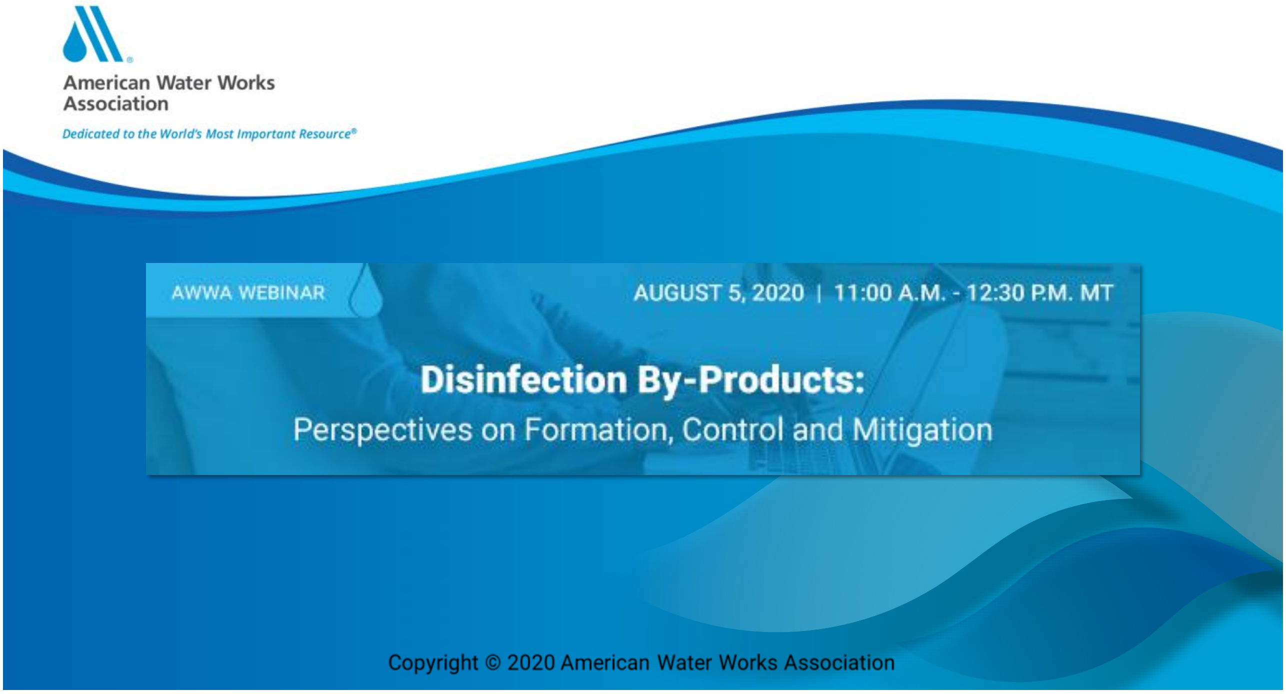

American Water Works Association

Dedicated to the World's Most Important Resource®

AWWA WEBINAR

AUGUST 5, 2020 | 11:00 A.M. - 12:30 P.M. MT

Disinfection By-Products:

Perspectives on Formation, Control and Mitigation

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WEBINAR MODERATOR

Chris Owen

Director of Water and Reuse Innovations

Hazen and Sawyer

Chris is the Director of Water and Reuse Innovations for Hazen and Sawyer. She has 29 years of experience in water quality, research, treatment and regulatory compliance. Her utility roles have included regulatory compliance, research, laboratory management, source water assessment and protection, and distribution system issues. Research work included investigations of UF/MF/RO membranes, online monitoring, total coliform occurrence, enhanced coagulation, biofiltration, distribution system, corrosion, biostability, ion exchange, chloramine chemistry and stability, contaminants of emerging concern, and algal toxins. She is active in regulatory issues at the state and federal levels, promoting utility concerns and science-based decisions. She served on the USEPA SAB for Drinking Water and the USEPA NACEPT.

She is an active member of the American Water Works Association (AWWA), serving as a Trustee and the current Chair of the Water Science and Research Division. She is a Trustee for WateReuse FL and the President of the Board of Directors for the American Membrane Technology Association. She has been active in the Water Research Foundation (WRF) and the WateReuse Foundation for more than 20 years.

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PANEL OF EXPERTS

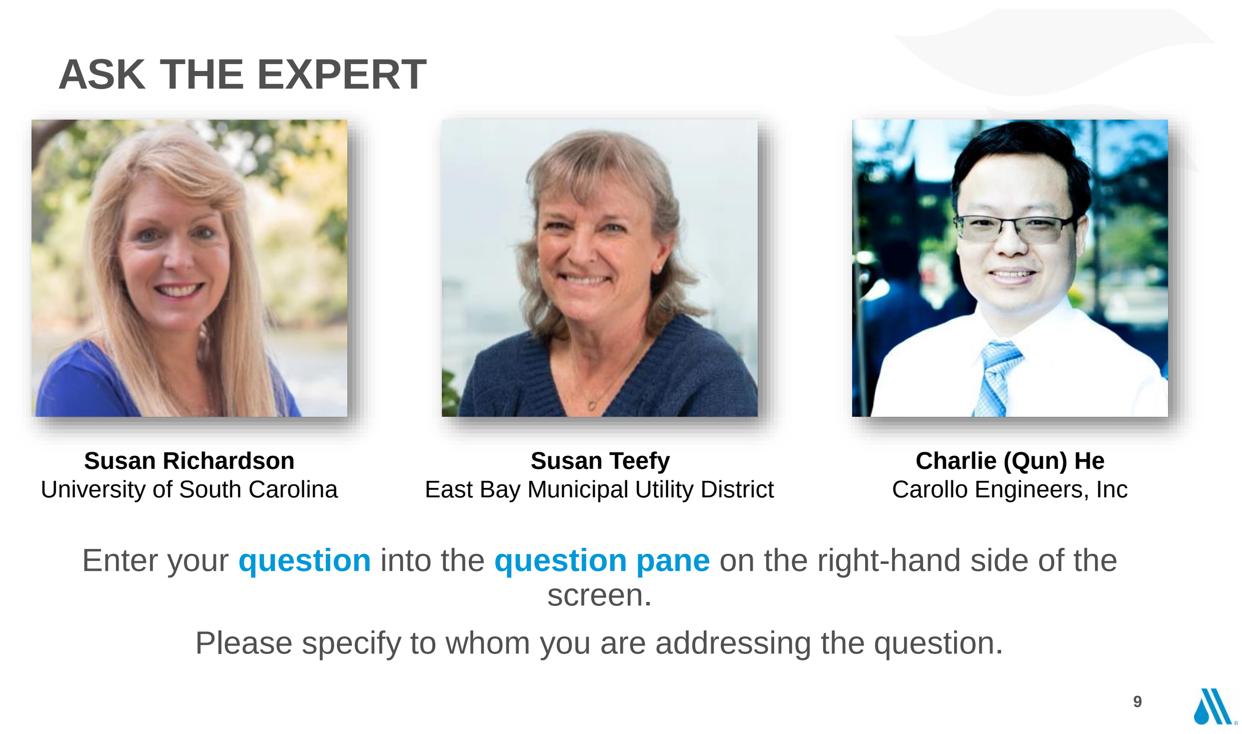
Susan Richardson
Arthur Sease Williams
Professor of Chemistry
University of South Carolina

Susan Teefy
Manager of Water Quality
East Bay Municipal Utility
District

Charlie (Qun) He
Vice President, Chief
Technologist – Decision Support
Carollo Engineers, Inc

AGENDA

I.	Identifying Key DBP Drivers of Toxicity	Susan Richardson
II.	DBP Control Case Study	Susan Teefy
III.	An Integrated Approach for DBP Mitigation	Charlie He



ASK THE EXPERT

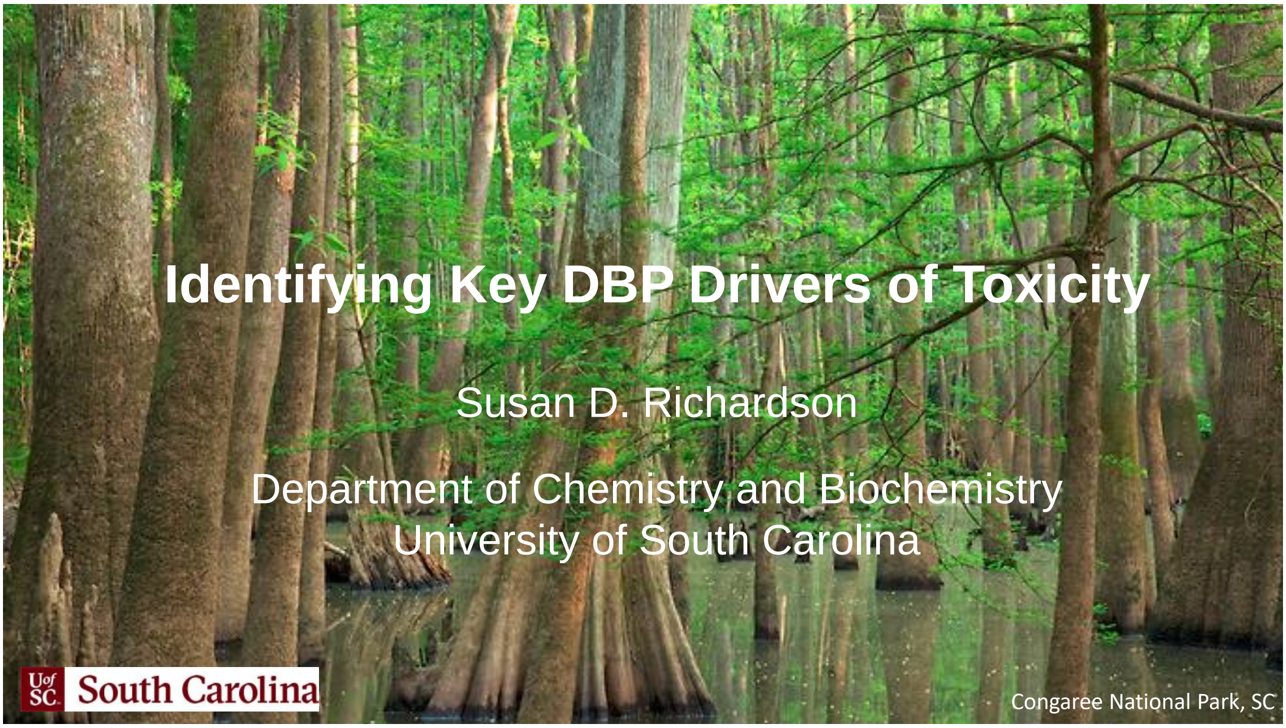
Susan Richardson
University of South Carolina

Susan Teefy
East Bay Municipal Utility District

Charlie (Qun) He
Carollo Engineers, Inc

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.



Identifying Key DBP Drivers of Toxicity

Susan D. Richardson

Department of Chemistry and Biochemistry
University of South Carolina

Congaree National Park, SC

Acknowledgements

From my group at USC:


Josh Allen


Hannah Liberatore

Our collaborators:


Michael Plewa
and Elizabeth Wagner
University of Illinois


Stuart Krasner
MWDSC
Also, Ai Jia, Tiffany Lee,
Carrie Guo, Raha Shirkhani
from Metropolitan

Funding:

And the many drinking water plants for graciously providing us samples !

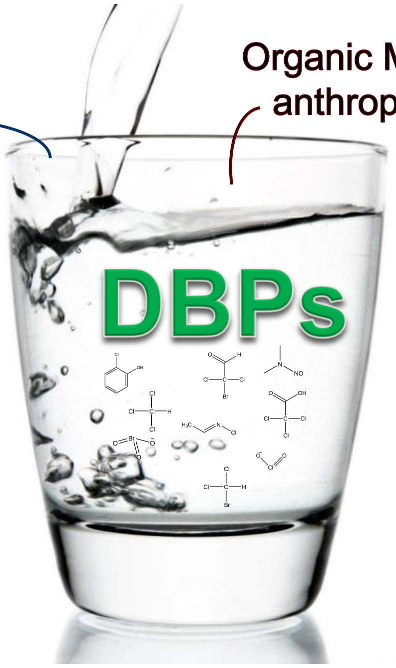
Overview

- Background on DBPs
  - How they are formed, why they are important
- Methods and results of our study
- Which are toxicity drivers
- Potential strategies for DBP removal

Goal for audience:
A better understanding of priority unregulated DBPs and which are driving cytotoxicity in drinking water

Disinfectants:
Cl_2, NH_2Cl
O_3, ClO_2

Organic Matter (natural or anthropogenic), Br^-, I^-



Disinfection by-products are always in your drinking water (usually at ppb levels)

> 700 DBPs identified!

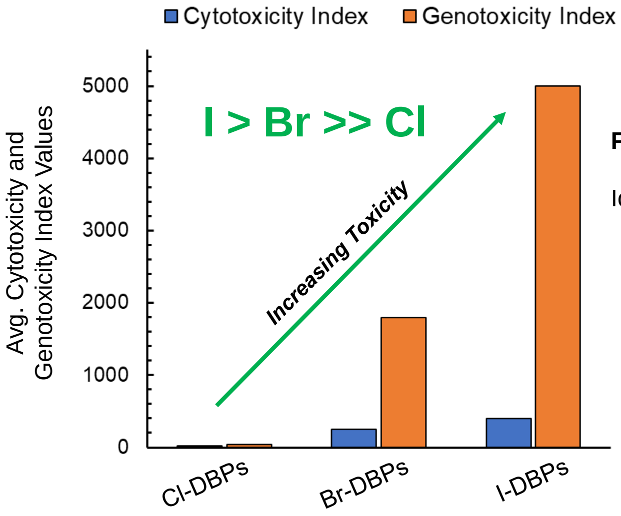
Why this is important

DBPs linked to human health effects:
Bladder cancer, miscarriage, and birth defects

The Quest

- Determine the drivers of these effects
- Minimize toxicity drivers to make drinking water safer

Cytotoxicity and Genotoxicity of Halogenated DBPs

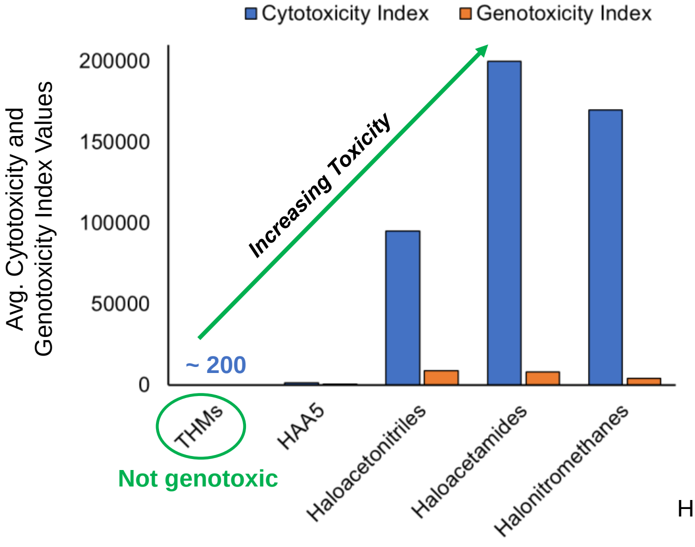


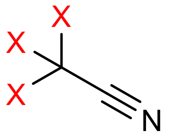
For example:

Iodoacetic acid > bromoacetic acid >> chloroacetic acid

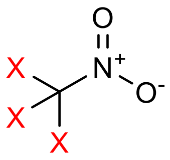
Yang, et al. *Environ. Sci. Technol.* **2014**, *48*, 12363-12369.

Cytotoxicity and Genotoxicity of Nitrogenous DBPs

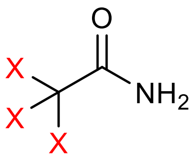




Haloacetonitriles (HANs)

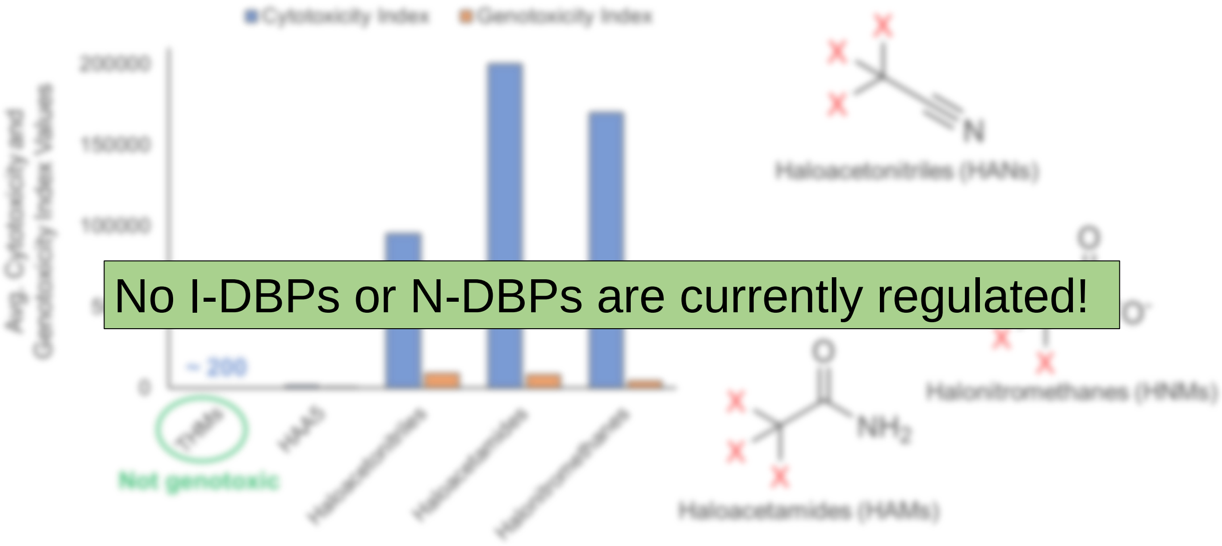


Halonitromethanes (HNMs)



Haloacetamides (HAMs)

Plewa et al. *ACS Symposium Series.* **2008** No. 995, 36.

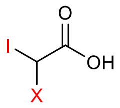


No I-DBPs or N-DBPs are currently regulated!

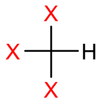
Plewa et al. *ACS Symposium Series.* **2008** No. 995, 36.

