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Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

Chlorine Disinfection and CT Calculations

Tuesday April 15, 2025 (1:00 to 2:00 pm EST)

Instructor: Greg Pearson, Great Lakes Environmental Infrastructure Center, MTU

This program is made possible under a cooperative agreement with US EPA.

Certificate of Completion

This session has **NOT** been submitted for pre-approval of Continuing Education Credits, but eligible attendees will receive a certificate of attendance for their personal record.

To receive a certificate:

- You must attend the entire session
- You must register and attend using your real name and unique email address - group viewing credit will not be acceptable
- You must participate in polls
- Certificates will be sent via email within 30 days

If you have questions or need assistance, please contact smallsystems@syr.edu.

EFCN environmental finance center network

About Us

The **Environmental Finance Center Network (EFCN)** is a university- and non-profit-based organization creating innovative solutions to the difficult how-to-pay issues of environmental protection and water infrastructure.

The EFCN works collectively and as individual centers to address these issues across the entire U.S, including the 5 territories and the Navajo Nation. The EFCN aims to assist public and private sectors through training, direct professional assistance, production of durable resources, and innovative policy ideas.

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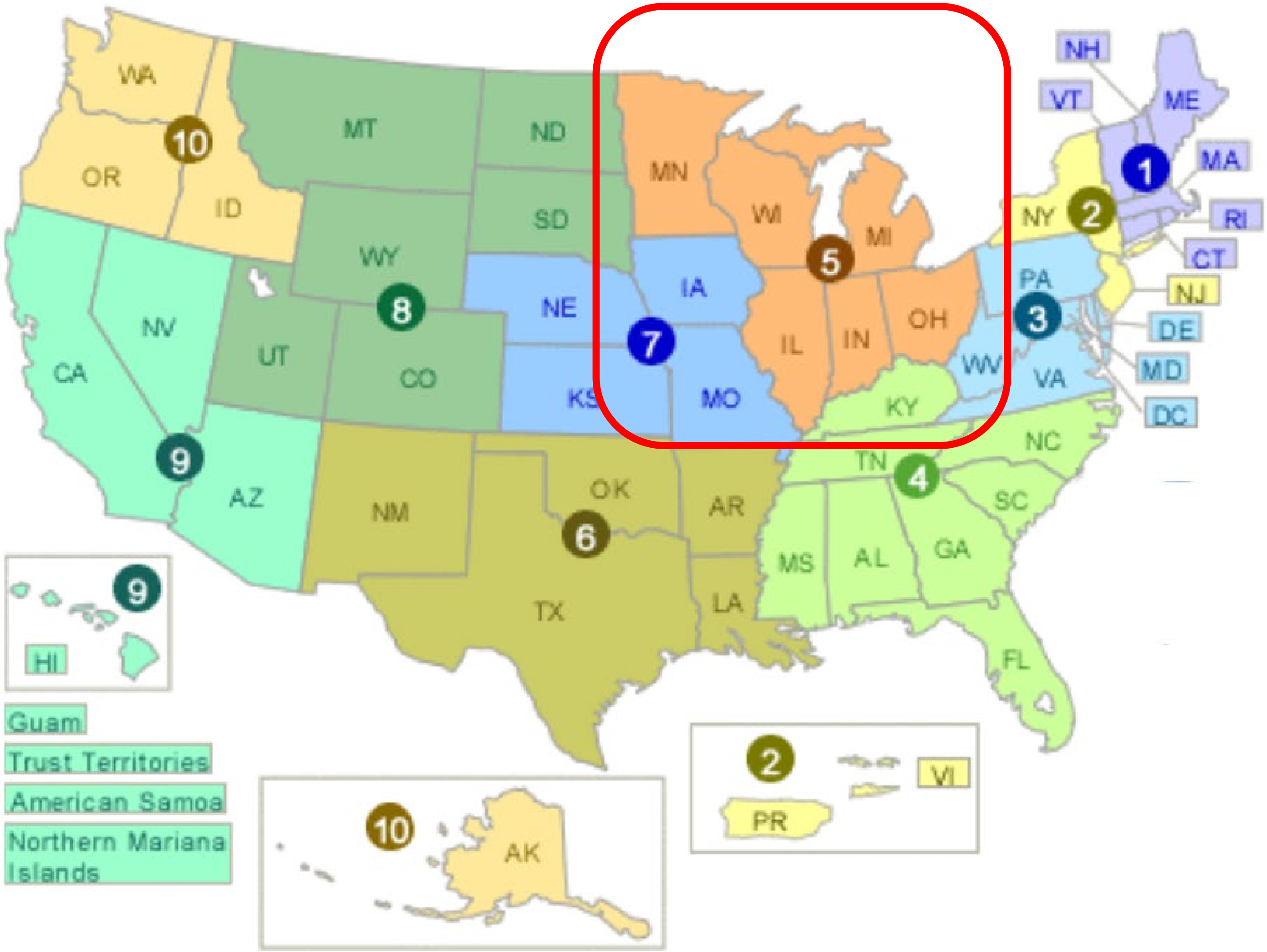
Nationwide reach of EFC Network



Great Lakes Environmental Infrastructure Center

Environmental Finance Center for EPA Region 5

Serve small communities (population of less than 10,000) throughout EPA Region 5: Indiana, Illinois, Michigan, Minnesota, Ohio, Wisconsin, and 35 federally recognized American Indian governments.

Training, Research, and Technical Assistance with a mission to help water and wastewater utilities increase technical, managerial, and financial capacity (TMF).

Examples: Asset management, infrastructure funding, financial management, compliance and operations

GLEIC Staff
Tim Colling P.E., Director
Daryl Gotham, P.E. Senior Research Engineer
John Sullivan P.E. , Senior Research Engineer
Greg Pearson, MBA Water & Wastewater Systems Trainer

Disinfection Overview

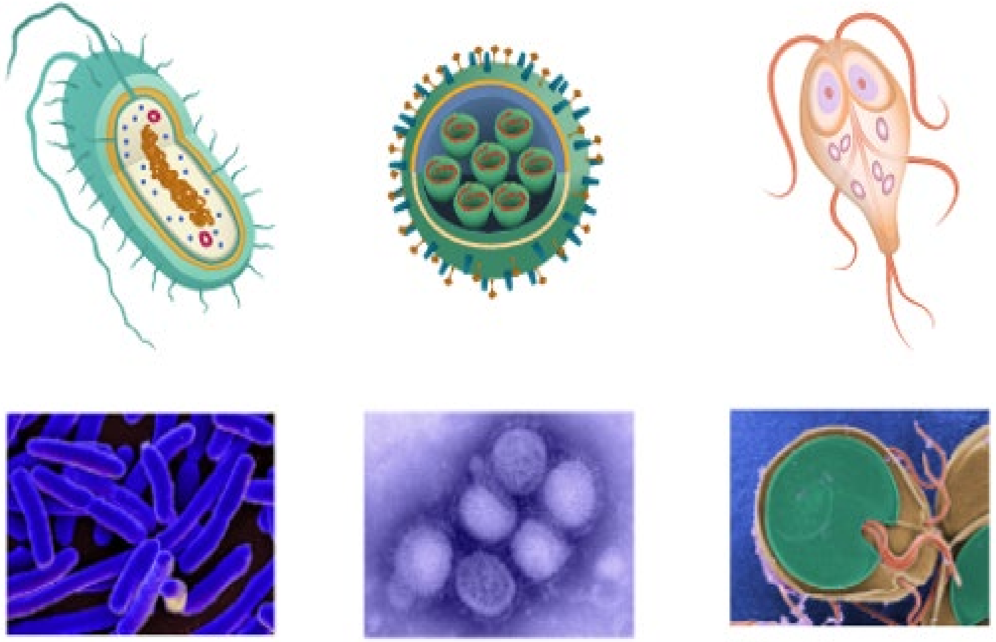
Pathogen Groups

Disinfection: The inactivation and/or destruction of pathogenic organisms in drinking water to protect public health.

