Presented by the SWIG Technical Services Team

New Mexico Environment Department

Drinking Water Bureau

Optimizing Water Systems for DBPs

Overview

- Introduction
- What are Disinfection Byproducts (DBPs)?
- Why are DBPs Regulated?
- DBP Formation
- What Data is There in NM?
- DBP Regulation in NM
- DBP Control Strategies
  - Define the Problem
  - Troubleshooting DBP Problems
- Quantitative Approach to DBP Reduction

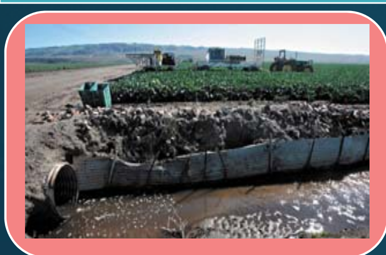
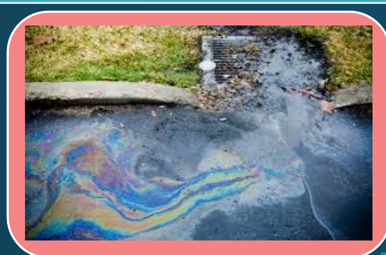
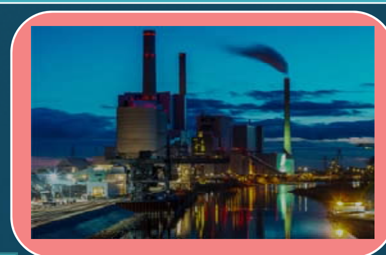
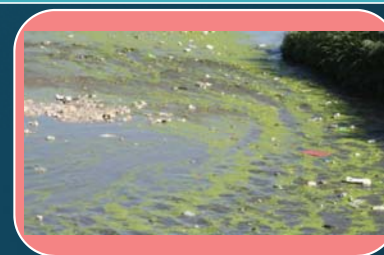
What are Disinfection Byproducts (DBPs)

- **Disinfection byproducts** are chemical, organic and inorganic substances that can form during a reaction of a **disinfectant** with naturally present organic matter (**NOM)** (primarily humic & fulvic acids) in the water.

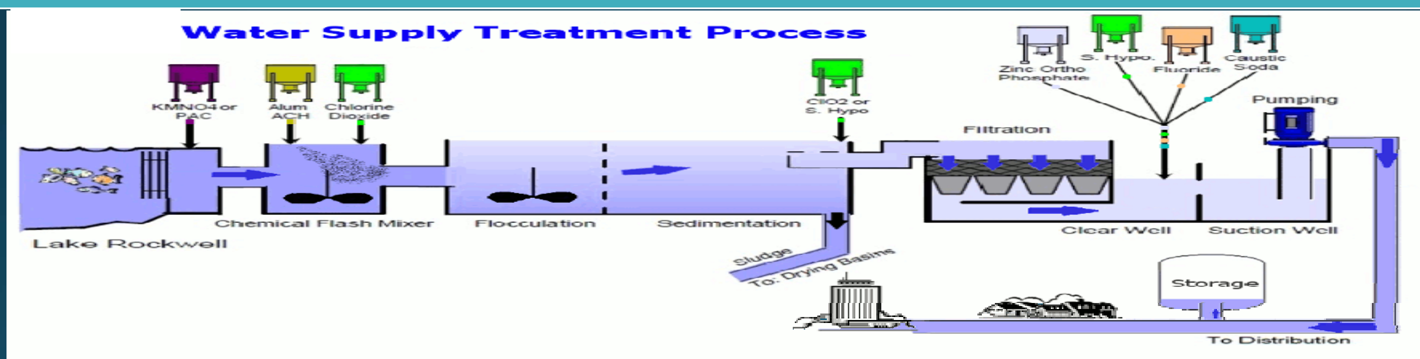
- Two Groups:
  - Total Trihalomethanes (TTHM)
  - Haloacetic Acids (HAA5)

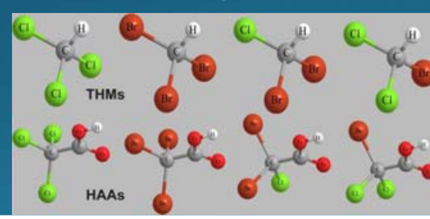
What are Disinfection Byproducts (DBPs)

DBP Precursors in Source Water

Disinfectant Interaction with Organic Matter



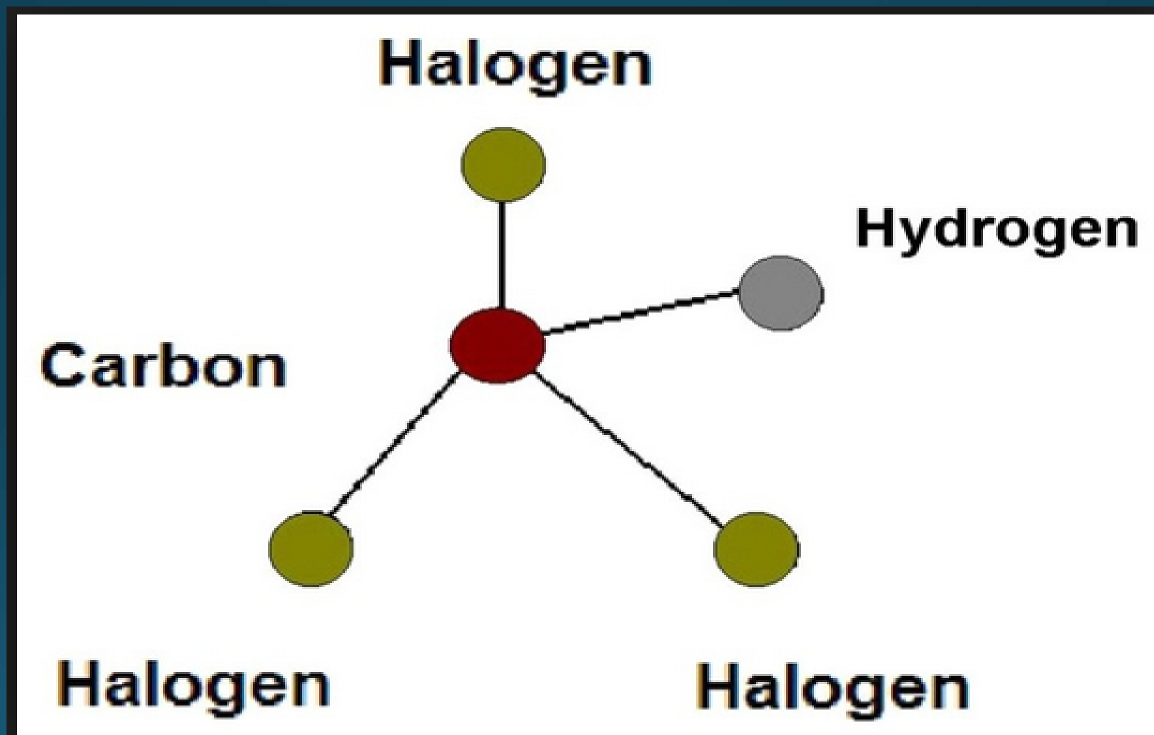


DBPs Formation

Disinfectant	DBPs Formed
Chlorine (Cl2)	Trihalomethanes, Haloacetic Acids, Haloacetonitriles
Chloramine	Chloral Hydrate; N-nitrosodiemthylamine (NDMA)
Chlorine Dioxide	Chlorate, chlorite, chlorophenols, quinones
Ozone	Aldehydes, carboxylic acids, quinones, peroxides, Bromates, Brominated Products
UV	None
Titanium Dioxide	3-methyl-2,hexanedione, dihydro-4,5-dichlro-2(3H)

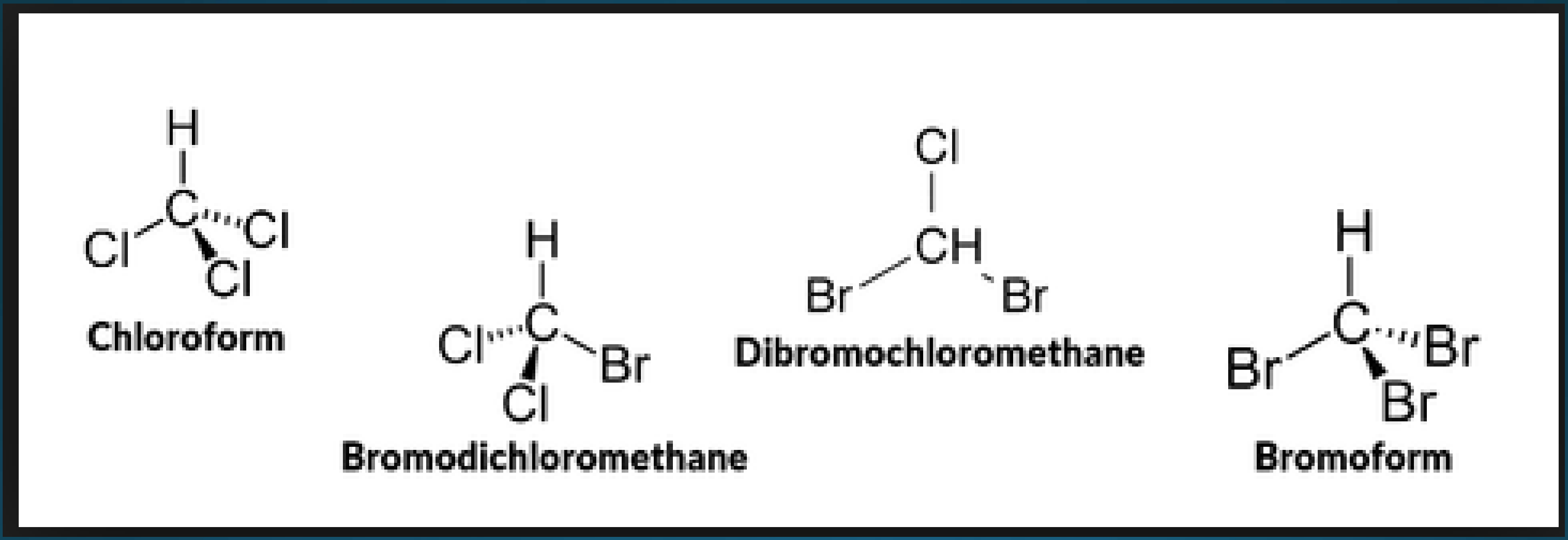
TTHM General

- Chemical compound in which 3 of the 4 hydrogen atoms of Methan (CH_4) are replaced by Halogen (Cl, Br) atoms



