

TRADEOFFS IN DISINFECTION BYPRODUCT MANAGEMENT

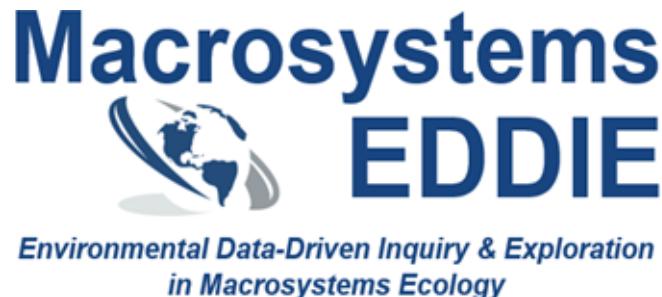
Lofton, M.E., Cooke, R.L., and Carey, C.C. 20 September 2025.

Macrosystems EDDIE: Exploring Tradeoffs in Water Quality Management Using Environmental Data.

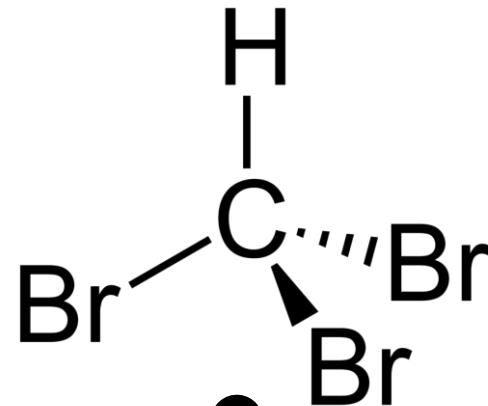
Macrosystems EDDIE Module 10, Version 1.

https://serc.carleton.edu/eddie/teaching_materials/modules/module10.html

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Operators must balance the risks of incomplete disinfection and DBP formation



Balancing the presence of harmful pathogens with the presence of DBPs

Goal #1: Ensure disinfection

- Chlorine should be added until all harmful pathogens are destroyed
- In addition, enough chlorine should be added to produce some **free residual chlorine** which keeps the water free of pathogens in the distribution system



*Spring Hollow Reservoir Treatment Plant
Photo credit: Western Virginia Water Authority*

Goal #1: Ensure disinfection

- The amount of chlorine added is the **chlorine dose**
- The chlorine used up by pathogens and other substances in the water is the **chlorine demand**
- The chlorine left over from the dose after demand is satisfied is the **chlorine residual**



*Spring Hollow Reservoir Treatment Plant
Photo credit: Western Virginia Water Authority*

Goal #1: Ensure disinfection

Dose = Demand + Residual
(all in mg/L)

- **Example Question:** What chlorine dosage should be applied to raw water with a **demand** of 0.5 mg/L and an intended **residual** of 1.1 mg/L?

- **Answer:**

$$\text{Dose (mg/L)} = 0.5 \text{ mg/L} + 1.1 \text{ mg/L}$$

$$\text{Dose} = 1.6 \text{ mg/L}$$

Goal #1: Ensure disinfection

- This leads us to the “pounds” formula:

$$\text{Chemical} \left(\frac{\text{lb}}{\text{day}} \right) = \text{Dose} \left(\frac{\text{mg}}{\text{L}} \right) \times \text{Flow (MGD)} \times 8.34 \left(\frac{\text{lb}}{\text{gal}} \right)$$

The equation says that the **chlorine added per day** is equal to the **chlorine dose** times the **flow** times the **constant: 8.34 lb/gal** (which is the number of pounds of water per gallon).