The effectiveness of chlorine disinfection depends primarily on:

1. Residual concentration
2. Contact time

(Other factors include pH, turbidity, temperature, & reducing compounds)



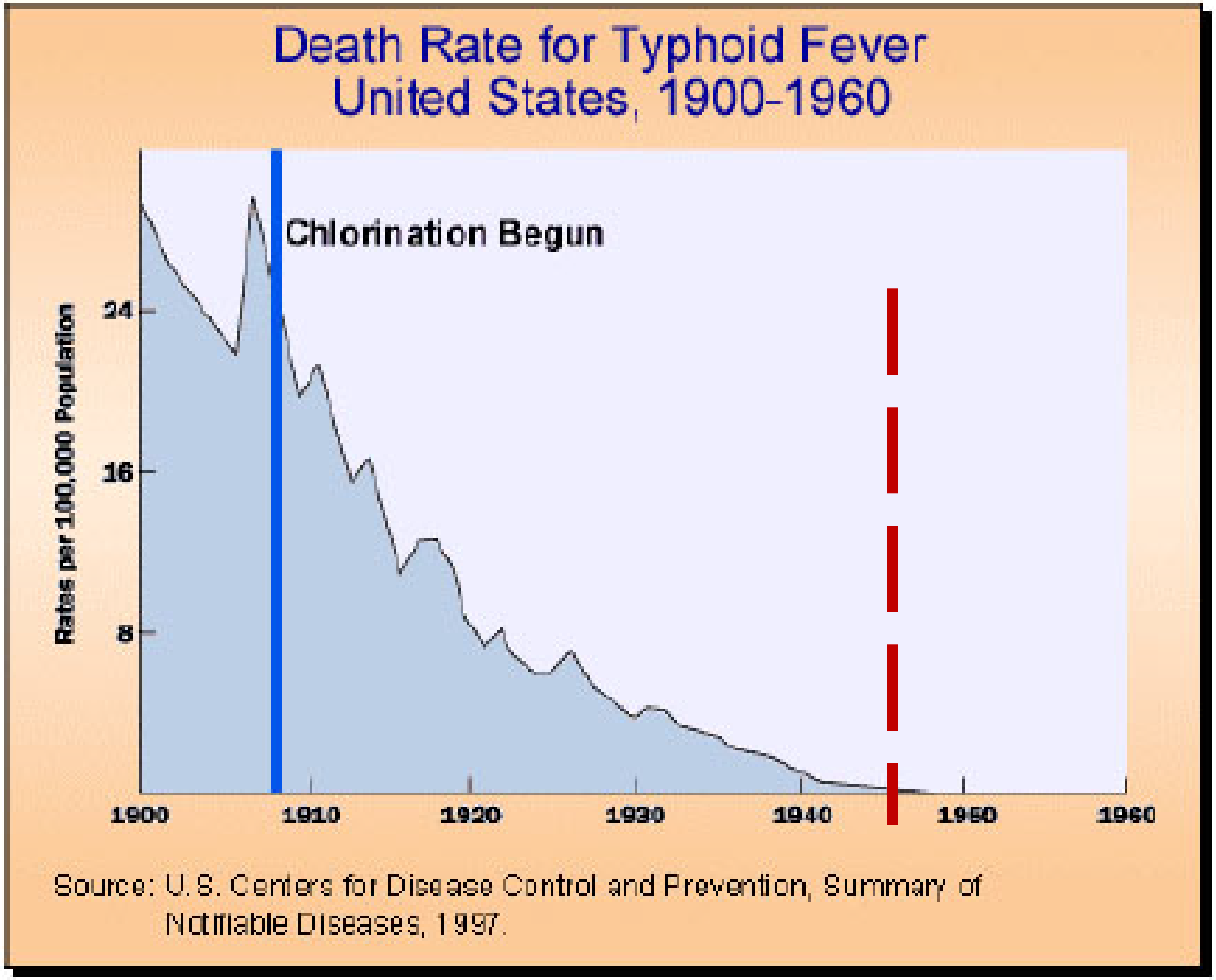
E. coli Bacterium

Influenza virus Virus

Giardia Protozoan

Health impact of chlorine disinfection

- 1908 Jersey City Water Works first system in US to chlorinate drinking water
- 1,000s of deaths due to water borne diseases (typhoid, cholera, and other pathogens)
- Finally achieved less than 1 death per 100,000 by around 1945
- Germ Theory in1860s, French chemist Louis Pasteur



Three Essential Questions

1. Theoretical

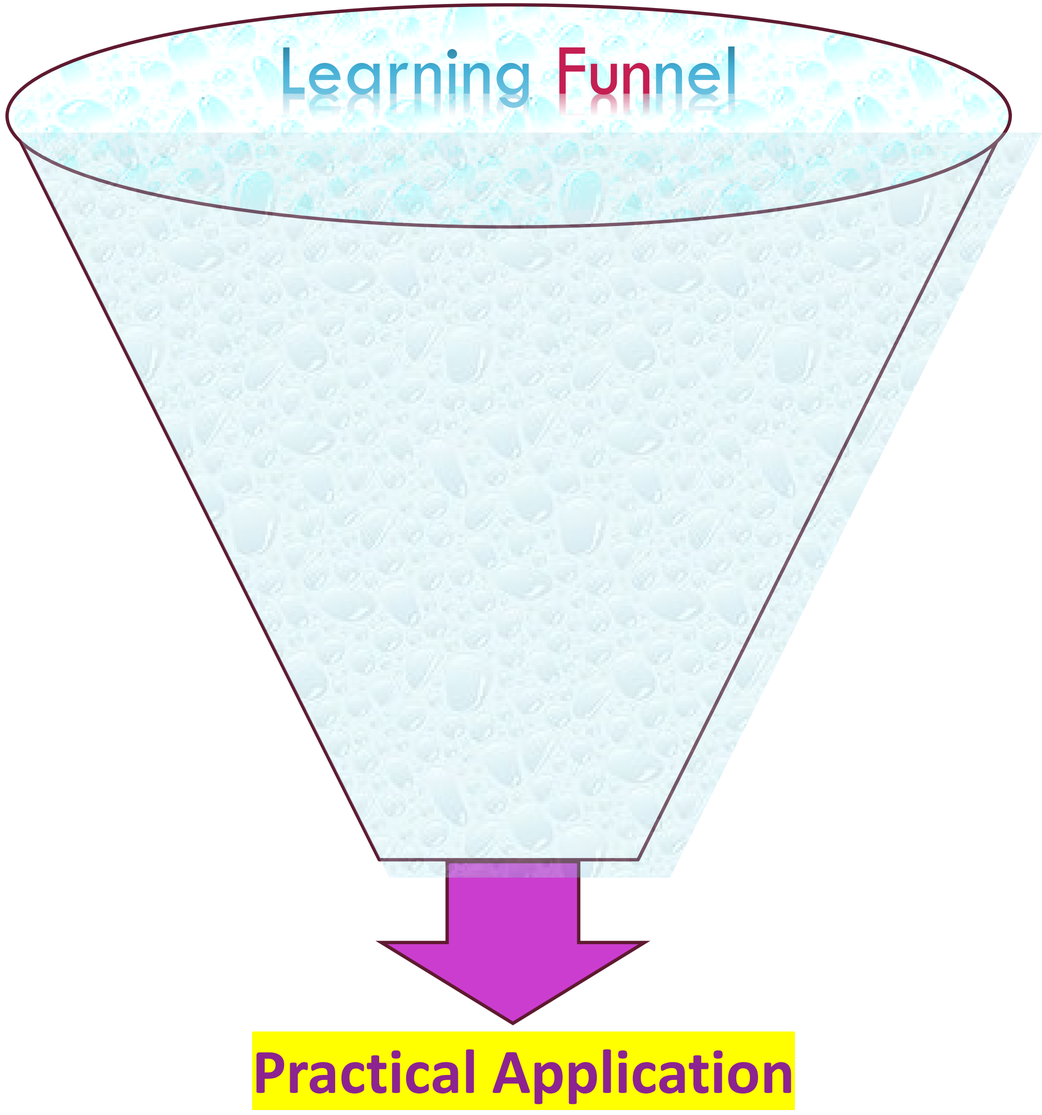
How do we understand the concepts of chlorine dose, demand, and residual?

2. Operational Math

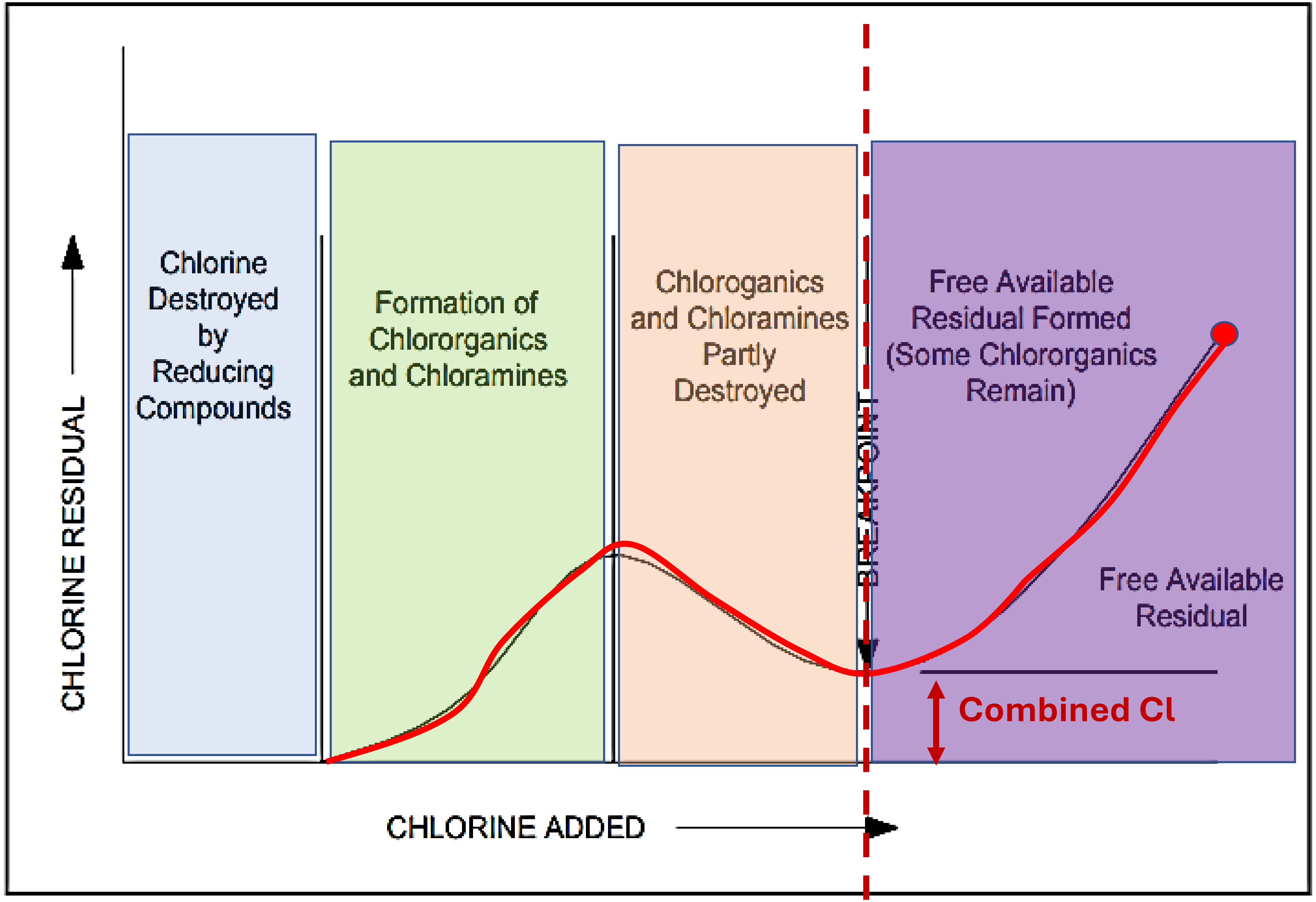
How do we calculate dosage and feed rates for the gas, solid, and liquid forms of chlorine?

