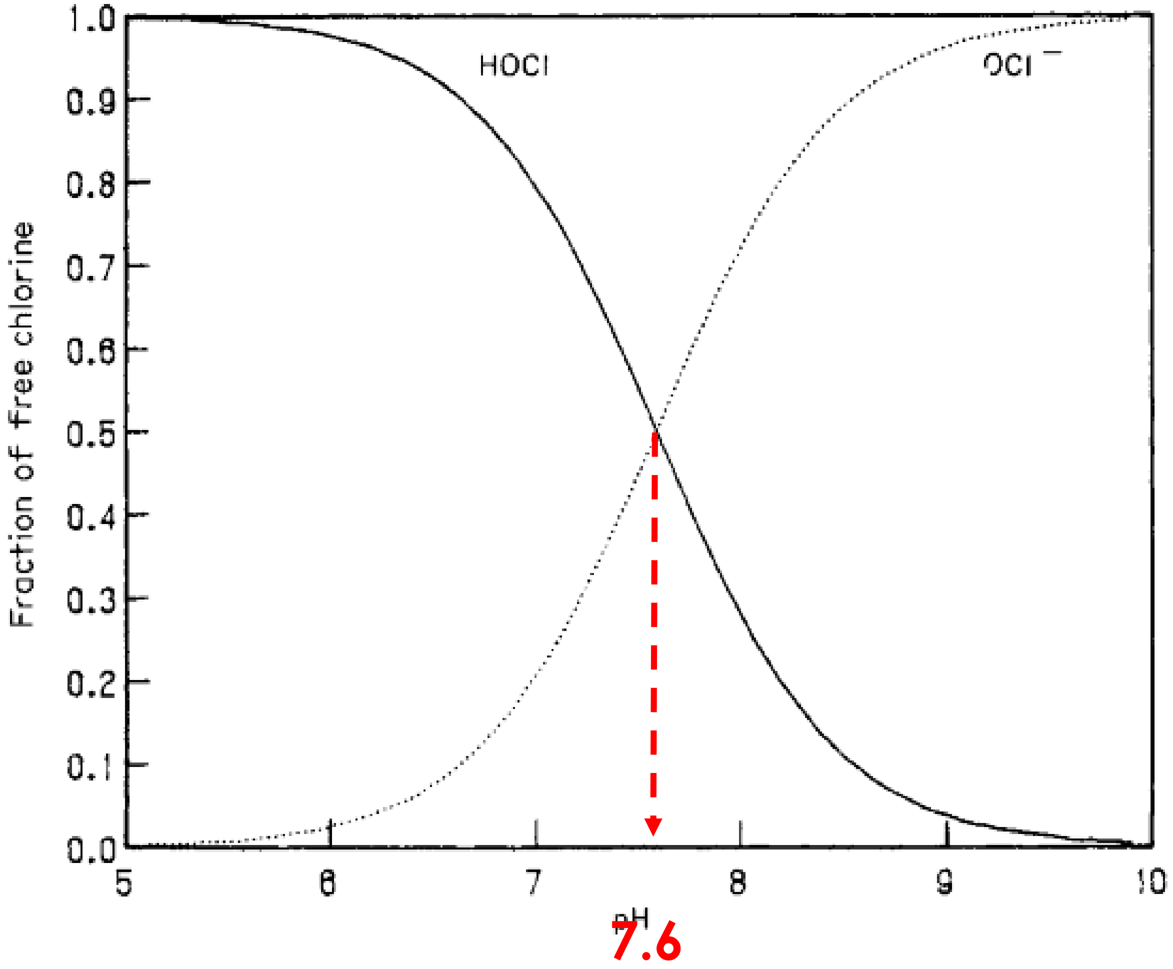
CT values for 3-Log Inactivation of *Giardia* Cysts by Free Chlorine (0.5 °C portion of table for 0.4 to 1.2 mg/L)

Chlorine Concentration (mg/L)	Temperature <= 0.5 °C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	137	163	195	237	277	329	390
0.6	141	169	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451

Note: Temperature and pH affect the CT values!