- **Example Question:** What should the chlorine feed rate setting be in lb/day if the plant **flow** is 0.8 MGD and the required chlorine **dose** is 1.6 mg/L?
- **Answer:**
Chemical (lb/day) = 1.6 mg/L x 0.8 MGD x 8.34 lb/gal
Chemical = **10.7 lb/day**

Goal #1: Ensure disinfection

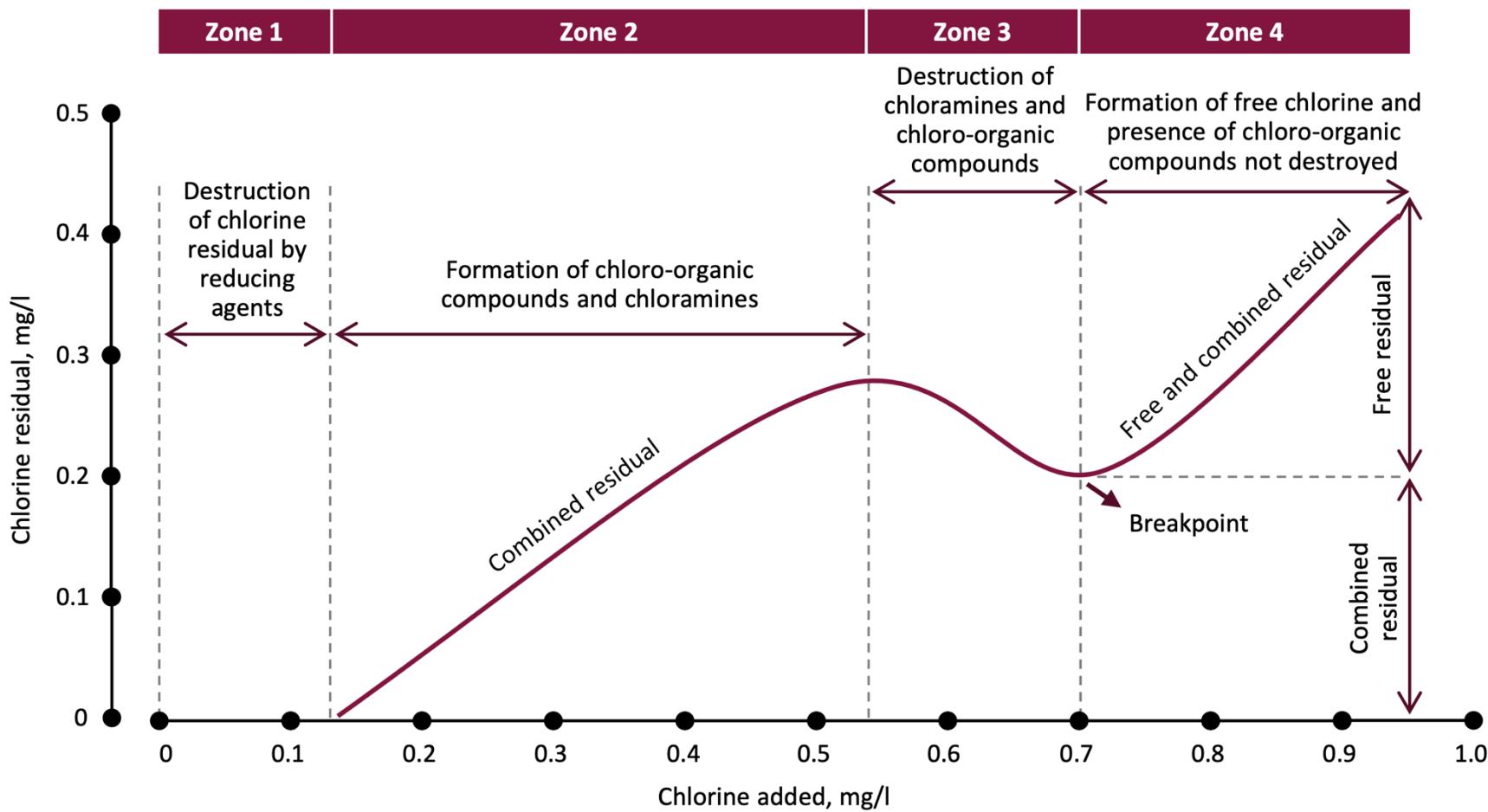
- **Breakpoint chlorination** is a useful framework that helps operators know how much chlorine is needed for disinfection and production of free residual chlorine



*Spring Hollow Reservoir Treatment Plant
Photo credit: Western Virginia Water Authority*

Goal #1: Ensure disinfection

Chlorine should be added until the “breakpoint” on the figure is reached to ensure complete disinfection.