Goal of our study:
Identify the drivers of cytotoxicity and genotoxicity in drinking water

>70 DBPs Quantified Using GC-MS

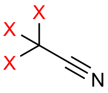


Iodoacetic acids
(IAAs)

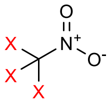


Iodo-trihalomethanes
(I-THMs)

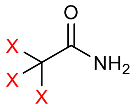
I-DBPs



Haloacetonitriles
(HANs)



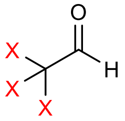
Halonitromethanes
(HNMs)



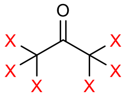
Haloacetamides
(HAMs)

N-DBPs

X = H, Cl, Br, I



Haloacetaldehydes
(HALs)

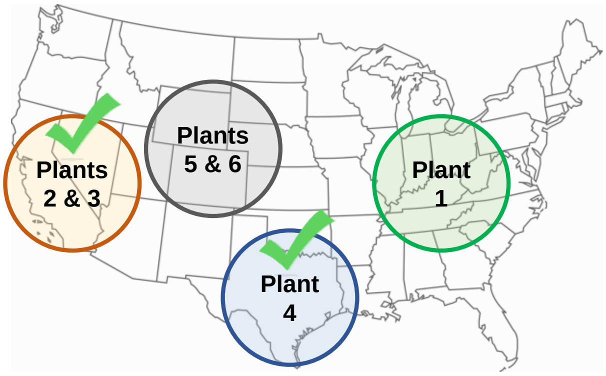


Haloketones
(HKs)

Also measured:
THM4 and HAA9
TOCl, TOBr, and TOI
Sucralose
TOC, SUVA, Br^-, I^- of raw water
Mammalian cell cytotoxicity and genotoxicity

Cuthbertson, et al. *Anal. Chem.* **2020**, *92*, 3058-3068.

Plants Sampled



Investigated:

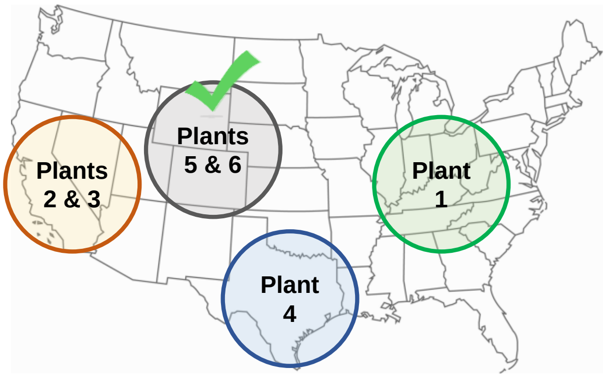
- Disinfectant used (Cl_2, NH_2Cl, O_3)
- Source water impacts
  - High Br^- and I^- (saltwater intrusion)

Plant 2: Cl_2, GAC
Plant 3: O_3, NH_2Cl, biofiltration
Plant 4: NH_2Cl, conventional treatment

In Plants 2-4:

- Br^- ranged from 120 – 334 µg/L
- I^- was detected at least once in each plant, from 27 – 32 µg/L

Plants Sampled



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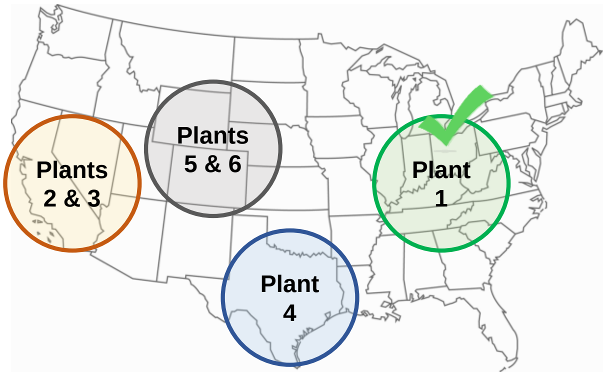
  - High Br^- and I^- (saltwater intrusion)
    Plant 2: Cl_2, GAC
    Plant 3: O_3, NH_2Cl, biofiltration
    Plant 4: NH_2Cl, conventional treatment
  - Plants 5 & 6: Wastewater-impacted sources
    - More DBP precursors
    - Also high in Br^- (92 – 143 µg/L)
    - Each use NH_2Cl with advanced treatment strategies (GAC, riverbank filtration, soil aquifer treatment for Plant 6, ultrafiltration for Plant 5

Plants Sampled



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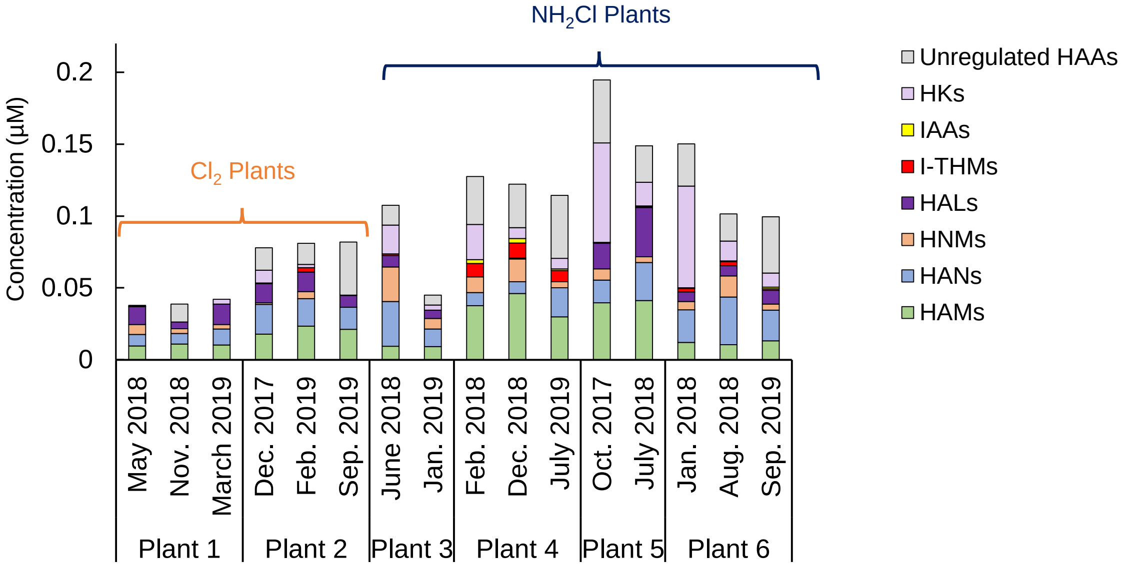
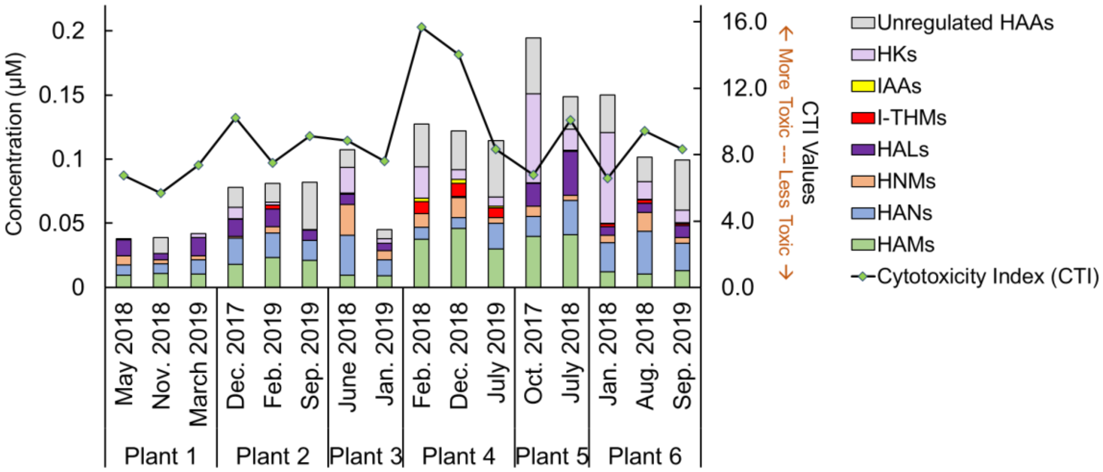
    Plant 3: O_3, NH_2Cl, biofiltration
    Plant 4: NH_2Cl, conventional treatment
  - Plants 5 & 6: Wastewater-impacted sources
    - More DBP precursors
    - Also high in Br^- (92 – 143 µg/L)
  - Plant 1 – GAC/Cl_2
    - Minimal wastewater or halide impacts (Br^-: 20 – 44 µg/L; I^-: < 10 µg/L)

2-3 Samplings each across different seasons

Unregulated DBP Formation

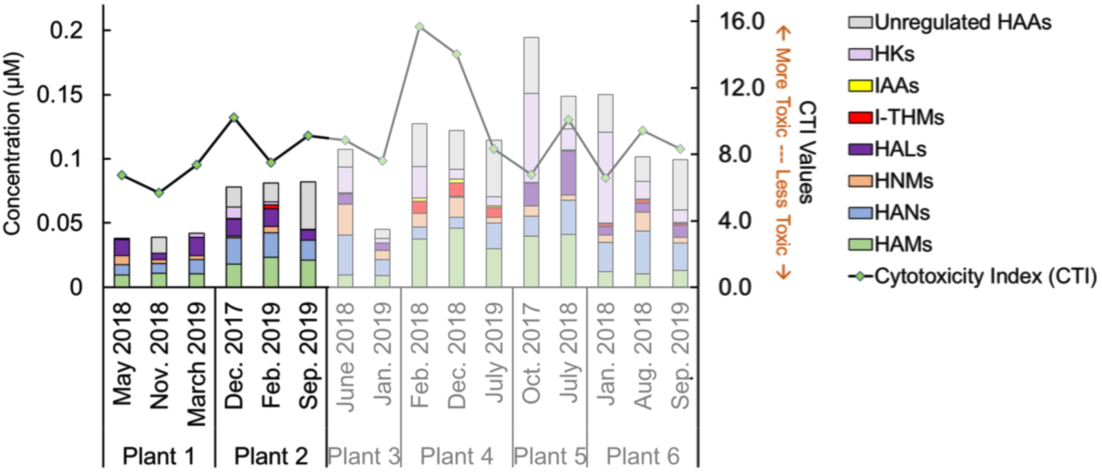


Cytotoxicity and Unregulated DBPs



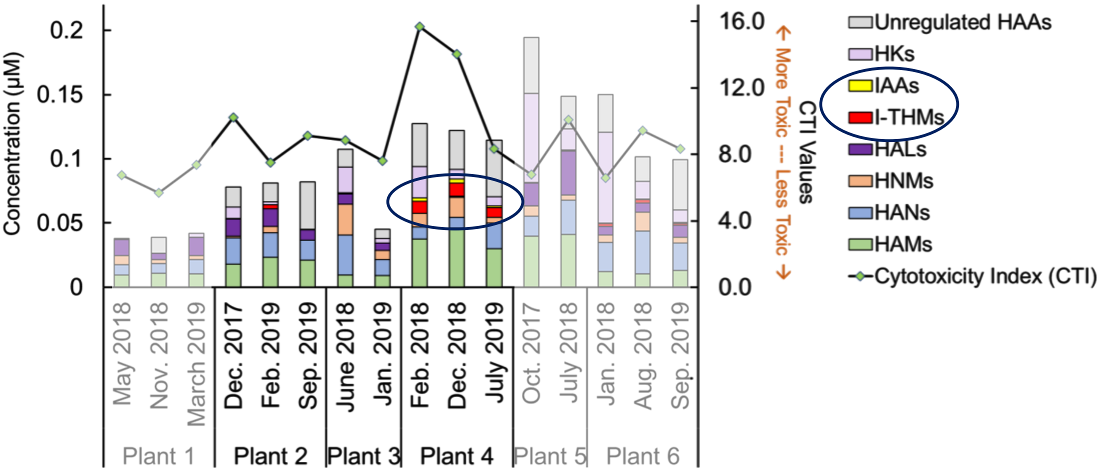
GAC/Cl_2 Plants (1-2)

Plant 1: - Less DBP formation, likely from the use of GAC, and resulting cytotoxicity than most plants
- Lower DBP formation than Plant 2, likely because of less halide impact



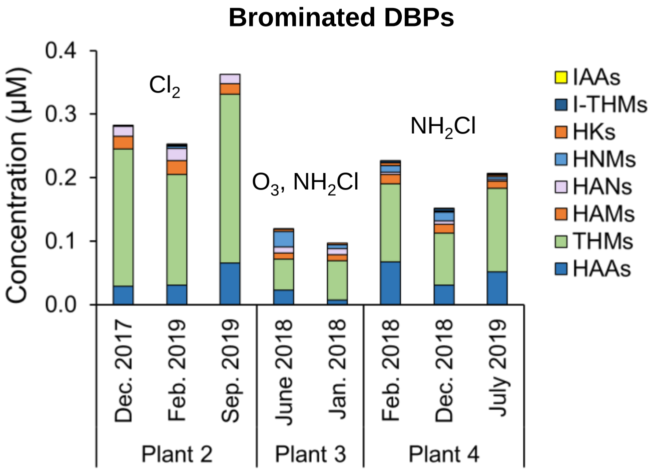
High Halide, Low Wastewater-Impacted Plants (2-4)

Plant 4: – Higher [I-DBPs] in Plant 4, which uses NH_2Cl, where cytotoxicity was highest
– Chloroiodoacetamide and iodoacetonitrile detected for the first time in U.S. drinking water



Br-DBPs in Halide-Impacted Waters

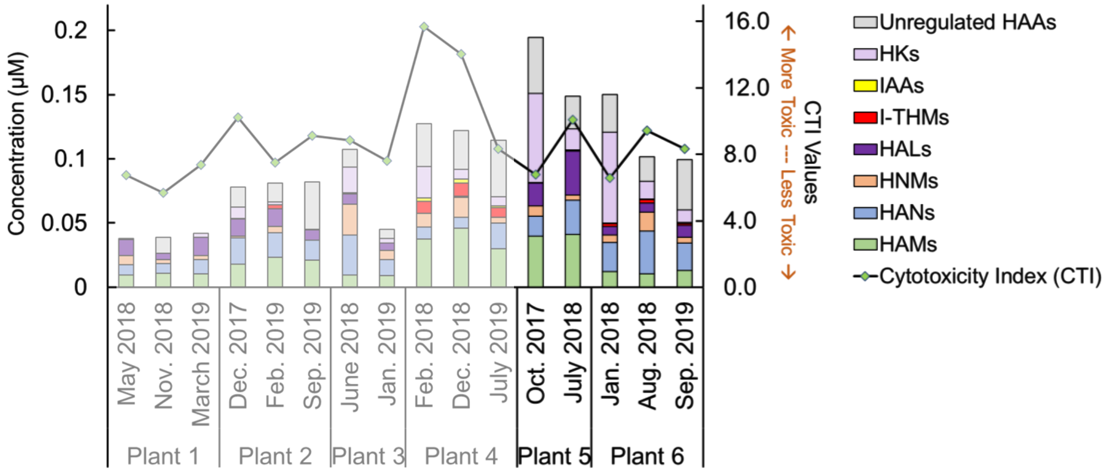
- While Plant 2 had the most Br-DBP formation, only 27% of Br^- on average was converted into Br-DBPs based on TOBr data
  - Previous studies have reported up to 94% conversion in chlorinated waters[1]
  - Removal of NOM by GAC is likely responsible for limiting Br-DBP formation
- Plants 3 and 4 each use NH_2Cl, but the additional use of O_3 by Plant 3 likely limited organic Br-DBP formation



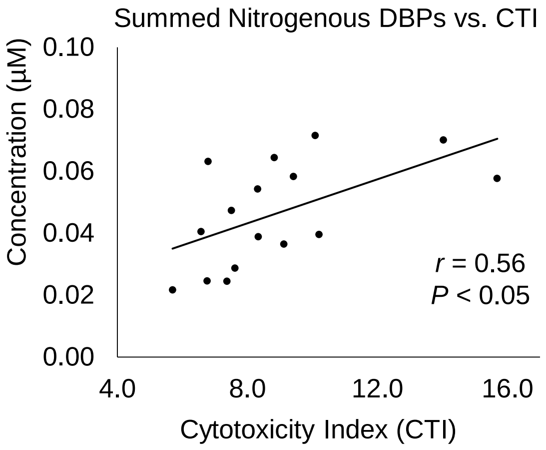
[1] Tan et al. *Sci.Total Environ.* **2016,** *541*, 1572-1580.

Wastewater-Impacted Plants (5-6)

- Highest unregulated DBP formation on 3 occasions
- Higher [DBP] did not always result in higher cytotoxicity, but cytotoxicity trended well with N-DBPs



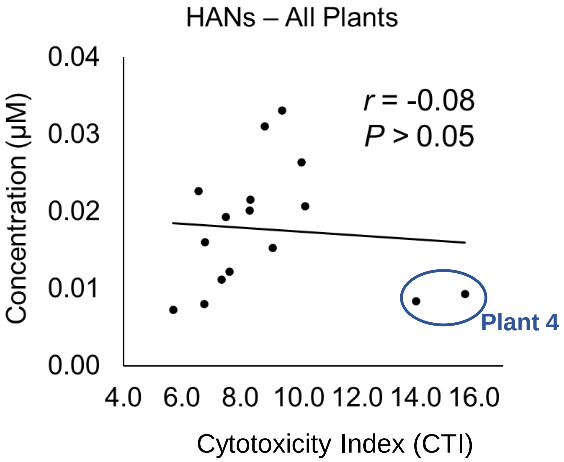
N-DBPs are Drivers of Drinking Water Cytotoxicity



- Nitrogenous DBPs (HANs, HAMs, HNMs) appear to be important drivers of cytotoxicity
- Supports the recent verification that DBP toxicity is additive[1]

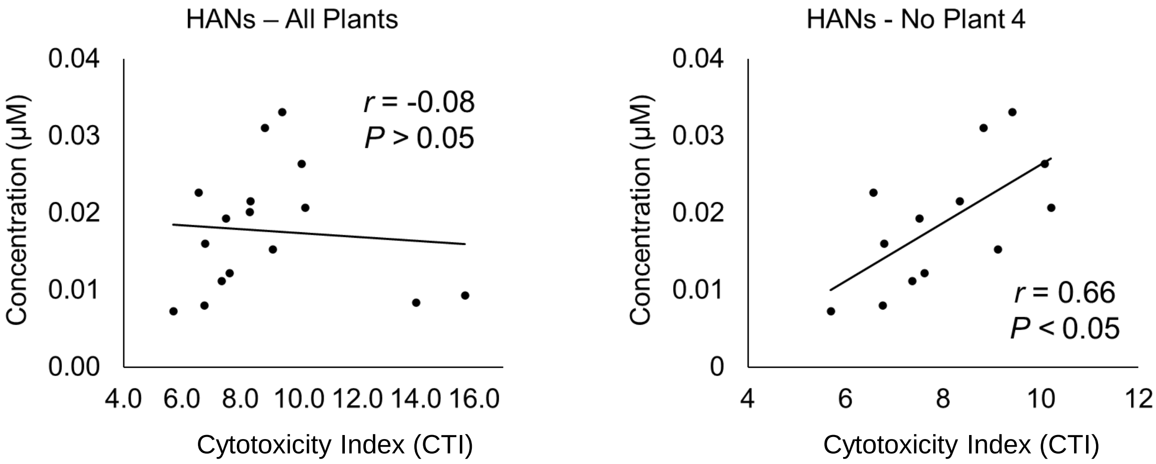
[1] Lau, et al. *Environ. Sci. Technol.* **2020**, *in press.*