3. Compliance

How do we evaluate CT values to achieve log treatment compliance for viruses and giardia ?



Chlorine curve (total residual as chlorine is added)



Legend:

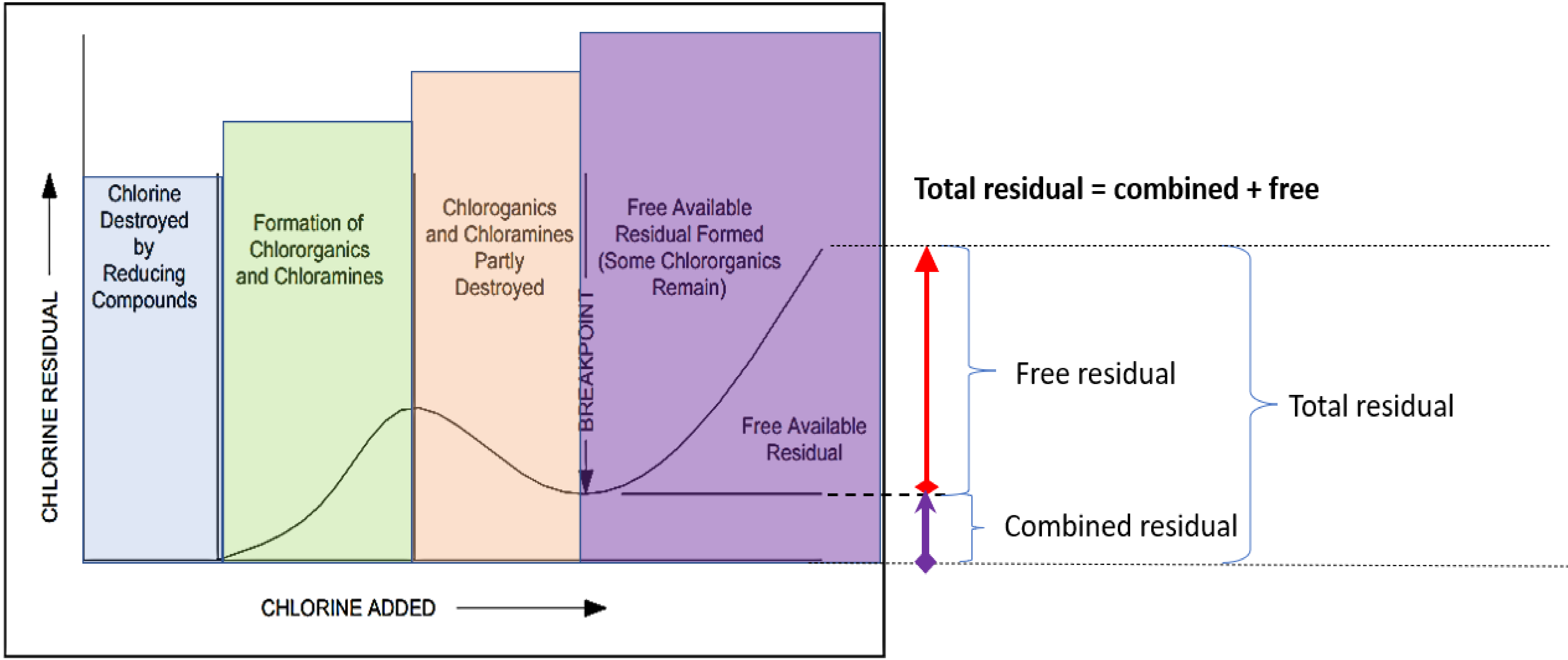
A: Reducing compounds use up chlorine.

B: Chloramines produced (combined chlorine)

C: Chloramines partly destroyed (also di and trichloramines produced)

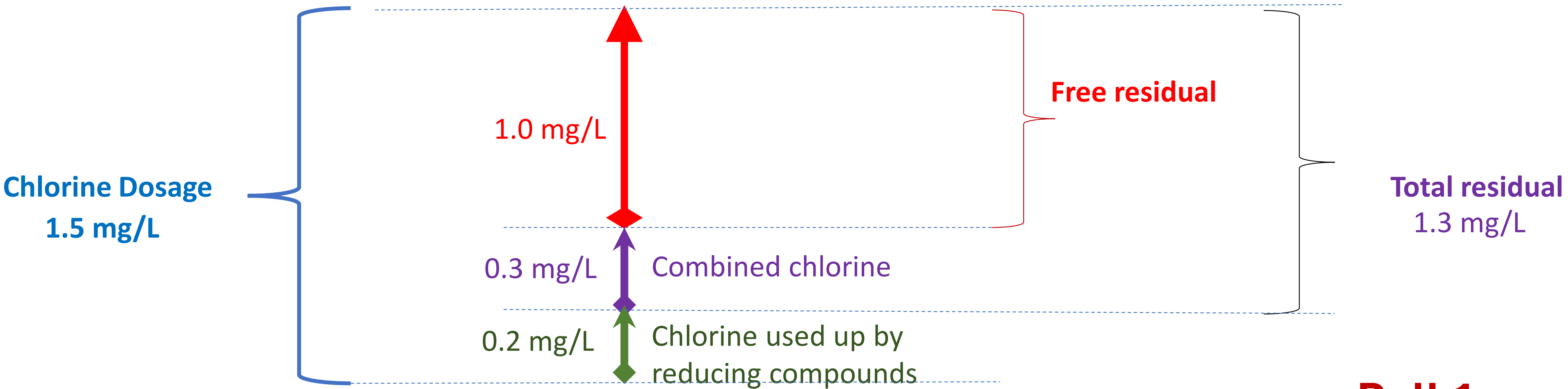
----- Breakpoint -----

D: After "breakpoint" free residual begins to build


Chlorine Destroyed by Reducing Compounds
Formation of Chlororganics and Chloramines
Chloroganics and Chloramines Partly Destroyed
Free Available Residual Formed (Some Chlororganics Remain)
BREAKPOINT
Free Available Residual
CHLORINE RESIDUAL
CHLORINE ADDED
Total residual = combined + free
Free residual
Total residual
Combined residual

Dose = Demand + Residual

A dose of 1.5 mg/L chlorine is added to water resulting in a measured free residual of 1.0 mg/L and a total residual of 1.3 mg/L. What is the demand from reducing compounds?



Poll 1

How do we find the demand? (Dose – total residual)

1.5 mg/L – 1.3 mg/L = 0.2 mg/L demand

1.5 mg/L = 1.0 mg/L free residual + 0.3 mg/L combined + 0.2 mg/L demand

Poll #1

A drinking water with a demand of 0.4 mg/L has a total chlorine residual of 1.7 mg/L. What was the chlorine dose?