How Free Chlorine varies with pH

$$HOCl + H_2O \xleftrightarrow{pKa=7.6} H_3O^+ + OCl^-$$



HOCl is a more effective disinfectant than OCl^-

So, **chlorine is more effective at lower pH** values where HOCl is predominant

So as pH gets higher, we need more CT (more disinfection) for the same log removal:

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

Free Chlorine Concentration mg/L	pH ≤ 6						pH = 6.5						pH = 7.0						pH = 7.5					
	Log Inactivation						Log Inactivation						Log Inactivation						Log Inactivation					
	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3	0.5	1	1.5	2	2.5	3
≤ 0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195	40	79	119	158	198	237
0.6	24	47	71	94	118	141	28	56	84	112	140	168	33	67	100	133	167	200	40	80	120	159	199	239
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205	41	82	123	164	205	246
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210	42	84	127	169	211	253
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215	43	86	130	173	216	259
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	221	44	89	133	177	222	266
1.6	26	52	79	105	131	157	32	63	95	126	158	189	38	75	113	151	188	226	46	91	137	182	228	273
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231	47	93	140	186	233	279
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236	48	95	143	191	238	286
2.2	28	56	85	113	141	169	34	67	101	134	168	201	40	81	121	161	202	242	50	99	149	198	248	297
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247	50	99	149	199	248	298
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252	51	101	152	203	253	304
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257	52	103	155	207	258	310
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261	53	105	158	211	263	316

Higher temperatures generally lead to more effective disinfection

Notice how the required CT values are lower when the water temp is higher:

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

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

How do we get **C**?

When calculating CT, **the value of C** is <u>the concentration of the disinfectant at the outlet of the contact tank</u>.

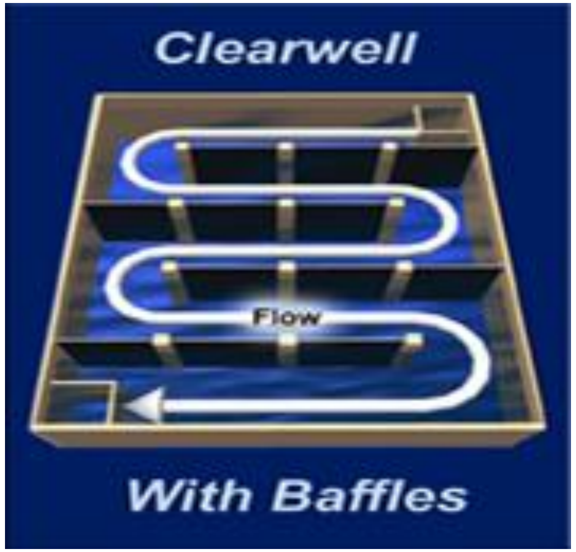
Take a water sample and measure the amount of free chlorine (e.g., using the DPD method). Determine the concentration in mg/L.

Why do we measure C there?

Because, the concentration of disinfectant (e.g., free chlorine) decreases as it reacts in the contact tank. Measuring at the outlet gives us a conservative estimate of the concentration in the tank.

How do we get **T**?

First, let's think about how the disinfectant is in **contact** with the water (and the pathogens in it):



How do we get **T**?

The time (T) that the disinfectant is in contact with water can be determined in a couple of ways:

1. Get the t_{10} from a residence time distribution curve

2. Use the Flow rate, Volume of the contact basin and a Baffling Factor

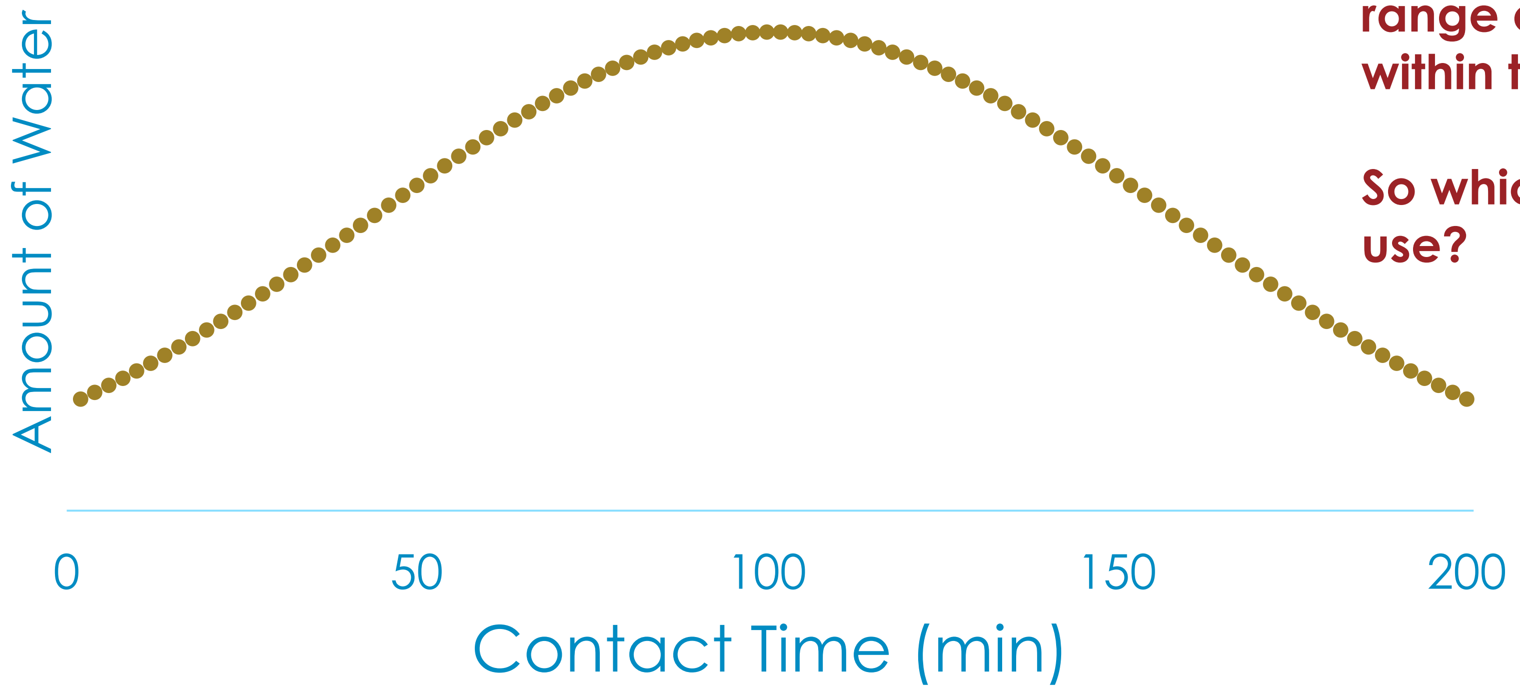
What's a t_{10}?

When you add water to a contactor, it doesn't flow perfectly through the system in single-file order, like this:

This is called "Ideal Plug Flow". In reality, some water can bypass the normal flow path and short-circuit the contact tank, leaving the outlet earlier than we want.

What's a t_{10}?

A **residence time distribution (RTD) curve** can tell you the different amounts of time water spends in the contact tank:

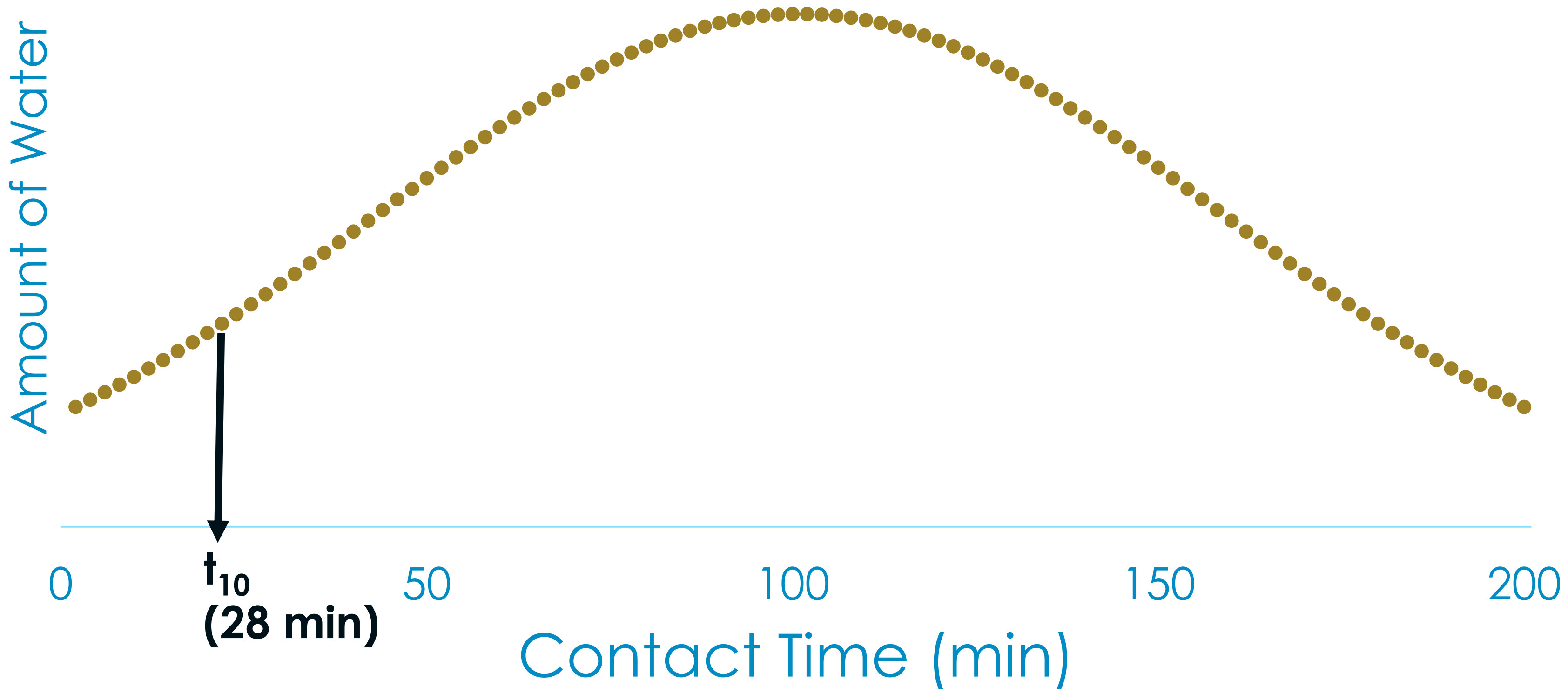


The RTD tells you the range of contact times within the tank.

So which time should you use?

$\mathbf{T} = t_{10}$ from the RTD

To be on the safe side, the contact time **T** is taken as the time **the first 10% of the water passes through the contactor** (known as $\mathbf{t_{10}}$). This should be provided by the manufacturer.



What if we don’t have an RTD and the manufacturer doesn’t give us any information on the t_{10}?

You can estimate it using a Baffling Factor (BF)

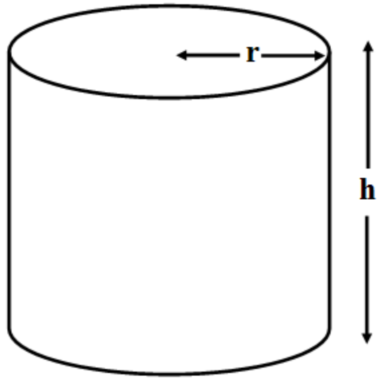
Baffling Factor Method

1. Calculate the volume of the contact basin (V)
2. Measure the peak hourly flowrate through the contact basin (Q)
3. Calculate the Theoretical Detention Time (TDT)
   - This could also be called the Theoretical Retention Time (TRT), or Ideal Retention Time.
4. Determine the Baffling Factor (BF) using the BF Table
5. Calculate T by multiplying the TDT by the BF

1. Calculate the Volume of Contactor

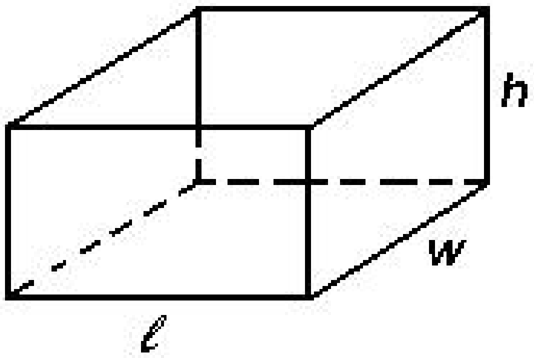
Volume of cylinder:

$$V = \pi r^2 h$$



Volume of rectangular basin:

$$V = lhw$$



2. Measure flow rate (Q) to contactor

- Use a flow meter to read the flowrate

- Use the **peak hourly flowrate** for the calculation
  - Try to always use the “worst case scenario”

3. Calculate the Theoretical Detention Time (TDT)

TDT = V/Q

Example:

A chlorine contactor with serpentine baffles has a volume of 250 m^3 and the peak hourly flow rate is 2 m^3/min. The chlorine residual is 0.8 mg/L.