Haloacetonitrile (HAN)/Cytotoxicity Correlations

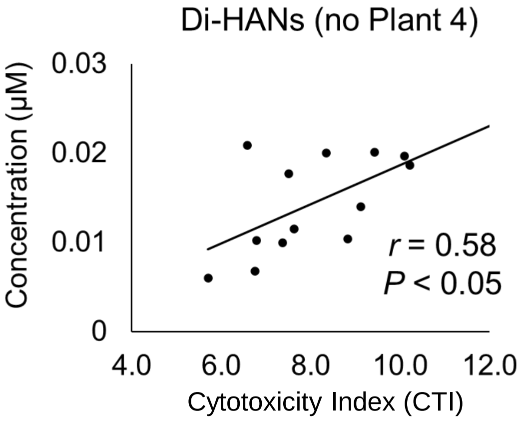


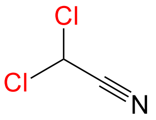
- While HANs were low, Plant 4 had two of the highest summed HAM concentrations. This was important in overall N-DBP correlation

HAN/Cytotoxicity Correlations

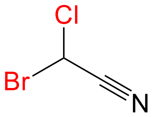


Di-HANs are Drivers of Drinking Water Cytotoxicity

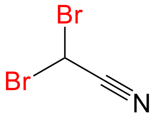




Dichloroacetonitrile
(DCAN)



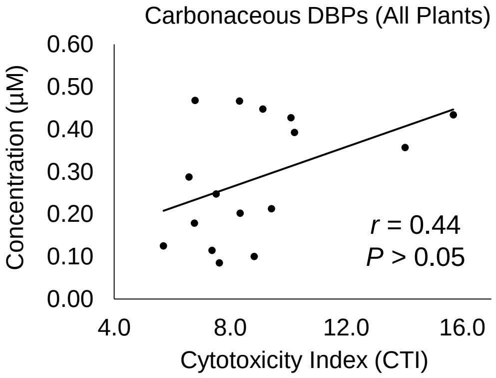
Bromochloroacetonitrile
(BCAN)



Dibromoacetonitrile
(DBAN)

- Greatest influence on HAN cytotoxicity correlations
- **Ubiquitous** in disinfected water from all plants
- DBAN is 5th most cytotoxic DBP

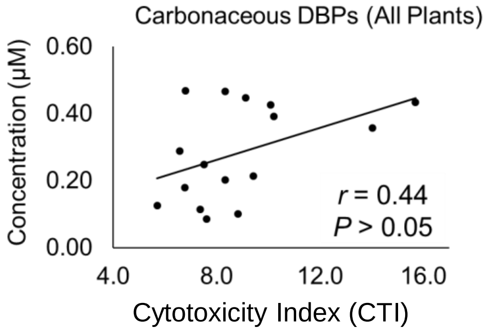
Carbonaceous DBPs and Cytotoxicity

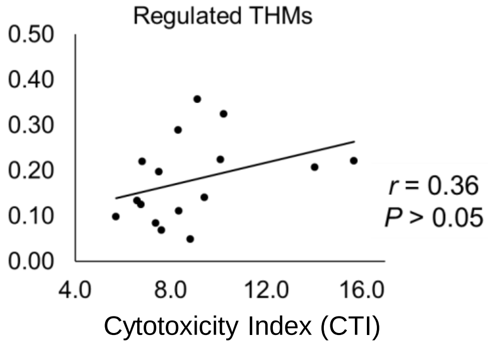


Carbonaceous DBPs: HAAs, THMs, HKs, HALs, I-THMs, IAAs

- ➢ Unlike N-DBPs, summed carbonaceous DBPs did not correlate with cytotoxicity

Regulated THMs Do Not Correlate With Cytotoxicity in Drinking Water

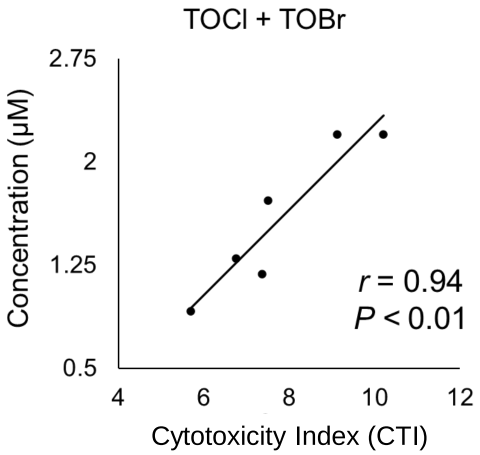




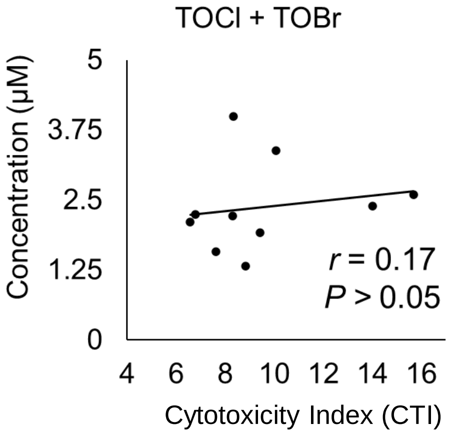
- ➢ Unlike N-DBPs, summed carbonaceous DBPs did not correlate with cytotoxicity
- ➢ Regulated THMs had no correlation with cytotoxicity and likely contribute little to the observed cytotoxicity

TOCl and TOBr/Cytotoxicity Correlations

Cl_2 Plants



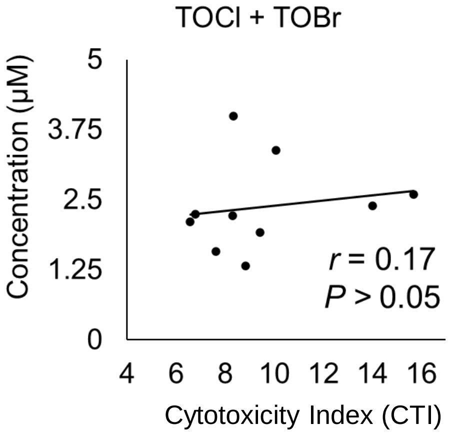
NH_2Cl Plants



TOCl and TOBr/Cytotoxicity Correlations

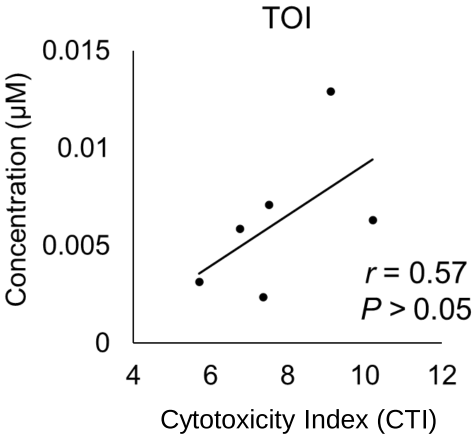
NH_2Cl Plants

Other factors likely play an important role in NH_2Cl water cytotoxicity

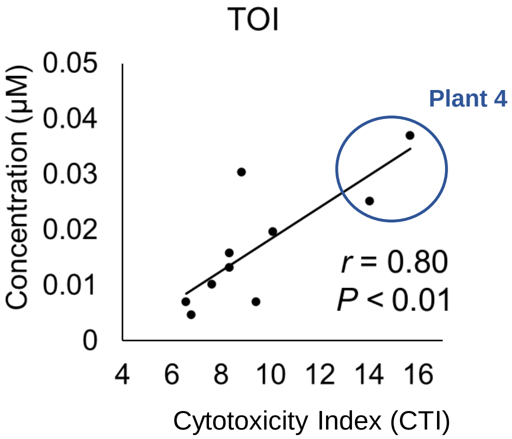


TOI/Cytotoxicity Correlations

Cl_2 Plants



NH_2Cl Plants



Summary and Strategies for Removal

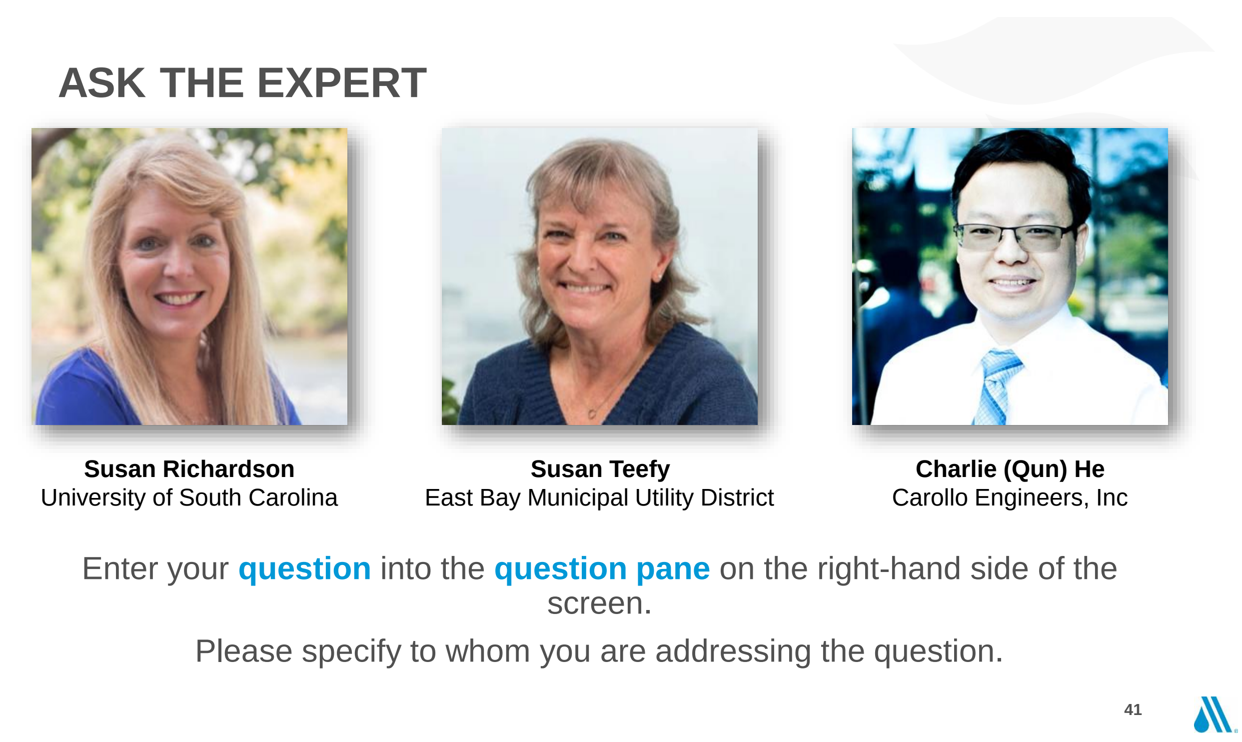
- Drinking water is a complex mixture of hundreds of compounds
  - Difficult to attribute toxicity solely to any single chemical or chemical class
- <u>N-DBPs are important drivers</u> of cytotoxicity, particularly di-HANs
  - Di-HAN standards are inexpensive can be easily measured with existing EPA methods, so future regulation and monitoring would be feasible
- <u>I-DBPs are drivers</u> of cytotoxicity in iodide-impacted waters using NH_2Cl disinfection
  - GAC/Cl_2 or the use of O_3 could help mitigate I-DBP formation
- Halide removal strategies, such as ion-exchange resins, could help reduce Br-DBP and I-DBP formation, but can be expensive

The goal:
Clean and Safe Drinking Water

Thank you!

My research group at USC

Special thanks to Michael & Elizabeth: 20 years of our labs working together!



ASK THE EXPERT

Susan Richardson
University of South Carolina

Susan Teefy
East Bay Municipal Utility District

Charlie (Qun) He
Carollo Engineers, Inc

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.

DBP CONTROL CASE STUDY

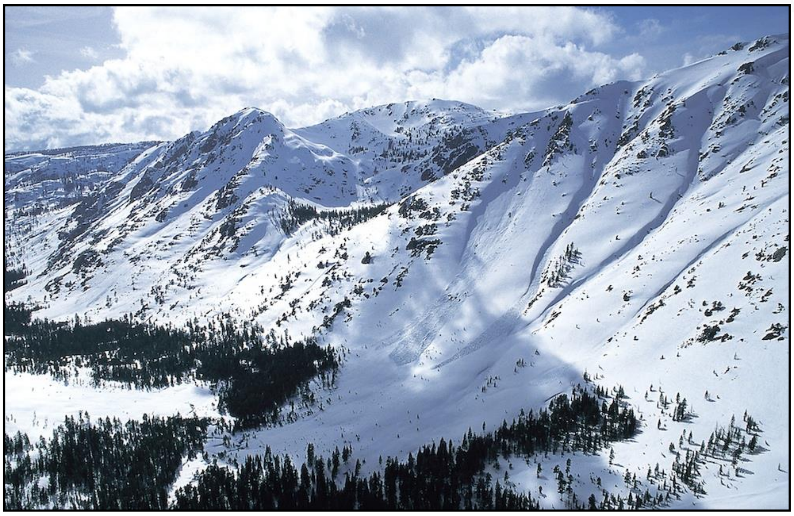
Susan Teefy
Manager of Water Quality
East Bay Municipal Utility District
Oakland, California

AGENDA

- Background/introduction
- Historical DBP control efforts
- Current and future DBP control strategies
- Modifying old facilities to meet new requirements

WATER STORAGE

- Watershed in the Sierra Nevada mountains
- Snowmelt feeds Mokelumne River



PARDEE RESERVOIR

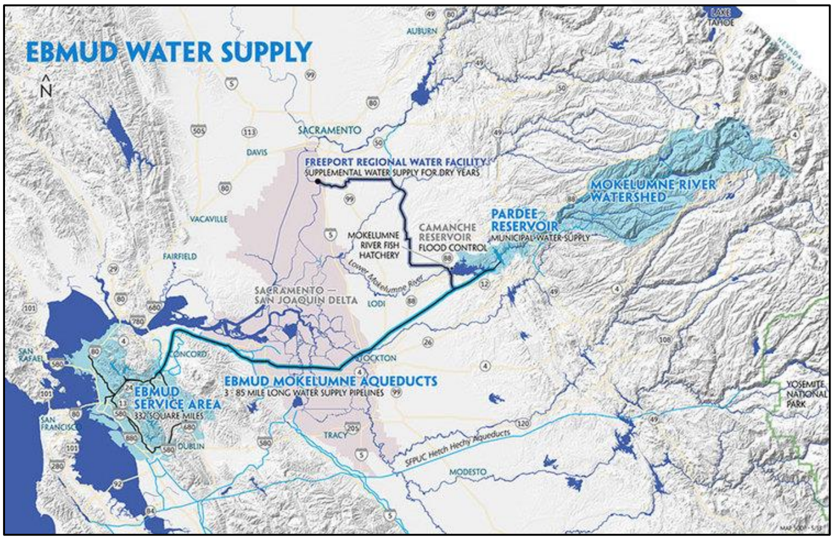
- Water is stored in Pardee Reservoir
- Gravity feed to the east bay

MOKELUMNE AQUEDUCTS

- Convey water from Pardee Reservoir across Central Valley and Delta
- Mostly buried, some parts are above grade
- Lime is added at headworks for corrosion control
- 1929, 1949, 1963

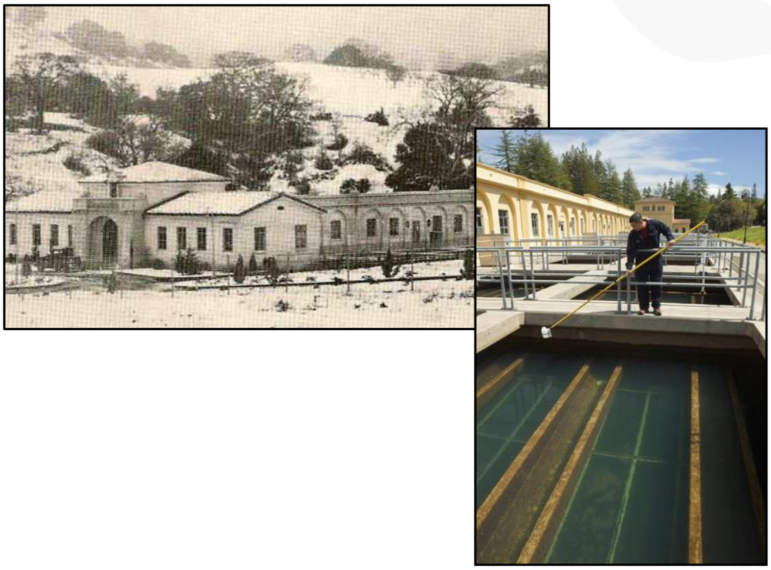
TREATMENT AND DISTRIBUTION

- 1.4 million people
- Six treatment plants, all surface water
- 332 square miles
- 4,300 miles of pipes
- 165 storage reservoirs
- 124 pressure zones (0 – 1,500 ft)



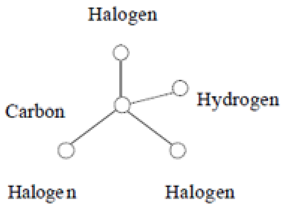
ORINDA WATER TREATMENT PLANT

- 200 mgd
- Low turbidity, low organic carbon source water
- Minimal treatment needed
    - Coagulation, filtration, disinfection
- Plant was not designed for today's regulations
- All of EBMUDs plants are older than USEPA)

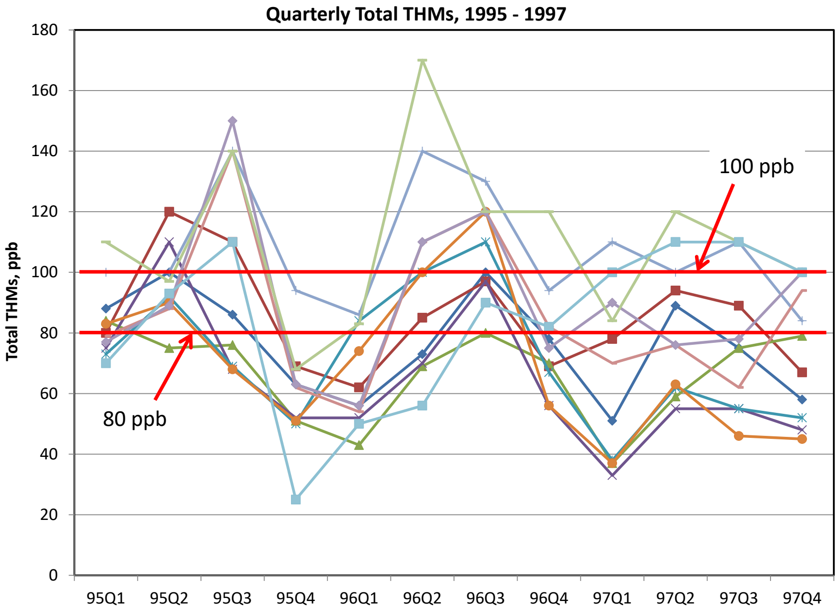


SIMPLIFIED THM REGULATORY HISTORY

- 1979: 100 ppb
  - Four sites per treatment plant each quarter
  - Rolling annual average of all sites
  - Some sites can be very high
- 2002: Lower to 80 ppb
  - Continue rolling annual average of all sites
- 2012: 80 ppb at highest individual site
  - Number of sites based on population
  - Study DBP levels, select sites with highest values
  - No more averaging high sites with low sites

