Improved Jar Testing Optimization with TOC Analysis

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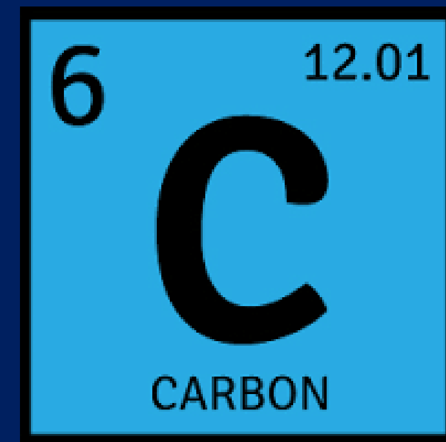
Outline of Presentation

1. What is total organic carbon (TOC)?
2. Importance of jar testing
3. Presentation of experimental data
4. Discussion on the value of TOC

What is TOC?

TOC = Total Organic Carbon



Total amount of **organic carbon** in natural water

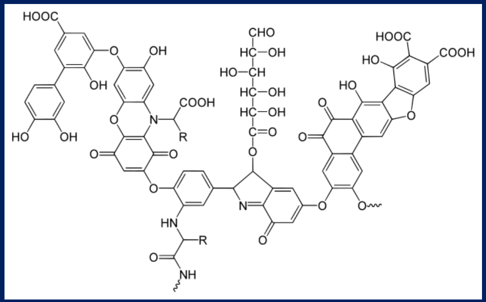
Where does TOC come from?

Organic compounds come from plants, animals, etc. They can become bound to dissolved or suspended material in natural water sources

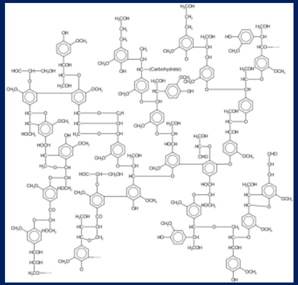
→ **Natural Organic Matter (NOM)**

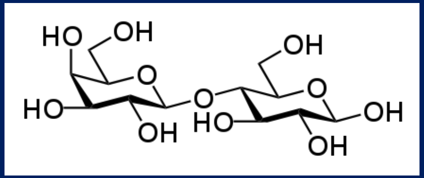
What is TOC?

Examples of TOC and NOM



Humic & Fulvic Acids





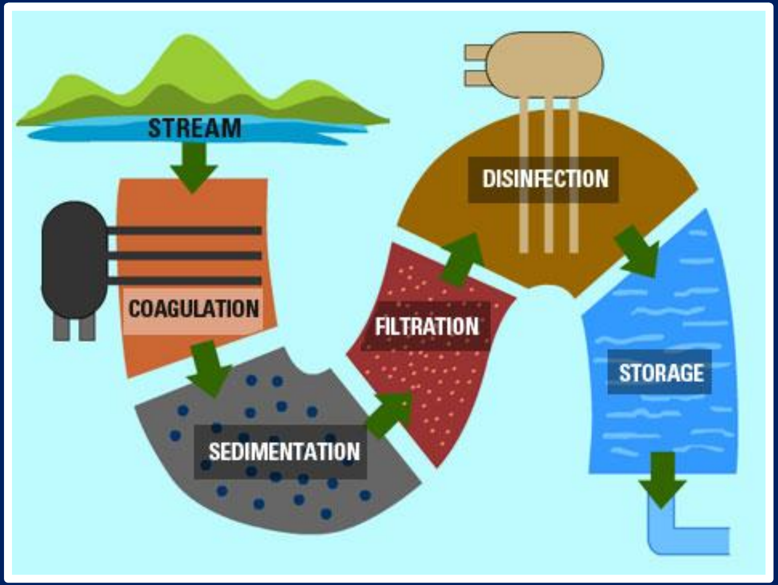
Lignin

Carbohydrates

Why is TOC important?

Conventional Water Treatment: TOC removal is regulated

Influent TOC



Effluent TOC

Why is TOC important?

Conventional Water Treatment: TOC removal is regulated

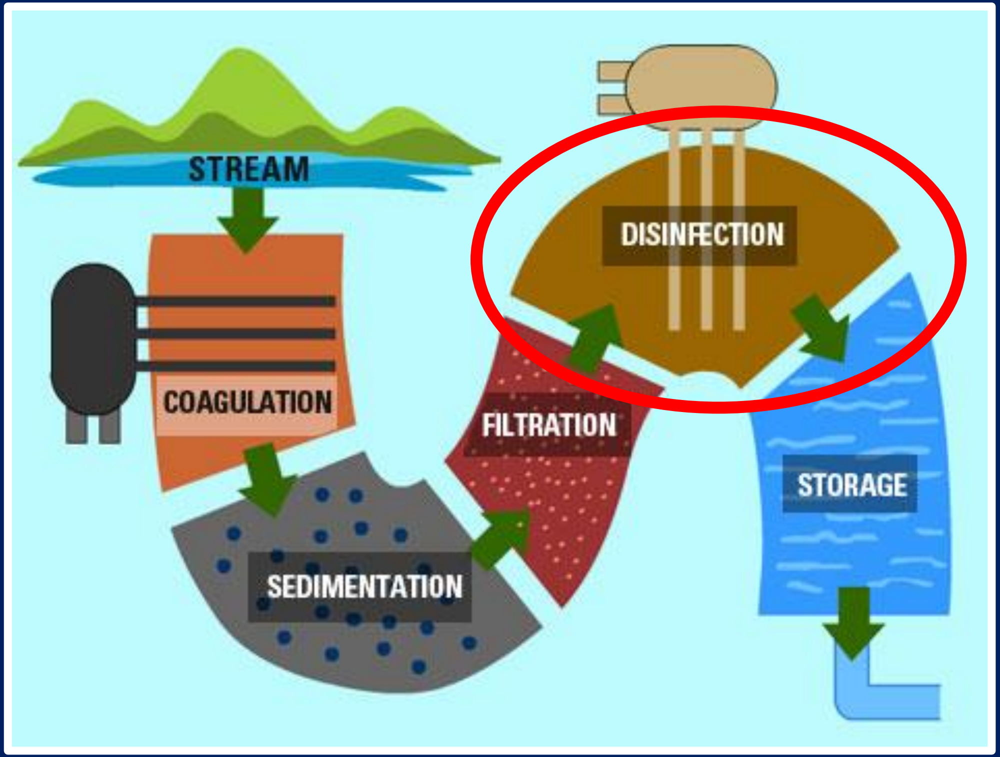
Source Water TOC (mg/L)	Source Water Alkalinity, mg/L as $CaCO_3$		
	0-60	>60-120	>120
> 2.0 to 4.0	35.0%	25.0%	15.0%
> 4.0 to 8.0	45.0%	35.0%	25.0%
> 8.0	50.0%	40.0%	30.0%

Drinking water plants required to remove a certain percentage of the influent TOC based on the alkalinity of the water and the incoming concentration of TOC

Why is TOC important?

Disinfection By-Products (DBPs)

All water treatment plants



NOM

+

Disinfectant

=

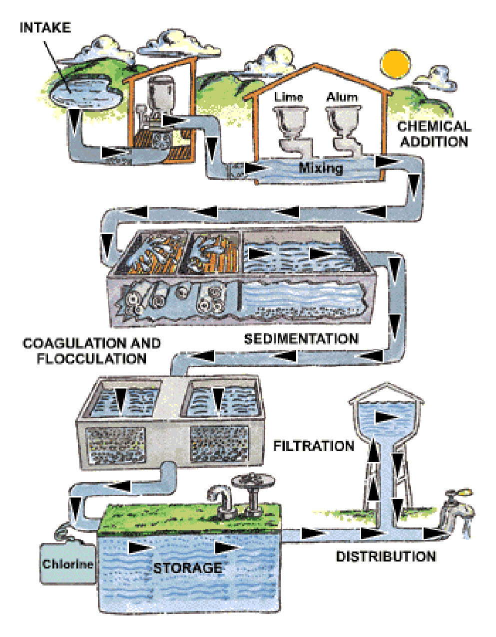
DBPs

Why is TOC important?

Disinfection By-Products (DBPs)

DBP Formation is dependent on:

- ✓ Temperature
- ✓ pH
- ✓ Time



Currently regulated DBP's:

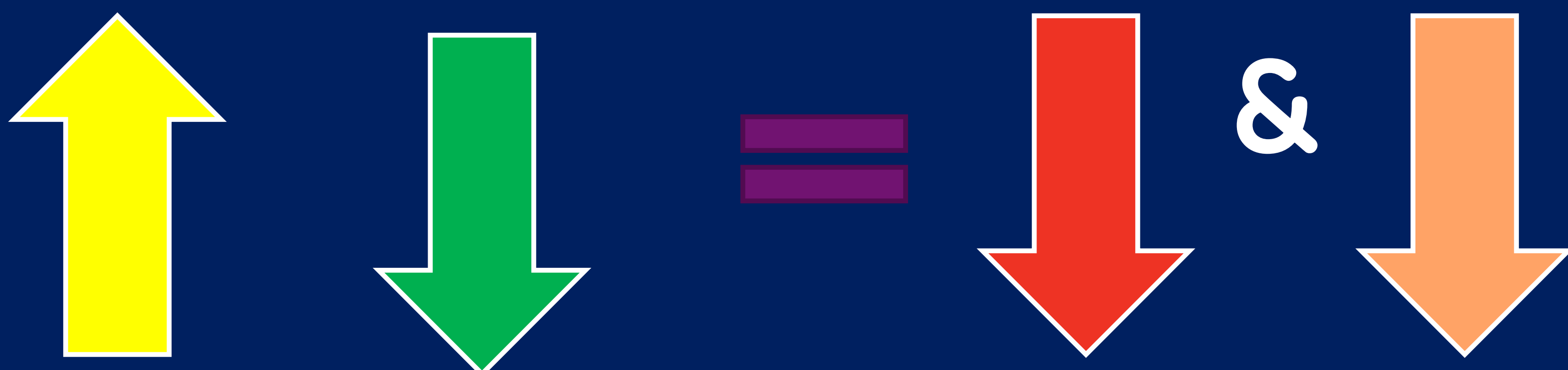
Trihalomethanes (THMs)
Haloacetic Acids (HAAs)
Chlorite
Bromate
…more are coming…

Why is TOC important?

Disinfection By-Products (DBPs)

Water treatment plants want to minimize microbial growth AND DBP formation

Lowering TOC is the best solution for both!



Why is TOC important?

Regulated TOC removal

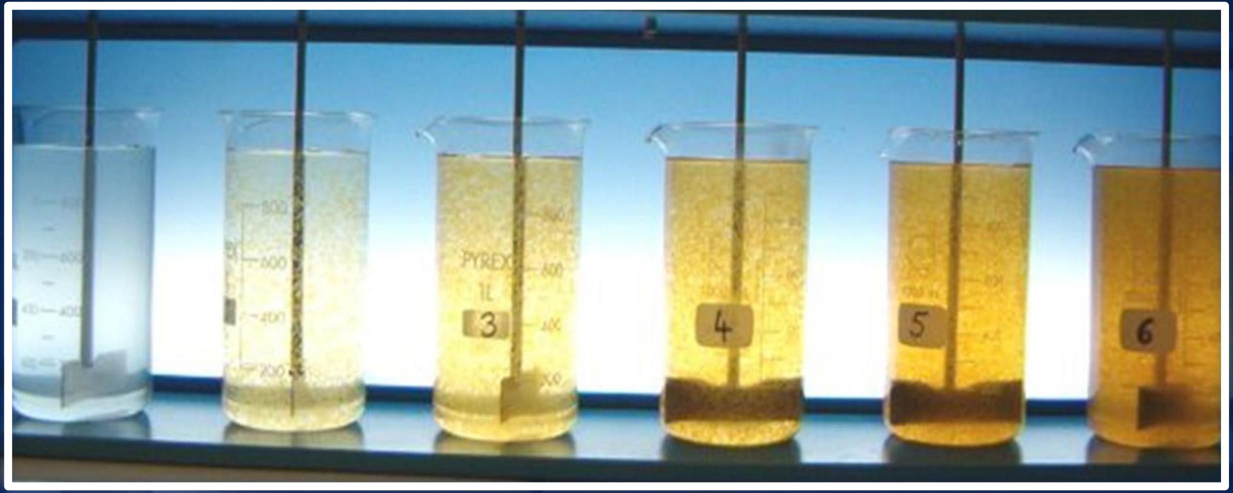
&

Regulated DBP levels

…sometimes even meeting the regulated TOC percent removal doesn't mean that you will meet the DBP regulation limits for the furthest point in the distribution system…

Jar Testing

Simulation of the coagulation and flocculation steps in the water treatment process



Important for determining the optimal coagulant and dosage for a plant's raw water

Jar Testing

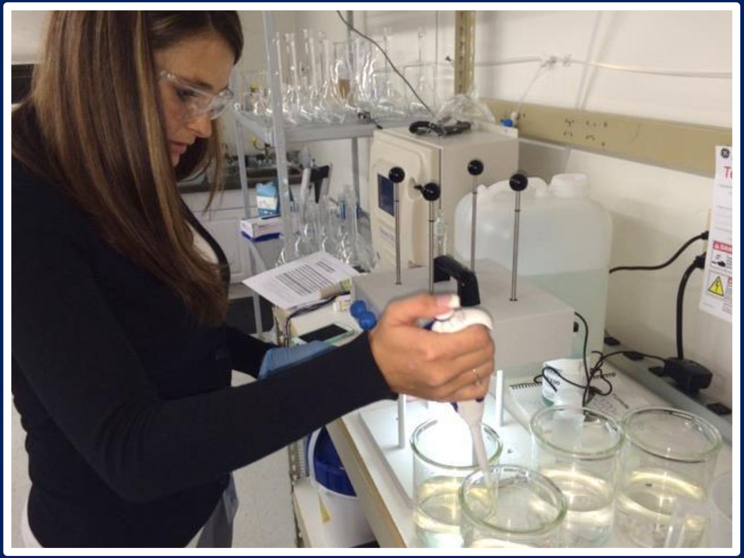
Jar testing is beneficial for plants so that they can optimize their treatment process