How do I know if “breakpoint chlorination” has been reached?

- You can determine whether the breakpoint has been reached by comparing the values of the **actual vs. expected increases in the chlorine residual**.
- **Expected increase in residual** is the amount of residual we expect, given the addition of a specific amount of chlorine and **assuming we have already reached the breakpoint!!**
- **Actual increase in residual** is the amount of residual we actually get, given the addition of a specific amount of chlorine
- If the actual residual is **less than** the expected residual, we have **not** reached the breakpoint.
- On the next slides, we will walk through the **three steps** of this calculation and work an **example problem**.

Step 1: Calculate expected increase in residual

$$\text{Expected residual (mg/L)} = \frac{\text{Increase in chlorine (lb/day)}}{\text{Flow (MGD)} \times 8.34 \text{ (lb/gal)}}$$

The equation says that the **expected increase in residual** is equal to the **increase in chlorine** divided by the **flow** times the **constant: 8.34 lb/gal** (which is the number of pounds of water per gallon).

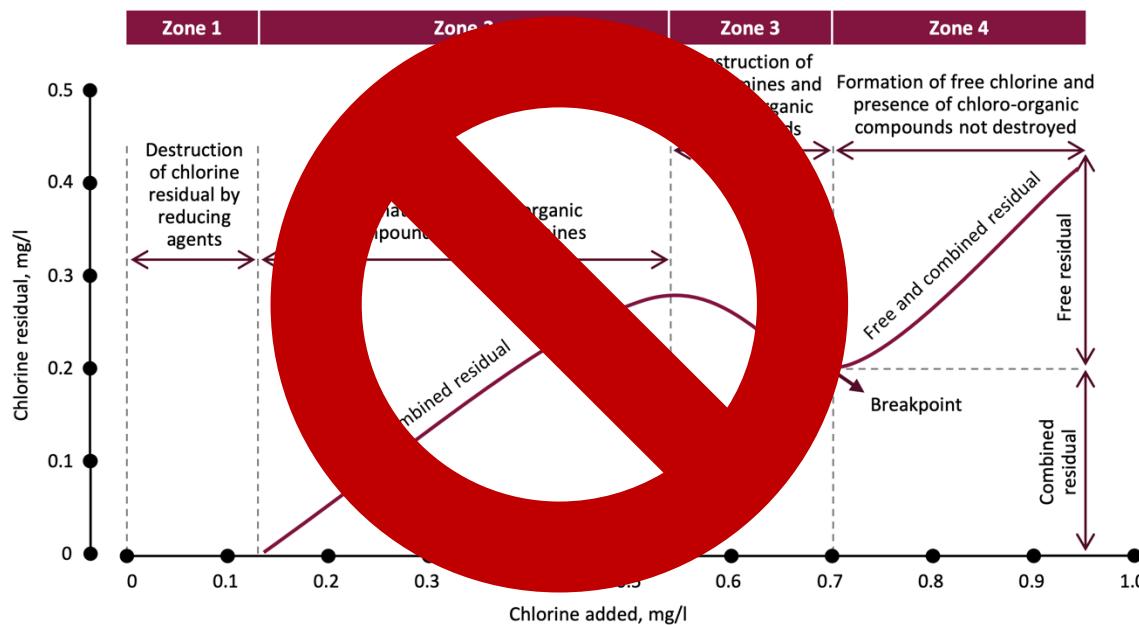
Step 2: Calculate actual increase in residual

$$\text{Actual residual (mg/L)} = \text{New residual(mg/L)} - \text{Old residual(mg/L)}$$

The equation says that the **actual increase in residual** is equal to the **residual after more chlorine is added (new residual)** minus the **residual before more chlorine was added (old residual)**.

Step 3: Compare the actual and expected increases in residual

If the **actual residual** is less than the **expected residual**, breakpoint was not reached!!



Example problem and solution

A chlorinator setting of 15 lbs chlorine per day results in a chlorine residual of 0.3 mg/L. The chlorinator setting is increased to 20 lb/day. The chlorine residual increases to 0.45 mg/L at this new dosage rate. The average flow being treated is 1.4 MGD. On the basis of these data, is the water being chlorinated past the breakpoint?