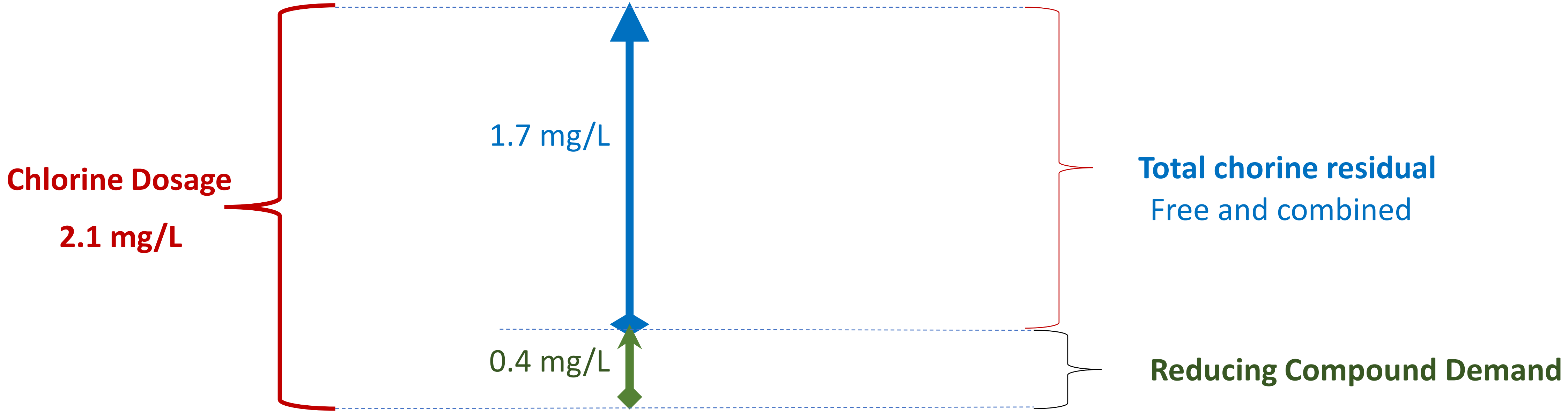
a. 1.3 mg/L

b. 1.4. mg/L

c. 2.1 mg/L

d. 5.7 mg/L

Dose = Residual + demand

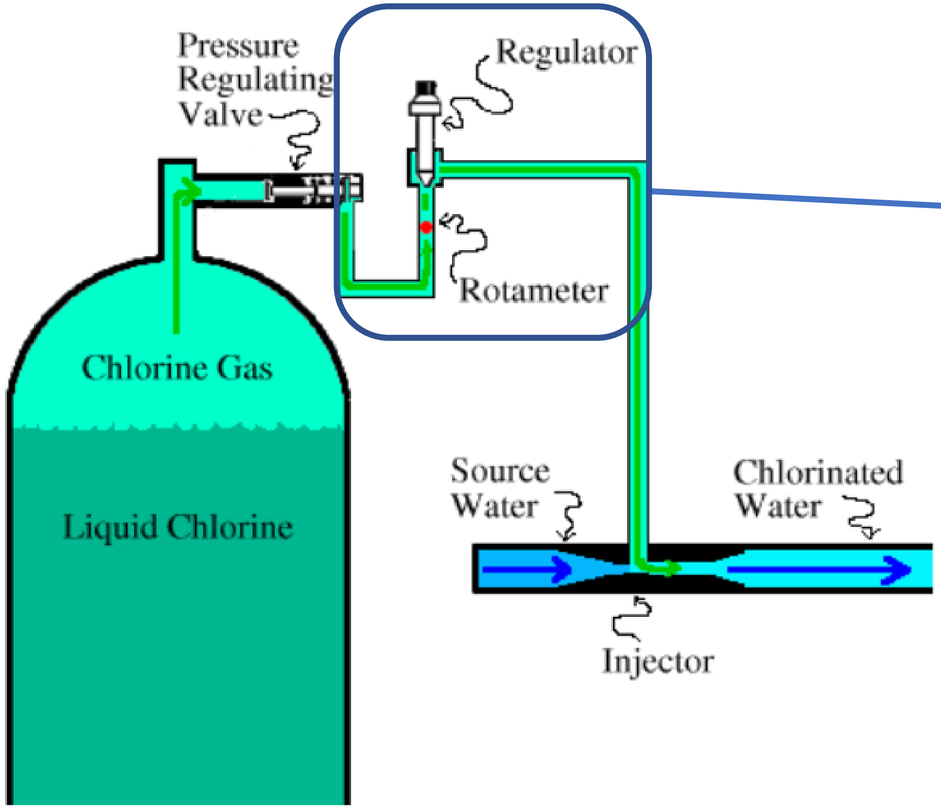


Dose = **0.4 mg/L** demand + **1.7 mg/L total** residual = **2.1 mg/L**

Gas chlorine feed rate

Pounds per Day = MGD(flow) x mg/L(dose) x 8.34 lbs/gallon

Note that pounds per day is a **rate** of feed.



Rotameter will provide units in lbs/day

Up to approximately 40 lbs/day

What is the feed rate setting for chlorine gas in lbs/day if the plant flow is 1.2 MGD and the dosage concentration is 1.5 mg/L?

Solution: Plug in 1.2 MGD for flow, and 1.5 mg/L for dosage into the formula. Remember, the constant 8.34lbs/gal does not change.

Chlorine Feed in lbs/day =

1.2 MGD x 1.5 mg/L x 8.34 lbs./gal = 15 lbs./day

The lbs. formula

Pounds per Day = MGD(flow) x mg/L(dose) x 8.34 lbs/gallon

1 MG = 1 million gal
(how many MG in total?)

Parts per million
(how many millionths in each MG?)

Weight of water
(Weight of 1 gal of water. Weight of substance is considered a portion of the total water weight)

Conceptual example: 1.2 MGD x 1.5 mg/L x 8.34 lbs./gal = 15 lbs/day

water weight = 1,200,000 gal x 8.34 lbs./gal = 10,008,000 lbs

$\frac{\text{1.5 parts chlorine}}{\text{1,000,000 parts water}}$ x 10,008,000 lbs = 15 lbs (the weight of chlorine)

Pounds formula can be arranged to solve for dose.

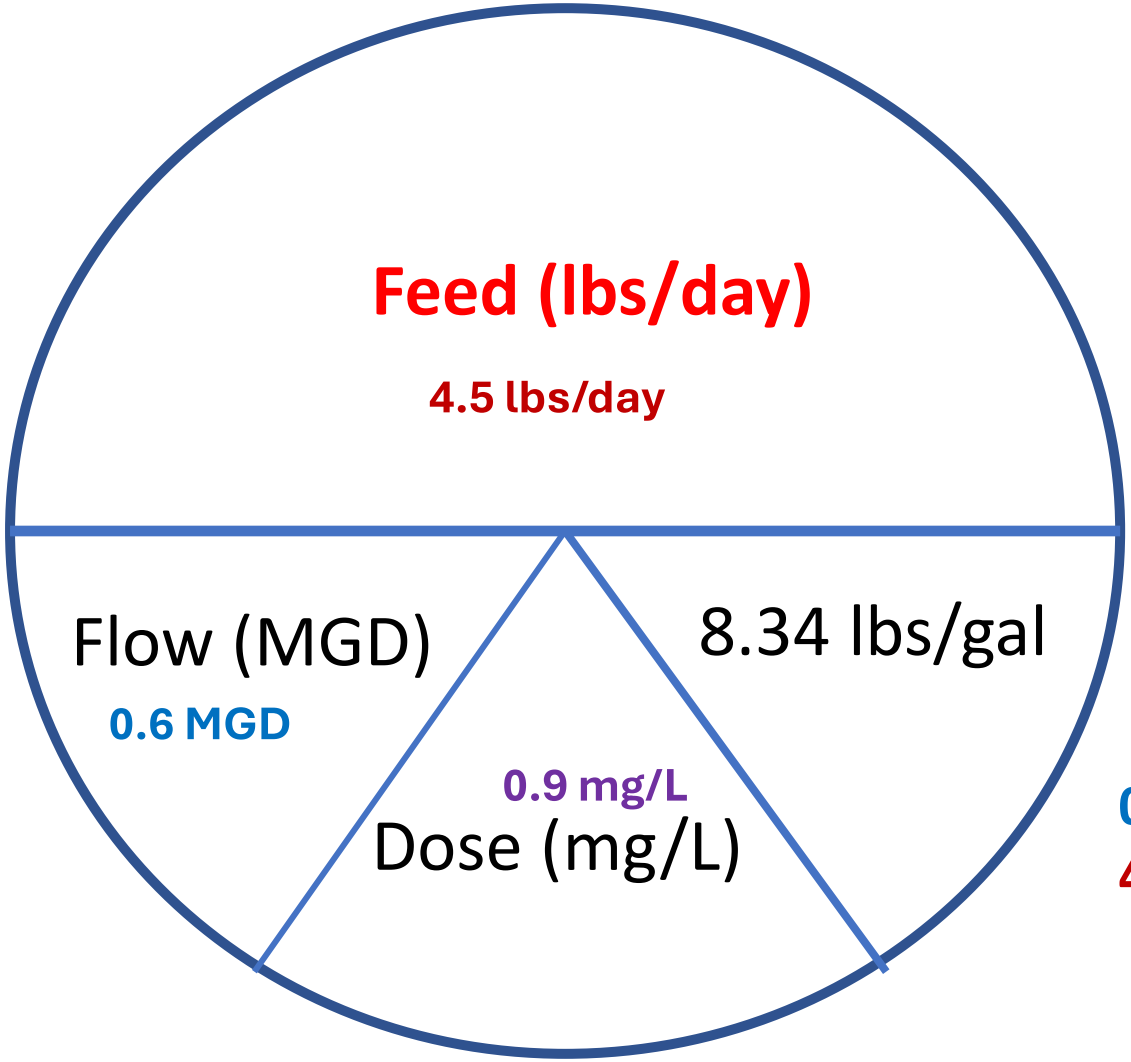
Pounds per Day = MGD(flow) x mg/L(dose) x 8.34 lbs/gallon

$$\frac{\text{Pounds per day}}{[\text{Flow(MGD)} \times 8.34\text{lb/gal}]} = \frac{\text{Dose (mg/L)} \times \text{Flow (MGD)} \times 8.34 \text{ lbs./gal}}{[\text{Flow (MGD)} \times 8.34\text{lb/gal}]}$$

$$\text{Dose (mg/L)} = \frac{\text{Pounds per Day}}{[\text{Flow(MGD)} \times 8.34\text{lb/gal}]}$$