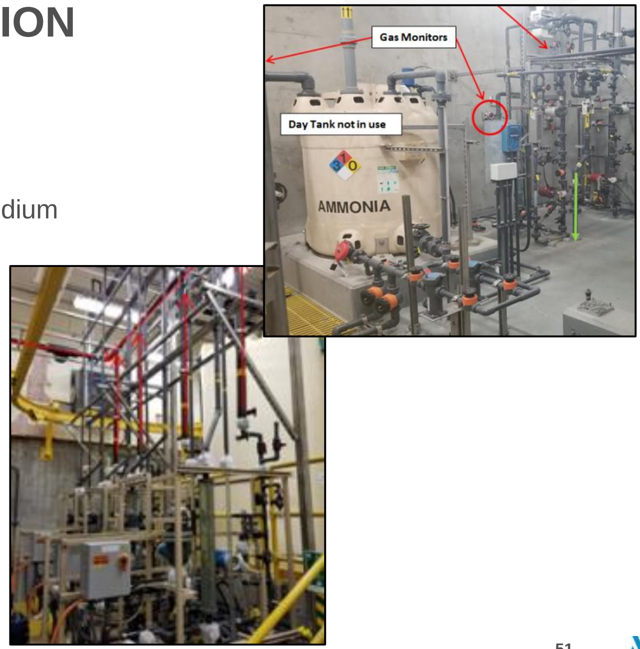


- In compliance with regulations
- Some individual samples >100 ppb
- Rolling average below 100 ppb, generally <80 ppb
- Change was needed to ensure compliance



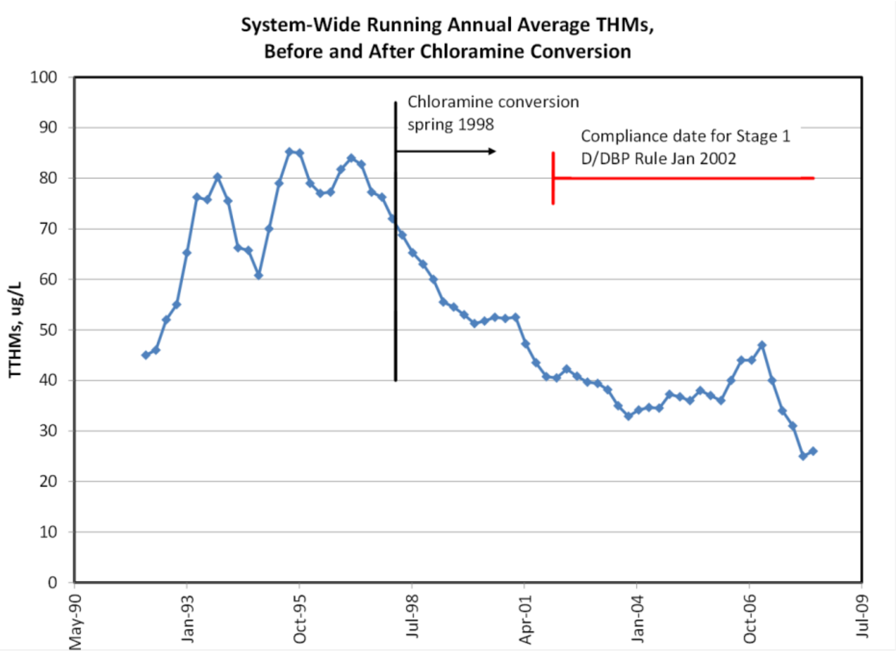
CHLORAMINE CONVERSION

- Add ammonia to form chloramine
- Also, convert from gaseous chlorine to sodium hypochlorite (safer, RMP requirements)
- Improve chlorine residuals throughout distribution system
  - Help with total coliform rule compliance
  - Help with SWTR detectable residual compliance
- Fewer T&O complaints
- On line in 1998



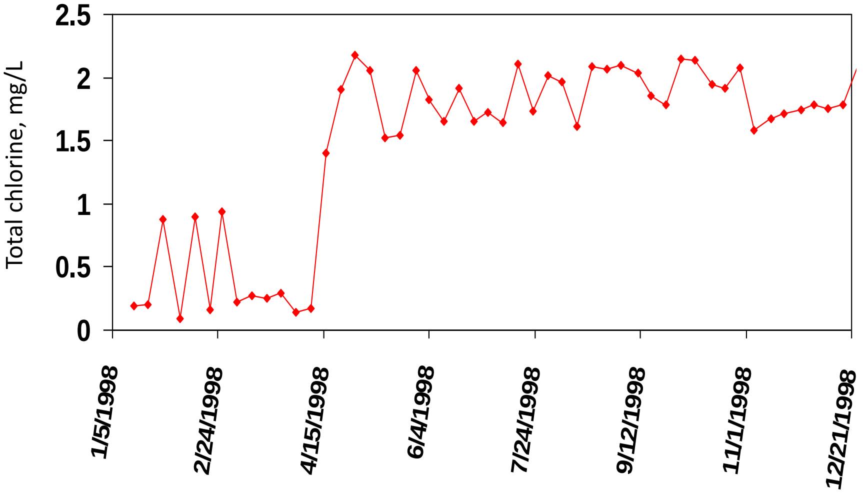
LOWER THMS

- In compliance with regulations
- Significant decline in THM levels throughout system
- In general, all sites <<80 ppb



HIGHER RESIDUALS IN DISTRIBUTION SYSTEM

- One representative sample tap (out of 125)
- In compliance with regulations
- Many locations that previous did not have a detectable chlorine residual improved



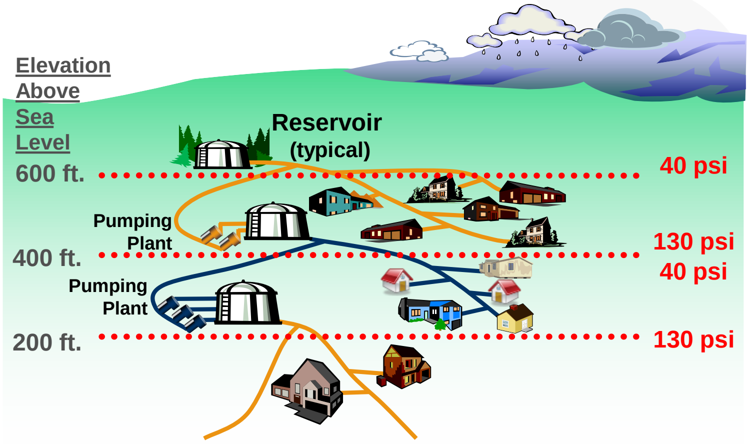
NITRIFICATION

NITRIFICATION CONTROL MEASURES

- Increase chloramine residual
- Additional monitoring
- Inspect and clean reservoirs
- Breakpoint chlorination of individual reservoirs
- Reduce storage
  - Approx. 40 reservoirs out of service
  - Replace large open-cut reservoirs with smaller tanks
- Minimize free ammonia

HIGH WATER AGE

- Large distribution system, long residence times
- Customers using less water, longer residence times
- Wildland-urban interface, need to keep sufficient storage on hand for fire fighting



CENTRAL RESERVOIR

- Constructed in 1909
- Intended to impound raw water behind dam
- 154 million gallon capacity
- Once water was delivered from Pardee Reservoir, used as finished water storage

CENTRAL RESERVOIR

- Lining and roof added in 1960s
- Continued to be used as finished water reservoir

CENTRAL RESERVOIR

- Freeway installed adjacent to reservoir site
- Surrounded by many homes and businesses
- Elevation too low to properly cycle

CENTRAL RESERVOIR

- Dam needs to be upgraded to modern standards
- Capacity is too large, required storage is about 50 MG
- Mechanical mixers installed

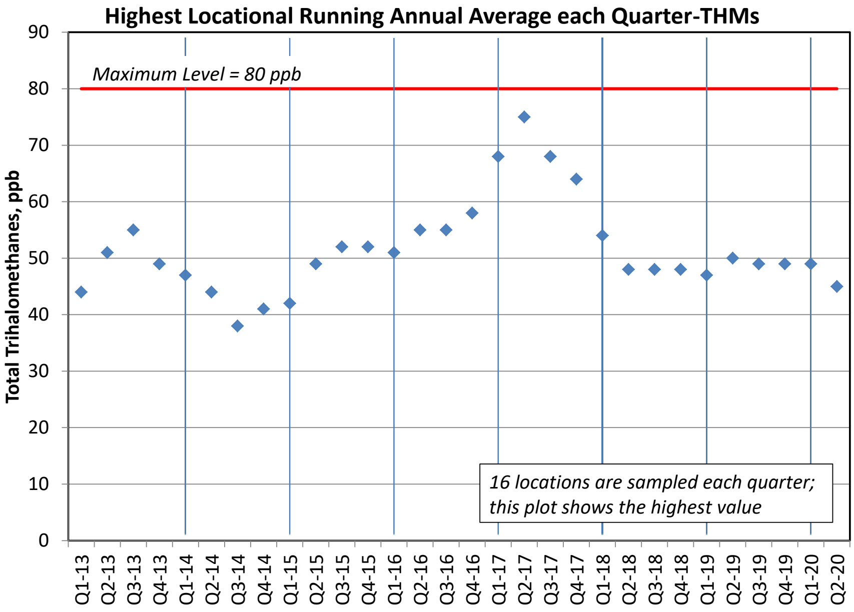
CENTRAL RESERVOIR

- Three concrete tanks, 17 MG each
- Increase elevation by >20 feet
- At least five year construction schedule
- At least $120 M cost

CURRENT AND FUTURE DBP CONCERNS

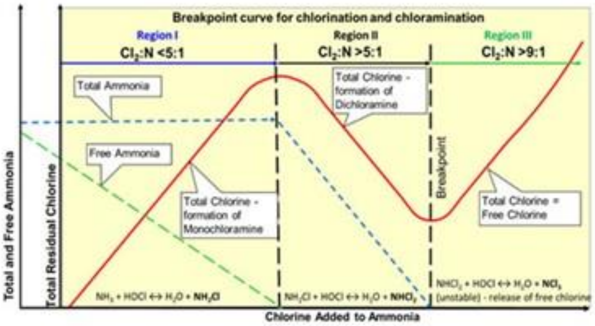
SPRING 2017

- Highest LRAA reached 75 ppb
- Drought 2013-2017
- Winter 2017 had very high rainfall, heavy runoff with high organics
- Drought operations exacerbate nitrification control efforts



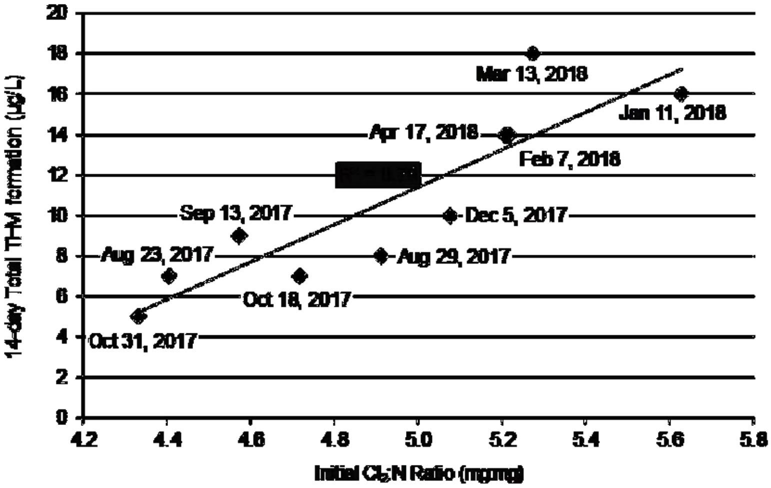
CHLORINE – TO – NITROGEN RATIO

- Breakpoint curve: 5:1 is optimal
- Original target in 1998: 4.6:1
- Drought-associated increases in nitrification events
  - Various operational adjustments
  - Moved ratio closer to 5:1
- Began seeing increased THM formation in distribution system
  - <10 ppb was typical
  - Observed as high as 30 ppb increase in distribution system
- Investigated implications of >5:1 ratio



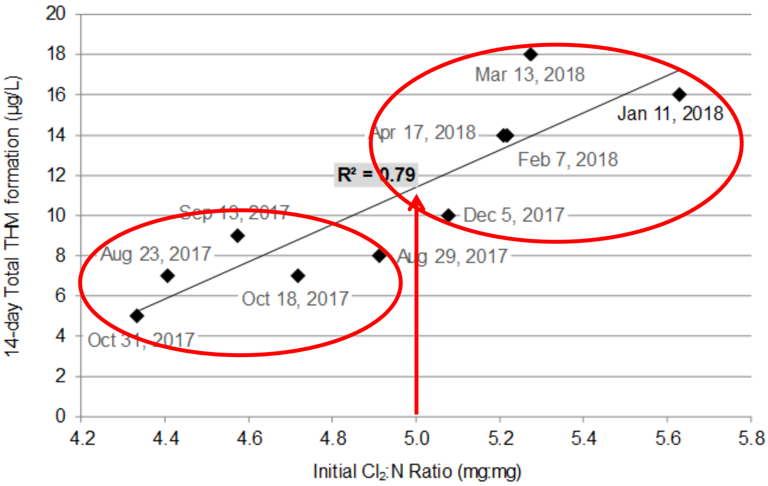
"ADDITIONAL" THM FORMATION

- Ammonia added to chlorinated water
- Held for 14 days
- Varying initial Cl2:N ratios (measured)



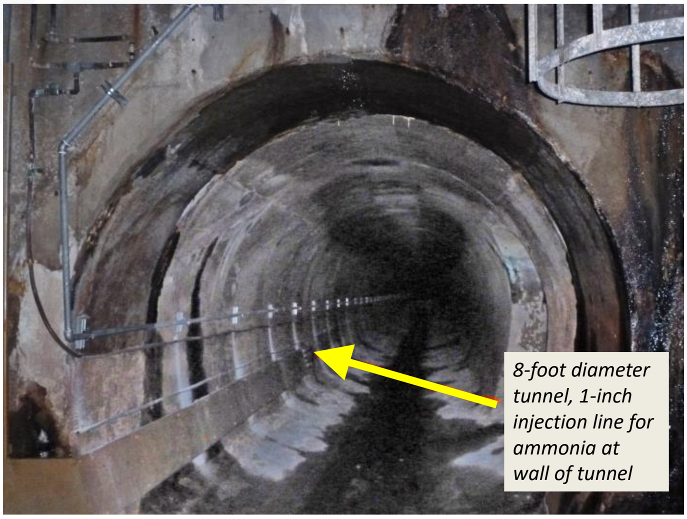
"ADDITIONAL" THM FORMATION

- When Cl2:N ratio exceeded 5:1, THM concentrations increased



AMMONIA INJECTION ISSUES

- Cannot collect proper plant effluent sample
- Plant flow rate changes frequently
- Although target is 5:1, periodically exceed this value
  - Increased formation of THMs
  - Accelerated degradation of chlorine residual
- Improvements needed to injection system
  - Operate at lower ratio until then
- Install analyzer at opposite end of tunnel, transmit signal back to operators



8-foot diameter tunnel, 1-inch injection line for ammonia at wall of tunnel

UPCOMING PLANT MODIFICATIONS

- Minimal cost for treatment currently
- Plant effluent THM concentrations are still occasionally high
- Drought followed by high rainfall can result in high levels of DBP precursors
- No organic carbon removal capability
- Only minimally meeting disinfection requirements with free chlorine
- Wildfire in the watershed is inevitable, only a matter of time
- As climate warms, expect more severe and more variable weather
- Conclusion: need to invest in additional treatment processes

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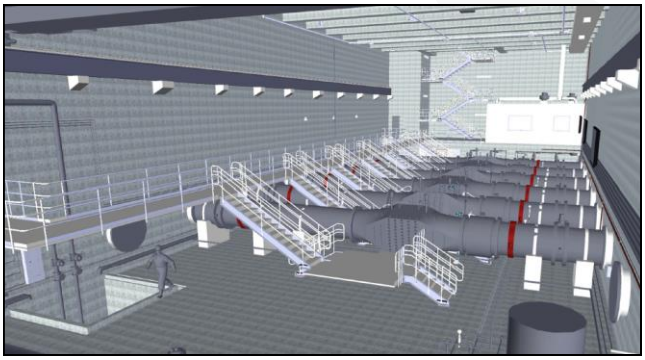
CURRENTLY IN DESIGN



- Phase 1:
    - Add UV after filtration for *Giardia* inactivation
    - Add small chlorine contact chamber for virus inactivation
- Phase 2:
    - Add clarification process, most likely ballasted flocculation, for additional carbon and solids removal
    - Ability to bypass when raw water quality is good
    - Solids handling facilities

SUMMARY

- Conversion from free chlorine to chloramine lowered THMs and increased stability of distribution system residuals
    - Caused nitrification issues
- Balance competing objectives
    - Disinfection vs. DBPs
    - DBP control vs. nitrification
    - High storage for emergencies and fire-fighting vs. high water age for nitrification
- Legacy systems can be modified to meet current standards
    - Takes a lot of time, costly

ASK THE EXPERT

Susan Richardson
University of South Carolina

Susan Teefy
East Bay Municipal Utility District

Charlie (Qun) He
Carollo Engineers, Inc

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.

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AN INTEGRATED APPROACH FOR DBP MITIGATION

Charlie He

Vice President, Chief Technologist – Decision Support

Carollo Engineers, Inc.