Plants want to pick the right coagulant dosage and treatment so that they can:

- ✓ Maximize TOC removal to meet regulations
- ✓ Minimize sludge production
- ✓ Minimize costs

Jar Testing

Simulation of the coagulation and flocculation steps in the water treatment process

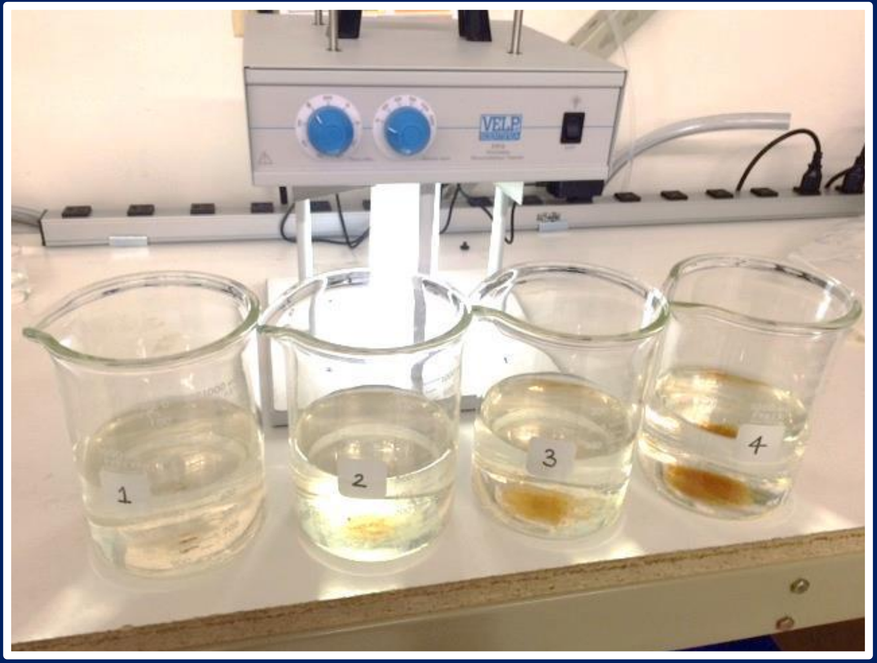


Add coagulant at different doses to raw water

Replicate plant contactors with flocculation simulator

Jar Testing

Simulation of the coagulation and flocculation steps in the water treatment process



Let the water settle

After flocculation and settling, sample the settled water to determine which coagulant dose was best

Jar Testing

Parameters typically measured:

- ✓ **Turbidity** – measure of water clarity
- ✓ **UV**– measure of the aromatic content of the organic material in the water

Jar Testing

Parameters typically measured:

- ✓ Turbidity – measure of water clarity
- ✓ UV– measure of the aromatic content of the organic material in the water

Issues: Doesn't distinguish between inorganic, organic, particulates. Is only a measure of how much light passes through water.

Jar Testing

Parameters typically measured:

- ✓ Turbidity – measure of water clarity
- ✓ UV– measure of the aromatic content of the organic material in the water

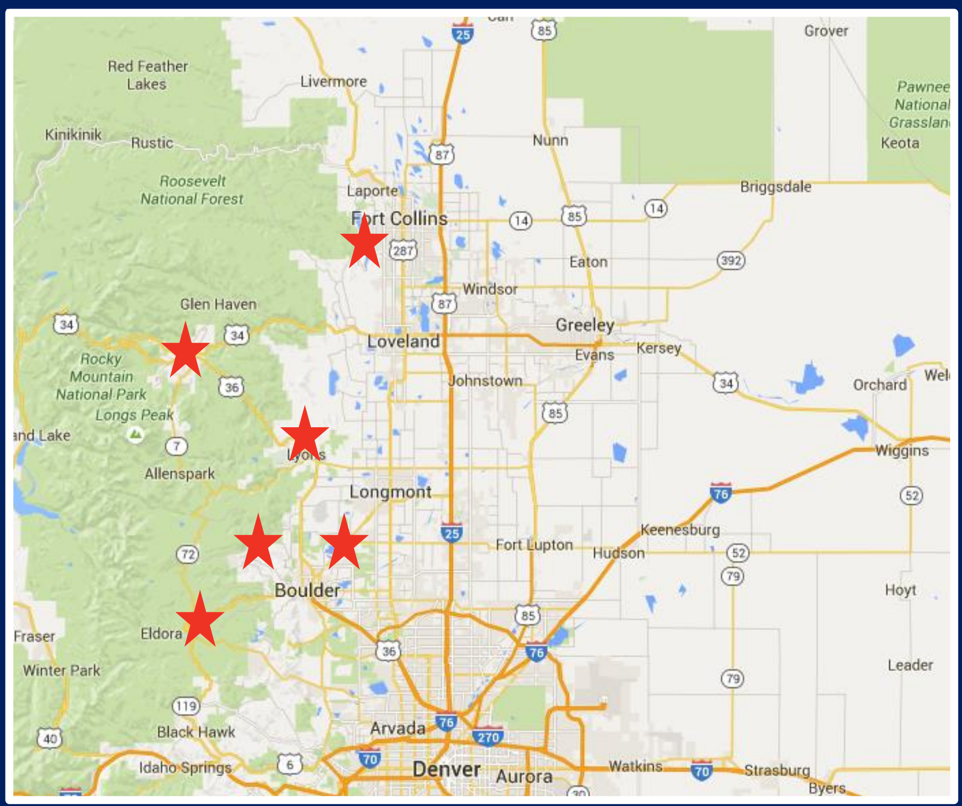
Issues: Not all organic molecules absorb in the UV spectrum, multiple interferences at 254 nm wavelength.

SUVA = UV/TOC

Jar Testing Experiment

Collected natural surface water from 10 sites

Water samples were representative of surface water feeding local water treatment plants



6 sites in Colorado

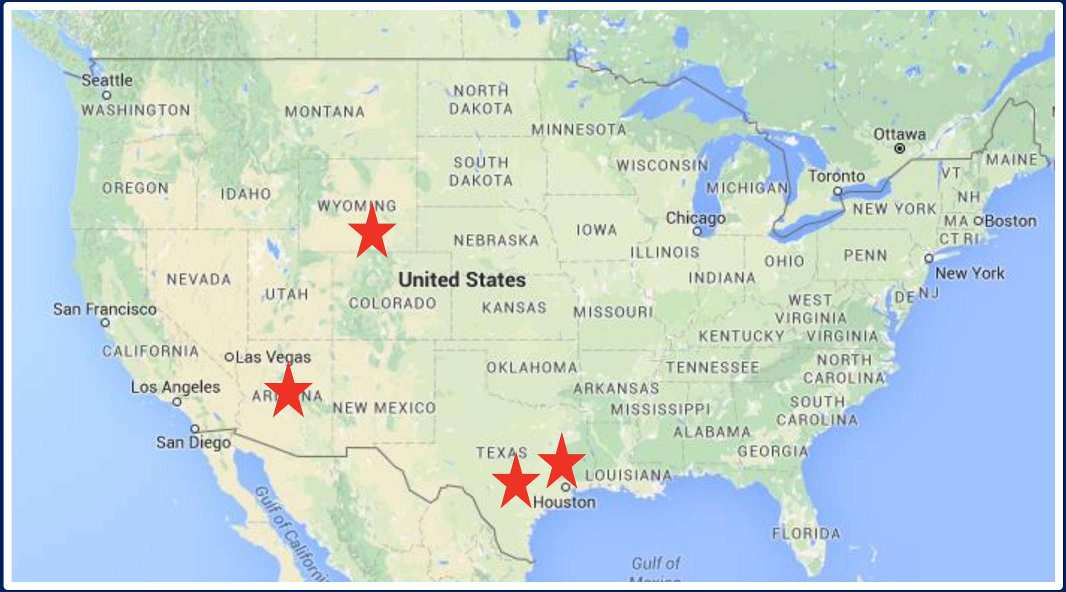
- ✓ river
- ✓ reservoir
- ✓ lake
- ✓ mountain
- ✓ plains

Jar Testing Experiment

Collected natural surface water from 10 sites

Water samples were representative of surface water feeding local water treatment plants

Wyoming: reservoir



Arizona: canal

Texas: river and lake

Jar Testing Experiment

Tested two different coagulants:

✓ Ferric Chloride (Ferric)
✓ Aluminum Sulfate (Alum)

Measured Parameters

Raw Water:

- Alkalinity
- pH
- TOC
- Turbidity
- UV

Settled Water:

- TOC
- Turbidity
- UV

Jar Testing Experiment

Tested two different coagulants:

✓ Ferric Chloride (Ferric)

✓ Aluminum Sulfate (Alum)

Goal: To investigate how turbidity, UV, <u>and TOC</u> all were influenced by different coagulant dosages

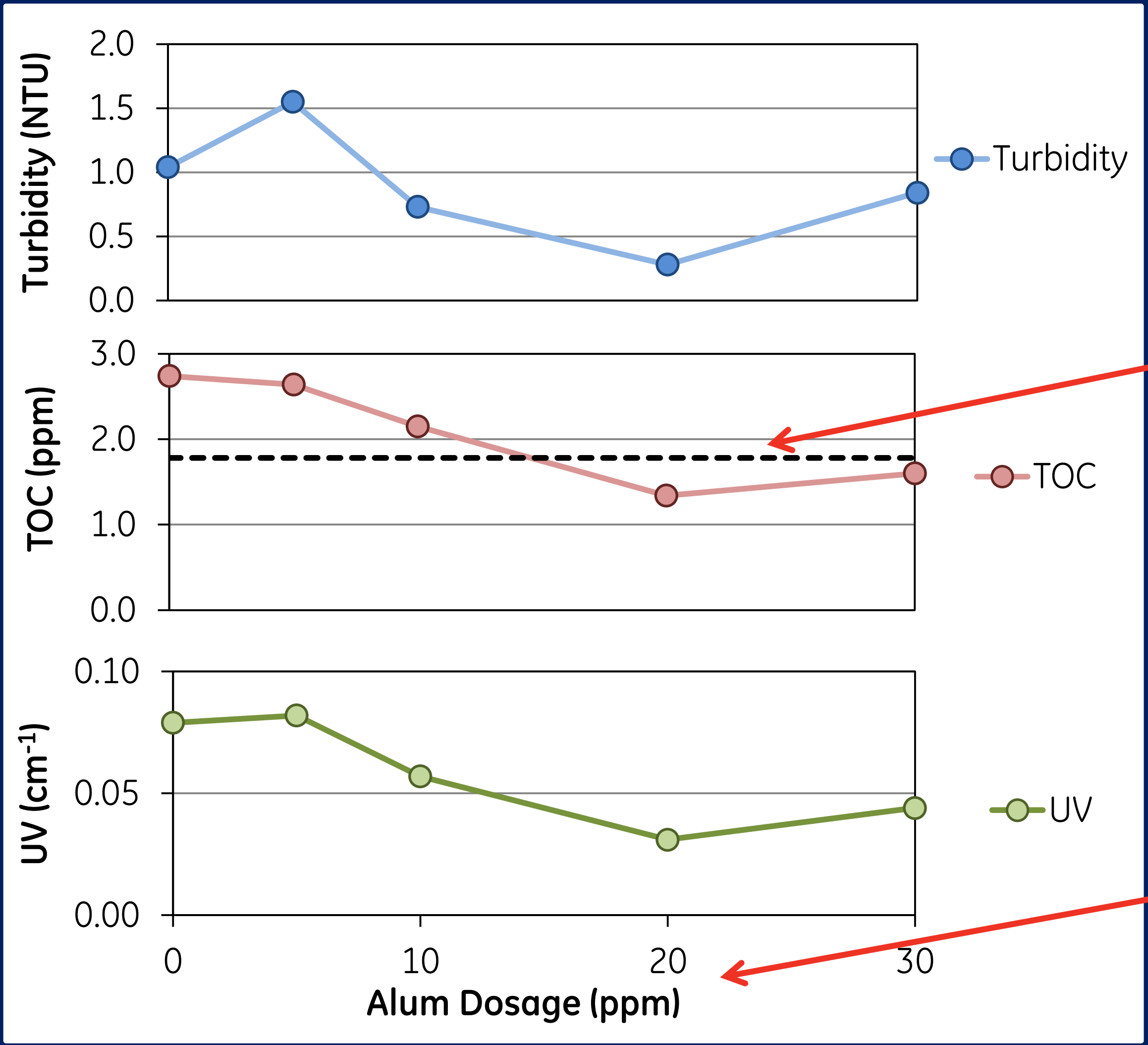
Spoiler alert: turbidity and UV were not always the best indicator of optimum TOC removal