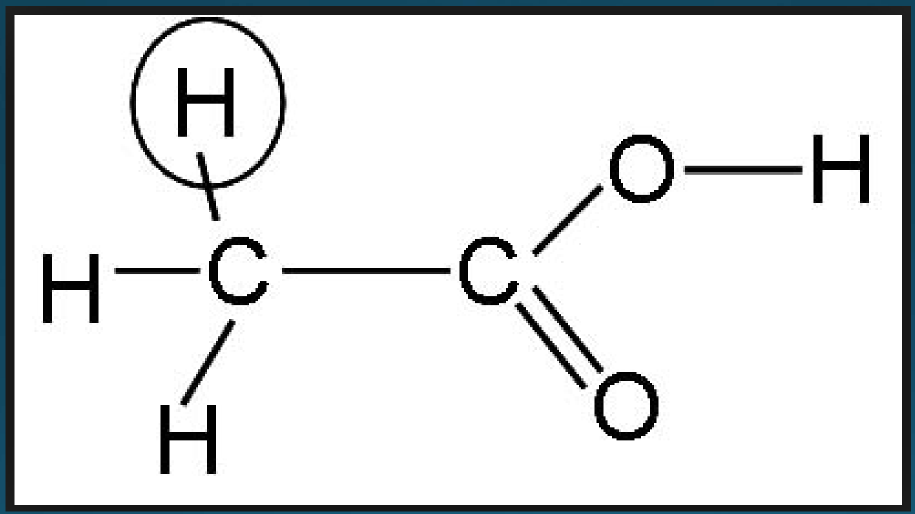
TTHM Speciation

- Names depend on # of Halogens (differentiate between Cl & Br)

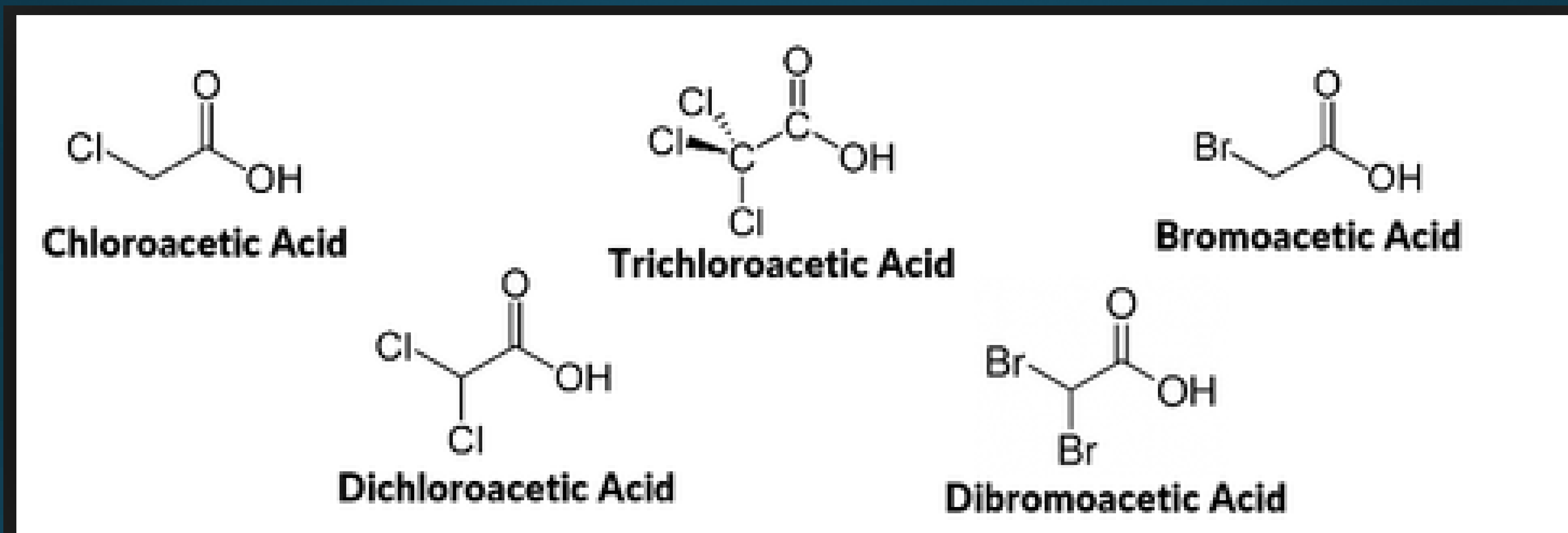


HAA5 General

- Haloacetic acids are carboxylic acids in which a halogen (Cl, Br) atom takes the place of hydrogen atoms

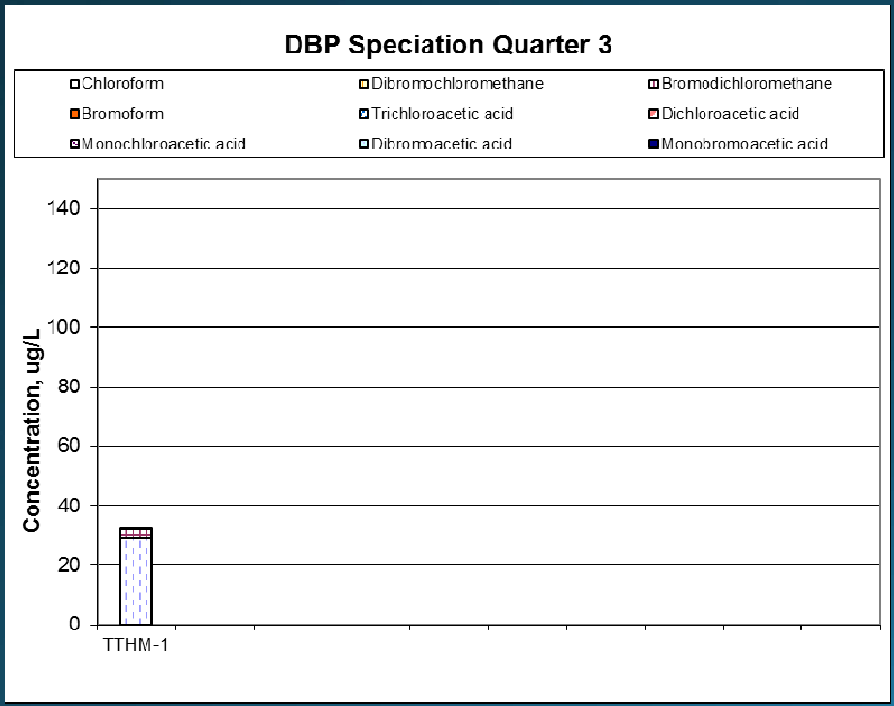


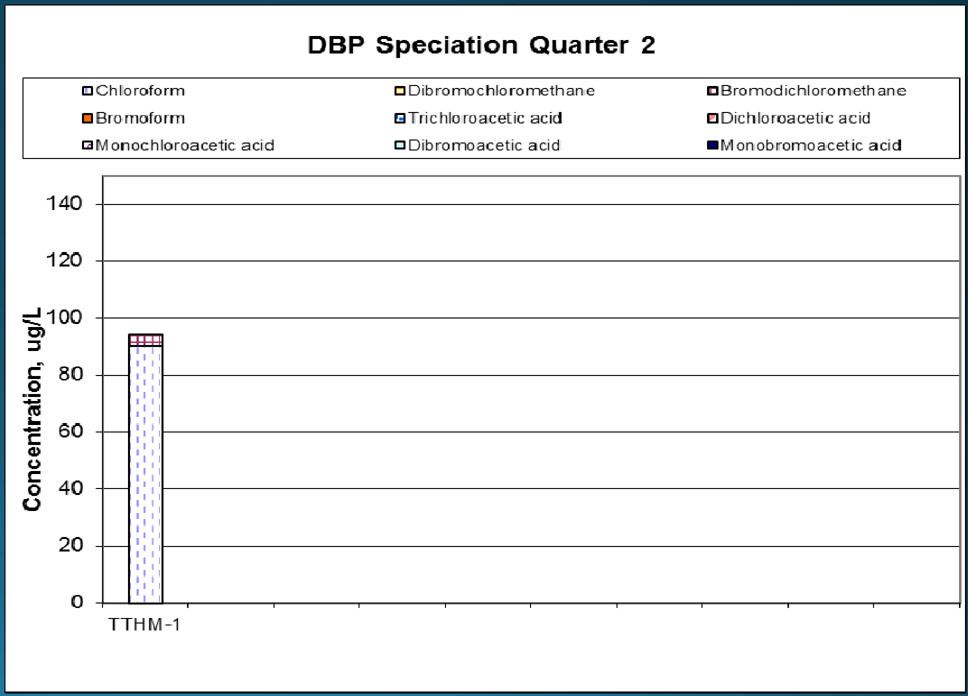
HAA5 Speciation



What does Speciation Tell us?

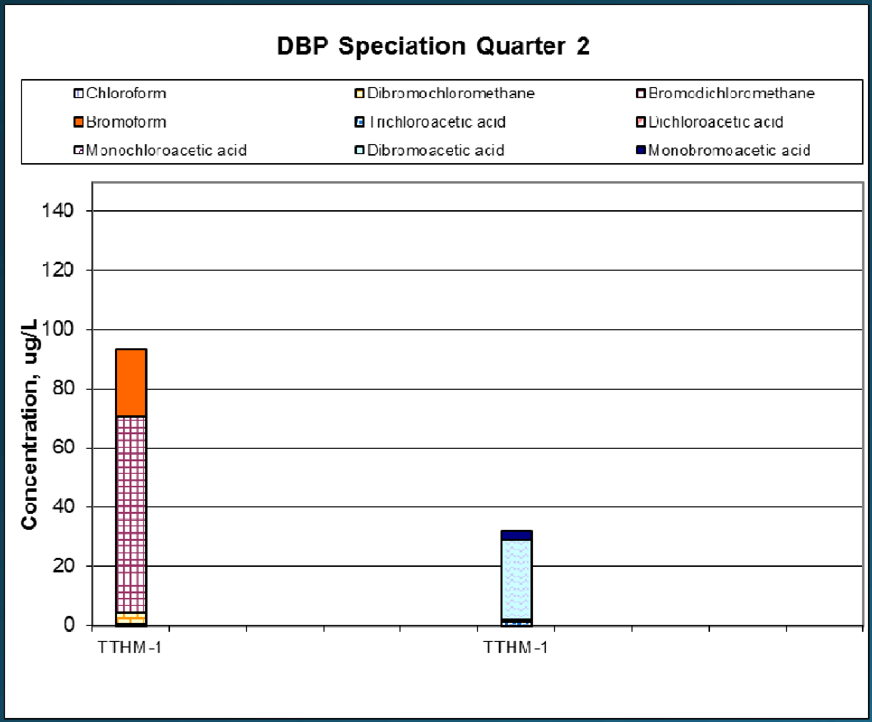
- Speciation is used to determine the root cause of DBP exceedances
- Seasonal trends – Cl dominated species increase during summer months- Chlorine overfeed. Disinfection efficiency increases with temperature, excess free chlorine in warmer periods.