LEARNING OBJECTIVES

1. Understand the chemical and environmental factors that drive DBP formation.
2. Will get a glimpse into ongoing research that is helping us understand current of emerging DBPs and their formation.
3. **Describe the variety of tools that a utility can use to manage DBPs in their distribution system.**
4. **Create an integrated and effective management approach to mitigate DBPs challenges in the distribution system.**

AN INTEGRATED APPROACH FOR DBP MITIGATION

COMBINING WATER QUALITY MODEL AND HYDRAULIC MODEL

PRESENTATION OUTLINE

- Distribution System Water Quality Overview
- Conventional and Integrated Approach
- Conventional and Innovative Tools
- Conventional and Innovative Charts

CURRENT DISINFECTION PRACTICES IN US

Type	No. of POE into Distribution system	Free Chlorine	Chloramine	Other Disinfectants				
				Ozone	Chlorine Dioxide	UV	Other	No Disinfection
Ground-water	8,846	81.3%	9.1%	0.5%	0.5%	0.2%	1.2%	6.8%
Surface Water	2,886	51.7%	27.9%	7.5%	8.1%	4.2%	1%	0%

Data Source: UCMR3 Exhibit 6.2

FACTORS INFLUENCING DISTRIBUTION SYSTEM WATER STABILITY AND DBP

Chemical Factors:

- **DBP: pH, temperature, TOC, UV254, chlorine dose, bromide, Cl:N ratio**
- **Corrosion and Stability: pH, TDS, calcium, alkalinity, temperature, chloride, sulfate, etc.**

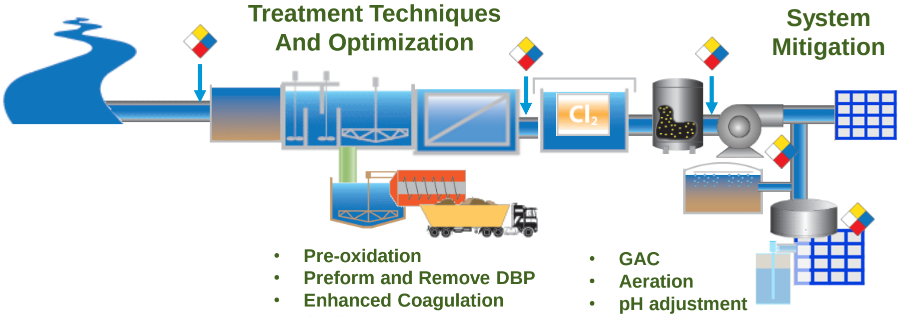
Biological Factors:

- Presence of biofilm, iron or sulfate-reducing bacteria and nitrification bacteria

Physical Factors:

- Pressure, flow, blends of sources,
- Water Age
- Pipe materials and age of pipe
- Soil moisture, and presence of electric currents

MANY FACTORS IMPACT DISTRIBUTION SYSTEM WATER QUALITY



Source Protection

Treatment Techniques And Optimization

Distribution System Mitigation

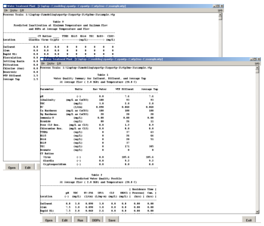
- Pre-oxidation
- Preform and Remove DBP
- Enhanced Coagulation
- GAC
- Aeration
- pH adjustment
- Blending
- Corrosion inhibitors

- GAC
- Aeration
- pH adjustment
- Blending
- Flushing
- Corrosion inhibitors
- Reducing water age

SEVERAL MODELING TOOLS ARE AVAILABLE FOR ANALYZING DISTRIBUTION SYSTEM WATER QUALITY

RTW Model

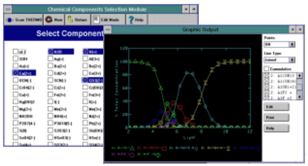
WaterPro Model



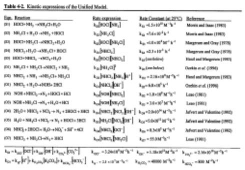
EPA WTP Model

Innovyze®

Hydraulic Model
(e.g., Infowater MSX: Multi-Species eXtension)



MINEQL+



Mechanistic DBP Models and Apps

Corrosion and Stability Indices

EMPIRICAL D/DBP MODELS

$$Cl_2 = C_0 * (TOC^{C1}) * (pH^{C2}) * (time^{C3}) * (temp^{C4}) * (Br^{C5}) * (CLdose^{C6}) * (UVA^{C7})$$

$$TTHM = T_0 * (TOC^{T1}) * (pH^{T2}) * (time^{T3}) * (temp^{T4}) * (Br^{T5}) * (CLdose^{T6}) * (UVA^{T7})$$

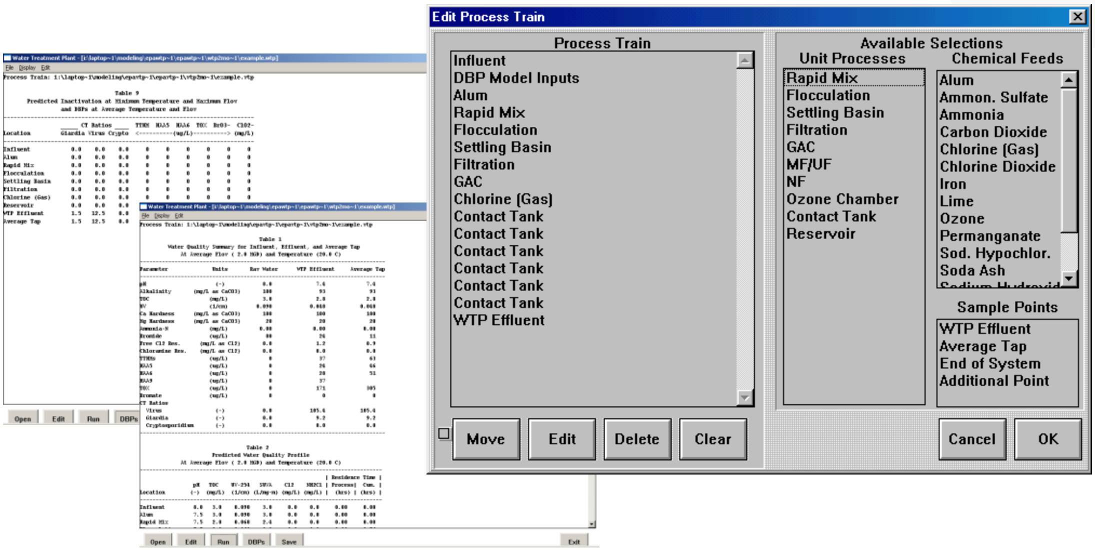
Coefficients were provided for
CASE I: All CAP raw and treated water
CASE II: All Lake Houston raw and treated water
CASE III: All Harwoods Mill Reservoir (VA) raw and treated water
CASE IV: All Lake Manatee Water (FL) raw and treated water
CASE V: All Water raw and treated combined

Reference: Arizona State University Thesis, He, 2001

Research Done By	Model Expression
Moore, Tuthnill, and Polakoff (1979)	$CHCl_3$ (in mg/L) = -11.24 + 22.23 Cl_2 Dose (in mg/L) (1.5) Which is based on applied chlorine dose, reflecting the fact that the extent of chloroform formation parallels that of chlorine consumption.
Trussell and Umphres (1978)	$\frac{dTTHM}{dt} = k_n (Cl_2)(TOC)^m$ (1.6) Where m is the order of the reaction with respect to the concentration of TOC precursor, and k_n is the reaction rate constant.
Kavanaugh et al. (1980)	$\frac{dTTHM}{dt} = k_n (TOC)(Cl_2 Dose - \frac{3TTHM}{f})^m$ (1.7) Which included a THM yield parameters (f).
Engerholm and Amy (1983)	$\mathrm{CHCl_3} = \mathrm{k_1 k_2} \cdot (\mathrm{TOC})^x \cdot (Cl_2 Dose / TOC)^y \cdot (\mathrm{Re}\,actionTime)^z$ (1.8) Where k_1 and k_2 are experimentally derived reaction constant related to pH and temperature respectively.
Urano, Wada, and Takemasa (1983)	$\mathrm{TTHM} = \mathrm{k} \cdot (p\mathrm{H} - 2.8) \cdot (TOC) \cdot (Cl_2 Dose)^{0.25} \cdot (\mathrm{Re}\,actionTime)^{0.36}$ (1.9) Where $\mathrm{k} = 3.5 \times 10^3 e^{(-4470/TEMP)}$
Amy, Chadik, and Chowdhury (1987)	$\mathrm{TTHM} = 0.00309 \cdot (\mathrm{UV} \cdot \mathrm{TOC})^{0.440} \cdot (Cl_2 Dose)^{0.409} \cdot (Br + 1)^{0.0358} \cdot (\mathrm{Re}\,actionTime)^{0.265} \cdot (Temperature)^{1.06} \cdot (pH - 2.6)^{0.715}$ (1.10)
Korshin G. V., Li C., and Benjamin M. M. (1997)	TOX=10834ΔUV_{272} (1.11) Where TOX is in μg/L and ΔUV_{272} is in cm^{-1} and represents the change in UV_{272} absorbance before and after chlorine addition.

Reference: Arizona State University Thesis, He, 2001

EPA WTP MODEL VERSION 1.5 (1992) – 2.0 (2001)



Process Train:

Influent
DBP Model Inputs
Alum
Rapid Mix
Flocculation
Settling Basin
Filtration
GAC
Chlorine (Gas)
Contact Tank
Contact Tank
Contact Tank
Contact Tank
Contact Tank
Contact Tank
WTP Effluent

Unit Processes:

Rapid Mix
Flocculation
Settling Basin
Filtration
GAC
MF/UF
NF
Ozone Chamber
Contact Tank
Reservoir

Chemical Feeds:

Alum
Ammon. Sulfate
Ammonia
Carbon Dioxide
Chlorine (Gas)
Chlorine Dioxide
Iron
Lime
Ozone
Permanganate
Sod. Hypochlor.
Soda Ash

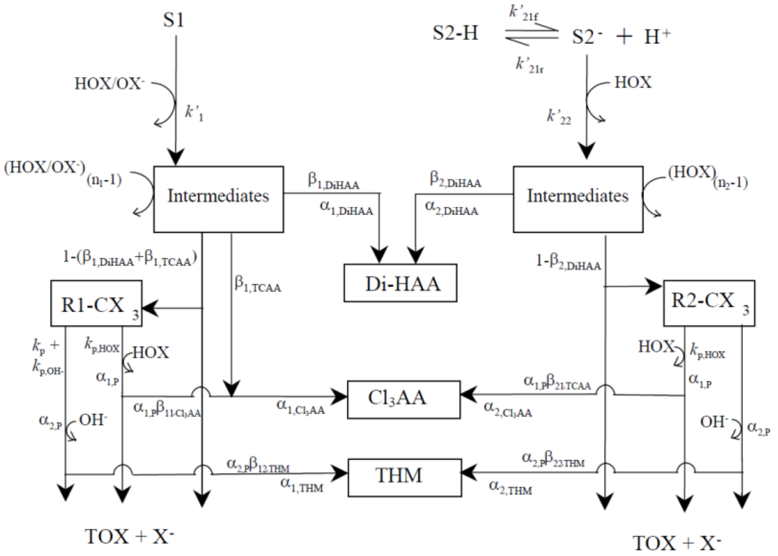
Sample Points:

WTP Effluent
Average Tap
End of System
Additional Point

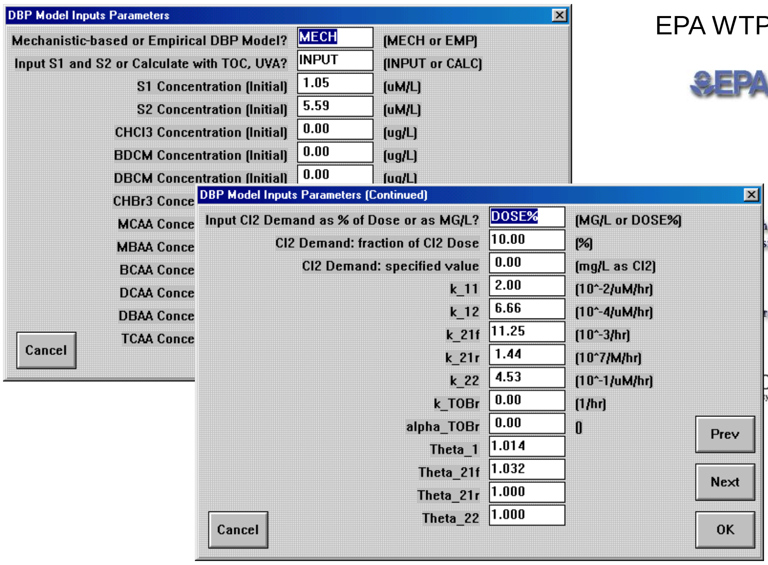
EPA WTP Model Version 2.0 (Empirical Model)

MECHANISTIC-BASED DBP MODELS

(Adapted from McCellan, 2000)



EPA WTP MODEL VERSION 2.1 (2002)



DBP Model Inputs Parameters

Mechanistic-based or Empirical DBP Model?	MECH	[MECH or EMP]
Input S1 and S2 or Calculate with TOC, UVA?	INPUT	[INPUT or CALC]
S1 Concentration [Initial]	1.05	[uM/L]
S2 Concentration [Initial]	5.59	[uM/L]
CHCl3 Concentration [Initial]	0.00	[ug/L]
BDCM Concentration [Initial]	0.00	[ug/L]
DBCM Concentration [Initial]	0.00	[ug/L]
CHBr3 Conce		
MCAA Conce		
MBAA Conce		
BCAA Conce		
DCAA Conce		
DBAA Conce		
TCAA Conce		

DBP Model Inputs Parameters (Continued)

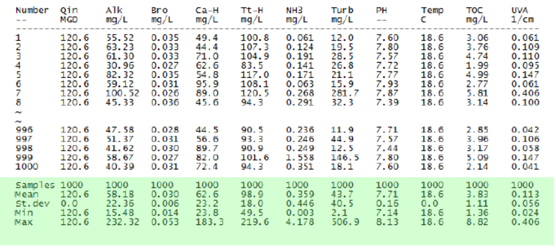
Input Cl2 Demand as % of Dose or as MG/L?	DOSE%	[MG/L or DOSE%]
Cl2 Demand: fraction of Cl2 Dose	10.00	[%]
Cl2 Demand: specified value	0.00	[mg/L as Cl2]
k_11	2.00	[10^-2/uM/hr]
k_12	6.66	[10^-4/uM/hr]
k_21f	11.25	[10^-3/hr]
k_21r	1.44	[10^7/M/hr]
k_22	4.53	[10^-1/uM/hr]
k_TOBr	0.00	[1/hr]
alpha_TOBr	0.00	[]
Theta_1	1.014	
Theta_21f	1.032	
Theta_21r	1.000	
Theta_22	1.000	

EPA WTP Model V 2.1 (Mechanistic Based)

This version of the WTP Model
he option to model DBP formation, chlorine and bromine consumption
sing mechanistic-based algorithms developed by researchers at
the University of Massachusetts,
Arizona State University
and University of Colorado at Boulder.
rogramming and testing was performed by Malcolm Pirnie, Inc.

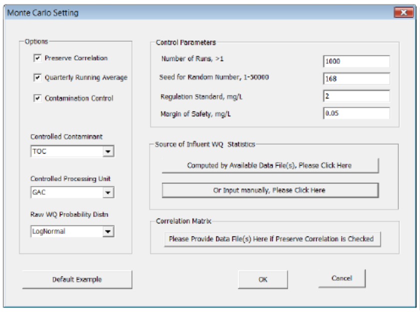
EPA WTP MODEL VERSION 3.0 (2016)

- **2-in-1**
  - **WTP2.2:** Mechanistic models for conventional treatment and GAC processes, with some updates for regulatory analysis
  - **WTP-ccam:** Scenario Analysis, Monte Carlo analysis, cost curve analysis.



```
Number   Qin     Alk     Bro     Ca-H    Tt-H    NH3     Turb    PH      Temp    TOC     UVA
--       MGD     mg/L    mg/L    mg/L    mg/L    mg/L    mg/L    --      C       mg/L    1/cm
-------------------------------------------------------------------------------------------------
1        120.6   55.52   0.035   49.4    100.8   0.061   12.0    7.60    18.6    3.06    0.061
2        120.6   63.23   0.033   44.4    107.3   0.124   19.5    7.80    18.6    3.76    0.109
3        120.6   61.30   0.033   71.0    104.9   0.191   28.5    7.57    18.6    4.74    0.110
4        120.6   30.96   0.027   62.6    83.5    0.141   26.8    7.72    18.6    1.99    0.095
5        120.6   82.32   0.035   54.8    117.0   0.171   21.1    7.77    18.6    4.99    0.147
6        120.6   59.12   0.031   95.9    108.1   0.063   15.9    7.93    18.6    2.77    0.061
7        120.6   100.52  0.026   89.0    120.5   0.268   281.7   7.87    18.6    5.81    0.406
8        120.6   45.33   0.036   45.6    94.3    0.291   32.3    7.39    18.6    3.14    0.100
~
~
996      120.6   47.58   0.028   44.5    90.5    0.236   11.9    7.71    18.6    2.85    0.042
997      120.6   51.37   0.031   56.6    93.3    0.246   44.9    7.57    18.6    3.96    0.106
998      120.6   41.62   0.030   89.7    90.9    0.249   12.5    7.44    18.6    3.17    0.058
999      120.6   58.67   0.027   82.0    101.6   1.558   146.5   7.80    18.6    5.09    0.147
1000     120.6   40.39   0.031   72.4    94.3    0.351   18.1    7.60    18.6    2.14    0.041

Samples  1000    1000    1000    1000    1000    1000    1000    1000    1000    1000    1000
Mean     120.6   58.18   0.030   62.6    98.9    0.359   43.7    7.71    18.6    3.83    0.113
St.dev   0.0     22.36   0.006   23.2    18.0    0.446   40.5    0.16    0.0     1.11    0.056
Min      120.6   15.48   0.014   23.8    49.5    0.003   2.1     7.14    18.6    1.36    0.024
Max      120.6   232.32  0.053   183.3   219.6   4.178   506.9   8.13    18.6    8.82    0.406
```

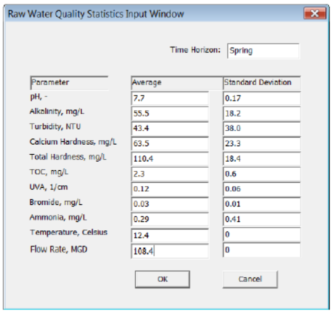


Monte Carlo Setting

Options
☑ Preserve Correlation
☑ Quarterly Running Average
☑ Contamination Control

Controlled Contaminant: TOC
Controlled Processing Unit: GAC
Raw WQ Probability Distn: LogNormal

Control Parameters
Number of Runs, >1: 1000
Seed for Random Number, 1-50000: 168
Regulation Standard, mg/L: 2
Margin of Safety, mg/L: 0.05

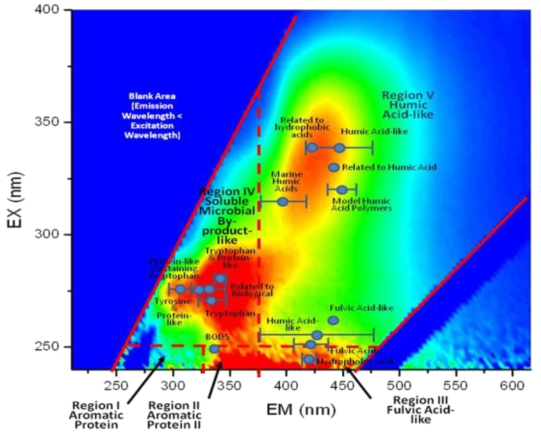


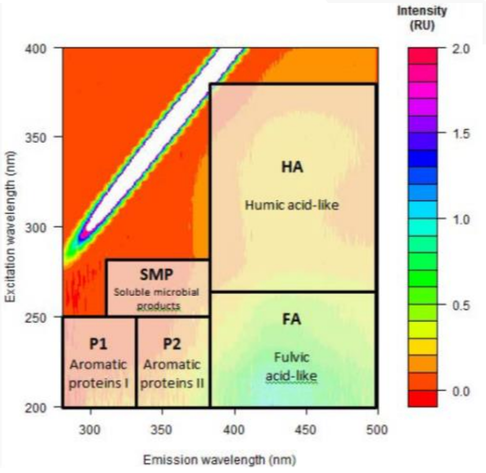
Raw Water Quality Statistics Input Window