- pH
- TOC
- Turbidity
- UV

- Turbidity
- UV

Experimental Data

Site 1: Saint Vrain River in Lyons, CO

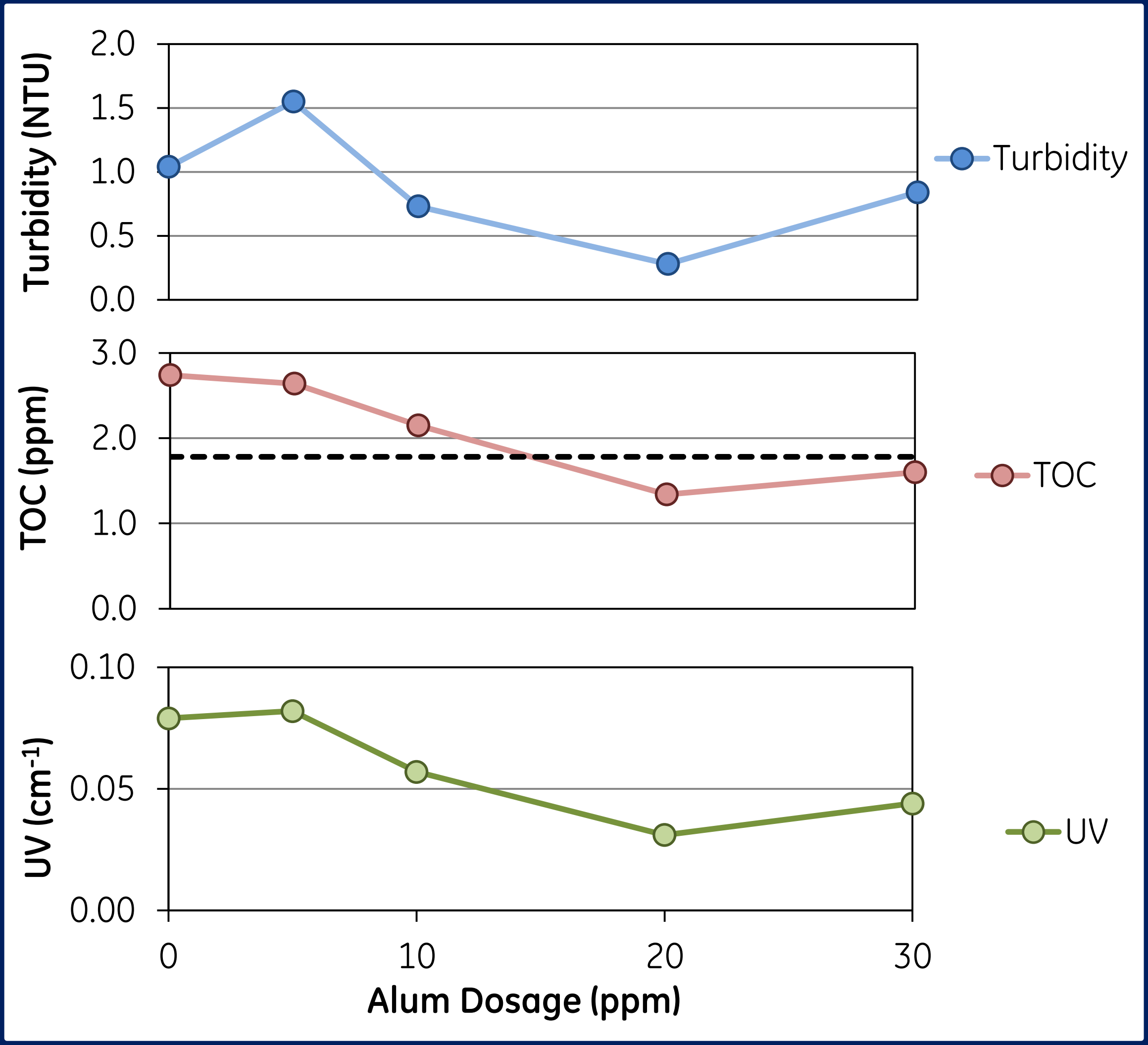


Black, dotted line corresponds to the regulated TOC removal based on alkalinity and influent TOC

Coagulant type and dosage is indicated on the x-axis

Experimental Data

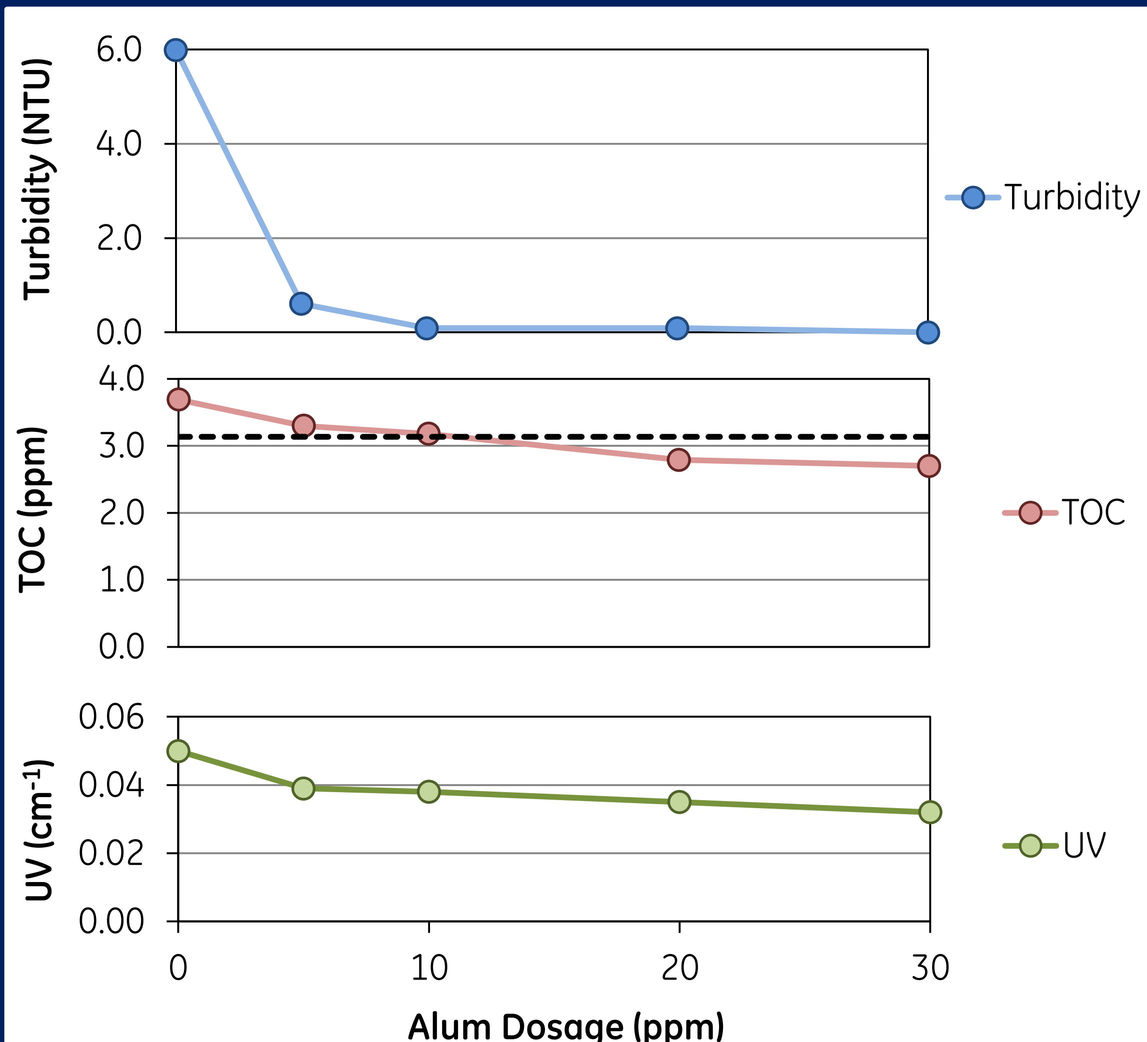
Site 1: Saint Vrain River in Lyons, CO



Lowest Turbidity was also lowest TOC and lowest UV

Experimental Data

Site 2: Coot Lake in Boulder, CO

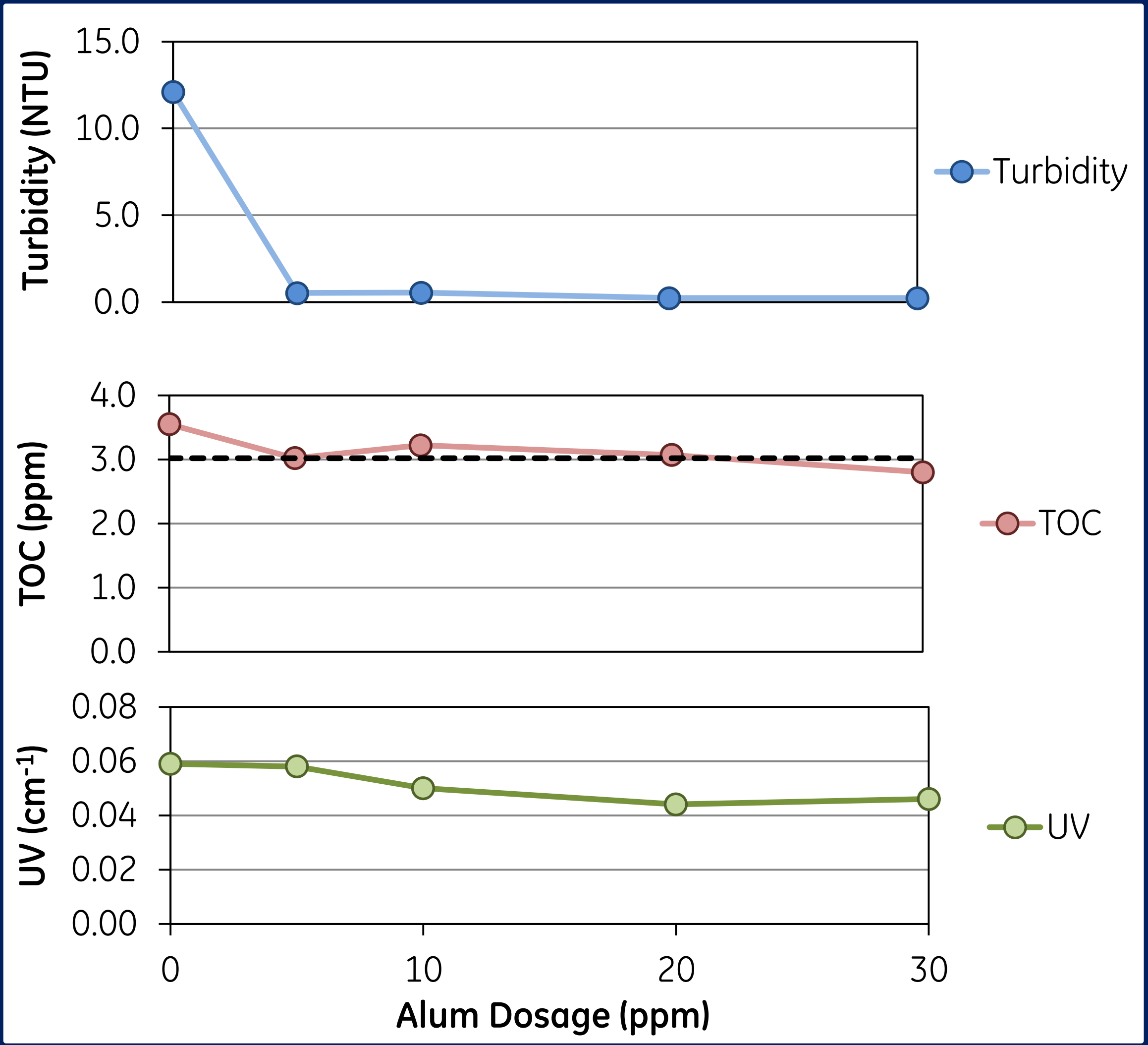


Lowest Turbidity was also lowest TOC

Low turbidity at 5 ppm Alum dosage didn't correspond to best TOC removal

Experimental Data

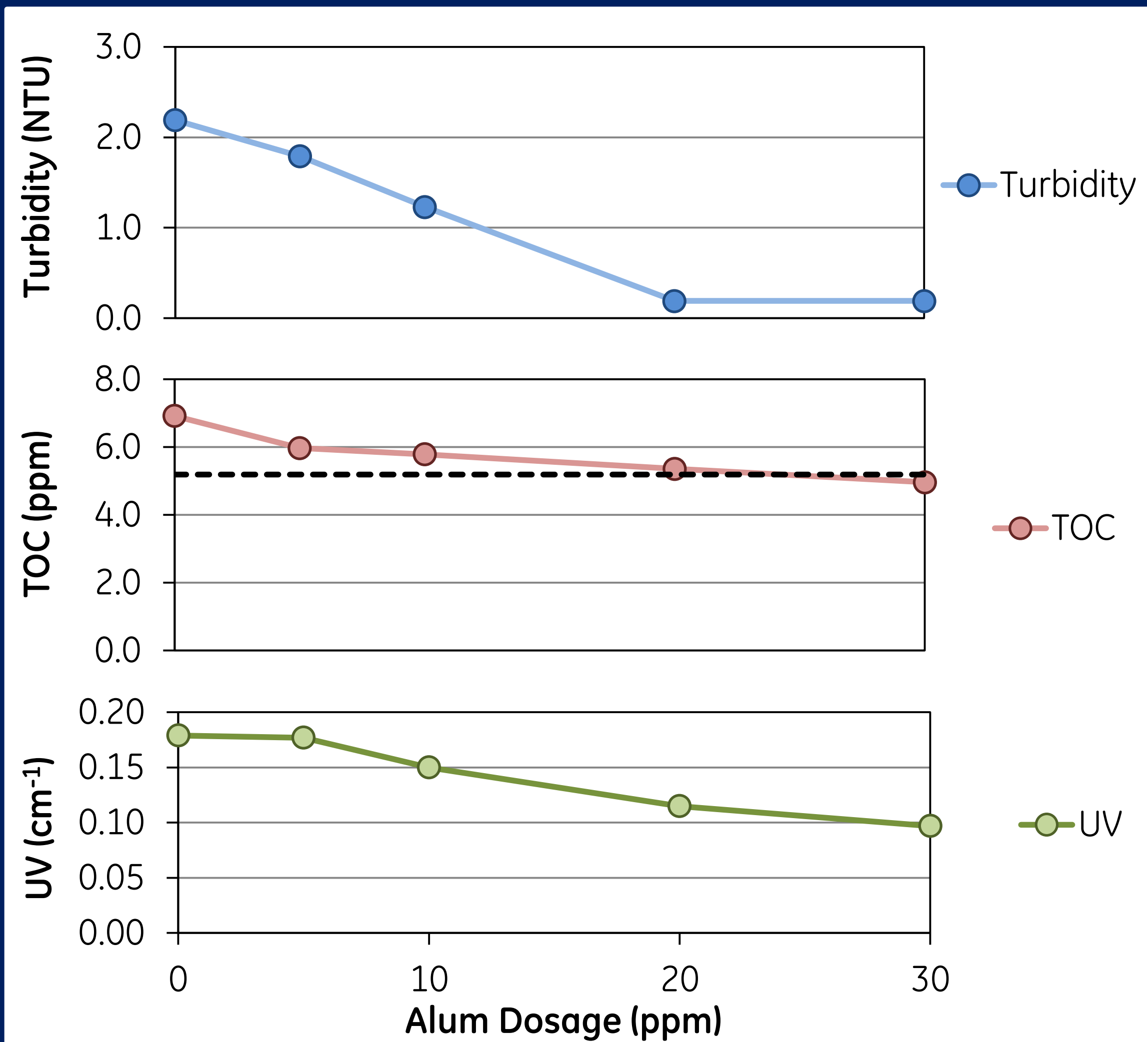
Site 3: Canal water from Gilbert, AZ



20 and 30 ppm Alum dosage had the same turbidity, but the TOC went down with the 30 ppm (even though UV went up)