Step 1

$$\text{Expected residual } \left(\frac{\text{mg}}{\text{L}} \right) = \frac{5 \left(\frac{\text{lb}}{\text{day}} \right)}{1.4 (\text{MGD}) \times 8.34 \left(\frac{\text{lb}}{\text{gal}} \right)} = 0.43 \left(\frac{\text{mg}}{\text{L}} \right)$$

Step 2

$$\text{Actual residual } \left(\frac{\text{mg}}{\text{L}} \right) = 0.45 \left(\frac{\text{mg}}{\text{L}} \right) - 0.3 \left(\frac{\text{mg}}{\text{L}} \right) = 0.15 \left(\frac{\text{mg}}{\text{L}} \right)$$

Step 3

The actual residual $(0.15 \frac{\text{mg}}{\text{L}})$ is less than the expected residual $(0.43 \frac{\text{mg}}{\text{L}})$, so we conclude the water is NOT being treated past the breakpoint!!

Goal #1: Ensure disinfection

- Chlorine feed systems for secondary disinfection should achieve a minimum chlorine residual at the entry point of **0.2 mg/L for more than 4 hours**
- Maximum residual is **4.0 mg/L** because of byproducts



*Spring Hollow Reservoir Treatment Plant
Photo credit: Western Virginia Water Authority*

Goal #2: Avoid DBP formation

- The best approach is to remove DBP precursors prior to disinfection
- Operators have several options:
 - Increased **coagulation/clarification** time or addition of more coagulant
 - **Activated carbon filters** that absorb organic matter
 - Pass water through a **membrane** that filters out DBP precursors



*Spring Hollow Reservoir Treatment Plant
Photo credit: Western Virginia Water Authority*

Goal #2: Avoid DBP formation

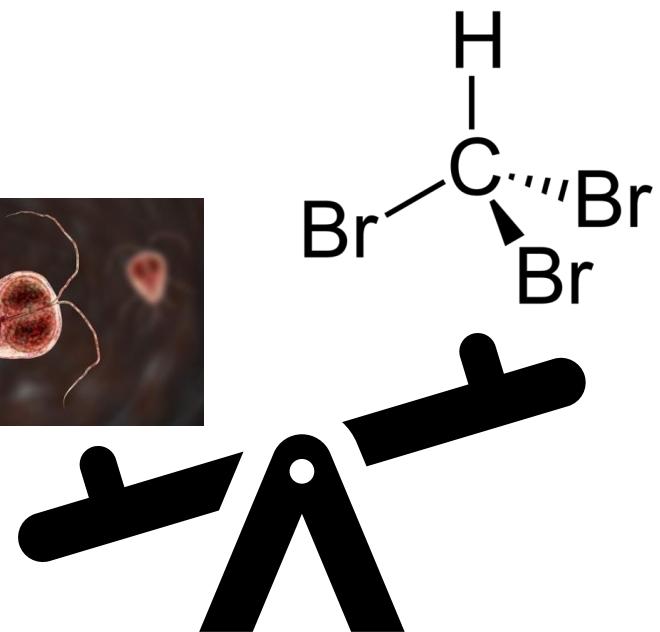
- Because excessive free chlorine residual can lead to formation of DBPs in the distribution system, the EPA and VDH have enacted MRDLs, or maximum residual detection limits

Disinfectant residual	MRDL (mg/L)
Chlorine	4.0 (as Cl ₂).
Chloramines	4.0 (as Cl ₂).
Chlorine dioxide	0.8 (as ClO ₂).

- Treated water must remain below these limits!!!

Strategy for balancing Goal #1 and Goal #2

1. Ensure water is chlorinated to breakpoint
2. Use additional treatment steps (increased coagulation, activated carbon filters, membrane technology) to remove DBP precursors prior to disinfection
3. Keep treated water under the EPA and VDH MRDL of 4.0 mg/L for free chlorine residual



End of slideshow – please proceed with module activities!



*Environmental Data-Driven Inquiry & Exploration
in Macrosystems Ecology*

Exploring tradeoffs in water quality management using environmental data