Time Horizon: Spring

Parameter	Average	Standard Deviation
pH, -	7.7	0.17
Alkalinity, mg/L	55.5	18.2
Turbidity, NTU	43.4	38.0
Calcium Hardness, mg/L	63.5	23.3
Total Hardness, mg/L	110.4	18.4
TOC, mg/L	2.3	0.6
UVA, 1/cm	0.12	0.06
Bromide, mg/L	0.03	0.01
Ammonia, mg/L	0.29	0.41
Temperature, Celsius	12.4	0
Flow Rate, MGD	108.4	0

FLORESCENT EMISSION EXCITATION MATRIX BASED DBP MODELS

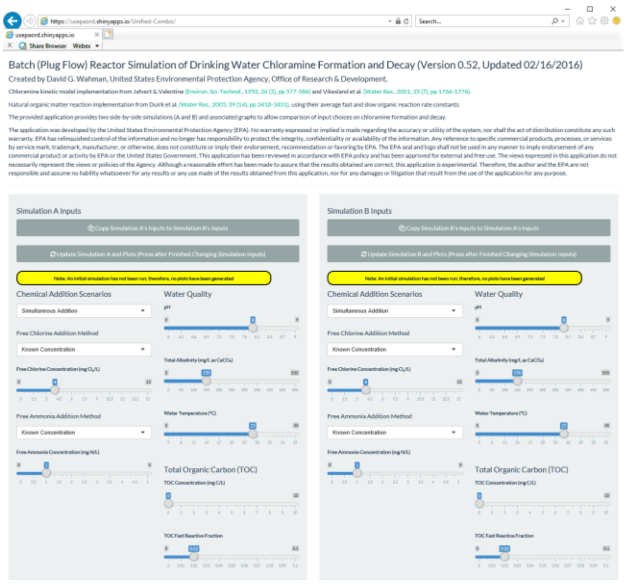




	TOC	TON	HOCl demand	UV_{254}	$\Phi P1_{,n}$	$\Phi P2_{,n}$	$\Phi FA_{,n}$	$\Phi SMP_{,n}$	$\Phi HA_{,n}$
THM4*	0.88 (3.5×10^{-12})	0.70 (1.9×10^{-7})	0.91 ($1.5\text{x}10^{-13}$)	0.76 (1.3×10^{-8})	0.15 (0.057)	0.32 (0.003)	0.85 (8.1×10^{-11})	0.46 (2.2×10^{-4})	0.72 (7.8×10^{-8})

Lyon, et. al, 2013

EPA CHLORINE AND CHLORAMINE WEB APP(2016)



Batch (Plug Flow) Reactor Simulation of Drinking Water Chloramine Formation and Decay (Version 0.52, Updated 02/16/2016)

Created by David G. Wahman, United States Environmental Protection Agency, Office of Research & Development.

Chloramine kinetic model implementation from Jafvert & Valentine (Environ. Sci. Technol., 1992, 26 (3), pp 577-586) and Vikesland et al. (Water Res., 2001, 35 (7), pp 1766-1776).

Natural organic matter reaction implementation from Duirk et al. (Water Res., 2005, 39 (14), pp 3418-3431), using their average fast and slow organic reaction rate constants.

The provided application provides two side-by-side simulations (A and B) and associated graphs to allow comparison of input choices on chloramine formation and decay.

The application was developed by the United States Environmental Protection Agency (EPA). No warranty expressed or implied is made regarding the accuracy or utility of the system, nor shall the act of distribution constitute any such warranty. EPA has relinquished control of the information and no longer has responsibility to protect the integrity, confidentiality or availability of the information. Any reference to specific commercial products, processes, or services by service mark, trademark, manufacturer, or otherwise, does not constitute or imply their endorsement, recommendation or favoring by EPA. The EPA seal and logo shall not be used in any manner to imply endorsement of any commercial product or activity by EPA or the United States Government. This application has been reviewed in accordance with EPA policy and has been approved for external and free use. The views expressed in this application do not necessarily represent the views or policies of the Agency. Although a reasonable effort has been made to assure that the results obtained are correct, this application is experimental. Therefore, the author and the EPA are not responsible and assume no liability whatsoever for any results or any use made of the results obtained from this application, nor for any damages or litigation that result from the use of the application for any purpose.

Simulation A Inputs

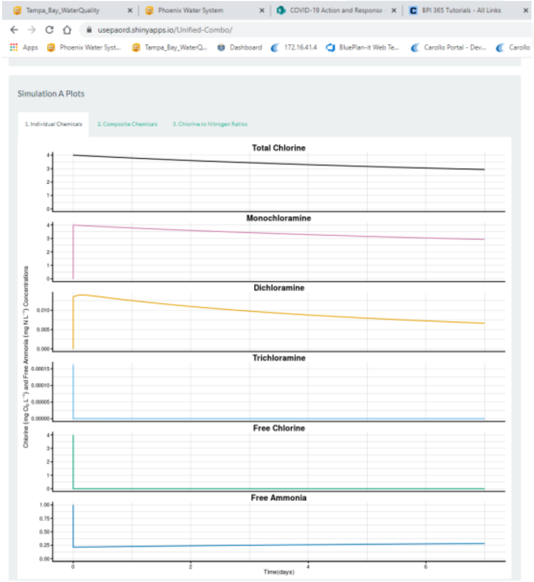
Note: An initial simulation has not been run; therefore, no plots have been generated

Chemical Addition Scenarios: Simultaneous Addition
Free Chlorine Addition Method: Known Concentration
Free Chlorine Concentration (mg Cl_2/L): 4
Free Ammonia Addition Method: Known Concentration
Free Ammonia Concentration (mg N/L): 1
Water Quality
Total Alkalinity (mg/L as $CaCO_3$): 150
Water Temperature (°C): 25
Total Organic Carbon (TOC)
TOC Concentration (mg C/L): 0
TOC Fast Reactive Fraction: 0.02

Simulation B Inputs

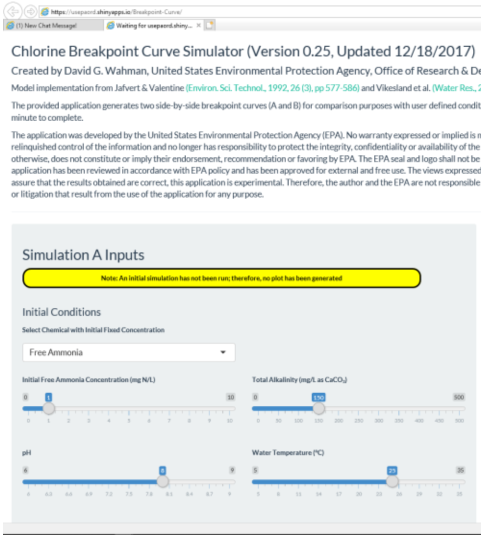
Note: An initial simulation has not been run; therefore, no plots have been generated

Chemical Addition Scenarios: Simultaneous Addition
Free Chlorine Addition Method: Known Concentration
Free Chlorine Concentration (mg Cl_2/L): 4
Free Ammonia Addition Method: Known Concentration
Free Ammonia Concentration (mg N/L): 1
Water Quality
Total Alkalinity (mg/L as $CaCO_3$): 150
Water Temperature (°C): 25
Total Organic Carbon (TOC)
TOC Concentration (mg C/L): 0
TOC Fast Reactive Fraction: 0.02



https://usepaord.shinyapps.io/Unified-Combo/

EPA CHLORINE BREAKPOINT CURVE WEB APP(2017)



Chlorine Breakpoint Curve Simulator (Version 0.25, Updated 12/18/2017)

Created by David G. Wahman, United States Environmental Protection Agency, Office of Research & De

Model implementation from Jafvert & Valentine (Environ. Sci. Technol., 1992, 26 (3), pp 577-586) and Vikesland et al. (Water Res., 2

The provided application generates two side-by-side breakpoint curves (A and B) for comparison purposes with user defined condit
minute to complete.

The application was developed by the United States Environmental Protection Agency (EPA). No warranty expressed or implied is n
relinquished control of the information and no longer has responsibility to protect the integrity, confidentiality or availability of the
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application has been reviewed in accordance with EPA policy and has been approved for external and free use. The views expressed
assure that the results obtained are correct, this application is experimental. Therefore, the author and the EPA are not responsible
or litigation that result from the use of the application for any purpose.

Simulation A Inputs

Note: An initial simulation has not been run; therefore, no plot has been generated

Initial Conditions

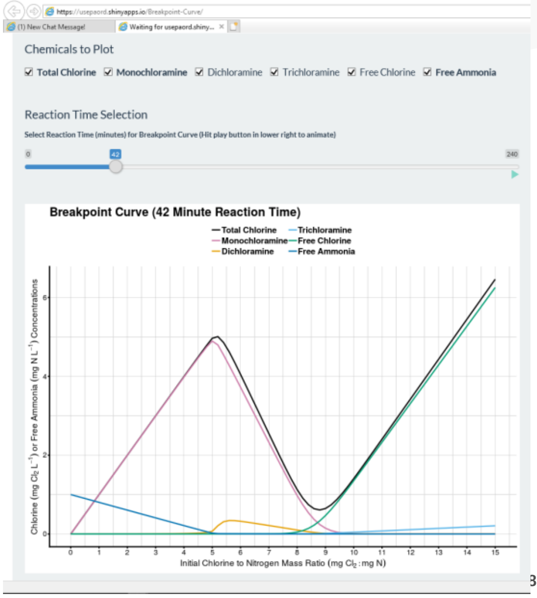
Select Chemical with Initial Fixed Concentration: Free Ammonia

Initial Free Ammonia Concentration (mg N/L): 1

Total Alkalinity (mg/L as $CaCO_3$): 150

pH: 8

Water Temperature (°C): 25



Chemicals to Plot

☑ Total Chlorine ☑ Monochloramine ☑ Dichloramine ☑ Trichloramine ☑ Free Chlorine ☑ Free Ammonia

Reaction Time Selection

Select Reaction Time (minutes) for Breakpoint Curve (Hit play button in lower right to animate): 42

EPANET MULTI-SPECIES EXTENSION FOR HYDRAULIC MODEL

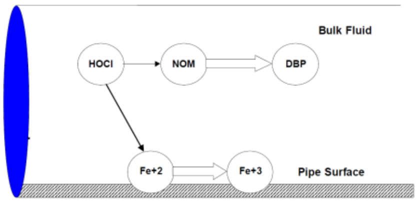


Figure 2-1 Example of reactions in the mobile bulk phase and at the fixed pipe surface phase.

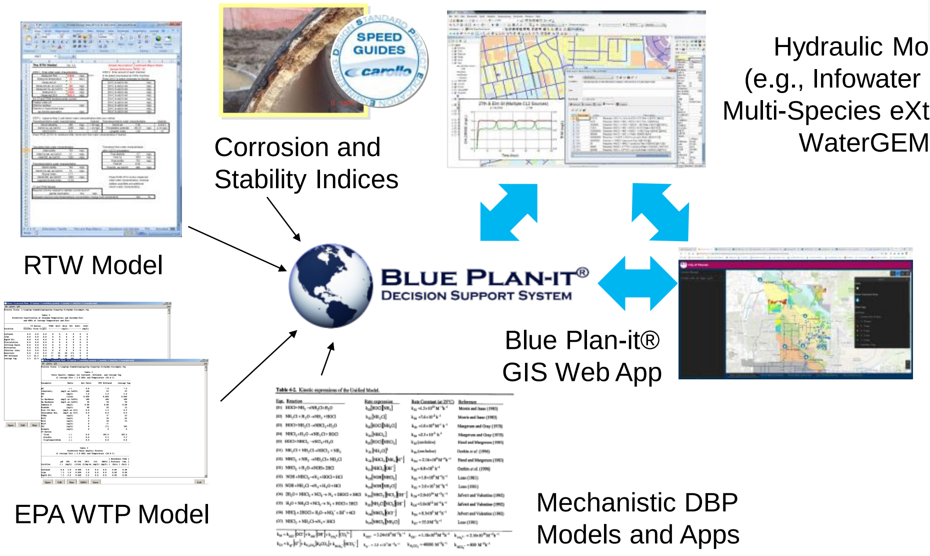
Table 5-1 Monochloramine decay model based on Vikesland et al. (2001) and Duirk et al. (2005)

	Reaction Stoichiometry	*Rate Coefficient/ Equilibrium Constant*[a]
R.1	$HOCl + NH_3 \rightarrow NH_2Cl + H_2O$	$k_1 = 1.5\times10^{10}\ M^{-1}h^{-1}$
R.2	$NH_2Cl + H_2O \rightarrow HOCl + NH_3$	$k_2 = 7.6\times10^{-2}\ h^{-1}$
R.3	$HOCl + NH_2Cl \rightarrow NHCl_2 + H_2O$	$k_3 = 1.0\times10^{6}\ M^{-1}h^{-1}$
R.4	$NHCl_2 + H_2O \rightarrow HOCl + NH_2Cl$	$k_4 = 2.3\times10^{-3}\ h^{-1}$
R.5	$NH_2Cl + NH_2Cl \rightarrow NHCl_2 + NH_3$	$k_5 = 2.5\times10^{7}\ [H^+] +$ $4.0\times10^{4}\ [H_2CO_3] +$ $800\ [HCO_3^-]\ M^{-2}h^{-1}$
R.6	$NHCl_2 + NH_3 \rightarrow NH_2Cl + NH_2Cl$	$k_6 = 2.2\times10^{8}\ M^{-2}h^{-1}$
R.7	$NHCl_2 + H_2O \rightarrow I$	$k_7 = 4.0\times10^{5}\ M^{-1}h^{-1}$
R.8	$I + NHCl_2 \rightarrow HOCl + \text{products}$	$k_8 = 1.0\times10^{8}\ M^{-1}h^{-1}$
R.9	$I + NH_2Cl \rightarrow \text{products}$	$k_9 = 3.0\times10^{7}\ M^{-1}h^{-1}$
R.10	$NH_2Cl + NHCl_2 \rightarrow \text{products}$	$k_{10} = 55.0\ M^{-1}h^{-1}$
R.11	$NH2Cl + S_1\times TOC \rightarrow \text{products}^b$	$k_{11} = 3.0\times10^{4}\ M^{-1}h^{-1}$ $S_1 = 0.02$
R.12	$HOCl + S_2\times TOC \rightarrow \text{products}^c$	$k_{12} = 6.5\times10^{5}\ M^{-1}h^{-1}$ $S_2 = 0.5$
E.1	$HOCl \leftrightarrow H^+ + OCl^-$	$pK_a = 7.5$
E.2	$NH_4^+ \leftrightarrow NH_3 + H^+$	$pK_a = 9.3$
E.3	$H_2CO_3 \leftrightarrow HCO_3^- + H^+$	$pK_a = 6.3$
E.4	$HCO_3^- \leftrightarrow CO_3^{2-} + H^+$	$pK_a = 10.3$

Notes:

a. All rate coefficients and equilibrium constants are for 25 degrees C.
b. S_1 is the fast reactive fraction of TOC.
c. S_2 is the slow reactive fraction of TOC.

BLUE PLAN-IT® DECISION SUPPORT SYSTEM OFFERS AN INTEGRATED APPROACH TO DBP MITIGATION



RTW Model

Corrosion and Stability Indices

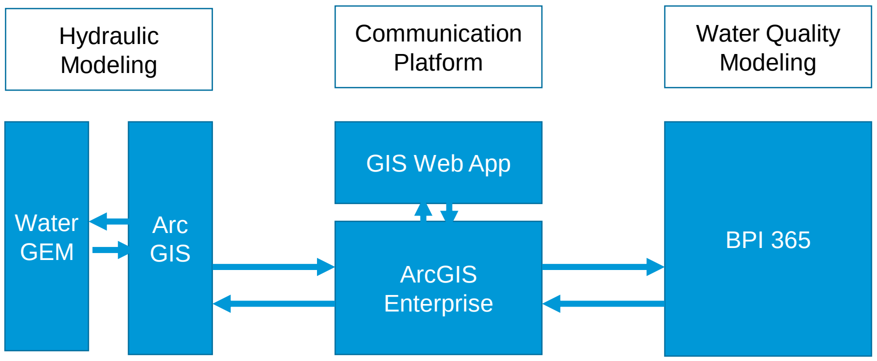
Hydraulic Model (e.g., Infowater MSX: Multi-Species eXtension; WaterGEM)