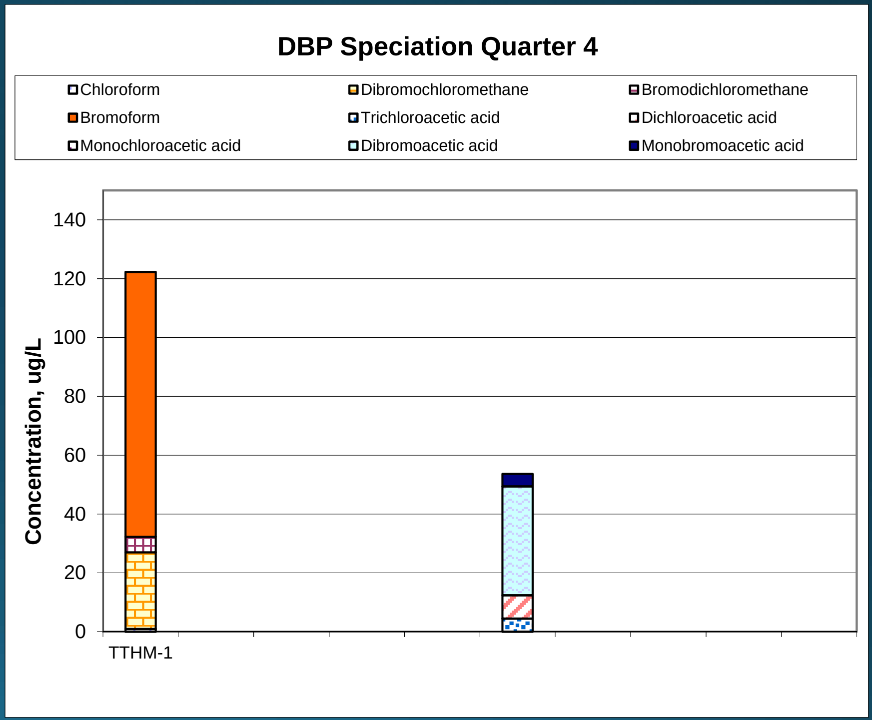




What doe speciation tell us?

- Presence of Brominated species – Bromine present in source water





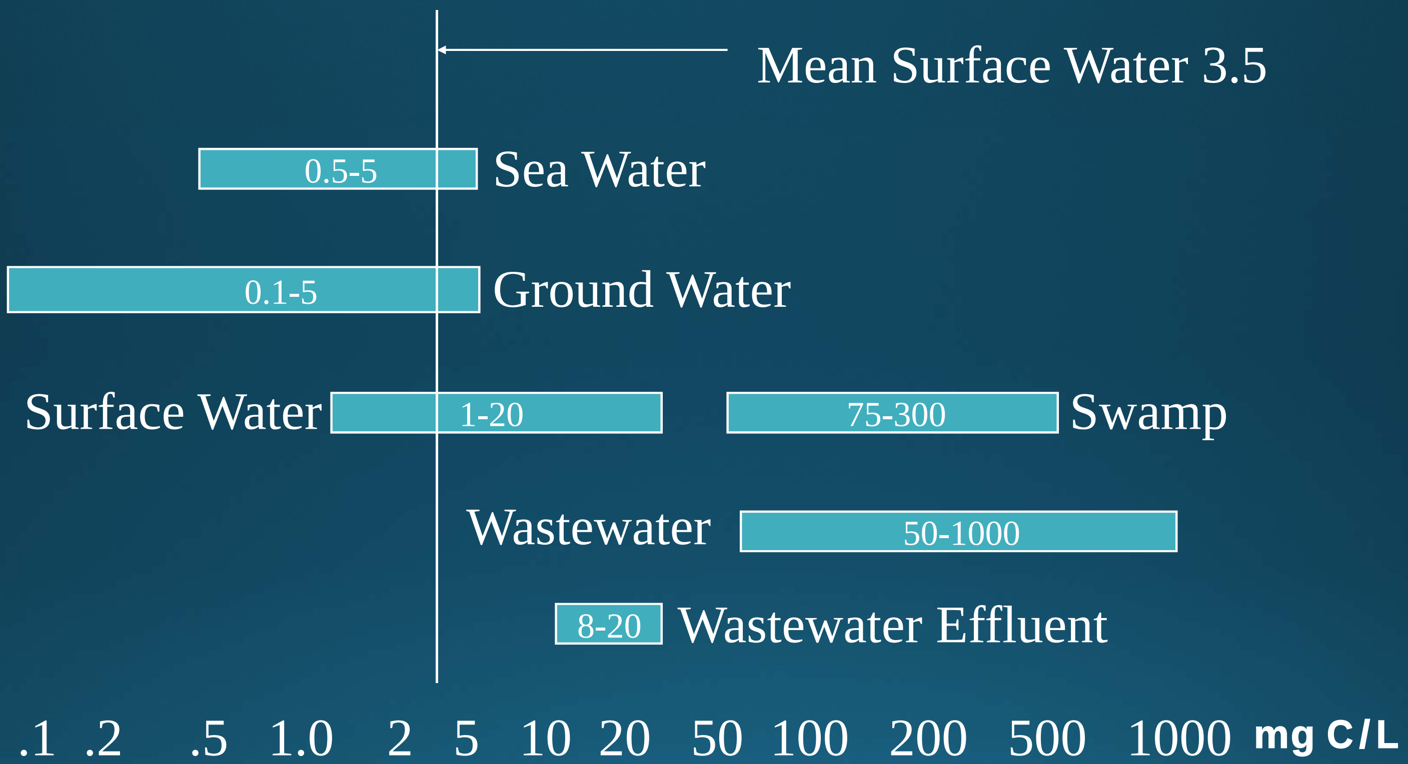
Means of Identifying Natural Organic Matter

NOM Species	Description	Significance
TOC	Total amount of all forms of Organic Carbon Present	Good overall indicator of potential DBP problems
DOC	The TOC passing through a 0.45 micron filter is dissolved	Better indicator of the reactive portion of the TOC
UV254	Used to identify light absorption of reactive humic components	Identifies the reactive potion of the DOC
SUVA	Ratio of UV_{254} to DOC	Best indicator of reactive portion of the TOC

Raw Water Considerations

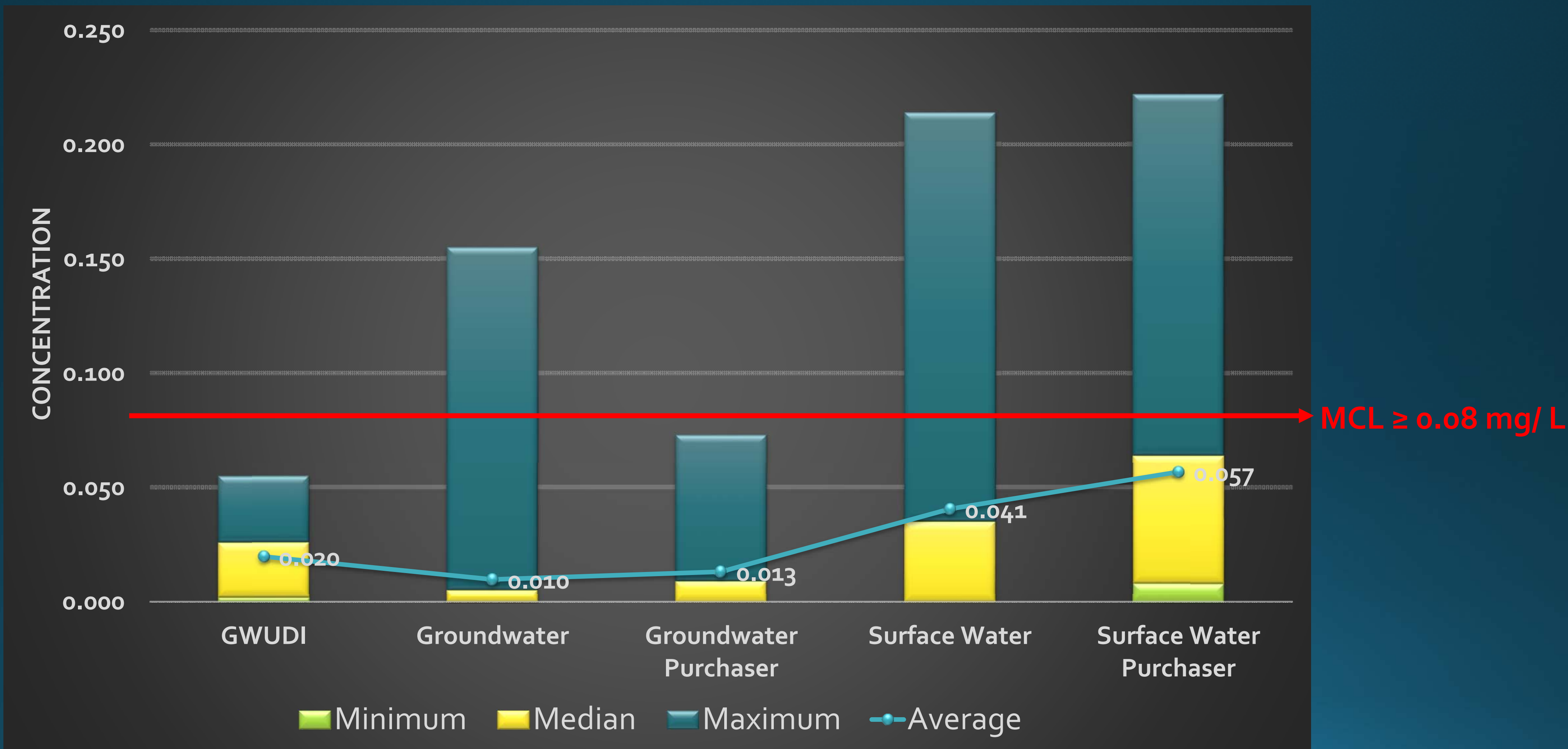
- DBP Investigations always begin with the Source Water.
- Generally, Subpart H systems will have higher levels of organic materials (TOC).
- Generally, Subpart H systems have greater fraction of emendable humic content opposed to GW.
- If Subpart H waters mix with ground waters the TOC may need to be characterized prior to disinfectant introduction.
- The humic content can be approximated by using SUVA.