Pie Formula

Example: Calculate the gas chlorine feed rate for a plant with a flow of **0.6 MGD** and a dose of **0.9 mg/L**



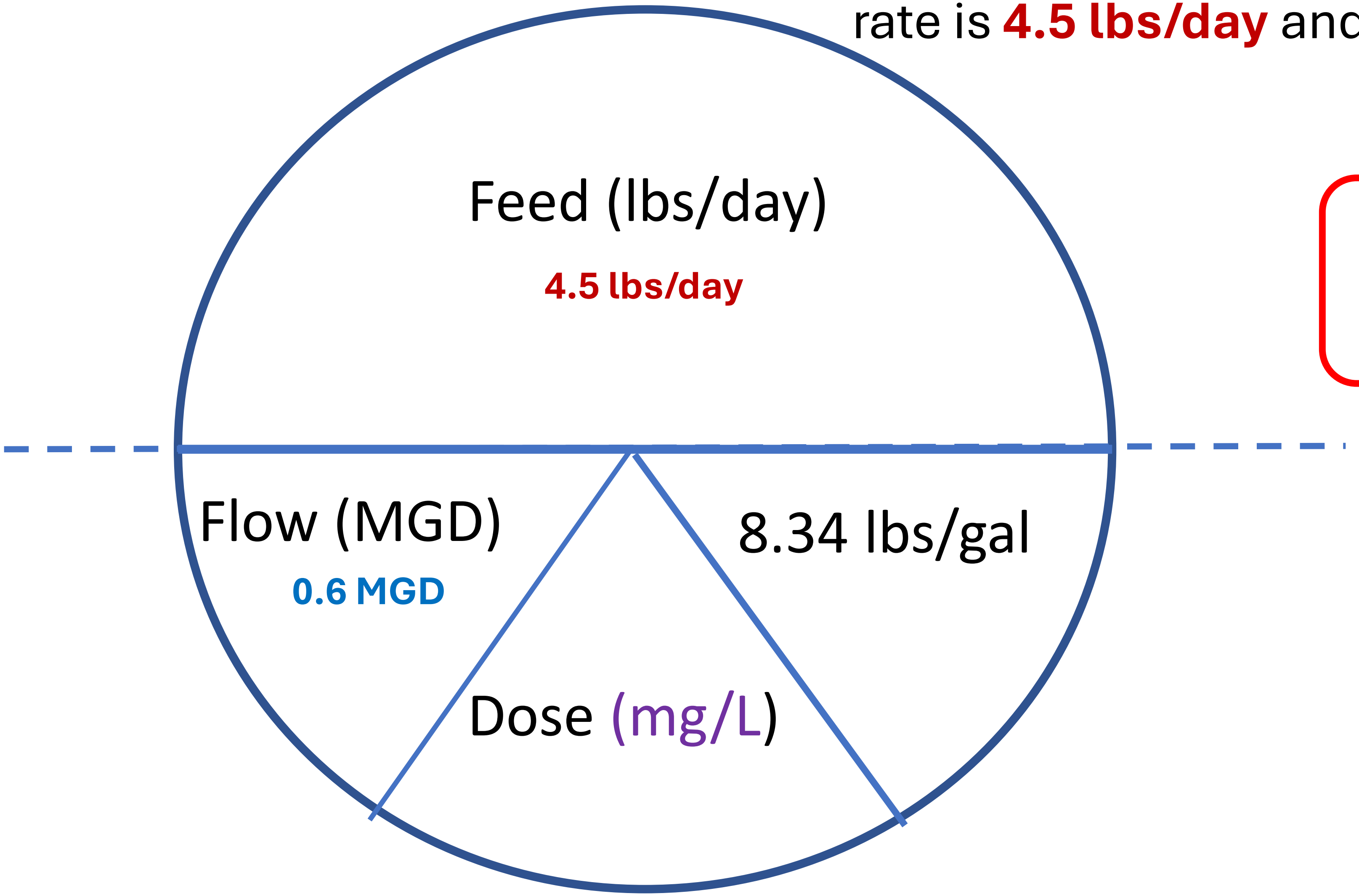
Multiply across bottom to solve top of chart.

MGD x mg/L x 8.34lb/gal = lbs/day

0.6 MGD x 0.9 mg/L x 8.34lb/gal = 4.5 lbs/day

Pie Formula (When solving for an unknown in the bottom.)

Example: Calculate the dose if gas chlorine feed rate is **4.5 lbs/day** and the plant flow is **0.6 MGD**.



$$\text{Dose} = \frac{\text{Feed in Pounds per day}}{\text{MGD} \times 8.34 \text{ lb/gal}}$$

$$\text{Dose} = \frac{4.5 \text{ pounds per day}}{0.6 \text{ MGD} \times 8.34 \text{ lbs/gal}}$$

Dose = 0.9 mg/L

Poll 2

Poll 2

An operator checks the settings at a treatment plant and notes that the gas chlorine feed rate is set at 30 pounds per day and that the plant flow is 2.1 MGD. What is the dose of chlorine in mg/L that is being administered to this water source?

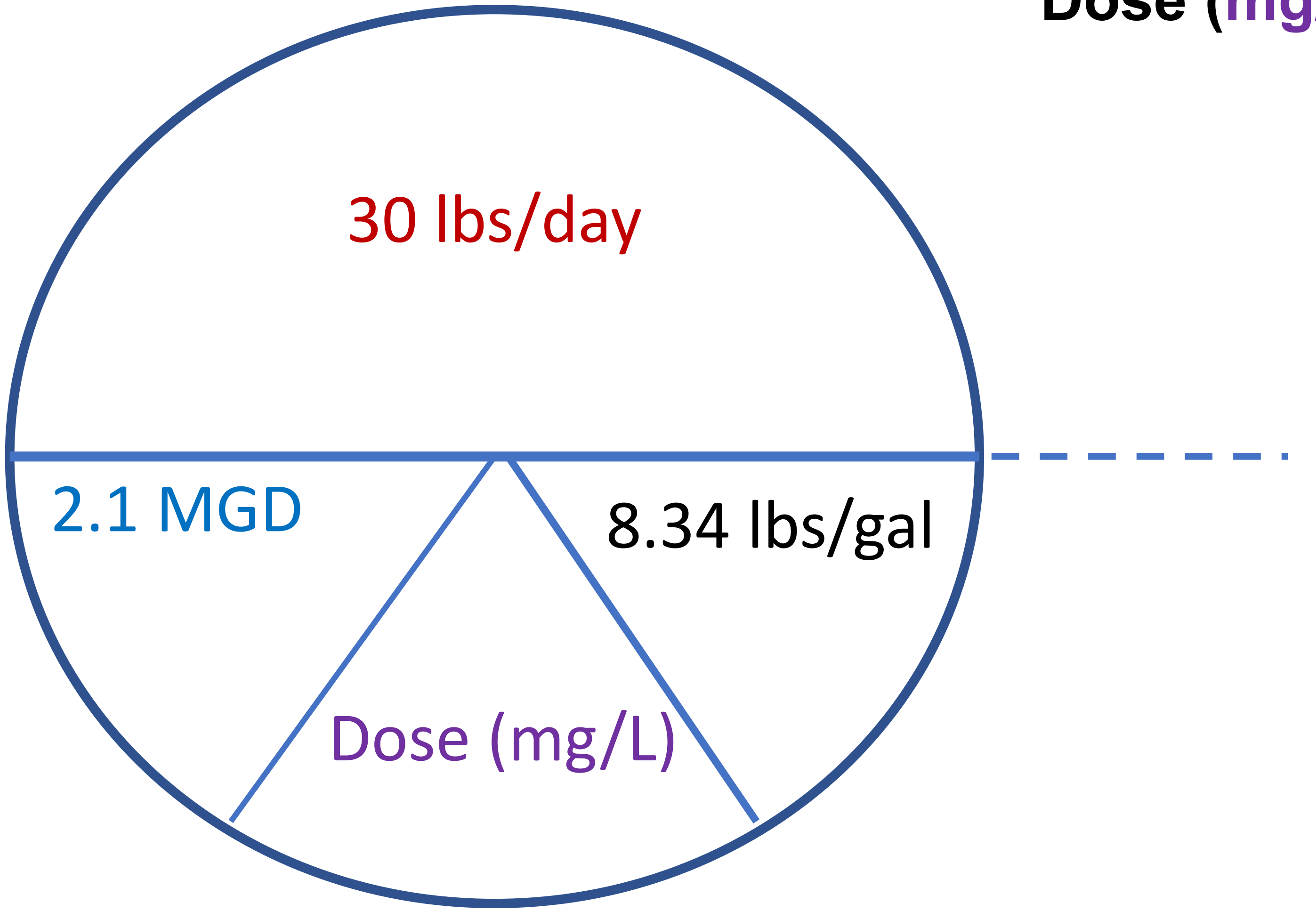
a) 1.7 mg/L

b) 0.58 mg/L

c) 0.33 mg/L

d) 0.15 mg/L

An operator checks the settings at a treatment plant and notes that the chlorine feed rate is set at **30 pounds per day** and that the plant flow is **2.1 MGD**. What is the **dose of chlorine in mg/L** that is being administered to this water source?



$$\text{Dose (mg/L)} = \frac{\text{Pounds per Day}}{[\text{Flow(MGD)} \times 8.34\text{lb/gal}]}$$

$$\text{Dose} = \frac{\text{30 Pounds per day feed}}{\text{2.1 MGD} \times \text{8.34 lb/gal}}$$

$$= 1.71 \text{ mg/L}$$

Calcium Hypochlorite
(Also called high test hypochlorite or HTH).