Experimental Data

Site 4: San Gabriel River from Austin, TX

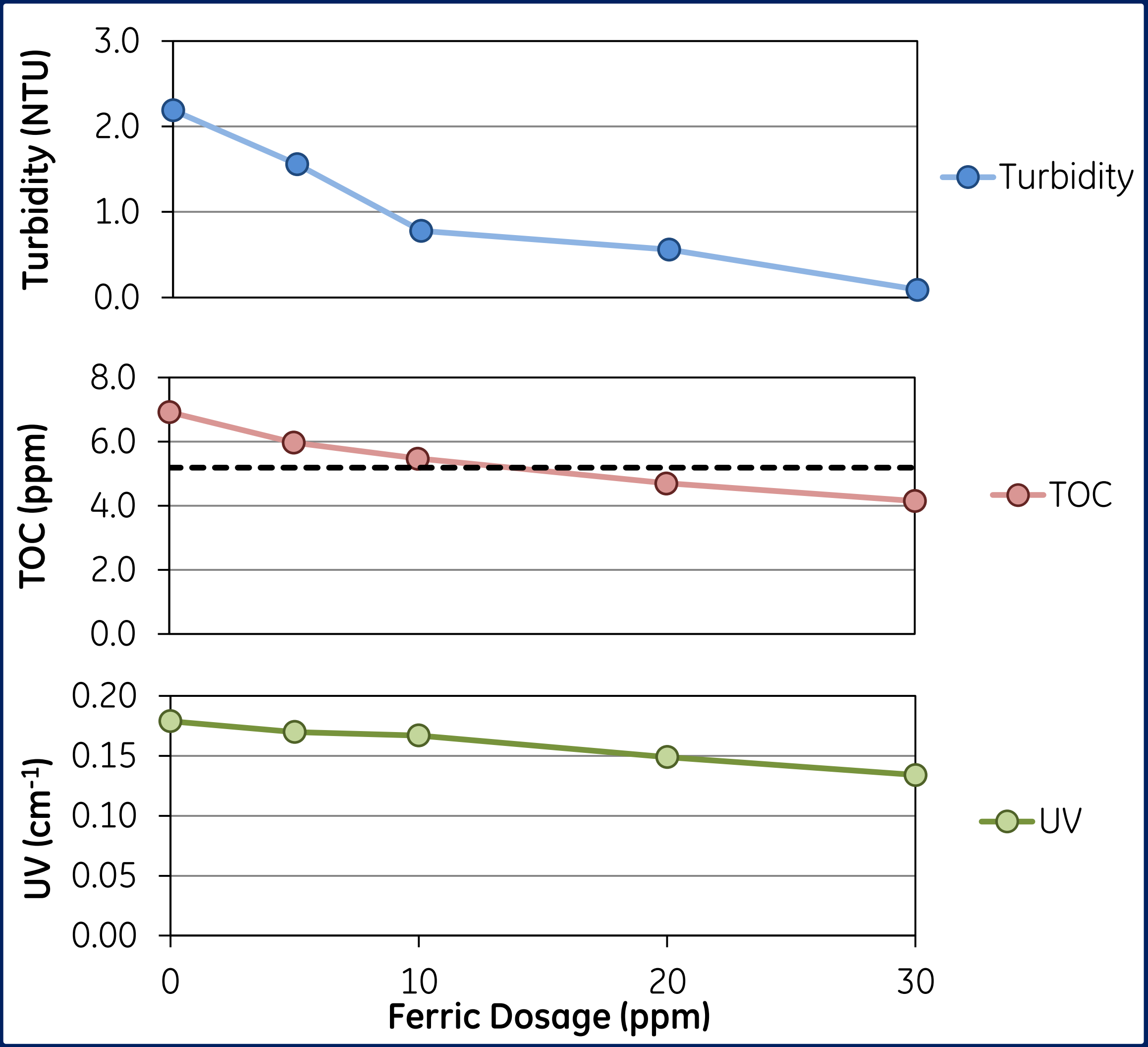


20 and 30 ppm Alum dosage had the same turbidity, but there was slightly better TOC removal with the 30 ppm

But…

Experimental Data

Site 4: San Gabriel River from Austin, TX



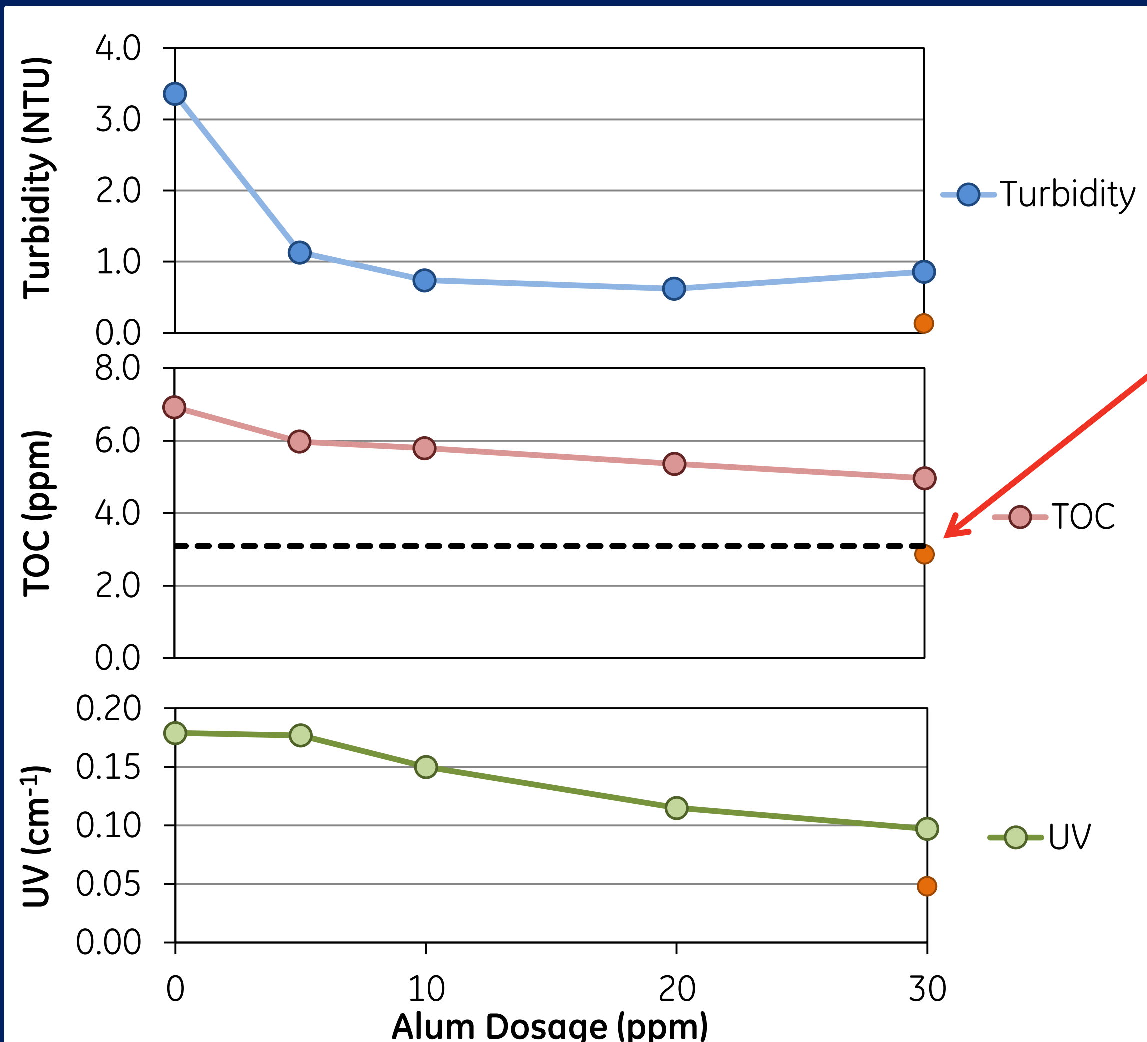
The Ferric was actually a better coagulant than Alum for TOC removal

Could potentially dose less with the Ferric (20 ppm) than the Alum (30 ppm) based on TOC removal

UV with Ferric has interferences, would have picked wrong chemical

Experimental Data

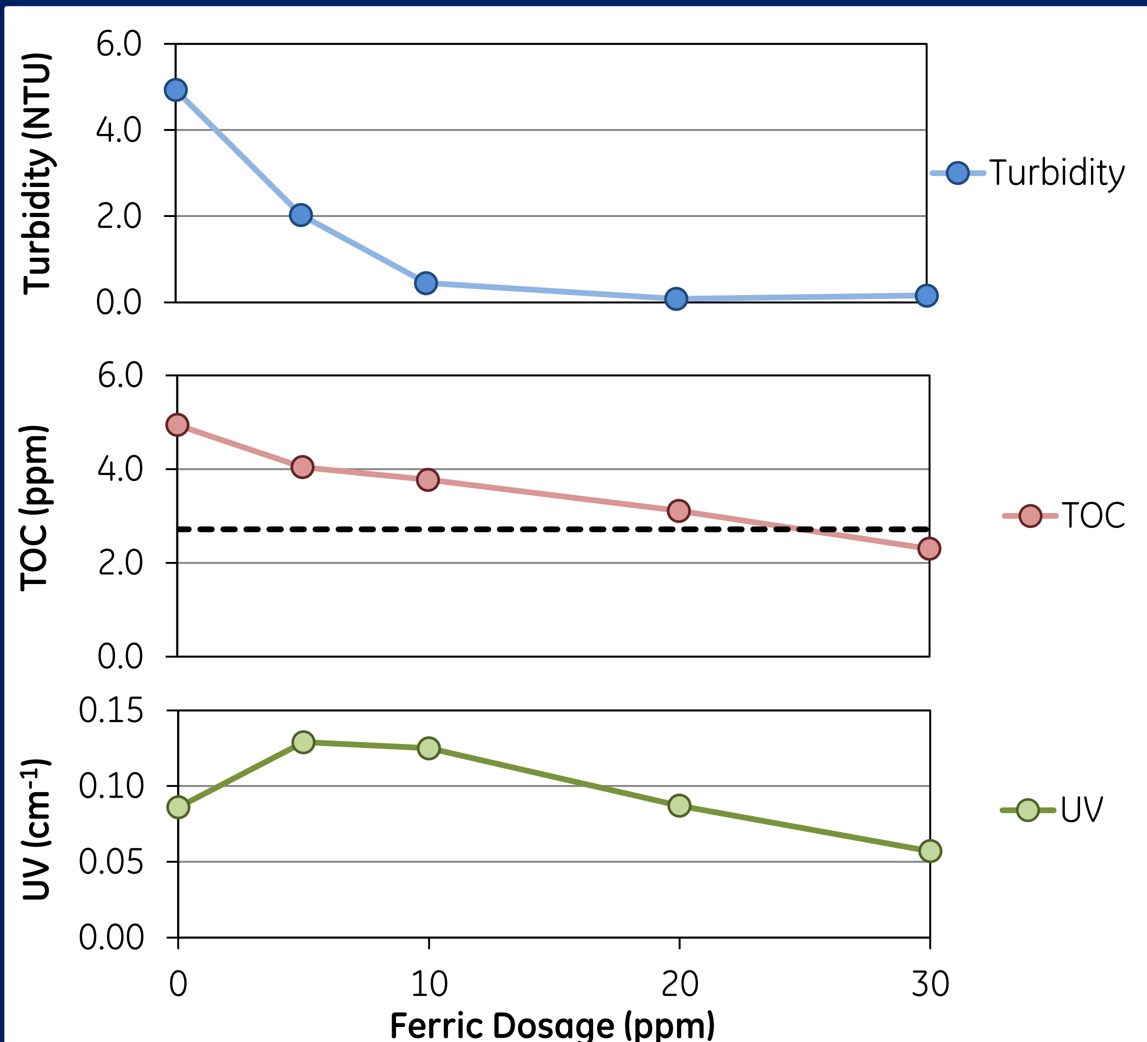
Site 5: Lady Bird Lake in Austin, TX



Adjusting pH to 6.2 on this water with the 30 ppm alum was the only way to remove enough TOC (the turbidity also went way down with pH adjustment)