Organic Materials (NOM) Commonly Approximated by Total Organic Carbon (TOC)

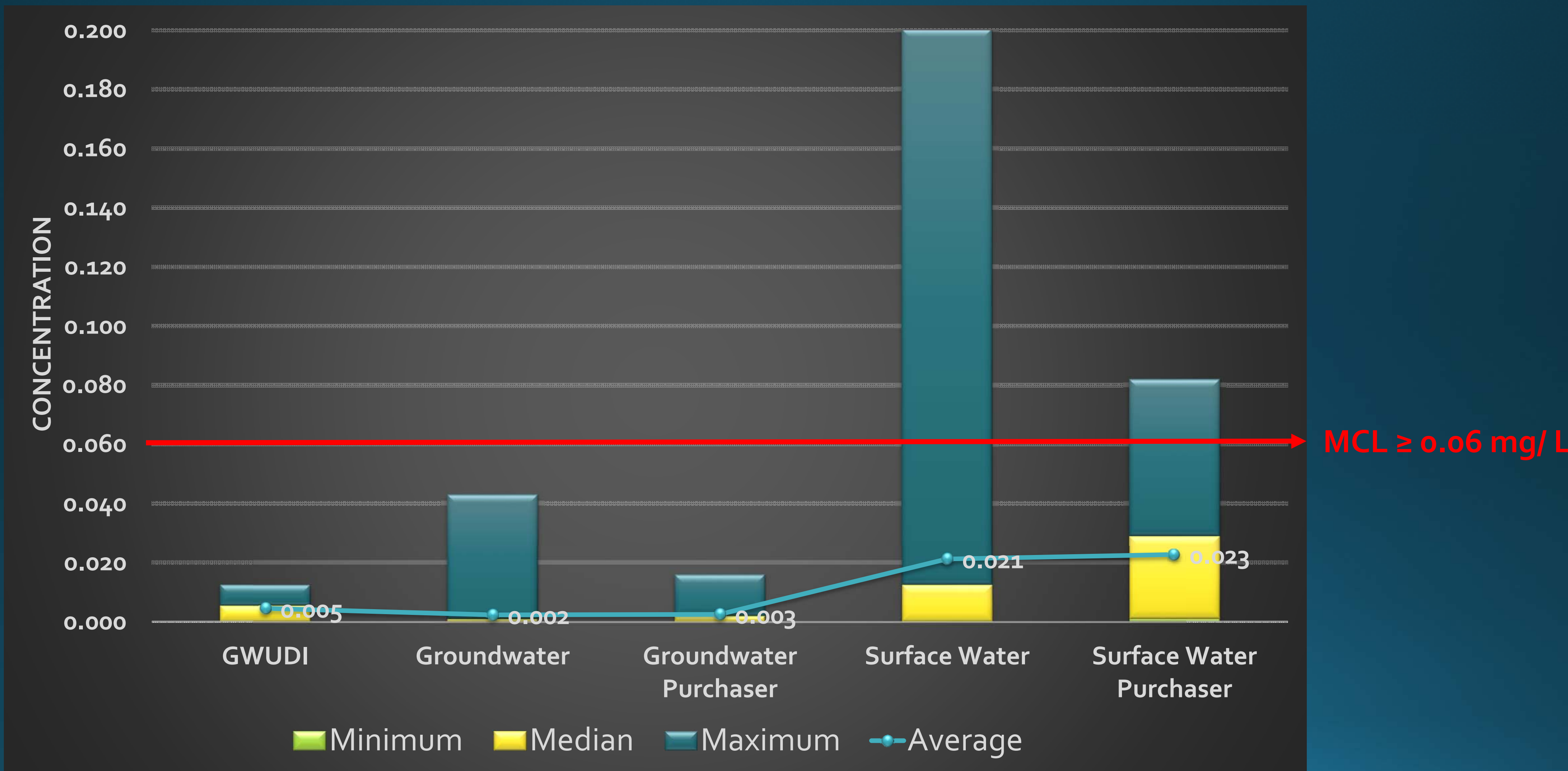


- Total Organic Carbon (TOC) is a direct measure of organic carbon (total carbon - inorganic carbon).
- The fraction of NOM that is a precursor for DBPs is the dissolved portion.

NM SDWIS TTHM Data by Source (mg/ L), 2013-2015



NM SDWIS HAA5 Data by Source (mg/ L), 2013-2015



Why Are DBPs Regulated?

- **Exposure Routes**:
- Ingestion 
- Inhalation 
- Skin Absorption 

- **Harmfully Effects**:
- Liver
- Kidney
- Reproductive System
- Cancer
- Central Nervous System Problems
- Anemia

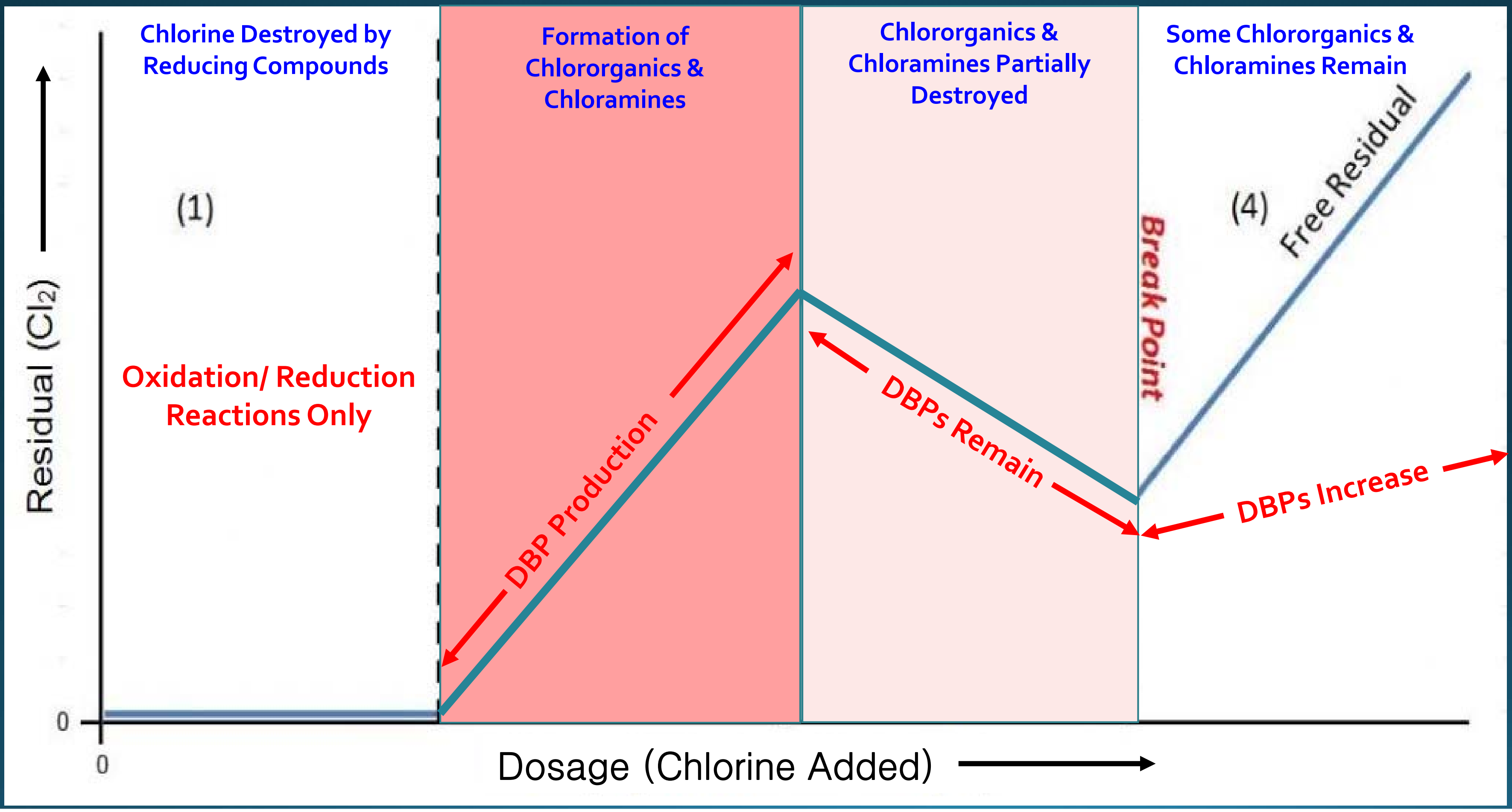
Factors Affecting DBP Formation

- Type of Disinfectant
- Disinfectant Dosage
- Disinfection Contact Time
- Type of Level of TOC Precursor
- Disinfection Point
- pH and Water Temperature
- Residence Time in the Distribution System

Factors Affecting Disinfection By-Product Production w/ Cl_2

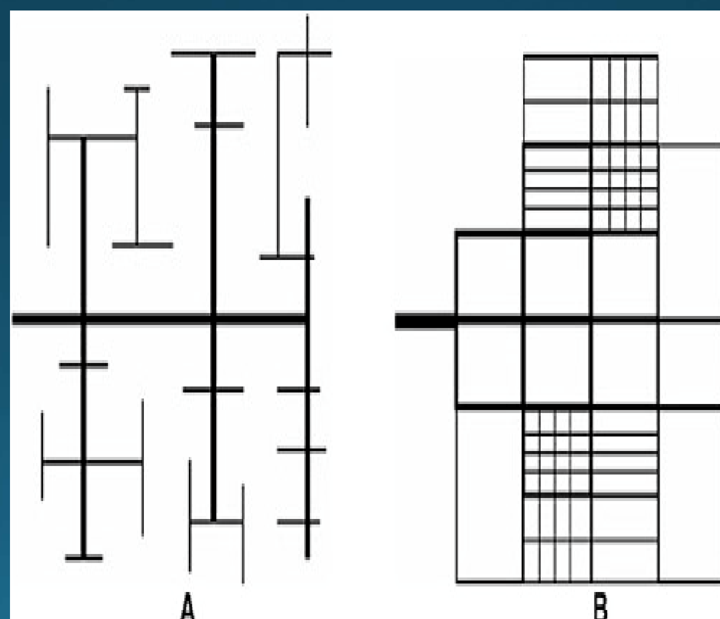
- Turbidity and the Type of NOM present
- Concentration of Chlorine Added and How Well it is Mixed
- Presence of Bromide Ion
- Hydrogen Sulfide (H_2S), Iron (Fe) and Ammonia (NH_3) Content
- Age of Water System (amount of CI pipeline)
- Water Temperatures
- Longer Contact Times (MRT)
- Foreign Debris in the Water System

DBPs Formation in the Chlorinated Treatment System



DBPs Formation in the Storage & Distribution

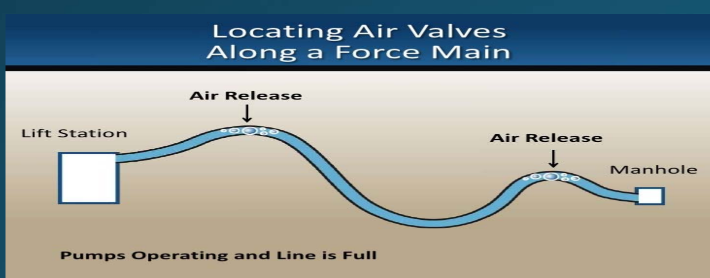
- Water Age
- Low Demand Areas
- Dead Ends Pipelines- Maximum Residence Time (MRT)