Top part of equation calculates lbs of pure Cl

$$\text{Lbs} = \frac{\text{Volume MG} \times \text{Dose in mg/L} \times 8.34\ \text{lbs./gal}}{\%\ \text{strength of HTH}}$$

Dividing by % strength gives weight of material needed.




Calcium hypochlorite can be in the form of tablets, pellets, or powder. It is generally 65% to 70% strength.

Disinfecting a water main

A new 8-inch water main, 500-feet in length, has been installed and needs to be disinfected with a dose of 50 mg/L. How many pounds of 65% strength HTH will be required?

Step 1: Calculate volume of main in MG

Volume = D^2 x 0.785 x L x 7.48 gal/cf [Diam and Length in ft.]

$$V = \frac{0.67ft \times 0.67ft \times 0.785 \times 500ft \times 7.48gal/cf}{1,000,000\ gal/MG} = \mathbf{0.001318\ MG}$$

Step 2: Use calcium hypochlorite formula

$$Pounds = \frac{0.001318\ MG \times 50mg/L \times 8.34lb/gal}{0.65} =$$

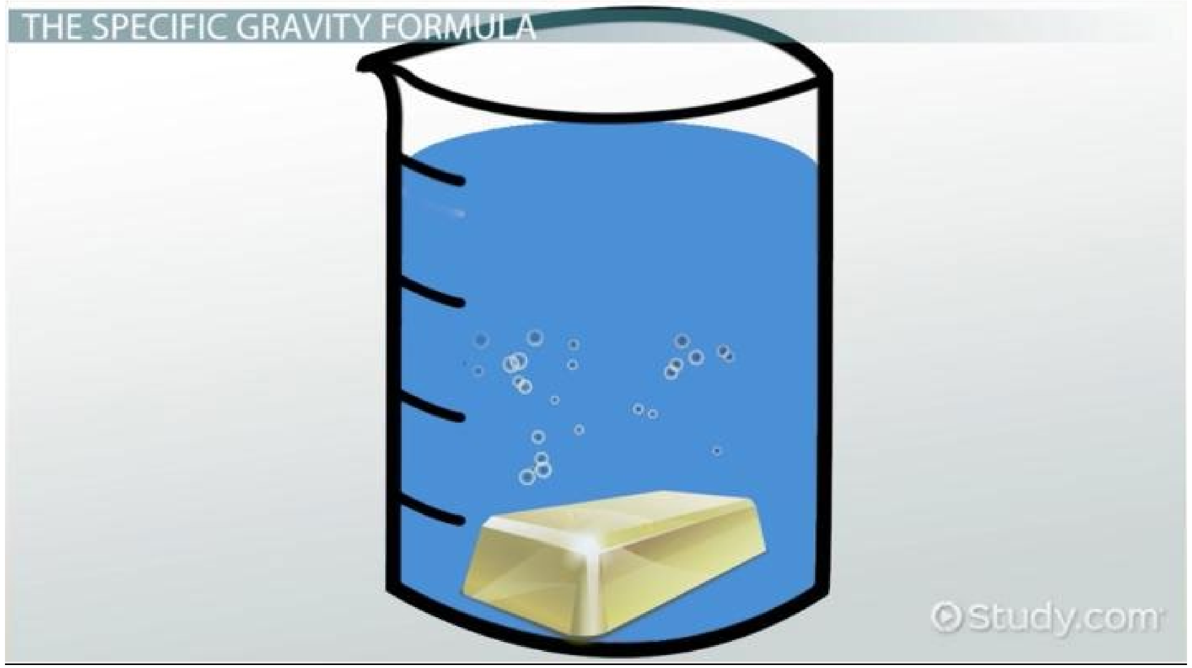
Specific gravity

Water has a specific gravity of 1.0. The ratio of the weight of a substance to water is called specific gravity.

Calculate the weight of 1 gallon of 12.5% sodium hypochlorite, assuming it has a specific gravity of 1.2.

Solution: Multiple the weight of water by the specific gravity of 1.2.

1.2 x 8.34 lbs./gal = 10 lbs./gal



Calculating Feed Rates for Sodium Hypochlorite

$$\text{Gallons per day} = \frac{\text{MGD} \times \text{mg/L} \times 8.34\ \text{lbs./day}}{\%\text{strength} \times \text{weight per gallon}}$$

Top part of equation calculates lbs of pure Cl

Dividing by % strength gives weight of sodium hypochlorite liquid actually needed. Use the decimal equivalent of percent (i.e. 12.5% = 0.125)

Dividing by weight per gallon will give you the feed rate in gallons

$$\textbf{Gallons per day} = \frac{\text{MGD} \times \text{mg/L} \times 8.34\ \text{lbs/day}}{\%\text{strength} \times \text{s.g.} \times 8.34\ \text{lb/gal}}$$

Weight per gallon

What is the feed rate for 12.5% sodium hypochlorite with a s.g. of 1.2 when the plant flow is 0.5 MGD and the dosage is 0.9 mg/L?

Solution: Use the following formula, and plug in values for flow, dosage, specific gravity, and solution strength.

$$\text{Gallons per day} = \frac{\text{Flow (MGD)} \times \text{Conc. (mg/L)} \times 8.34\ \text{lbs/day}}{\%\text{strength} \times \text{s.g.} \times 8.34\ \text{lb/gal}}$$

$$\frac{0.5\ \text{MGD} \times 0.9\ \text{mg/L} \times 8.34\ \text{lb/gal}}{0.125 \times 1.2 \times 8.34\ \text{lb/gal}} =$$

Disinfection Contact Time

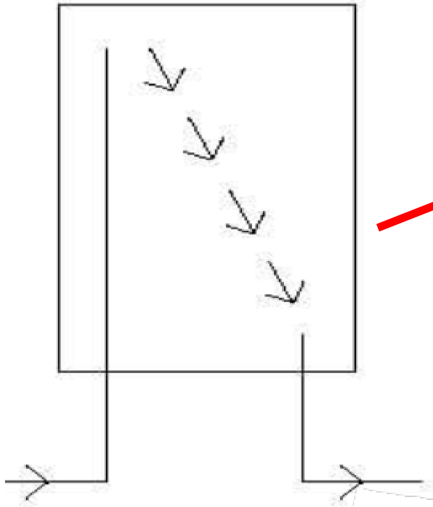
Theoretical Detention Time (assumes no short-circuiting).

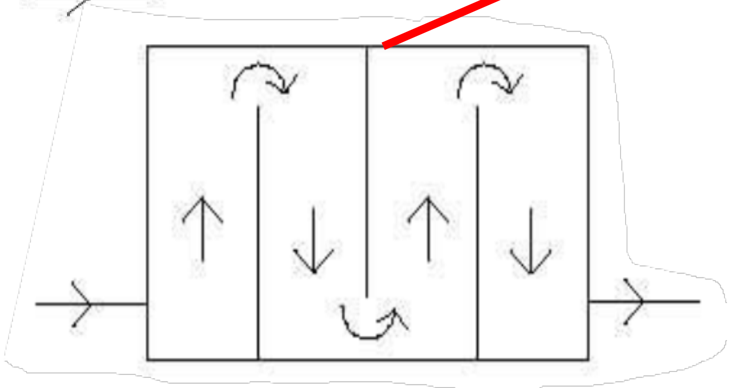
$$\text{Time} = \frac{\text{Volume}}{\text{Flow}}$$

Disinfection Contact Time (Uses a baffling factor to account for short circuiting)

$$\text{Time} = \frac{\text{Volume (gallons)} \times \text{Baffling Factor}}{\text{Flow (gallons per minute)}}$$