Experimental Data

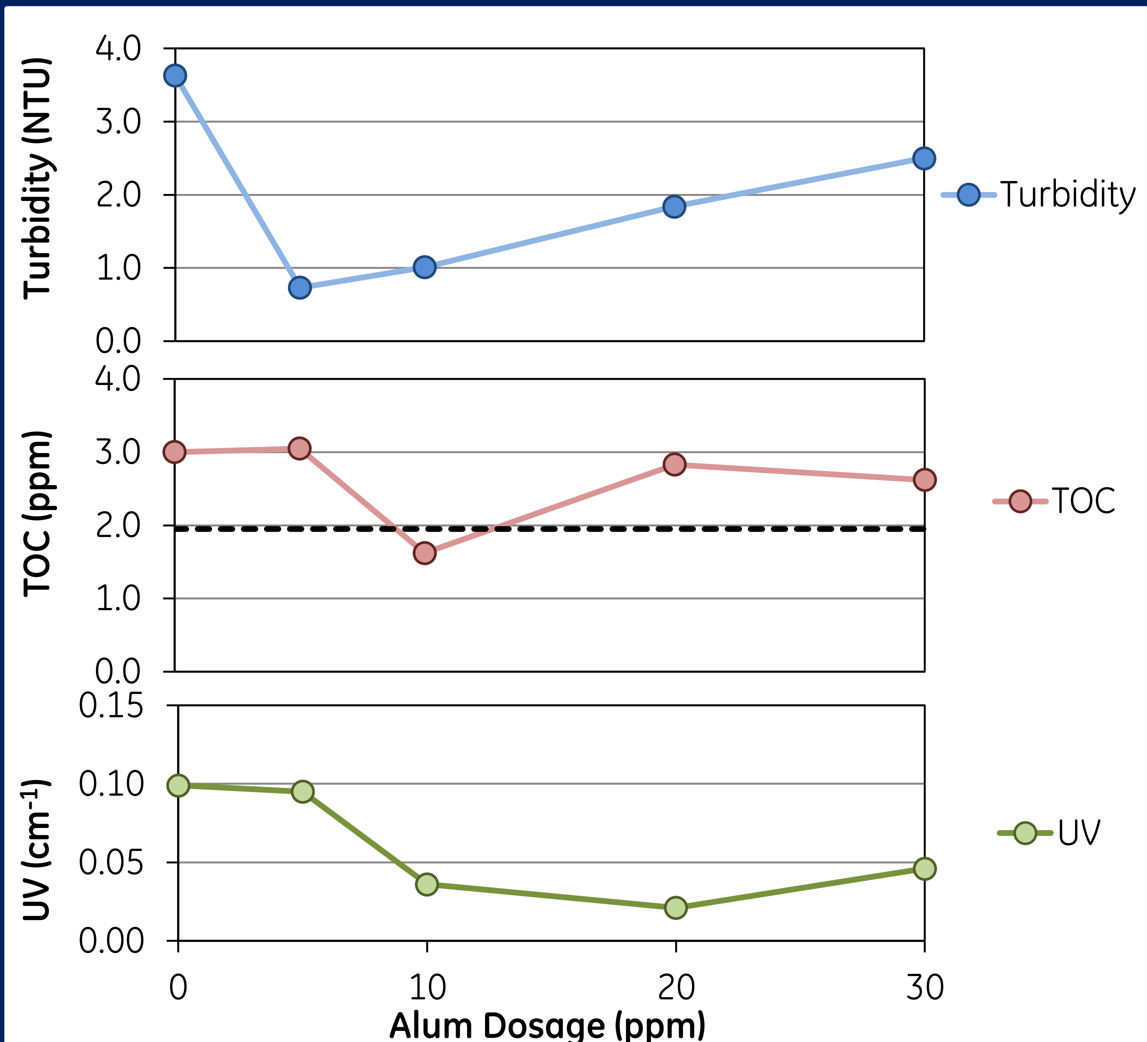
Site 6: Horsetooth Reservoir in Fort Collins, CO



Even though the turbidity of the 30 ppm Ferric went up, the TOC went down

Experimental Data

Site 7: Lake Estes in Estes Park, CO

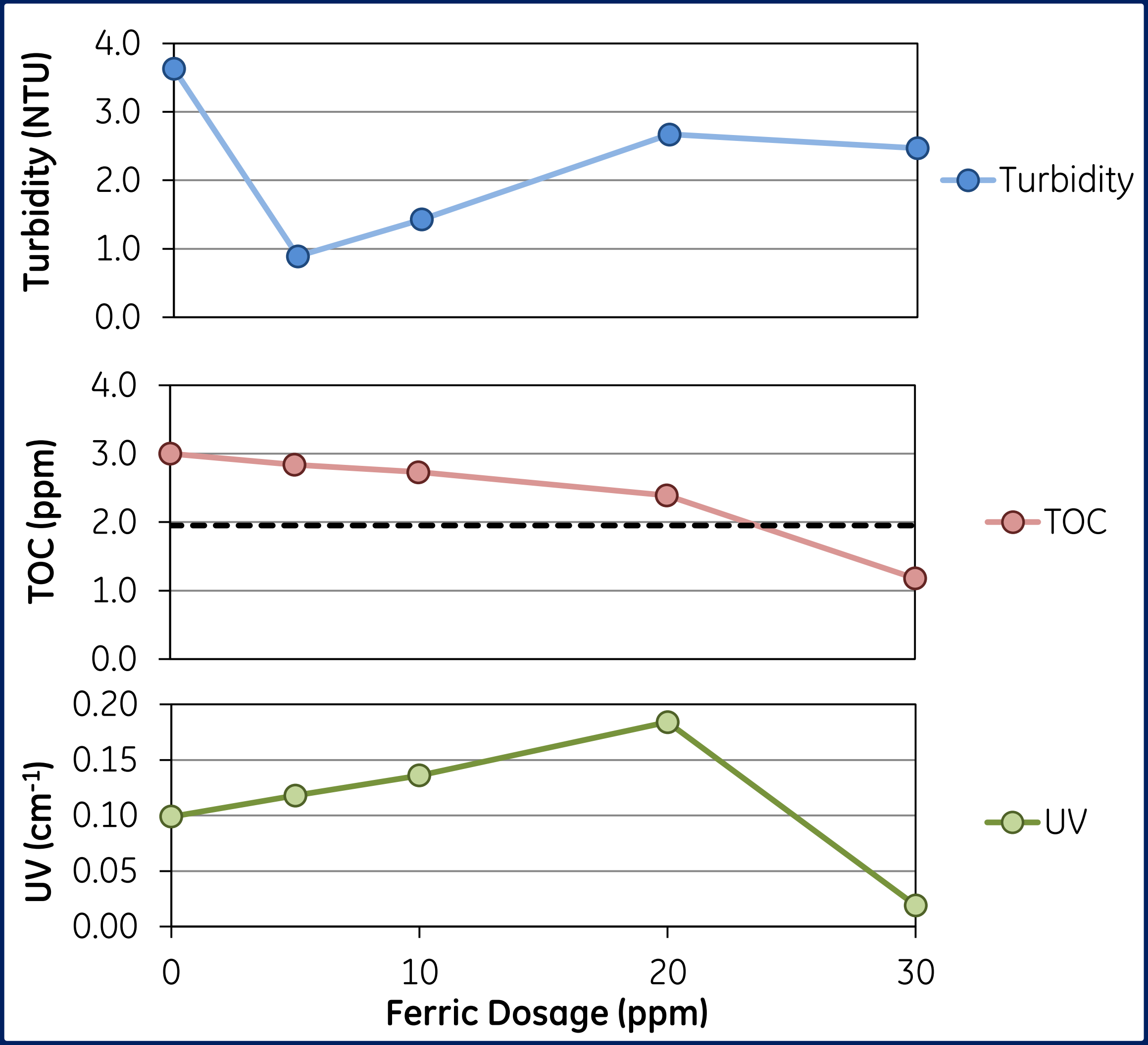


With the Alum, the lowest turbidity (5 ppm Alum) had no TOC removal

And…

Experimental Data

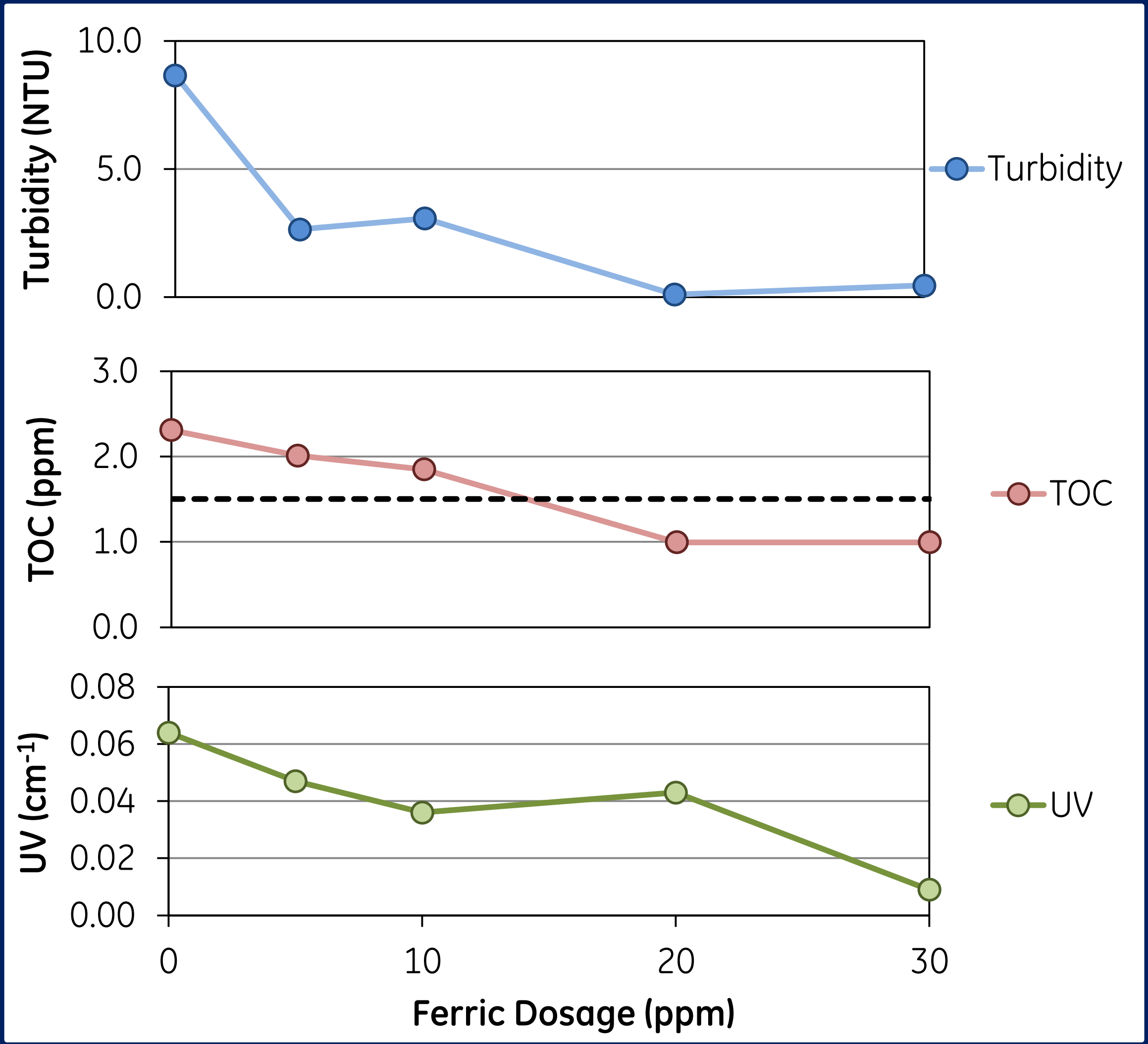
Site 7: Lake Estes in Estes Park, CO



Even the lowest turbidity with the Ferric had almost no TOC removal

Experimental Data

Site 8: Barker Reservoir in Nederland, CO

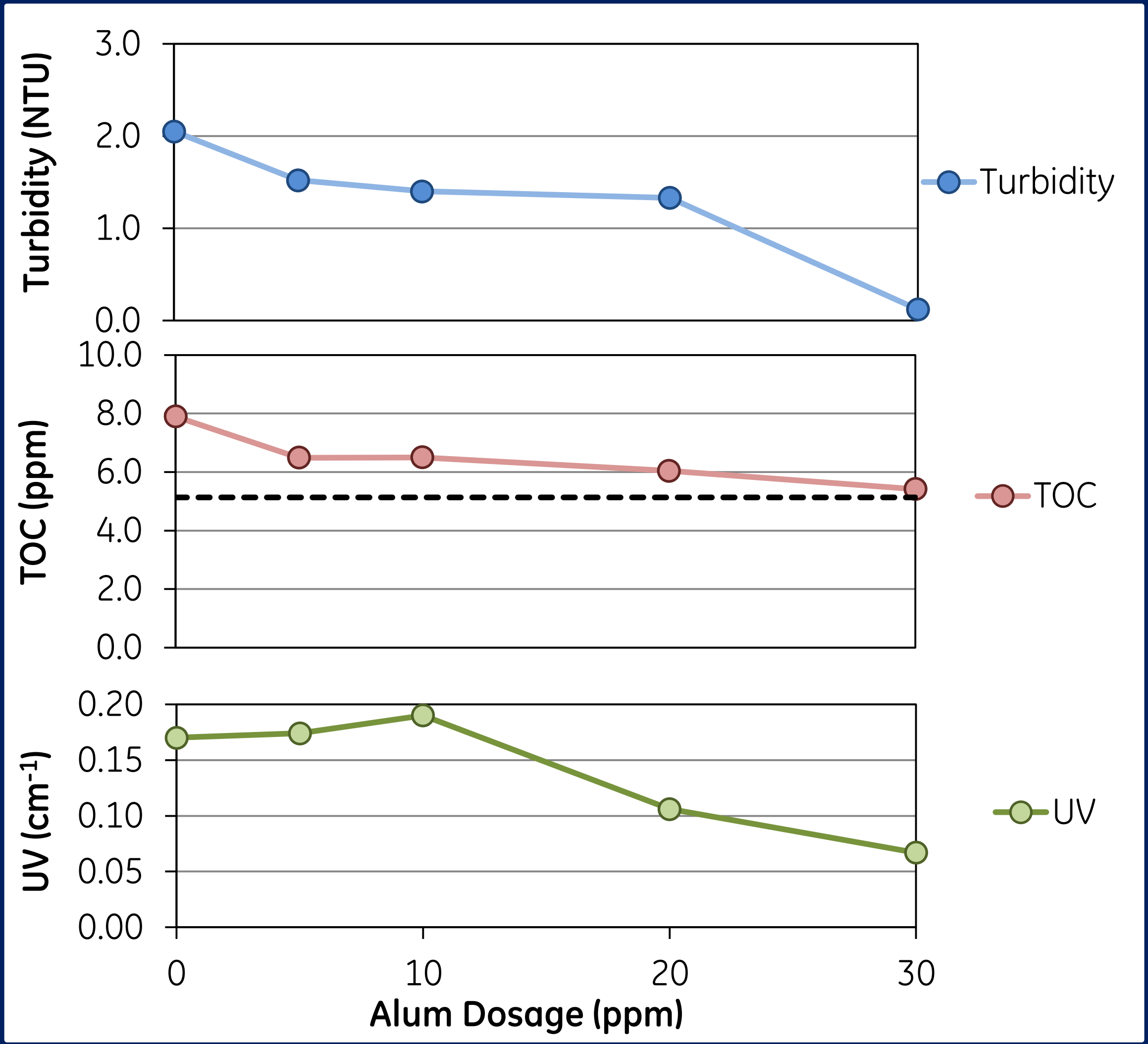


There was no difference in TOC between the 20 and 30 ppm Ferric dosages – a plant could get the same TOC removal with less chemical