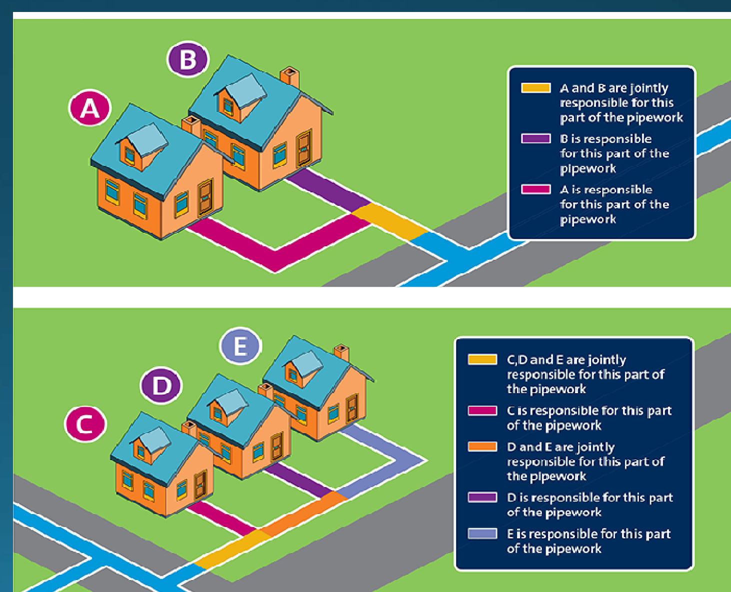


DBPs Formation in the Storage & Distribution

- Storage Tanks with poor water turnover
  - Thermal Stratification
  - Short Circuiting
  - Lack of Flow directing baffling

- Stagnant & Slow Moving Water Areas
- Note: Unlined CI Pipe (systems in existence before 1949) require higher residual chlorine levels





Tuburculation creates more surface area and growth and accumulation sites for biofilm and sediment

What are Disinfection Byproducts (DBPs)

Character	TTHM	HAA5
Vapor Pressure	Volatile	Semi-Volatile
pH	High pH (>8.5) forms >TTHMs	Low pH (<6.5) forms > HAA5s
Contact Time	>Formation with Contact Time	>Formation with Contact Time
Temperature (Formation)	>Formation at Higher Temp Waters	>Formation at Higher Temp Waters
Temperature (Persistence)	>Formation at Higher Temp Waters with Disinfectant	Dissipation at >Temp. Waters
Presence In Water System	> in Extremities (MRT)	> Near High Chlorine Dose and/or Residual Locations

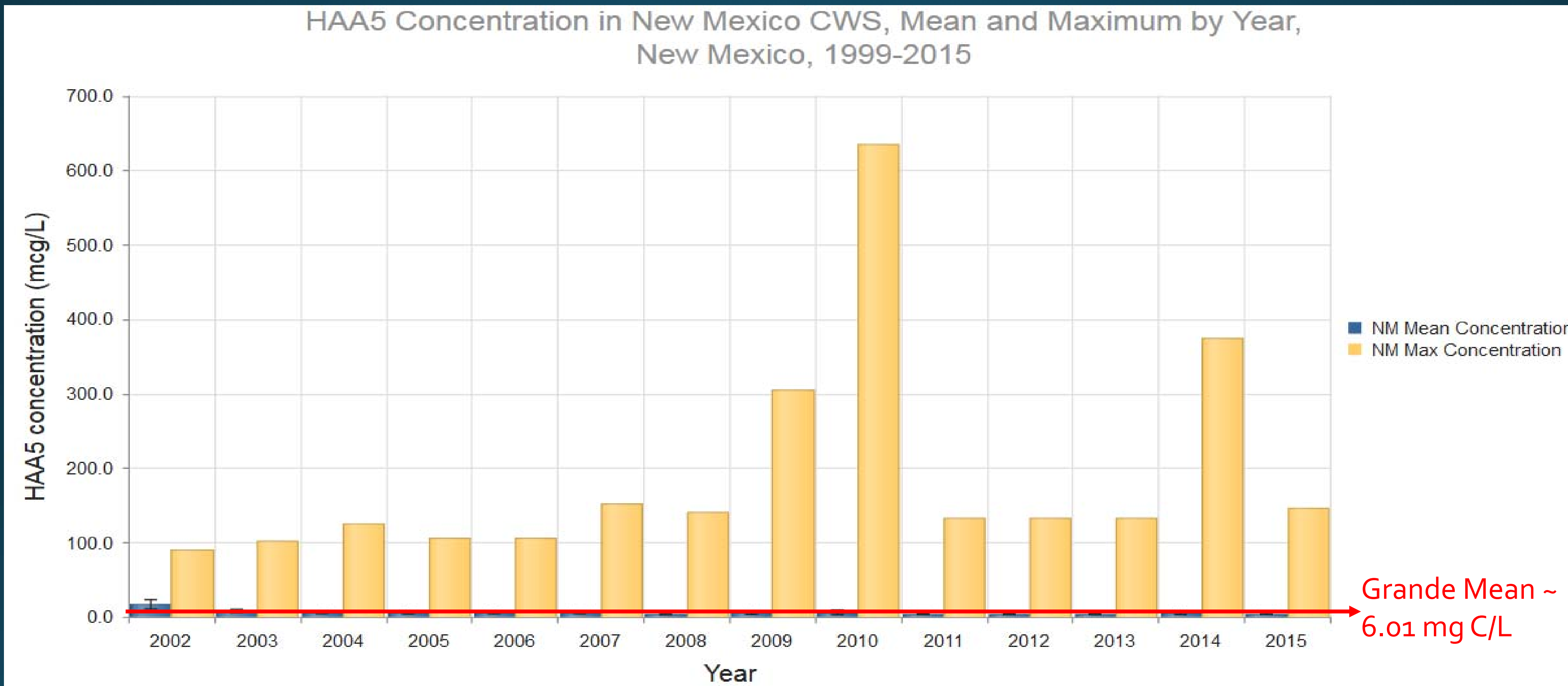
Where HAA5s are Found

- Areas of Low Demand
- Centralized System Areas w/ high Chlorine concentration and low movement
- Proximity to High Chlorine Dose and/or Residual Locations
- Areas of High Bacterial Growth Inside the System.
- HAA5 degrades → highest HAA5s are not found in high water age areas.

Ratio of TTHM to HAA5

- TTHMs to HAA5s generally are produced at a constant ratio relative to each other.
- Large variations indicate a change of system conditions.
- Increases in HAA5 levels indicate changes in water age.
- Increase in both TTHMs and HAA5s may indicate changes in disinfection concentrations and/ or too much disinfectant.
- Trending TOC and DBP data to assess performance can be very useful.

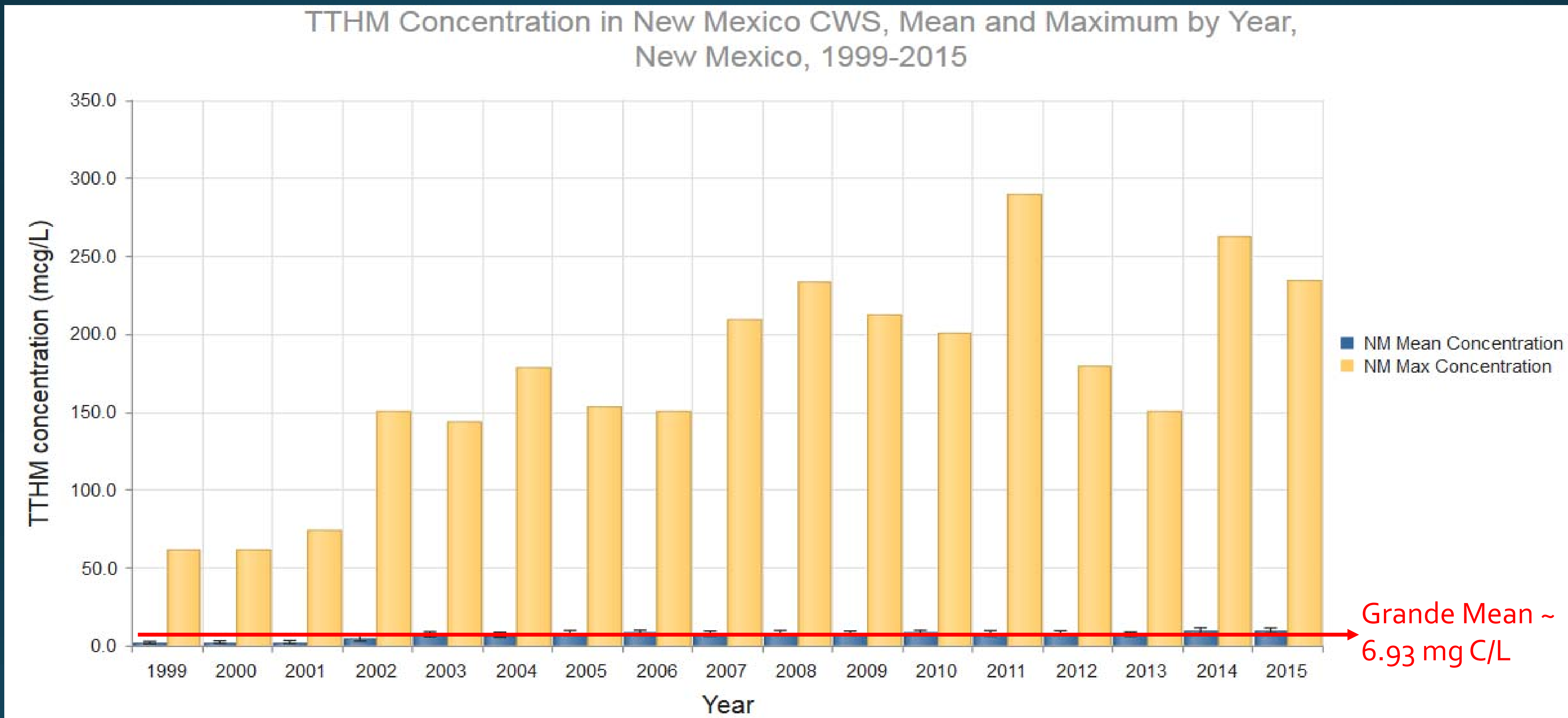
HAA5 Concentration in New Mexico CWS, 2002-2015