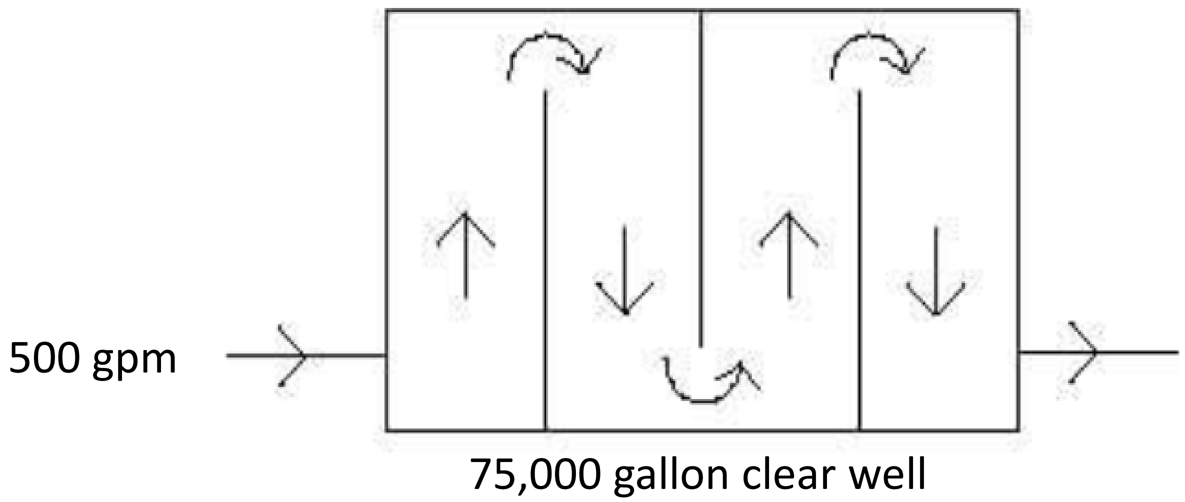
Baffling factor indicates the degree of short circuiting.





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.

What is the disinfection contact time for a tank that has a volume of **75,000 gallons** and a **baffling factor of 0.5**, if the flow through the tank is **500 gpm**?



Solution:

$$\text{Contact Time} = \frac{75{,}000 \text{ gallons} \times 0.5}{500 \text{ gpm}} =$$

CT Values and Log Inactivation Requirements:

SWTR log treatment requirements for viruses and giardia

- 3-log inactivation + removal of Giardia (99.9%)
- 4-log inactivation + removal of viruses (99.99%)

(The combination of filtration and disinfection must achieve minimum 3 log removal/inactivation of Giardia lamblia cysts and 4 log removal/inactivation of viruses)

Considerations:

- Multiple barriers that are robust (source protection, filtration, testing, etc.
- Disinfection byproduct formation (need to limit chlorination)
- Specific requirements of regulatory agency (state specific)
- Plant design (removal credits)

CT table for 4-log inactivation of viruses with chlorine

Temperature (°C)	Log Inactivation1	
	4.0	
	pH 6-9	pH 10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

To use the table
Match the daily minimum temperature and daily maximum pH of your water source. Disinfection is more effective at higher temperatures

Example: You measure pH and Temp

1. The temperature of your water is 16 degrees C
2. The pH of your water is 7.5
3. The table indicates we need to attain a CT value of 4 or greater to order to satisfy 4-log inactivation of viruses.

Log 4 Virus Inactivation Problem:

A small ground water system maintains a minimum free chlorine residual of **0.8 mg/L**. Contact time is provided by a **3,500-gallon** pneumatic storage tank with a **B.F. of 0.3**. Maximum flow through the tank is **200 GPM**. Determine if the system is attaining sufficient CT for 4-log virus inactivation when the water **temp is 16 C** and water **pH is 7.5**.

Step 1: Determine contact time.

$$\text{Time} = \frac{3{,}500 \text{ gallons} \times 0.3}{200 \text{ gpm}} = \textbf{5.25 minutes}$$

Step 2: Calculate CT being attained

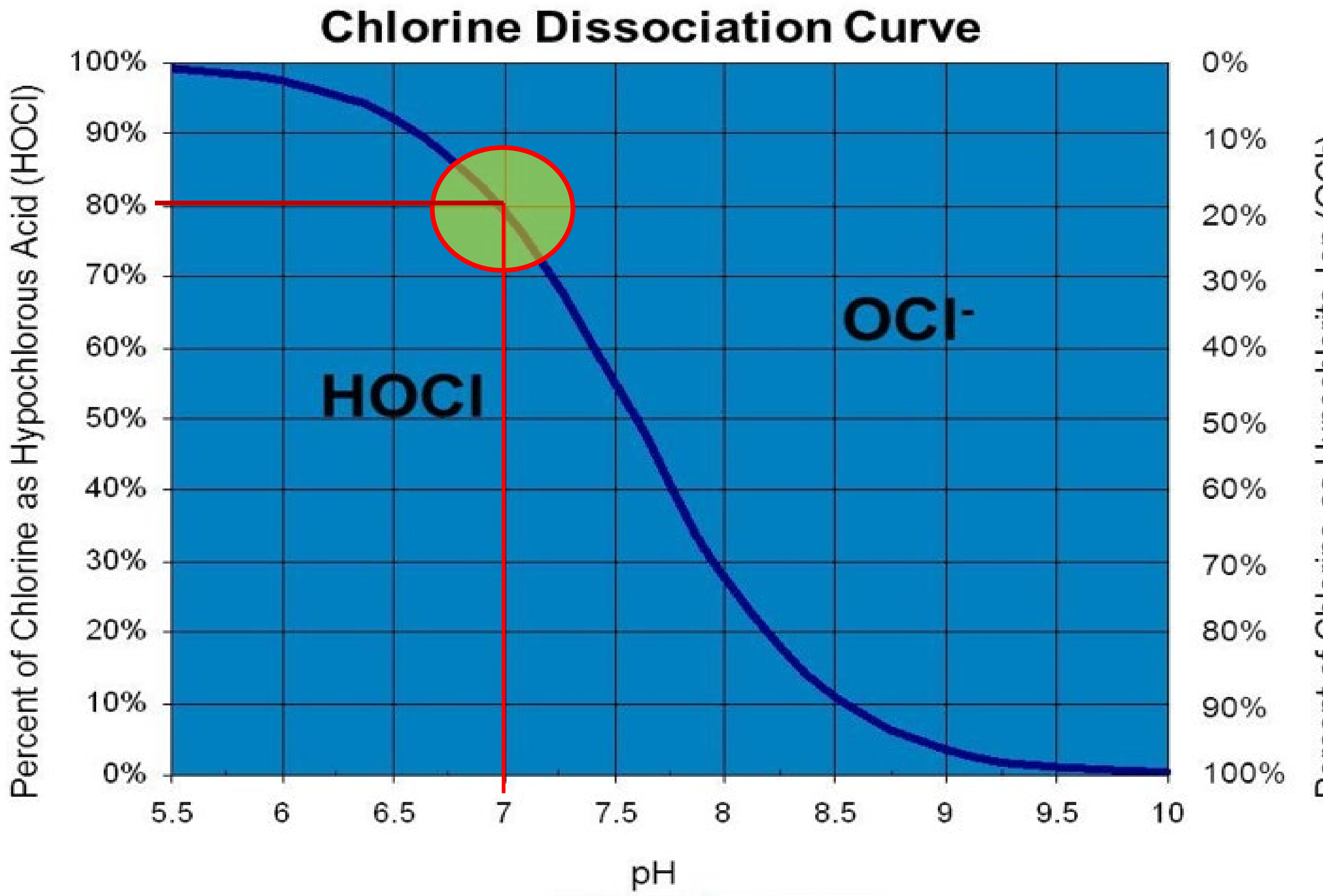
0.8 mg/L x 5.25 minutes = 4.2 mg-min/L

Step 3: Compare CT with required log 4 CT

Required CT for this pH and temp is 4.0. Actual CT is slightly greater; therefore, CT for log 4 virus is met.

Temperature (°C)	Log Inactivation1	
	4.0	
	pH 6-9	pH 10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

The effect of water pH on free chlorine residual



Notes:

Free chlorine residual consists of unreacted

- hypochlorous acid (HOCL) and
- hypochlorite ion (OCL-)

Hypochlorous acid is more effective because it has a greater ability to oxidize pathogens.