Lower UV at 30 ppm Ferric, but no greater TOC removal

Experimental Data

Site 9: Granite Springs Reservoir in Cheyenne, WY

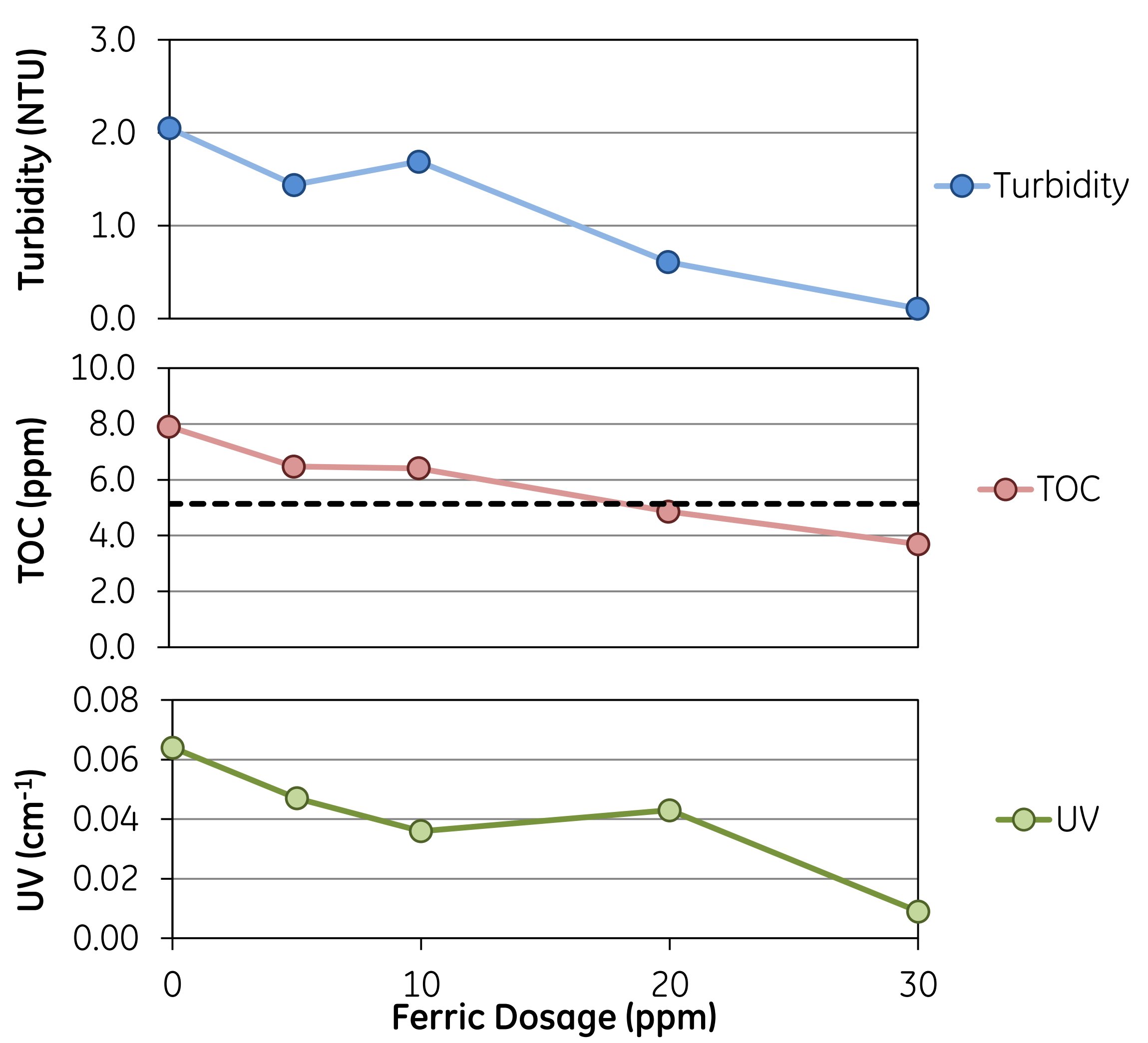


Even with the low turbidity on the 30 ppm dosage, the TOC removal did not meet the regulatory limit

But…

Experimental Data

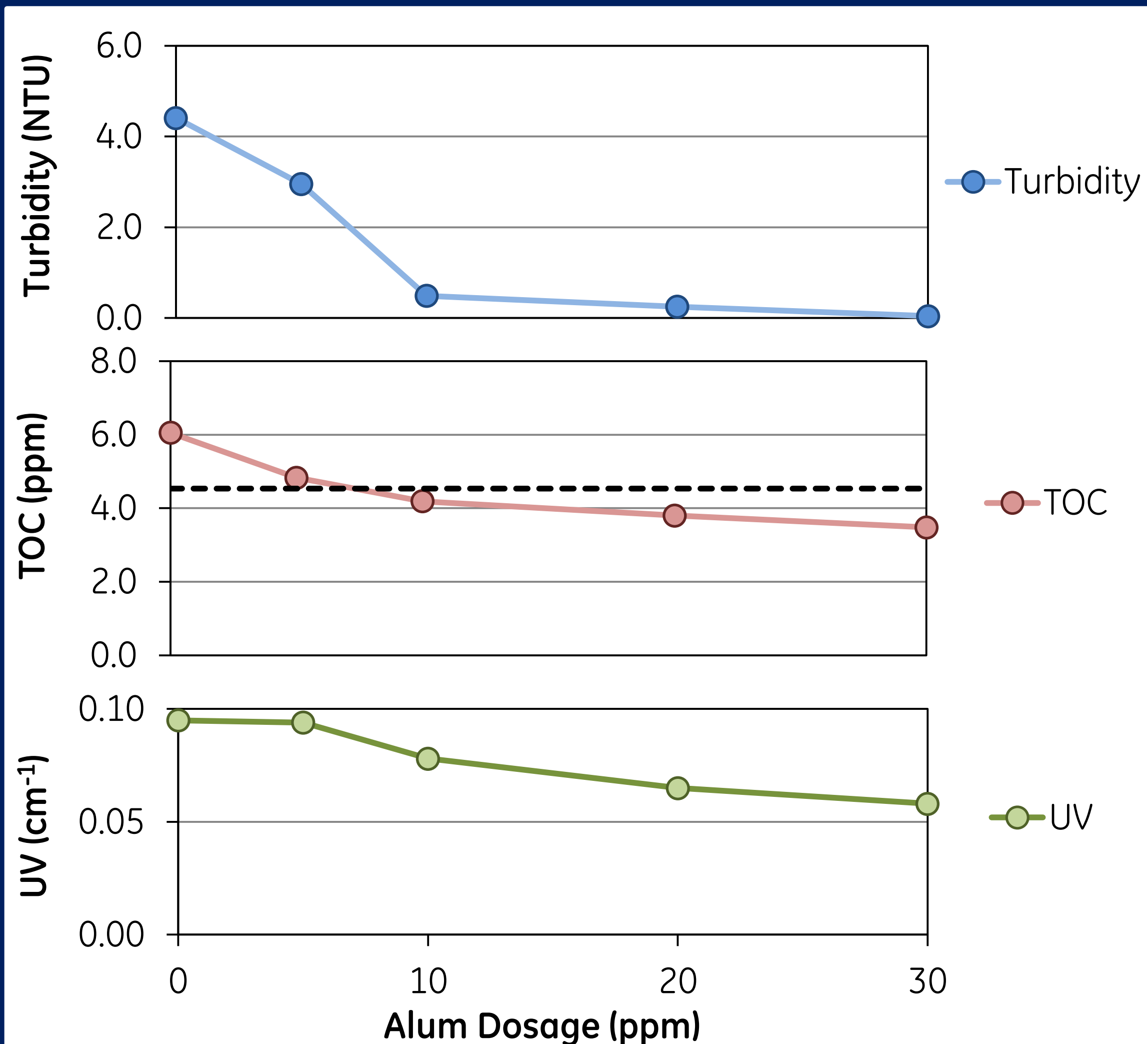
Site 9: Granite Springs Reservoir in Cheyenne, WY



With the Ferric, the lowest turbidity corresponded to the lowest TOC and lowest UV (and the plant would have met the TOC removal regulation)

Experimental Data

Site 10: Pine Brook Reservoir in Boulder, CO



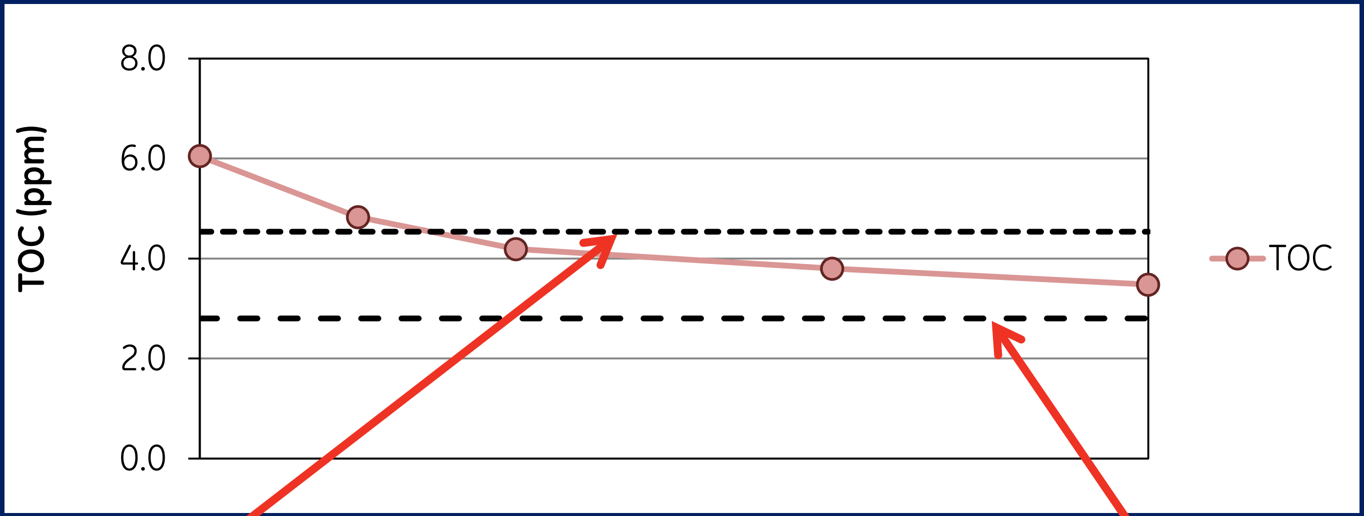
The lowest turbidity corresponded to the best TOC removal… but it isn't low enough (2.8 ppm) to meet the DBP regulations for this plant

Enhanced Coagulation

Enhanced Coagulation

Where a plant removes more TOC than required by regulations so that they will not have issues passing their DBP limits everywhere in their distribution system

Pine Brook Reservoir



Regulatory TOC removal if conventional treatment plant

Needs to be below 2.8 ppm for passage of DBP regulations

Measuring TOC gives much more information for enhanced coagulation

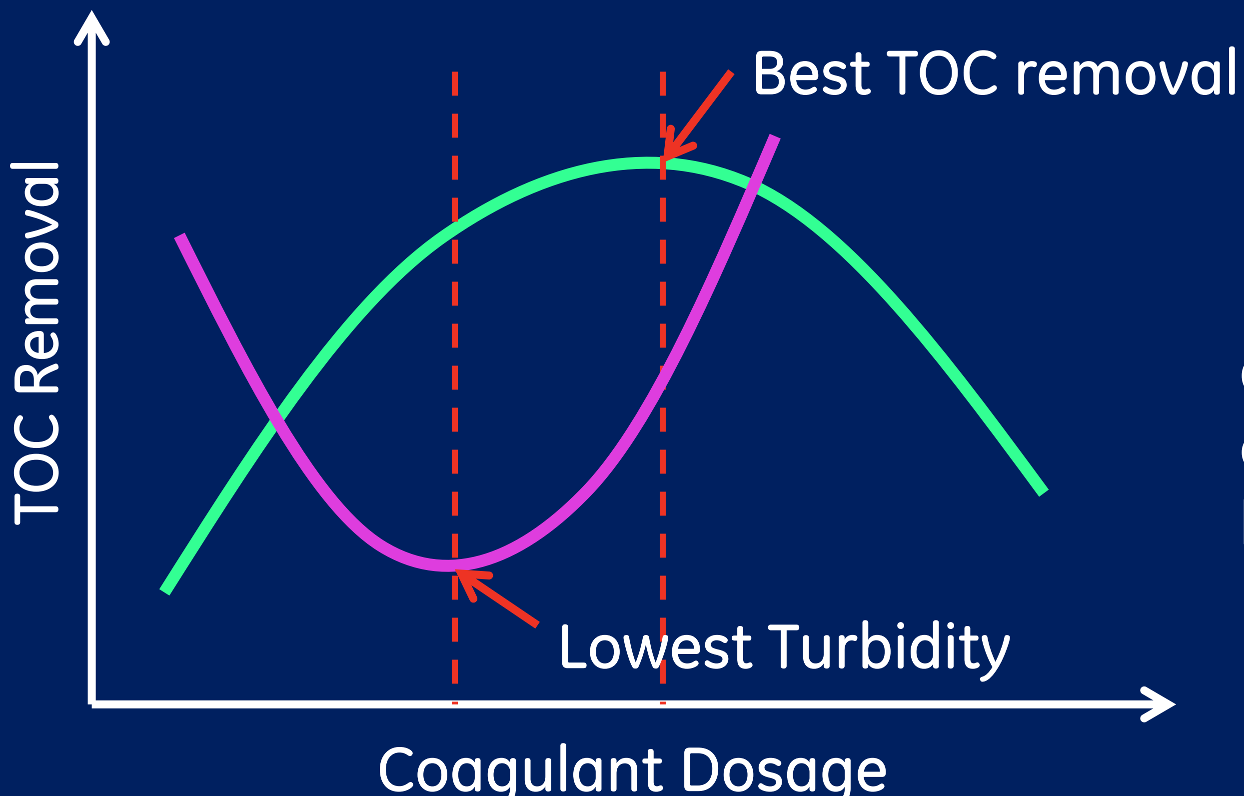
Data Summary

- The lowest turbidity and low UV also corresponded to the greatest TOC removal in less than half of the sites