New Mexico Environment Department's Drinking Water Bureau, New Mexico Safe Drinking Water Information System (SDWIS). Measured HAA5 concentrations in finished drinking water can be used to understand the distribution of potential haloacetic acids (HAAs) exposure level for populations served by community water supplies.

https://nmtracking.org/dataportal/indicator/view/CommWaterHAA5.MeanMax.Year.html

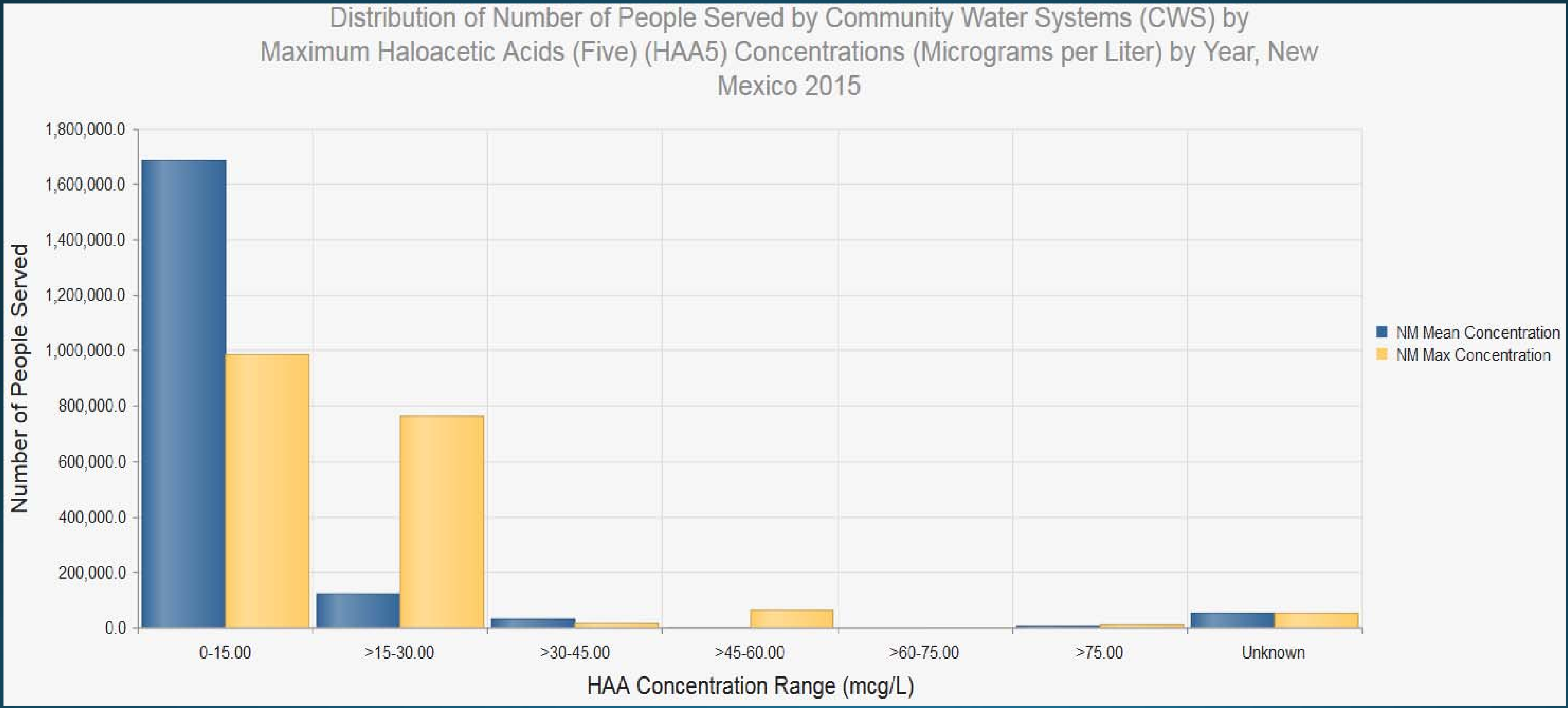
TTHM Concentration in New Mexico CWS, 1999-2015



New Mexico Environment Department's Drinking Water Bureau, New Mexico Safe Drinking Water Information System (SDWIS). Measured TTHM concentrations in finished drinking water can be used to understand the distribution of potential trihalomethanes (THM) exposure level for populations served by community water supplies.

https://nmtracking.org/epht-view/dataportal/indicator/view/CommWaterTHM.MeanMax.Year.html

Distribution of CWS Population Served by HAA5 Concentrations



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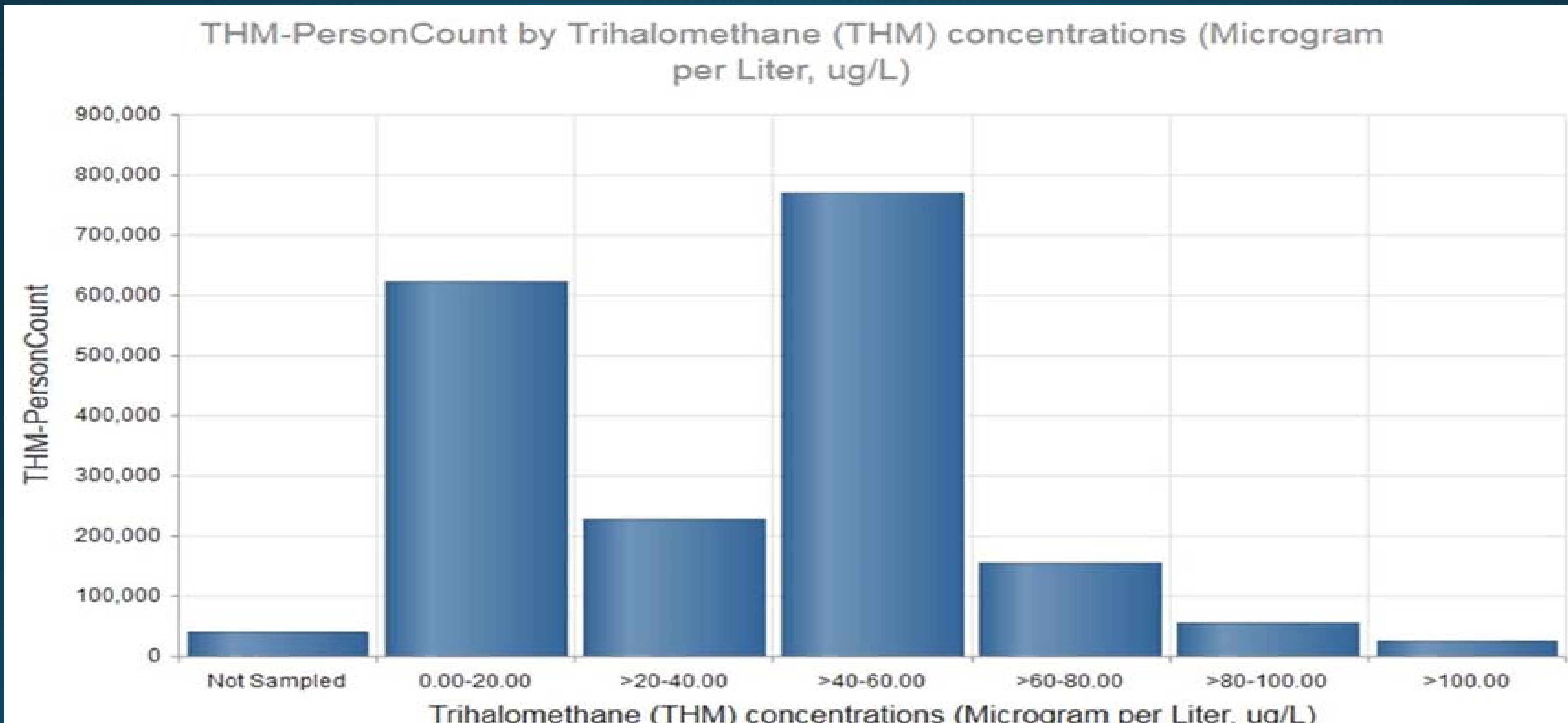

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Stage 2: Disinfection Byproducts Rule

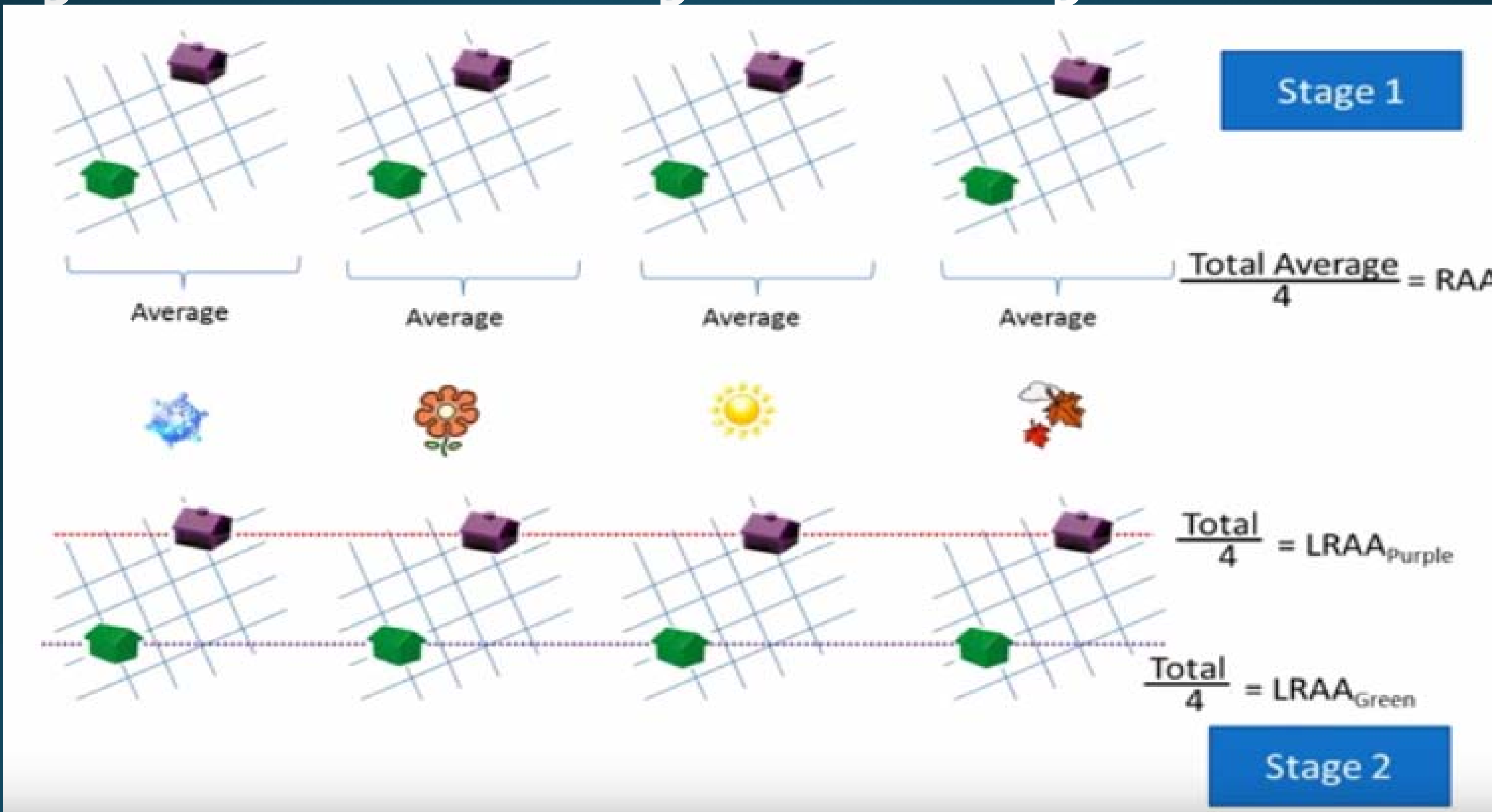
- **<u>Affects</u>**:
  - Community
  - Non-transient
  - Transient
  - Surface Water
  - Ground Water
  - Purchasing Systems
- Will take affect based on population categories.
- Must still comply with all requirements of Stage 1 until Stage 2 compliance begins.