From the graph we see that at a pH of 7.0, free residual is

- 80% HOCL and
- 20% is OCL-

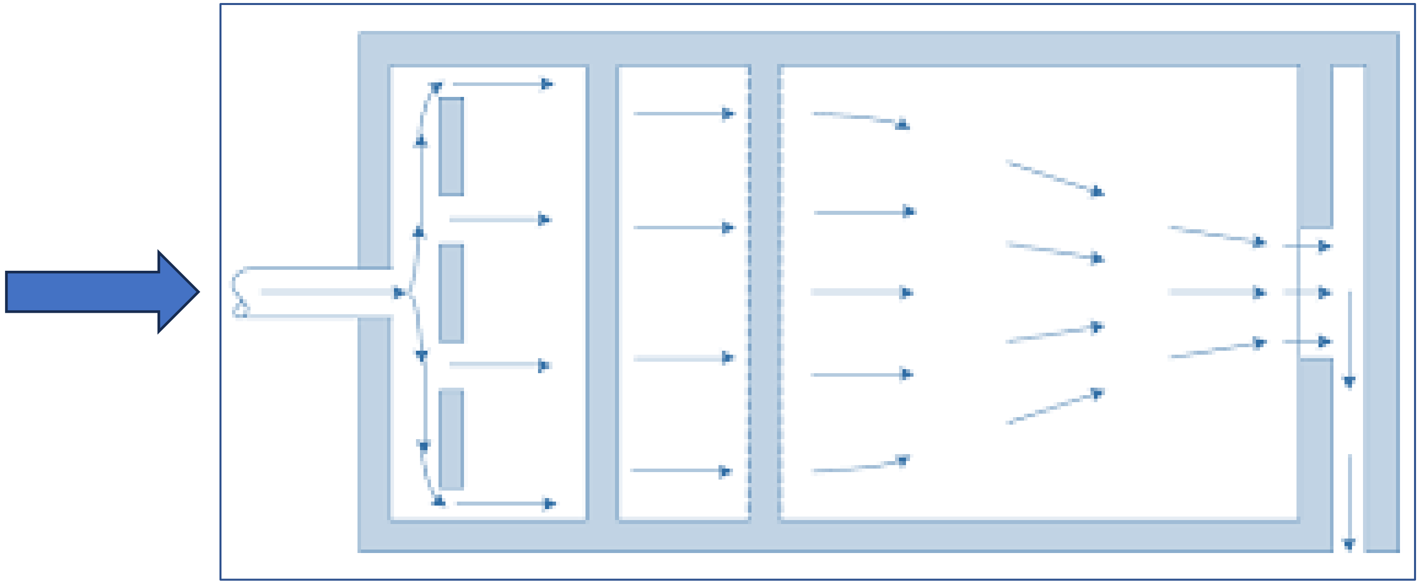
Log 3 Giardia Inactivation Problem:

A flow of **800 gpm** water is chlorinated to have a free residual of **1.2 mg/L** and enters a **75,000-gallon** clear well that has a baffling factor of **0.7.**

In our next poll (poll 3) , you will calculate the CT value for this disinfection process (which is the first step in solving this problem).

800 gpm

pH = 7.0
Temp = 15 C



75,000 gallon clear well
BF = 0.7

Poll 3

Poll 3

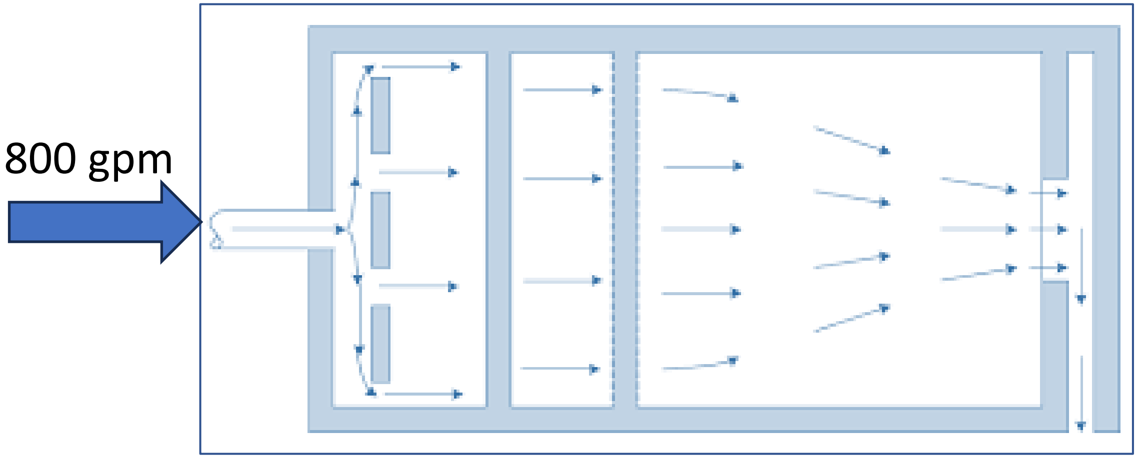
800 gpm water with a residual of 1.2 mg/L enters a 75,000-gallon clear well with a BF of 0.7. Calculate CT.

a) 150 mg-min/L
b) 105 mg-min/L
c) 87.5 mg-min/L
d) 72.9 mg-min/L

Log 3 Giardia Inactivation Problem:

A flow of 800 gpm water is chlorinated to have a free residual of 1.2 mg/L and enters a 75,000-gallon clear well that has a baffling factor of 0.7.

Minimum water temperature is 15 C , maximum pH is 7.0, and the minimum free chlorine residual is 1.2 mg/L. Determine if the system has sufficient contact time and residual to achieve 3-log inactivation for Giardia and meet regulatory requirements.



75,000 gallon clear well
BF = 0.7

Contact time

$$\frac{75{,}000 \text{ gal} \times 0.7}{800 \text{ gpm}} = \mathbf{65.6 \text{ min}}$$

CT

1.2 mg/L x **65.6 min** = **78.7 mg-min/L**

Next: Compare to table

Step 4: Determine required CT for 3-Log inactivation

Find the required CT on the Giardia inactivation table using water temperature of 15 C , maximum pH of 7.0, and the minimum free chlorine residual of 1.2 mg/L.

Required CT = 76 mg-min/L

Our calculated CT of 78.7 mg-min/L exceeds the minimum required CT of 76; therefore, compliance has been achieved!

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

Calculating log inactivation for compliance

Log inactivation (99.9) = **3** x $\frac{\textbf{CT achieved}}{\textbf{CT required}}$

$$3 \times \frac{78.7 \text{ mg-min/L}}{76 \text{ mg-min/L}} = \textbf{3.1 Log inactivation}$$

If the surface water treatment plant were credited with **2.0 log removal** (due to a filtration process), the total Log treatment (inactivation + removal) would be:
3.1 log inactivation + **2.0 log** removal = **5.1** total Log treatment.

If inactivation log treatment is lower (i.e. 1.5 log instead of 3.0)

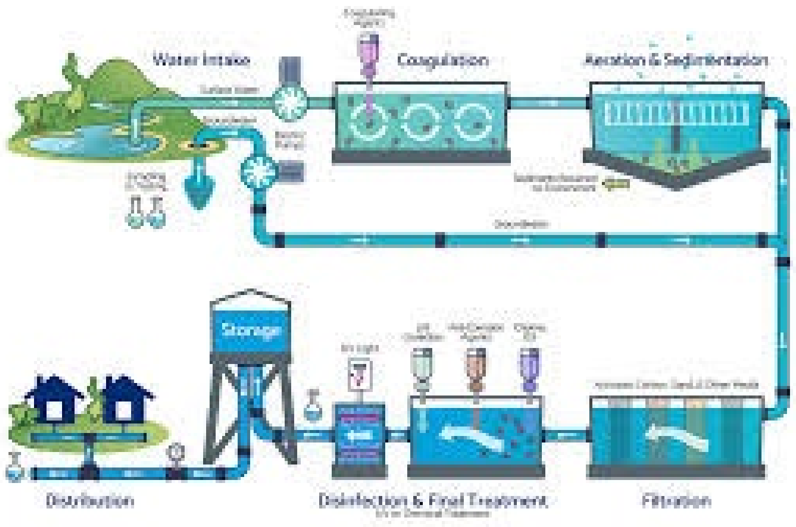
- Count removal credit from filtration (1.5 + 2.0 = 3.5)
- Increase residual and/or improve baffling (Increase CT)
- Add additional clear well volume (Increase contact time)
- Decrease pH of water (more effective disinfection)

Poll 4

Poll 4

A treatment plant achieved a CT of 60 but 80 is required. What is the total log treatment if the plant receives 2.5 log removal credits?

a) 0.52 log
b) 2.75 log
c) 3.50 log
d) 4.75 log



Solution

Log inactivation (99.9)

$3 \times \frac{60 \text{ mg-min/L}}{80 \text{ mg-min/L}}$ = **2.25 log inactivation**

Total log treatment

2.25 log inactivation + 2.5 log removal

= **4.75 log**

Recommended Reference Materials

1. **The CT Method: A Reference Guide: North Carolina Area Wide Optimization Program Team. April 21, 2020.** https://deq.nc.gov/media/16645/download

2. **Disinfection Profiling and Benchmarking - Technical Guidance Manual. EPA 815-R-20-003. USEPA, 2020.** https://www.epa.gov/system/files/documents/2022-02/disprof_bench_3rules_final_508.pdf

3. **USEPA Guidance Manuals for the Surface Water Treatment Rules.** https://19january2017snapshot.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules_.html

4. **Pipe disinfection calculator**: https://moruralwater.org/water-tools-files/tool_pdfc.php

5. **Drinking Water Regulations**. https://www.epa.gov/dwreginfo/drinking-water-regulations

6. **Surface Water Treatment Rules**. https://www.epa.gov/dwreginfo/surface-water-treatment-rules

For more resources and contact

Environmental Finance Center Network
https://efcnetwork.org/

- Funding guides
- Request technical assistance
- Register for training events
- Tools, resources, videos, articles

Great Lakes Environmental Infrastructure Center
at Michigan Tech
https://gleic.org/

Instructor contact,
Greg Pearson, MBA
gpearson@mtu.edu

Thank you for participating

Please share one thing you enjoyed learning about today in the chat.

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