Blue Plan-it® GIS Web App

EPA WTP Model

Mechanistic DBP Models and Apps

CASE STUDY: WORK FLOW DIAGRAM FOR CITY OF PHOENIX WATER QUALITY AND HYDRAULIC STUDY



Hydraulic Modeling

Communication Platform

Water Quality Modeling

Water GEM

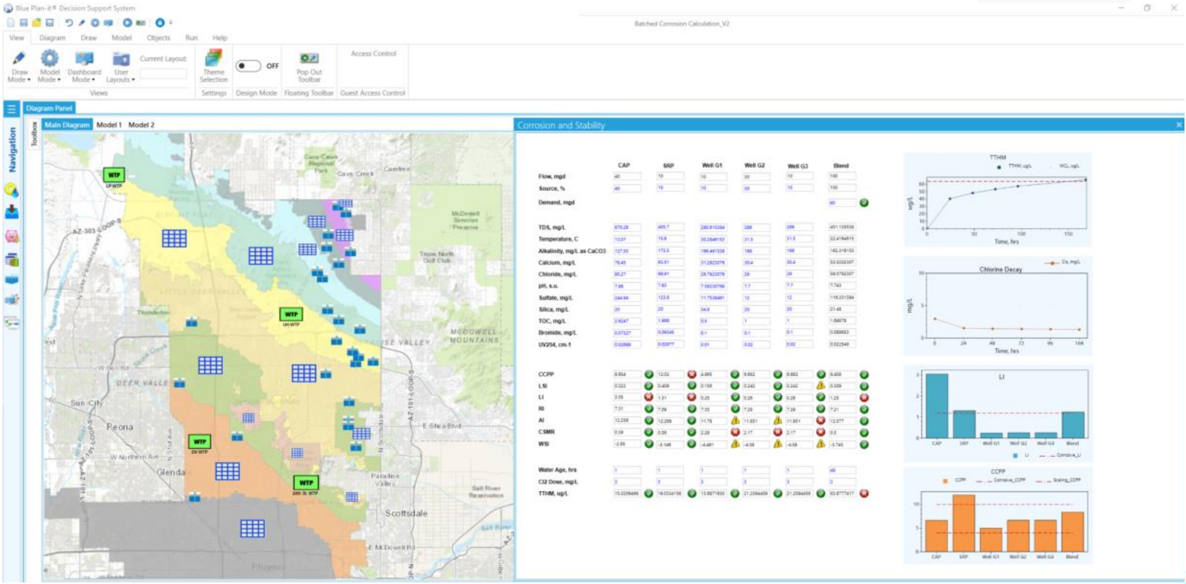
Arc GIS

GIS Web App

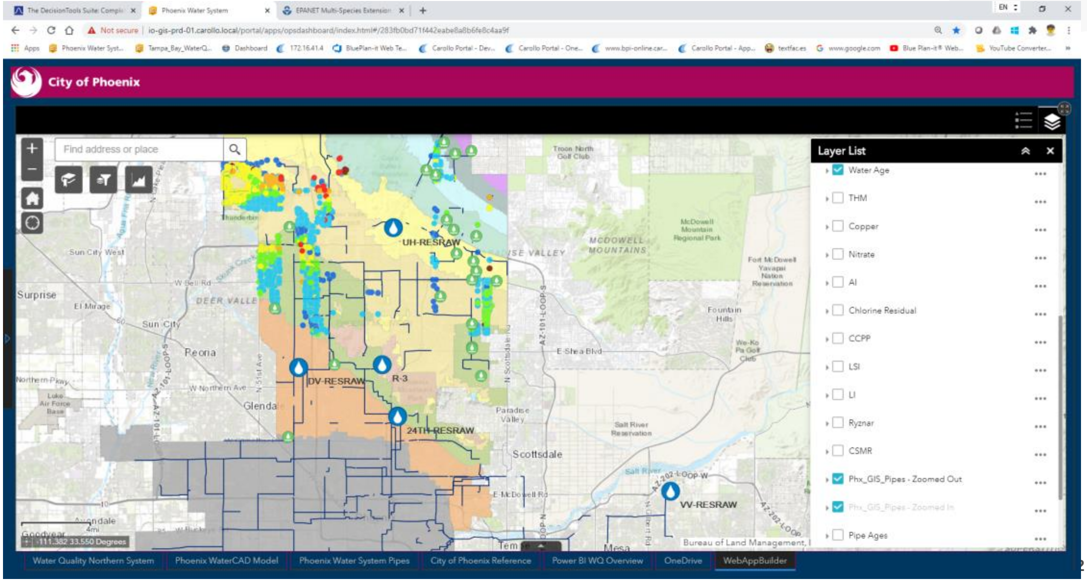
ArcGIS Enterprise

BPI 365

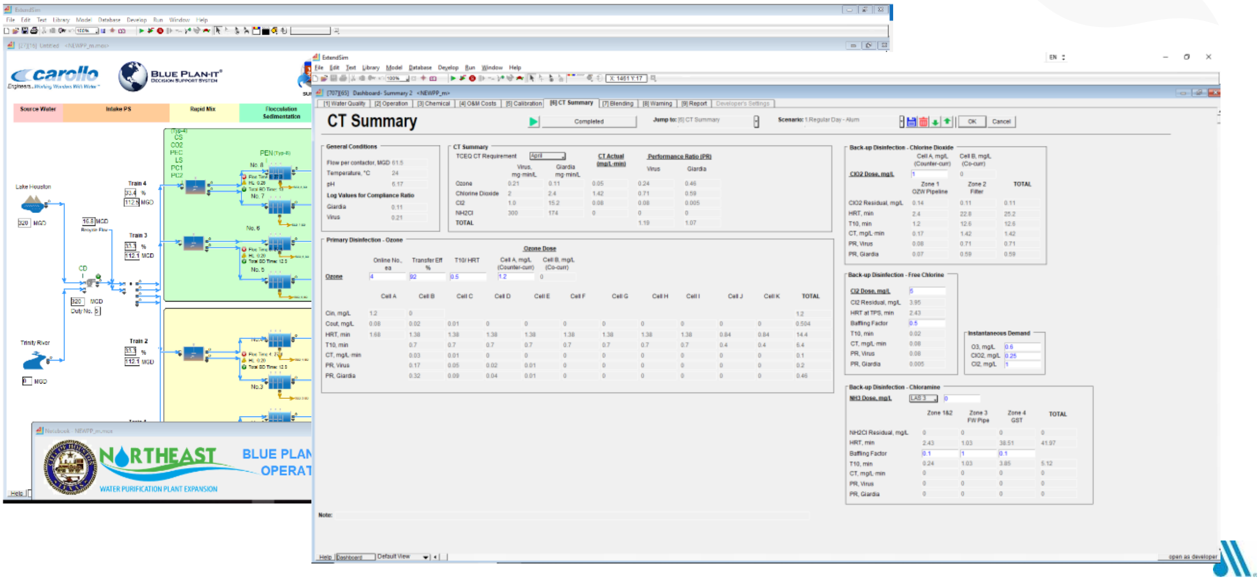
BLUE PLAN-IT® 365 FOR WATER QUALITY MODELING



INTEGRATED BPI AND GIS WEB APP DISPLAY MODELING RESULTS GEOGRAPHICALLY



INTEGRATED TREATMENT PLANT MODEL FOR OZONE, CLO_2, CHLORINE AND CHLORAMINE



CT Summary

Jump to: [6] CT Summary

Scenario: 1.Regular Day - Alum

General Conditions

Flow per contactor, MGD	61.5
Temperature, °C	24
pH	6.17
Log Values for Compliance Ratio	
Giardia	0.11
Virus	0.21

CT Summary

TCEQ CT Requirement: April

	Virus, mg·min/L	Giardia mg·min/L	CT Actual (mg/L-min)	Performance Ratio (PR) Virus	Performance Ratio (PR) Giardia
Ozone	0.21	0.11	0.05	0.24	0.46
Chlorine Dioxide	2	2.4	1.42	0.71	0.59
Cl2	1.0	15.2	0.08	0.08	0.005
NH2Cl	300	174	0	0	0
TOTAL				1.19	1.07

Primary Disinfection - Ozone

	Online No., ea	Transfer Eff %	T10/ HRT	Ozone Dose Cell A, mg/L (Counter-curr)	Ozone Dose Cell B, mg/L (Co-curr)
Ozone	4	92	0.5	1.2	0

	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F	Cell G	Cell H	Cell I	Cell J	Cell K	TOTAL
Cin, mg/L	1.2	0										1.2
Cout, mg/L	0.08	0.02	0.01	0	0	0	0	0	0	0	0	0.504
HRT, min	1.68	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	0.84	0.84	14.4
T10, min		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.4	0.4	6.4
CT, mg/L·min		0.03	0.01	0	0	0	0	0	0	0	0	0.1
PR, Virus		0.17	0.05	0.02	0.01	0	0	0	0	0	0	0.2
PR, Giardia		0.32	0.09	0.04	0.01	0	0	0	0	0	0	0.46

Back-up Disinfection - Chlorine Dioxide

	Cell A, mg/L (Counter-curr)	Cell B, mg/L (Co-curr)	
ClO2 Dose, mg/L	1	0	
	Zone 1 OZW Pipeline	**Zone 2 Filter**	**TOTAL**
ClO2 Residual, mg/L	0.14	0.11	0.11
HRT, min	2.4	22.8	25.2
T10, min	1.2	12.6	12.6
CT, mg/L-min	0.17	1.42	1.42
PR, Virus	0.08	0.71	0.71
PR, Giardia	0.07	0.59	0.59

Back-up Disinfection - Free Chlorine

Cl2 Dose, mg/L	5
Cl2 Residual, mg/L	3.95
HRT at TPS, min	2.43
Baffling Factor	0.5
T10, min	0.02
CT, mg/L-min	0.08
PR, Virus	0.08
PR, Giardia	0.005

Instantaneous Demand

O3, mg/L	0.6
ClO2, mg/L	0.25
Cl2, mg/L	1

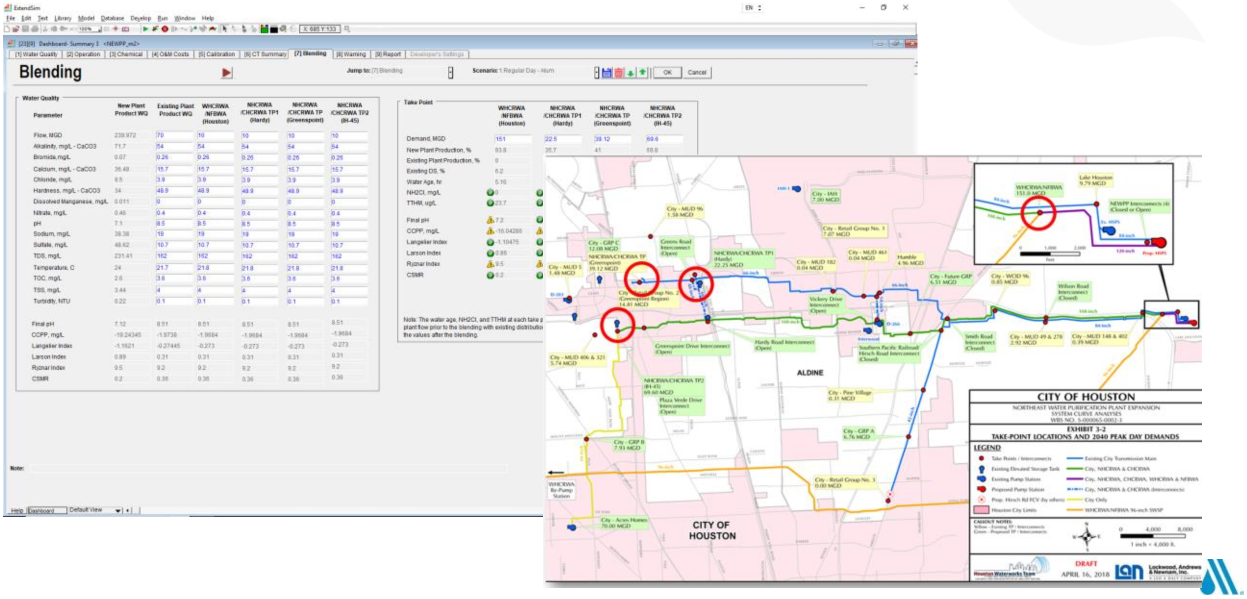
Back-up Disinfection - Chloramine

NH3 Dose, mg/L: LAS 3, 0

	Zone 1&2	Zone 3 FW Pipe	Zone 4 GST	TOTAL
NH2Cl Residual, mg/L	0	0	0	0
HRT, min	2.43	1.03	38.51	41.97
Baffling Factor	0.1	1	0.1	
T10, min	0.24	1.03	3.85	5.12
CT, mg/L-min	0	0	0	0
PR, Virus	0	0	0	0
PR, Giardia	0	0	0	0

Note:

PREDICT FINISHED WATER QUALITY AT EACH AUTHORITY TAKE-POINTS



Blending

Jump to: [7] Blending

Scenario: 1.Regular Day - Alum

Water Quality

Parameter	New Plant Product WQ	Existing Plant Product WQ	WHCRWA /NFBWA (Houston)	NHCRWA /CHCRWA TP1 (Hardy)	NHCRWA /CHCRWA TP (Greenspoint)	NHCRWA /CHCRWA TP2 (IH-45)
Flow, MGD	239.972	70	10	10	10	10
Alkalinity, mg/L - CaCO3	71.7	54	54	54	54	54
Bromide, mg/L	0.07	0.26	0.26	0.26	0.26	0.26
Calcium, mg/L - CaCO3	36.48	15.7	15.7	15.7	15.7	15.7
Chloride, mg/L	9.5	3.9	3.9	3.9	3.9	3.9
Hardness, mg/L - CaCO3	34	48.9	48.9	48.9	48.9	48.9
Dissolved Manganese, mg/L	0.011	0	0	0	0	0
Nitrate, mg/L	0.46	0.4	0.4	0.4	0.4	0.4
pH	7.1	8.5	8.5	8.5	8.5	8.5
Sodium, mg/L	38.38	19	19	19	19	19
Sulfate, mg/L	48.62	10.7	10.7	10.7	10.7	10.7
TDS, mg/L	231.41	162	162	162	162	162
Temperature, C	24	21.7	21.8	21.8	21.8	21.8
TOC, mg/L	2.6	3.6	3.6	3.6	3.6	3.6
TSS, mg/L	3.44	4	4	4	4	4
Turbidity, NTU	0.22	0.1	0.1	0.1	0.1	0.1
Final pH	7.12	8.51	8.51	8.51	8.51	8.51
CCPP, mg/L	-19.24345	-1.9738	-1.9684	-1.9684	-1.9684	-1.9684
Langelier Index	-1.1621	-0.27445	-0.273	-0.273	-0.273	-0.273
Larson Index	0.89	0.31	0.31	0.31	0.31	0.31
Ryznar Index	9.5	9.2	9.2	9.2	9.2	9.2
CSMR	0.2	0.36	0.36	0.36	0.36	0.36

Take Point

	WHCRWA /NFBWA (Houston)	NHCRWA /CHCRWA TP1 (Hardy)	NHCRWA /CHCRWA TP (Greenspoint)	NHCRWA /CHCRWA TP2 (IH-45)
Demand, MGD	151	22.5	39.12	69.6
New Plant Production, %	93.8	35.7	41	69.8
Existing Plant Production, %	0			
Existing DS, %	6.2			
Water Age, hr	5.16			
NH2Cl, mg/L	● 0	●		
TTHM, ug/L	● 23.7	●		
Final pH	⚠ 7.2	●		
CCPP, mg/L	⚠ -16.04286	⚠		
Langelier Index	● -1.10475	●		
Larson Index	● 0.86	●		
Ryznar Index	⚠ 9.5	⚠		
CSMR	● 0.2	●		

Note: The water age, NH2Cl, and TTHM at each take p
plant flow prior to the blending with existing distributio
the values after the blending.

Note:

CITY OF HOUSTON

NORTHEAST WATER PURIFICATION PLANT EXPANSION
SYSTEM CURVE ANALYSES
WBS NO. S-000065-0002-3

EXHIBIT 3-2
TAKE-POINT LOCATIONS AND 2040 PEAK DAY DEMANDS

LEGEND

- ● Take Points / Interconnects
- Existing Elevated Storage Tank
- Existing Pump Station
- Proposed Pump Station
- Prop. Hirsch Rd FCV (by others)
- Houston City Limits
- Existing City Transmission Main
- City, NHCRWA & CHCRWA
- City, NHCRWA, CHCRWA, WHCRWA & NFBWA
- City, NHCRWA & CHCRWA (Interconnects)
- City Only
- WHCRWA/NFBWA 96-inch SWSP

CALLOUT NOTES:
Yellow - Existing TP / Interconnects
Green - Proposed TP / Interconnects

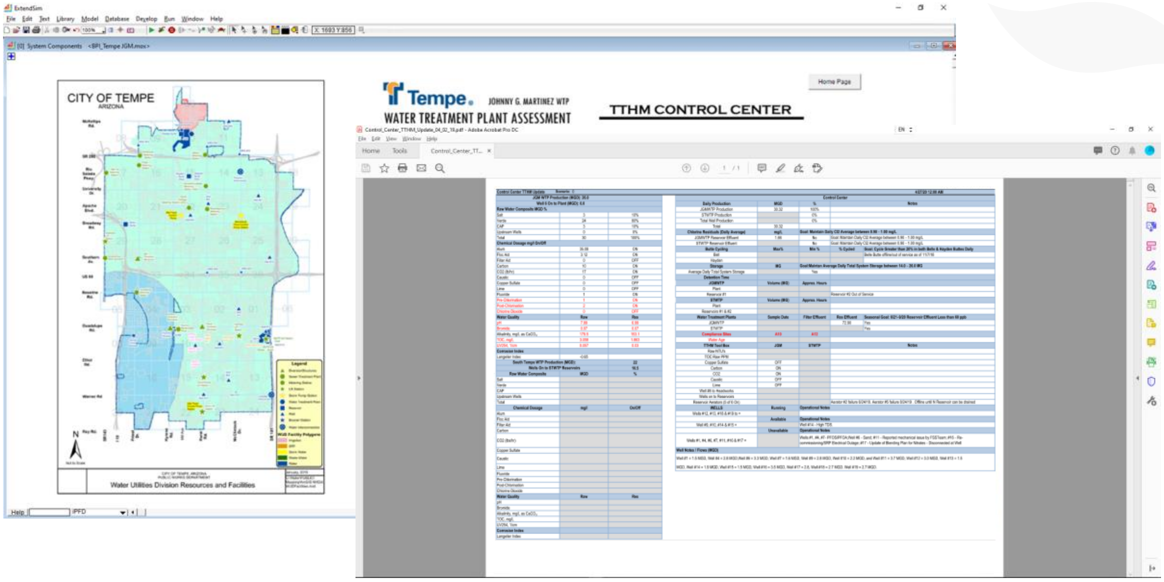
0 4,000 8,000
1 inch = 4,000 ft.

Houston Waterworks Team

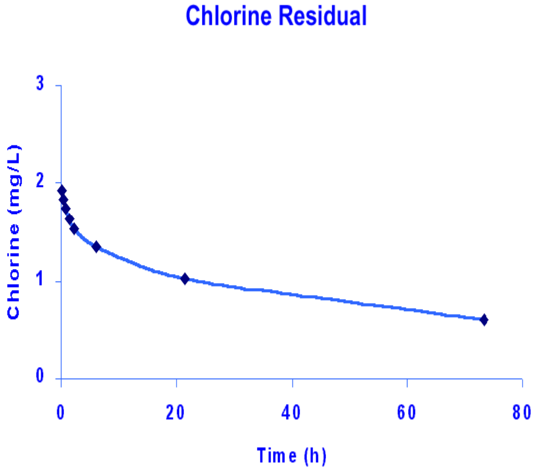
DRAFT
APRIL 16, 2018

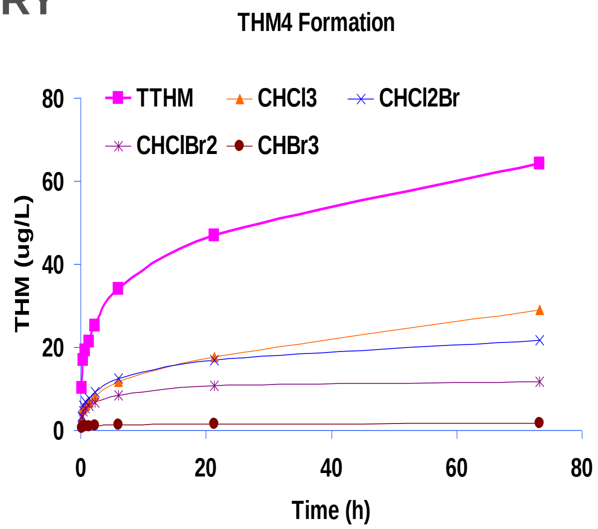
Lockwood, Andrews & Newnam, Inc.