Stage 2: Sampling Requirements

- **Criteria**:
- Population Served
- Source Water Type
- Dual Sampling

40 CFR 141.621 - Routine monitoring			
Source water type	Population size category	Monitoring Frequency	Distribution system monitoring location total per monitoring period
Subpart H (GWUDI & Surface Water Systems)	<500	per year	2
	500-3,300	per quarter	2
	3,301-9,999	per quarter	2
	10,000-49,999	per quarter	4
	50,000-249,999	per quarter	8
	250,000-999,999	per quarter	12
	1,000,000-4,999,999	per quarter	16
	≥5,000,000	per quarter	20
Groundwater Systems	<500	per year	2
	500-9,999	per year	2
	10,000-99,999	per quarter	4
	100,000-499,999	per quarter	6
	≥500,000	per quarter	8

Stage 2: Locational Running Annual Average



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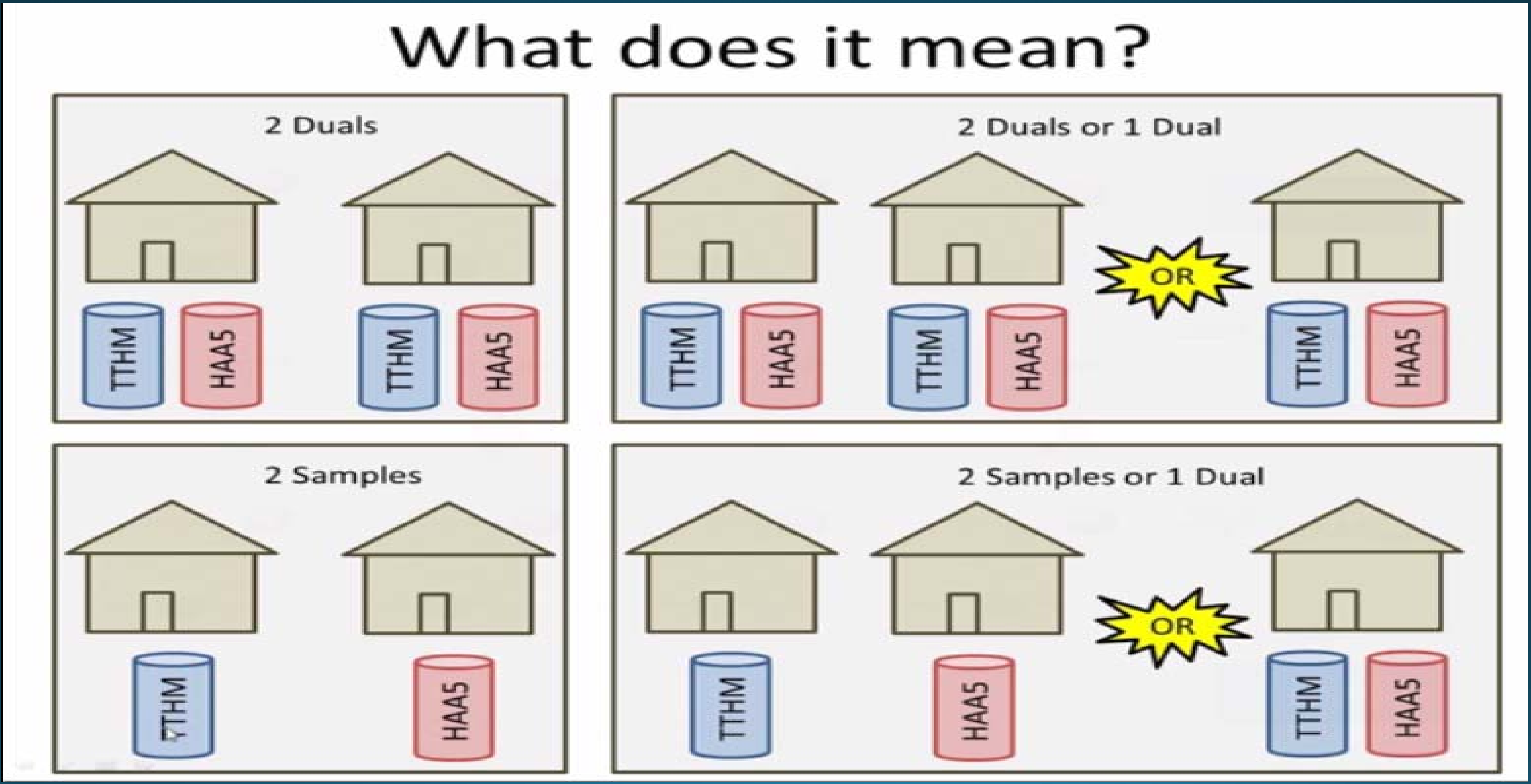


Stage 2: Operational Evaluation Levels (OEL)

- Applies to systems monitoring quarterly.
- Is a projection of what the next quarter's compliance might be:

$$\frac{Quarter\ A + Quarter\ B + (2\ \times Current\ Quarter\ C)}{4} = OEL\ \rightarrow Predicted\ Average\ (\bar{X})$$

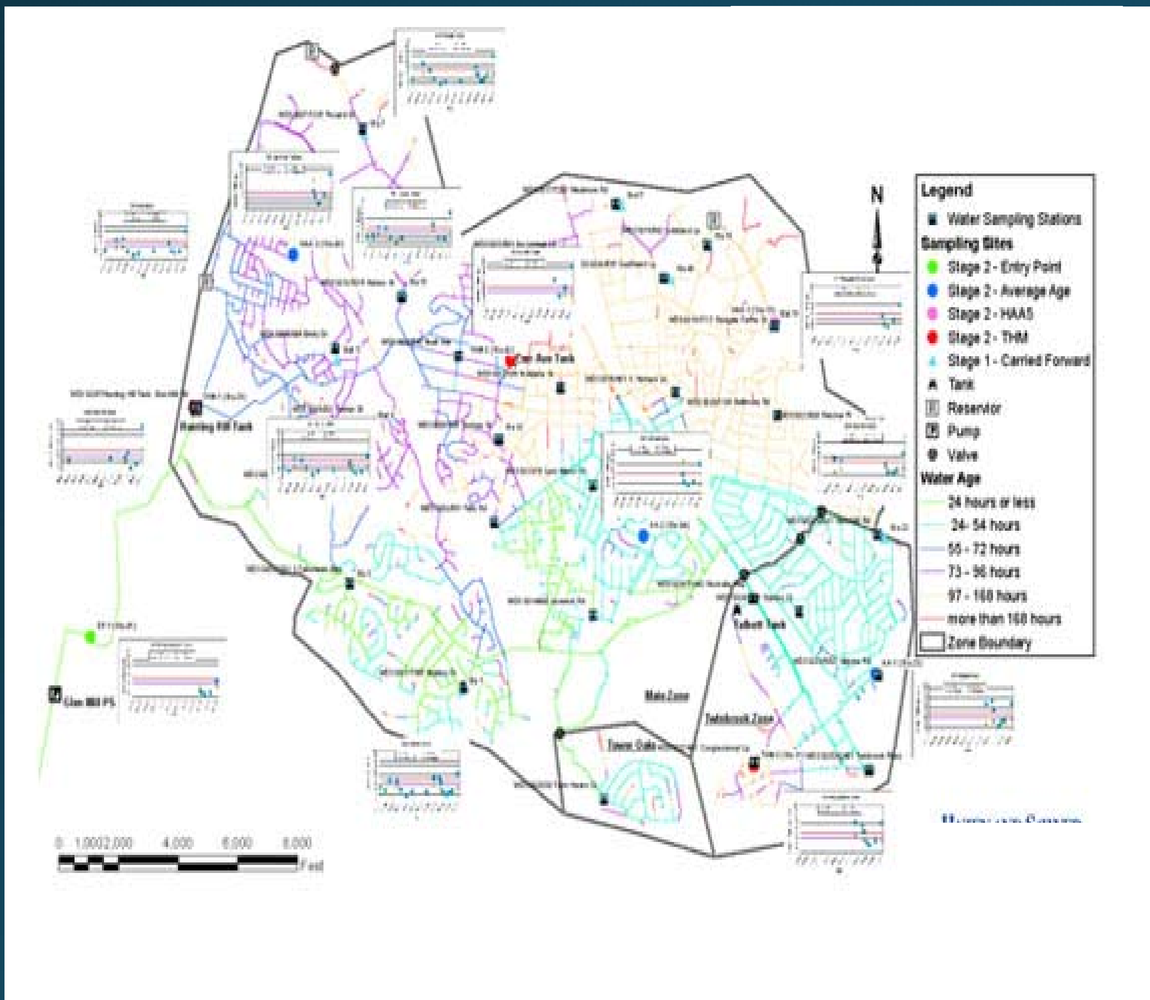
- A = TTHM or HAA5 result for the quarter before the previous quarter (mg/L)
- B = TTHM or HAA5 result for the quarter the previous quarter (mg/L)
- C = TTHM or HAA5 result for the current quarter (mg/L)

0.080 mg/L TTHM

0.060 mg/L HAA5

- This report must include an evaluation of the plant and distribution practices.

Stage 2: Combined Distribution Systems (CDS)



- Any Seller and Purchaser of water constitutes a CDS.
- If there is a Subpart H source within a CDS all system are designated Subpart H.