- Sometimes a slightly higher turbidity corresponded to better TOC removal

- At some sites, less chemical dosage is better for TOC removal (but was slightly worse for turbidity)

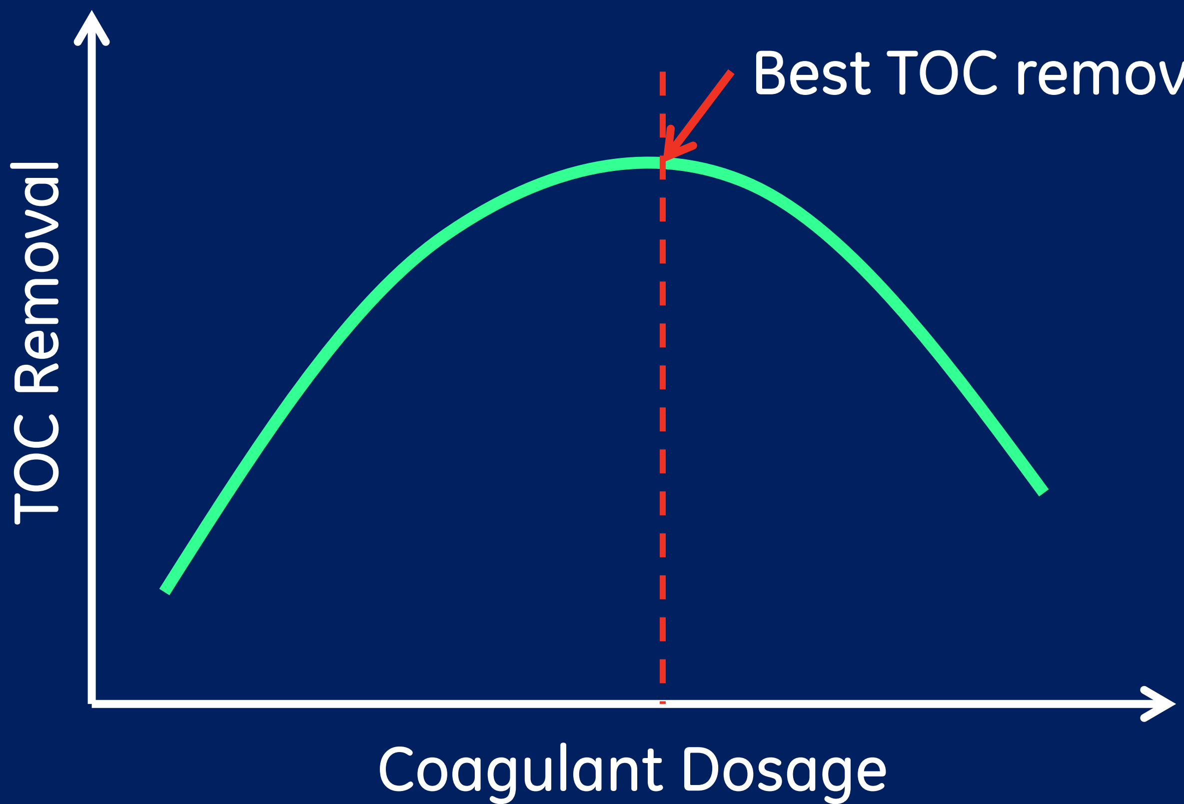
Value of Using TOC



Lowest Turbidity doesn't always correspond to the best TOC removal

Value of Using TOC

Law of Diminishing Marginal Returns

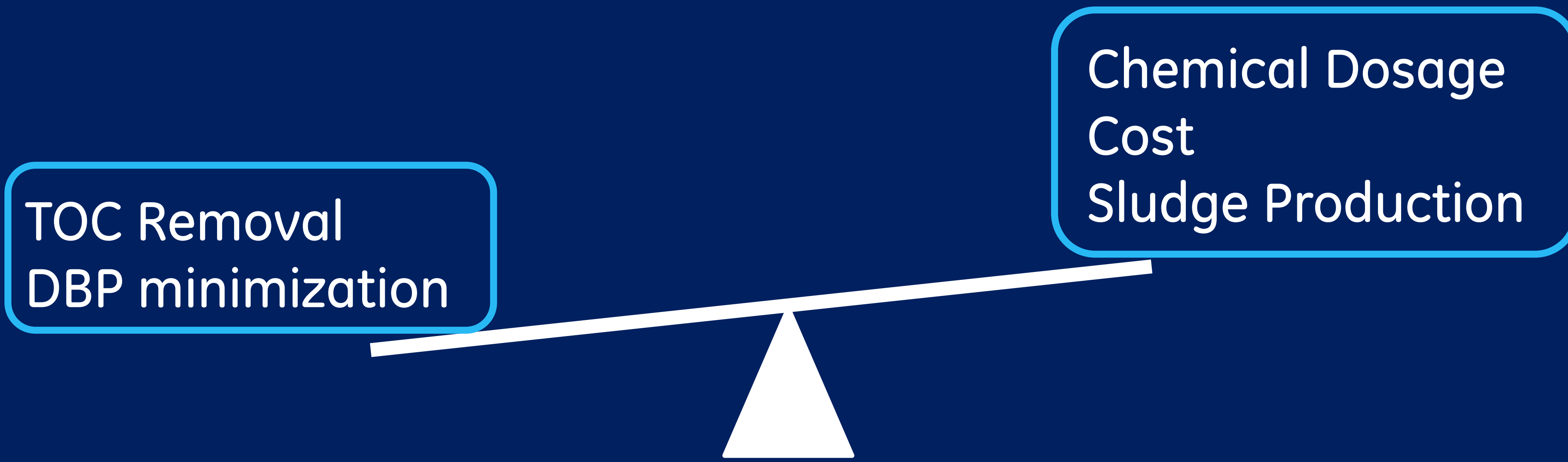


More coagulant isn't always better!!

Dosing coagulant blindly is not typically the best treatment option

Value of Using TOC

Most comprehensive insight into TOC removal and how it relates to chemical dosage, cost, and sludge production



Value of Using TOC

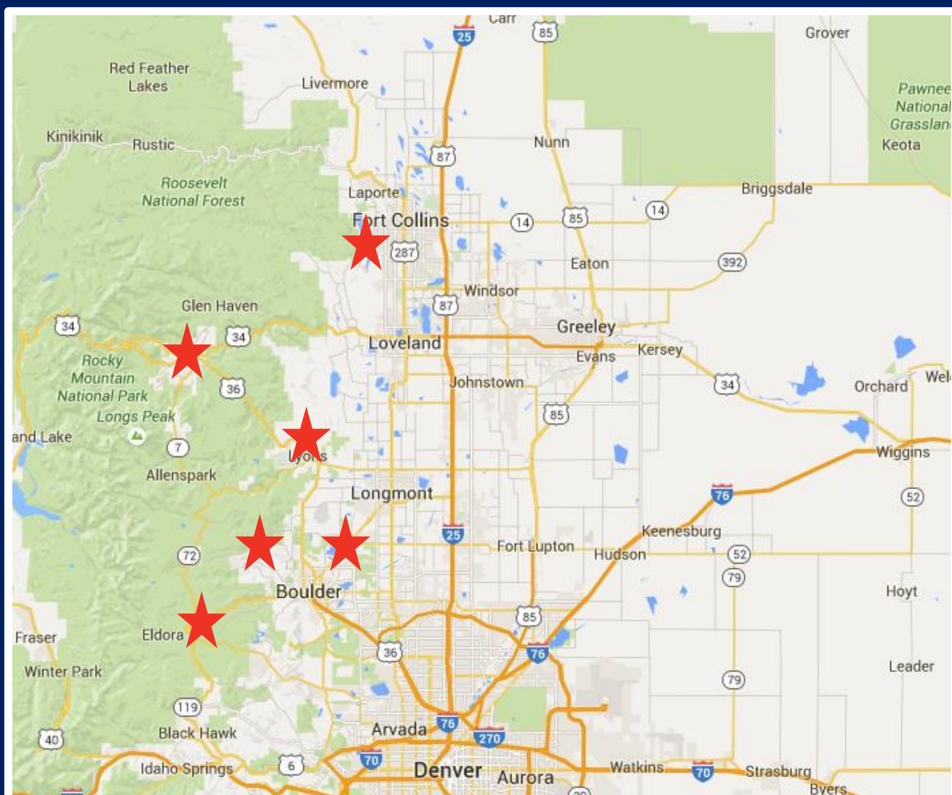
Most comprehensive insight into TOC removal and how it relates to chemical dosage, cost, and sludge production

But, sometimes these factors are actually on the same team! Turbidity and UV can give false information on process optimization.

TOC Removal DBP minimization Chemical Dosage Cost Sludge Production	Turbidity UV

Value of Using TOC

Every plant is different AND every plant changes throughout the year



- ✓ Even the six sites in Colorado all showed great diversity in the optimal water treatment

Site	TOC (ppm)	Alkalinity
Coot Lake	3.7	175
Pine Brook Res.	6.1	135
Barker Res.	2.3	25
Lake Estes	3.6	20
Horsetooth Res.	4.9	40
Saint Vrain River	2.7	40

Value of Using TOC

Every plant is different AND every plant changes throughout the year

Jar testing is a simulation that can help with water treatment optimization as source water changes throughout the year or with other major perturbations (e.g., flood, fire, drought, etc.)

Smarter jar testing using TOC can be extremely valuable to water treatment plants!

Value of Using TOC

Choosing the right chemical and proper dosage

Not all chemicals will work best for any given source water

Not all optimal treatment steps (pH adjustment) make the most sense in a process environment

Best to balance cost and treatment options for the long term

Some chemical companies will do blends and/or help optimize chemical dosages for a plant's source water (many of these chemical companies use TOC)

Value of Using TOC

Case Study: City of Englewood, CO

Problem: too much sludge and too much money spent on chemicals

Goal: Reduce chemical costs and sludge production

Value of Using TOC

Case Study: City of Englewood, CO

Before: only using turbidity with jar testing

After: expanded jar testing to include TOC and then scaled it up to the whole treatment process

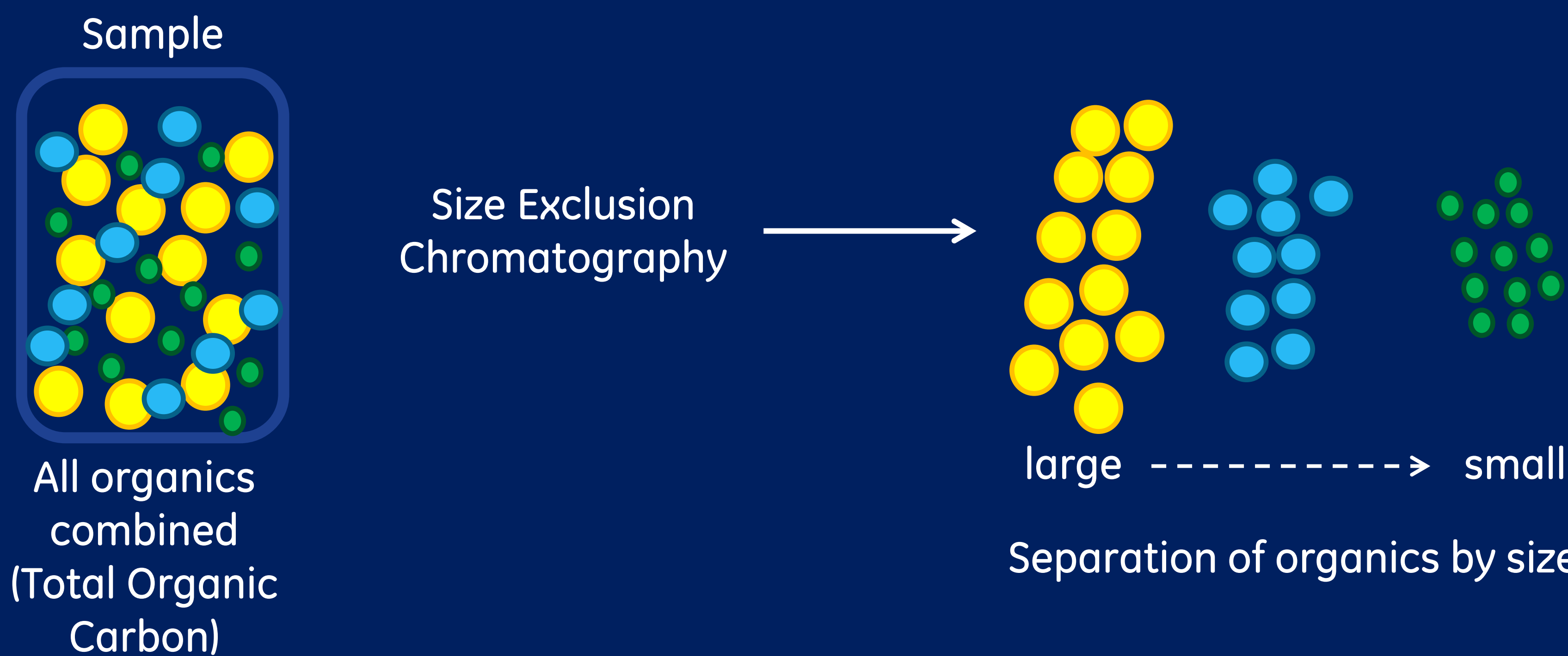
Plant saw a significant reduction in chemicals needed and sludge production