MODEL GENERATES PROCESS CONTROL REPORTS

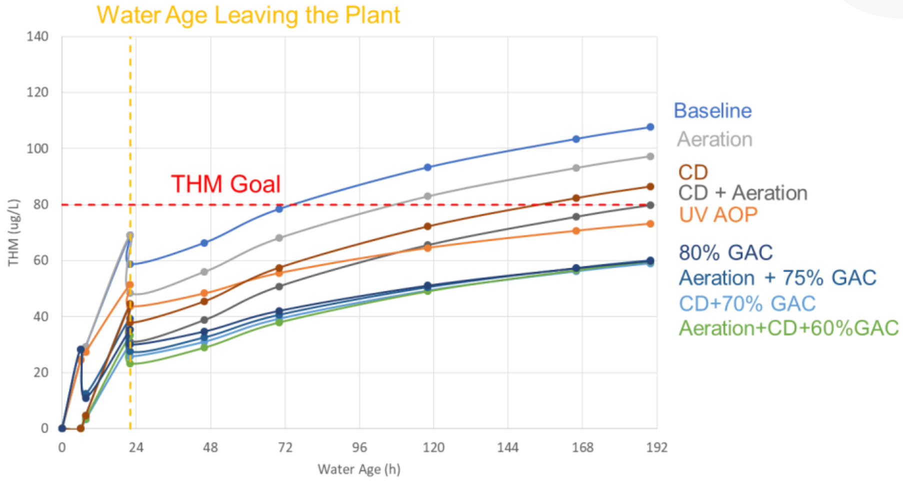


CHLORINATION AND TTHM FORMATION CURVES ARE WIDELY USED IN INDUSTRY



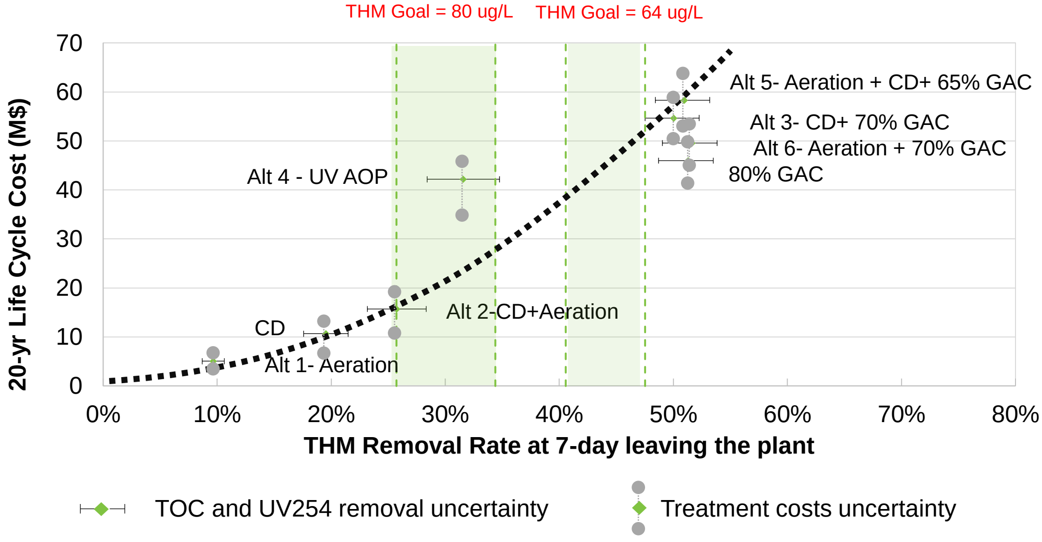


MODELING IMPACT OF TREATMENT ALTERNATIVES AND FLOW FLUCTUATIONS ON TTHMS

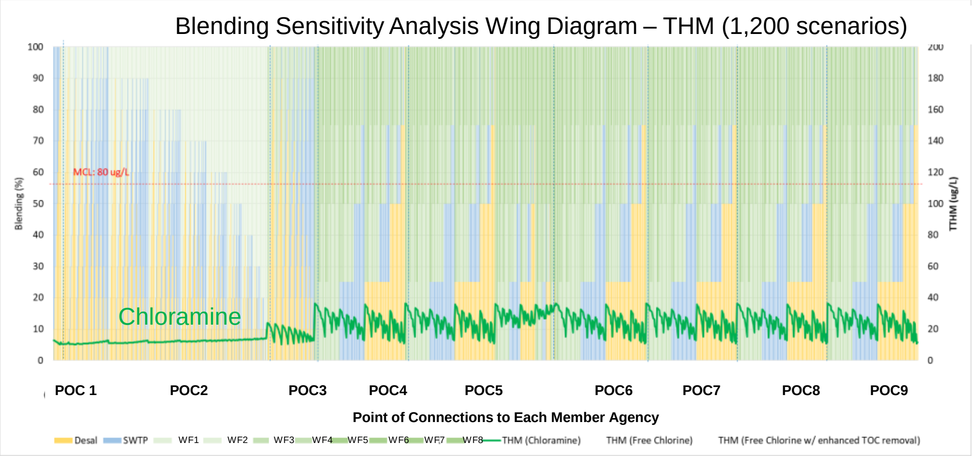


80% GAC means 80% of the filtered flow is treated by GAC

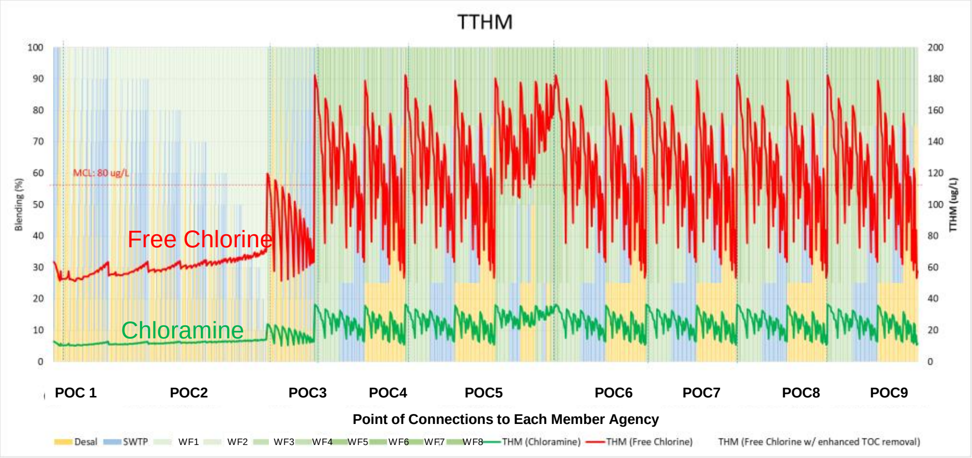
MODELING COST BENEFIT CURVES TO SUPPORT DECISION MAKING ON PROPOSED TREATMENT



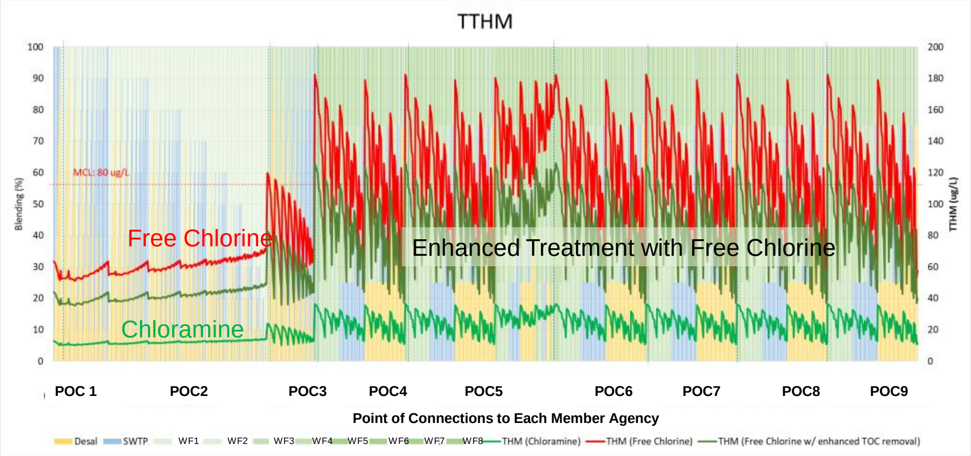
MODELING IMPACT OF TREATMENT ON THM AT EACH POINT OF CONNECTION (1200 SCENARIOS)



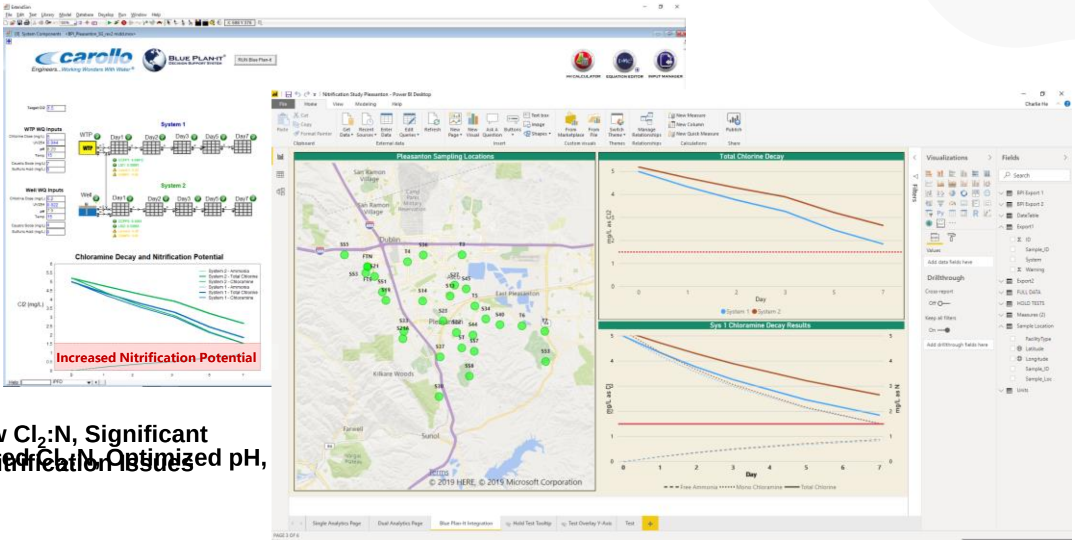
MODELING IMPACT OF TREATMENT ON THM AT EACH POINT OF CONNECTION (1200 SCENARIOS)



MODELING IMPACT OF TREATMENT ON THM AT EACH POINT OF CONNECTION (1200 SCENARIOS)



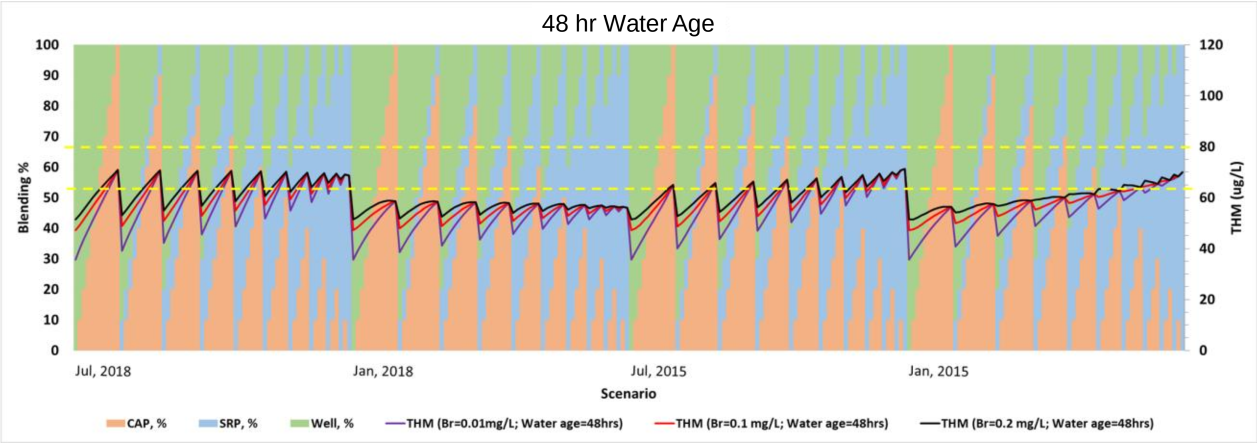
MODELING CHLORAMINE SYSTEM TO CONTROL NITRIFICATION



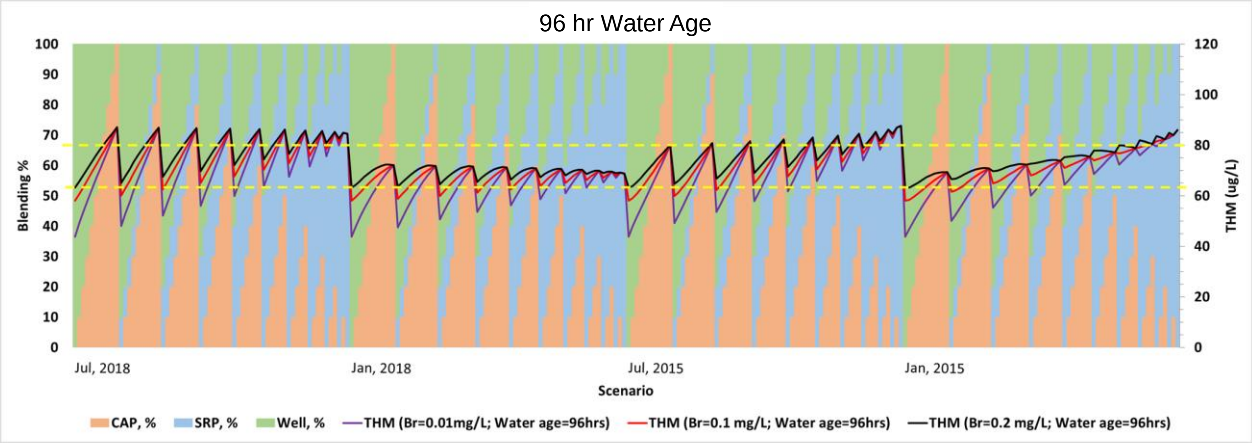
Low Cl_2:N, Significant Nitrification Issues

Increased Cl_2:N, Optimized pH,

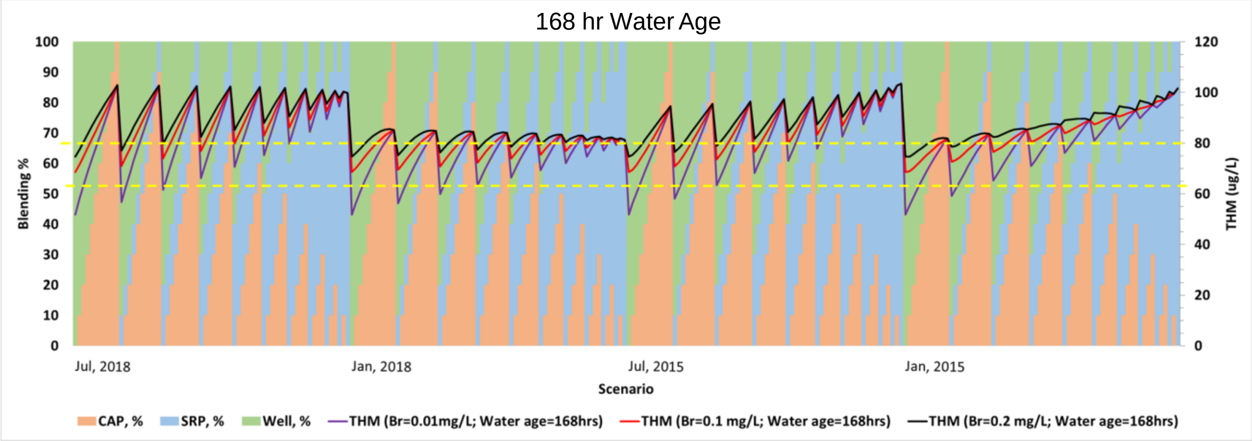
MODELING IMPACT OF BLENDING OF GROUNDWATER AND BROMIDE ON TTHMS (4000 SCENARIOS)



MODELING IMPACT OF BLENDING OF GROUNDWATER AND BROMIDE ON TTHMS



MODELING IMPACT OF BLENDING OF GROUNDWATER AND BROMIDE ON TTHMS



CONCLUSIONS

- Assessing distribution water quality requires combining several modeling tools
- Integrated approach to DBP mitigation offers several benefits:
  - Combine water treatment plant operations model and distribution system model for better water quality controls
  - Combine water quality modeling and hydraulic modeling for more accurate and geographical presentation
  - Combine steady state modeling and advanced computation techniques to better address WQ variations
  - Combine water quality modeling and cost estimates for more productive decision support

ASK THE EXPERT

Susan Richardson
University of South Carolina

Susan Teefy
East Bay Municipal Utility District

Charlie (Qun) He
Carollo Engineers, Inc

Enter your **question** into the **question pane** on the right-hand side of the screen.

Please specify to whom you are addressing the question.

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Oct 28 - A Closer Look at New and Not so New CEC's: PFAS, Microplastics and Solvents

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– Kenneth Mercer, Ph.D.,
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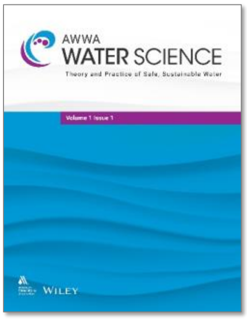

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PRESENTER BIOGRAPHY INFORMATION

Susan D. Richardson is the Arthur Sease Williams Professor of Chemistry in the Department of Chemistry and Biochemistry at the University of South Carolina; prior to coming to USC, she was a Research Chemist for several years at the U.S. EPA’s National Exposure Research Laboratory. Susan is the recipient of the 2008 American Chemical Society Award for Creative Advancements in Environmental Science & Technology, has received an honorary doctorate from Cape Breton University in Canada, was recognized as an American Association for the Advancement of Science (AAAS) Fellow and an ACS Fellow, and is currently the President of the American Society for Mass Spectrometry and an Associate Editor for Environmental Science & Technology. Susan has a Ph.D. in Chemistry from Emory University and a B.S. in Chemistry & Mathematics from Georgia College & State University.

Susan Teefy is the Water Quality Manager for the East Bay Utility District in Oakland, California. She has 30 years of experience in drinking water treatment, distribution, water quality and regulatory compliance issues. She has a bachelor’s degree in Civil Engineering from University of California, Berkeley, and a master’s degree in Environmental Engineering from University of North Carolina, Chapel Hill. She is also a licensed water treatment and water distribution operator in California. East Bay MUD’s treatment plants use free chlorine, ozone, and chloramine, and thus Susan has experience with several disinfection byproduct monitoring and control issues.

Charlie (Qun) He, a vice president and chief technologist with Carollo, has more than 19 years of experience in water and wastewater treatment, water quality, and water resources. Mr. He has extensive experience in water and wastewater treatment, with an expertise in developing and optimizing treatment strategies for complex industrial wastewater treatment. He has gained experienced working with semiconductor, data center, mining, chemical, power, textile, food and beverage, and manufacturing industries. He leads the company’s integrated decision support system team and is leading the research and development of Blue Plan-it® Decision Support System, an advanced water and wastewater system simulation and optimization tool. He is Carollo’s membrane desalination and concentrate management expert for the southwest region and one of the R&D Innovation Lead for the Carollo's Research Group. He is the chair of AWWA Manual of Practice 69 – Inland Desalination and Concentrate Management and the vice chair of the AWWA Joint Research Committee. He is the ex-chair of AZ Water Association Research Committee and the ex-chair of the AWWA Joint Research Committee. In addition, Mr. He is a LEED AP and has gained extensive exposure to the field of sustainability.

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