What is the TDT?

$$TDT = \frac{V}{Q} = \frac{250\ m^3}{2\ \frac{m^3}{min}} = 125\ minutes$$

4. Baffling Factor (BF)

Example:
A chlorine contactor with <u>serpentine baffles</u> has a volume of 250 m^3 and the peak hourly flow rate is 2 m^3/min. The chlorine residual is 0.8 mg/L.

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.

5. Calculate T

$$T = TDT \times BF$$

Example:
A chlorine contactor with serpentine baffles has a volume of 250 m^3 and the peak hourly flow rate is 2 m^3/min. The chlorine residual is 0.8 mg/L.

$$T = TDT \times BF = 125\,min \times 0.7 = 87.5\,min$$

What is the CT?

$$CT = C \times T = 0.8\frac{mg}{L} \times 87.5\,min = 70\ \frac{mg\ min}{L}$$

Log Credits

We calculated that the CT in the previous example is:

$$CT = 70\ \frac{mg\ min}{L}$$

Remember that CT table for 3-log removal of Giardia? Let's say pH is 6.5 and temperature is 0.5 °C. **What is the required CT value?**

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0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451

Log Credits

So, the required CT for 3-log removal of giardia is 172 mg min/L and our chlorination tank is giving us a CT of 70 mg min/L.

How many giardia removal log credits do we get for our chlorine tank?

$$Log\ Credits = \frac{CT_{calculated}}{CT_{required}} \times (Required\ Log\ Removal)$$

$$Log\ Credits = \frac{70\ \frac{mg\ min}{L}}{172\ \frac{mg\ min}{L}} \times (3\ Log\ Removal) = 1.2\ Log\ Credits$$

Example

You are targeting a CT value of 90 mg.min/L for 4-log removal of Viruses.

You take a sample at the outlet of the contact tank and measure the chlorine residual to be 1.5 mg/L.

You measure the water flow rate to be 2 m^3/min.

The contact basin volume is 300 m^3.

The contact basin has a baffle at the inlet and some baffles inside.

What is the calculated CT value? How many Log Credits have you achieved?

You are targeting a CT value of 90 mg.min/L for 4-log removal of Viruses.

You take a sample at the outlet of the contact tank and measure the chlorine residual to be 1.5 mg/L. ← **C**

You measure the water flow rate to be 2.25 m^3/min. ← **Q**

The contact basin volume is 300 m^3. ← **V**

The contact basin has a baffle at the inlet and some baffles inside.

What is the calculated CT value? How many Log Credits have you achieved?

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.

$$TDT = \frac{V}{Q} = \frac{300\ m^3}{2.25\ \frac{m^3}{min}} = 133.33\ minutes$$

$$T = TDT \times BF = 133.33\ min \times 0.5 = 66.67\ min$$

$$CT = C \times T = 1.5\frac{mg}{L} \times 66.67\ min = \mathbf{100}\ \frac{\mathbf{mg\ min}}{\mathbf{L}}$$

$$Log\ Credits = \frac{100\ \frac{mg\ min}{L}}{90\ \frac{mg\ min}{L}} \times (4\ Log\ Removal) = 4.44\ Log\ Credits$$

Summary

- How effective a disinfectant is depends on both **the concentration of the disinfectant (C)** and **the amount of time it's in contact with the water (T)**
  - **CT = C×T**
- **C** should be measured at the outlet of the contact tank
- **T** is the amount of time the first 10% of water leaves the contact tank (t_{10}) according to the RTD
- If you don't know t_{10}, you can estimate it using:
  - Volume of the contact tank (V)
  - Peak flow rate (Q)
  - Baffle Factor (BF)
- Look up the CT required to achieve target log removal for a pathogen
- Compare the calculated CT for your system with the required CT to determine how many log credits your system has achieved.

Questions?