1 year savings of > $100k in chemical and disposal costs

Size Distribution of Organics

Technology to determine size distribution of organics in water

Size Exclusion Chromatography with both UV and TOC detection



Size Distribution of Organics

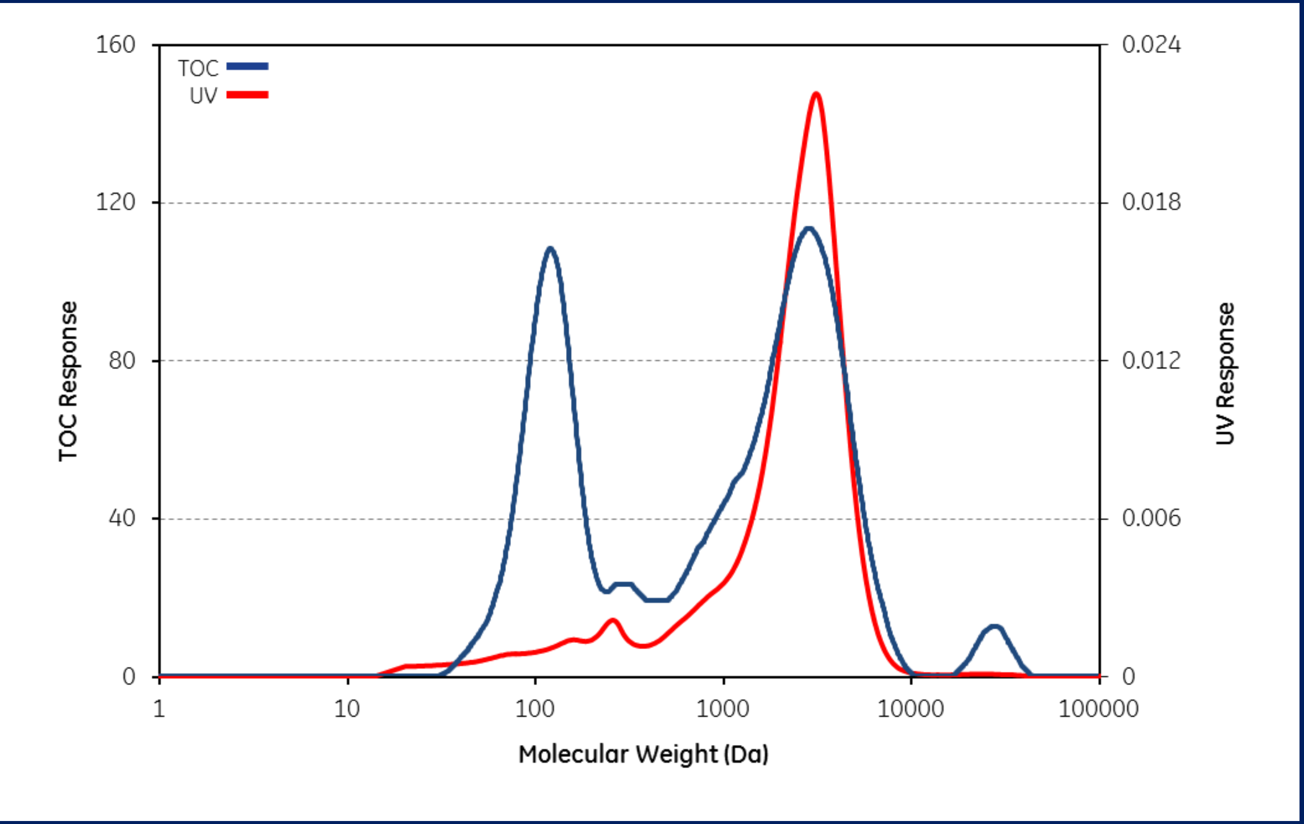
Size Exclusion Chromatography (SEC)

Why is this important?

- ✓ TOC detection because not all organics will be detected by UV
- ✓ Organics in some size fractions produce more DBP’s (humic acids, etc.)
- ✓ Complete picture or “footprint” of the organics to optimize treatment
- ✓ Shows changes in organic characteristics throughout the year

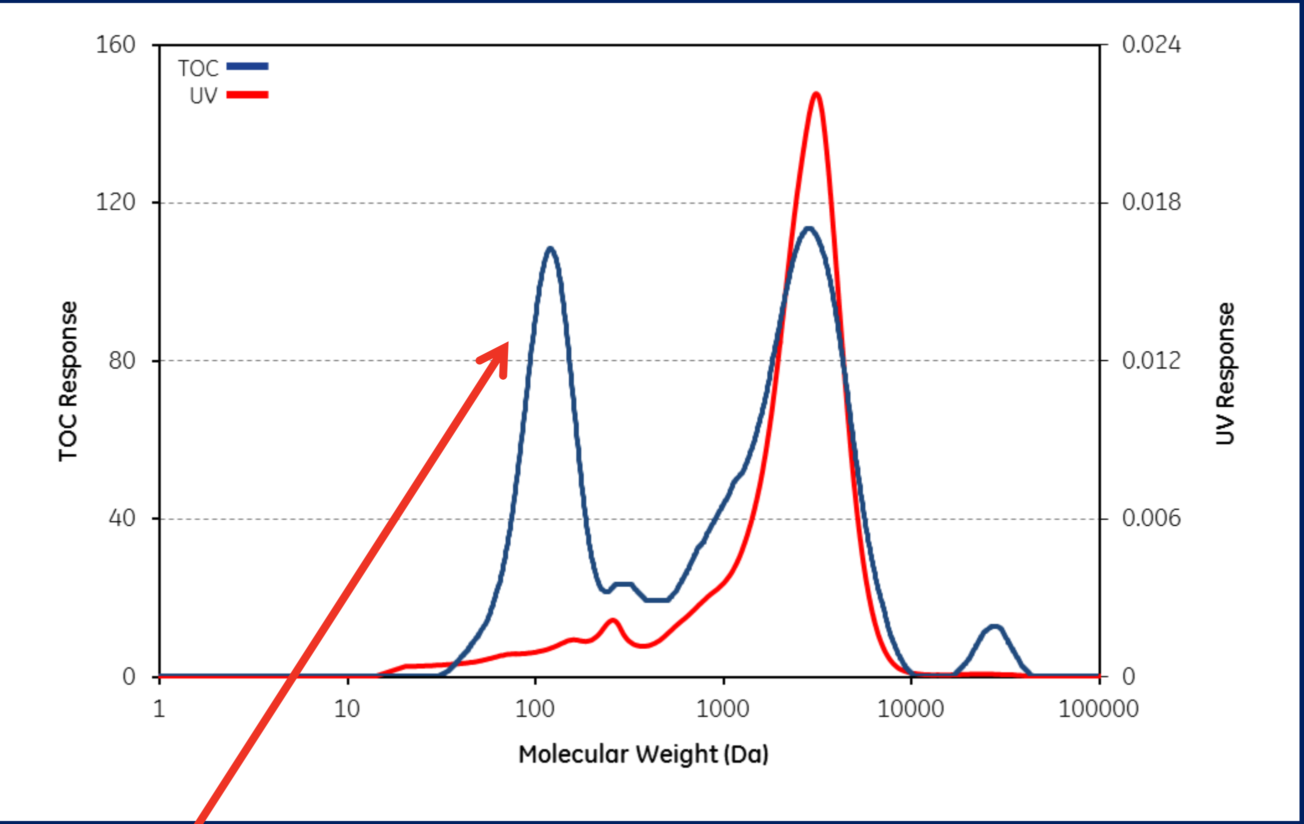
Size Distribution of Organics

Raw water coming into the Pine Brook Plant



Size Distribution of Organics

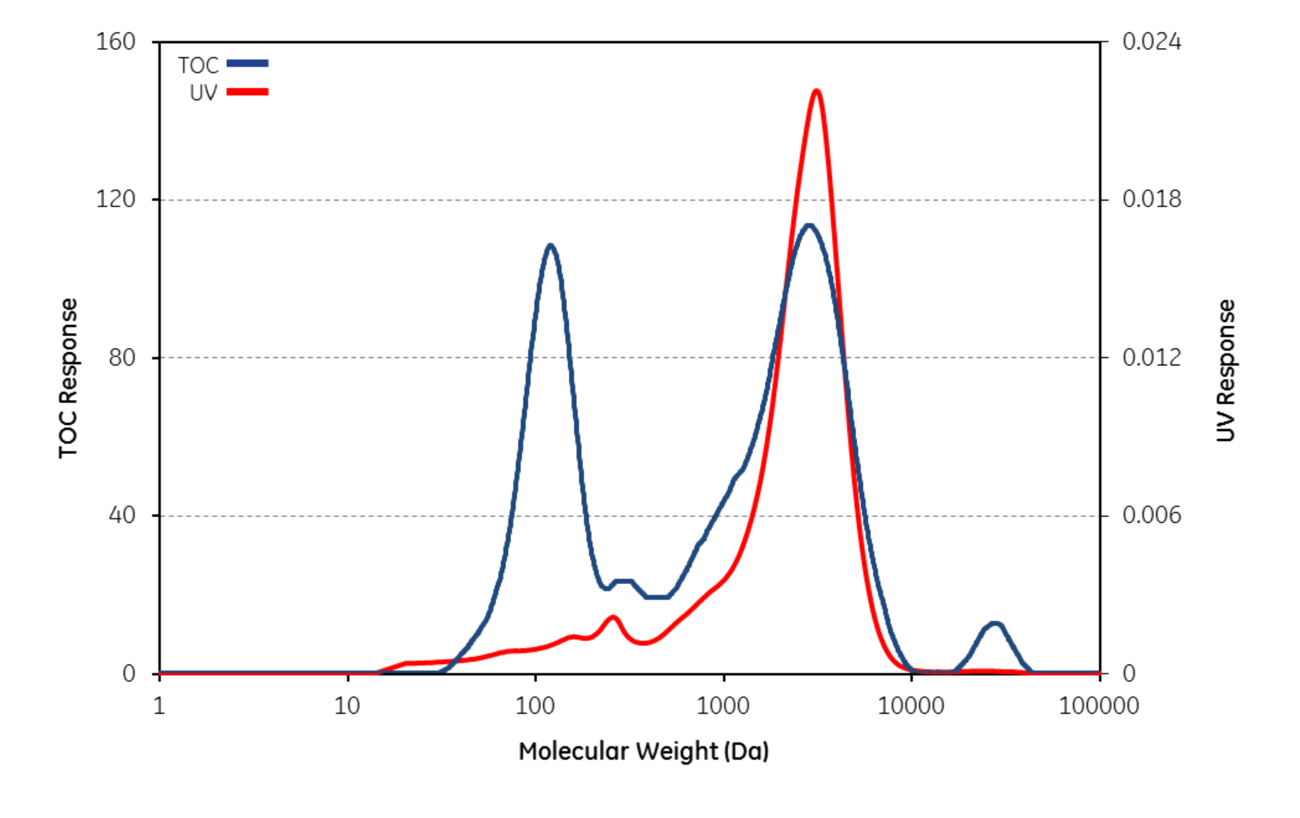
Raw water coming into the Pine Brook Plant



This whole size fraction of organics is not detected by UV!

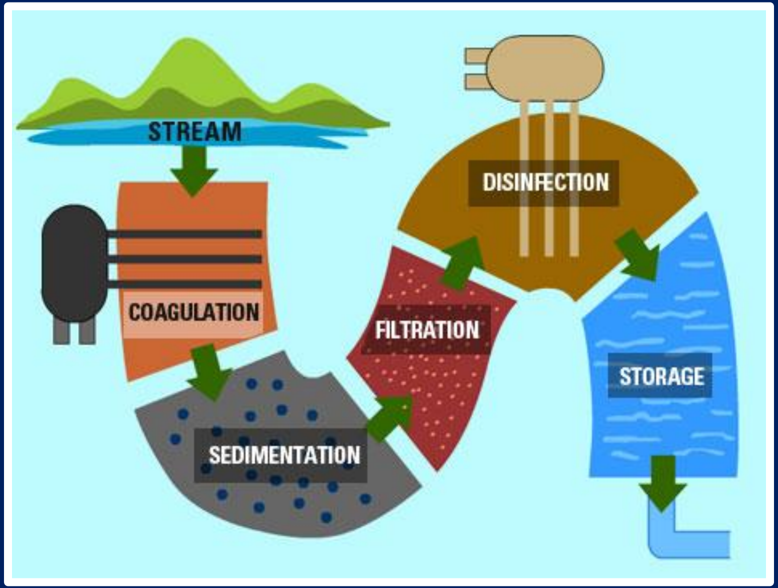
Size Distribution of Organics

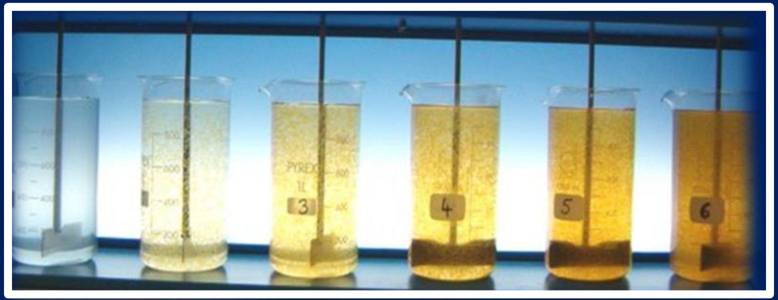
Raw water coming into the Pine Brook Plant



Better understanding the characteristics of the organics coming into the plant -> even smarter treatment

Summary





- ✓ TOC is important for regulatory requirements (DBP limits and %TOC removal)
- ✓ Jar testing that includes TOC as a measured parameter gives the most comprehensive information on optimizing the treatment process
- ✓ Every plant has different water that can change throughout the year, so optimization may change as well. Jar testing on site with TOC is a great way to help a plant minimize cost while still complying with regulatory limits.

Questions?