Stage 2: Maximum Contaminant Level & Maximum Residual Disinfectant Level

MCLs

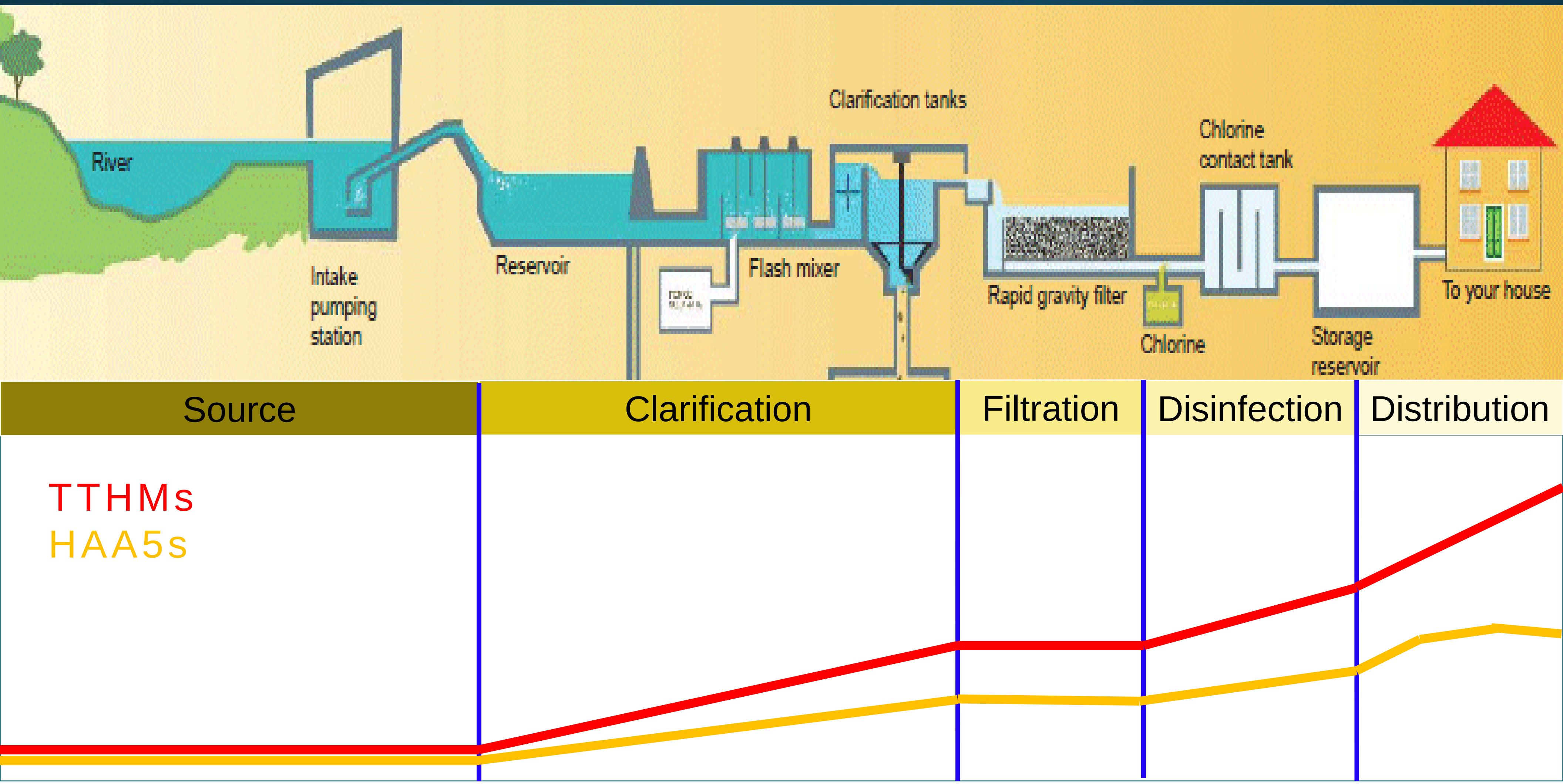
DBP	MCL	Compliance
TTHM	80 ug/L (0.08 mg/L)	Running Annual Average
HAA5	60 ug/L (0.06 mg/L)	Running Annual Average
Bromate	10 ug/L (0.01 mg/L)	Running Annual Average
Chloriate	1 mg/L (1.0 mg/L)	Daily at plant

MRDLs

DBP	MRDL
Chlorine	4.0 mg/L
Chloramines	4.0 mg/L
Chlorine Dioxide	0.8 mg/L

TOC monitoring at surface water plants.

Identify the Point of DBP Production in a Water System



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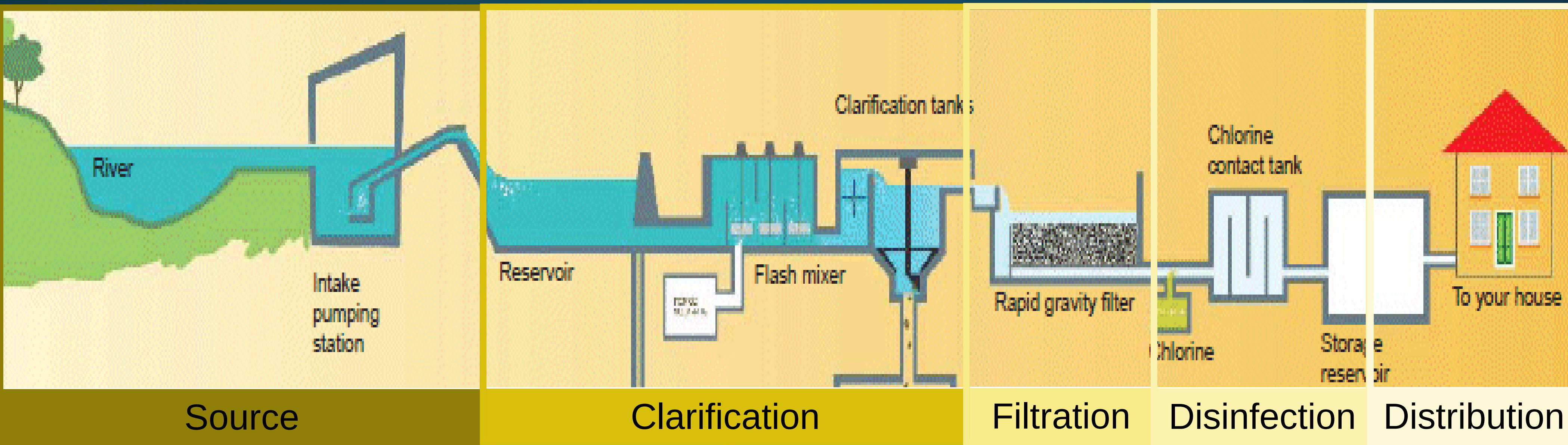


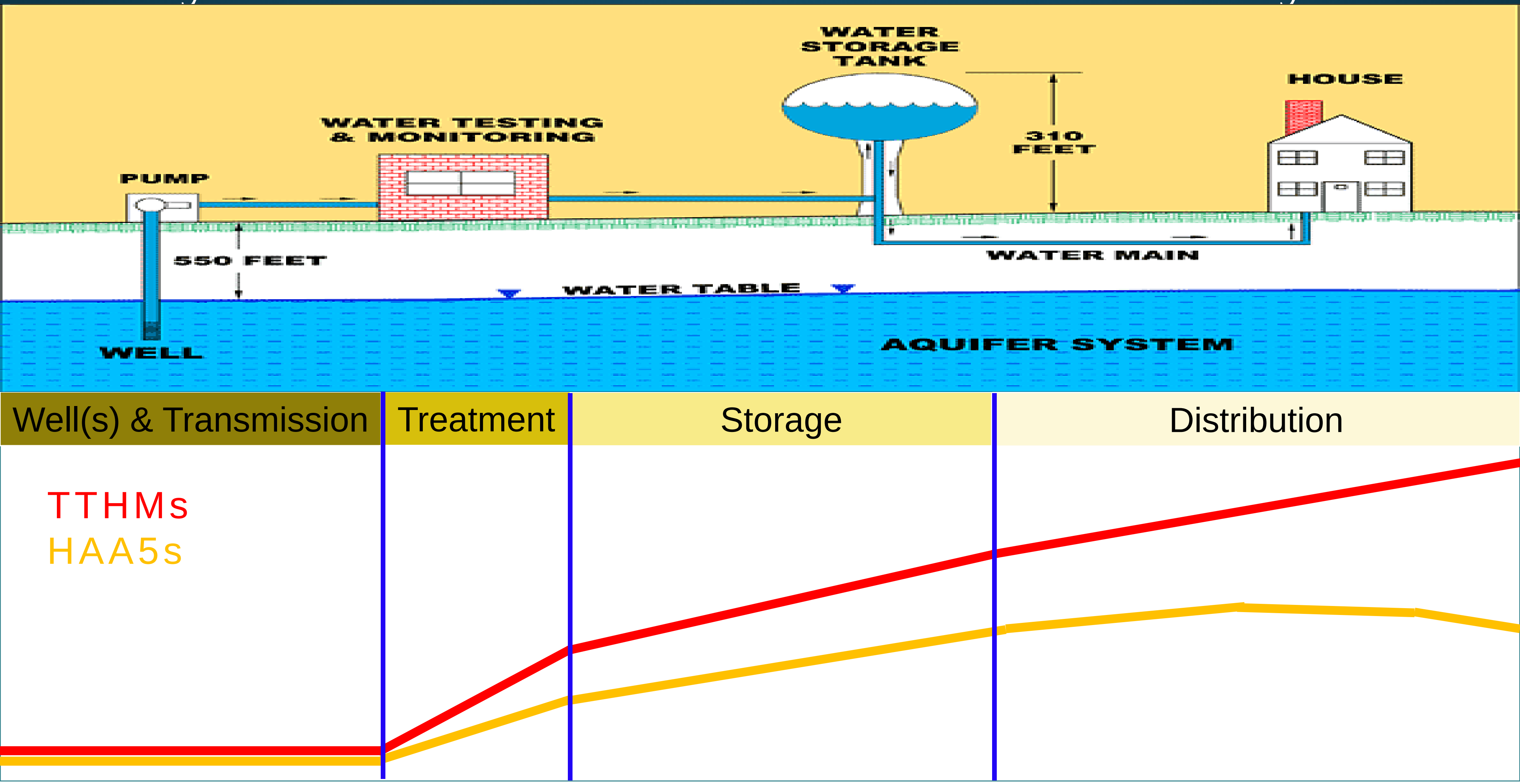
- Determine Source Water Precursors (TOC):
- Turbidity Concentrations
- Bromates

- Determine Efficacy of Clarification & Filtration:
  - TOC
  - TSS
  - DBP
- Evaluate Chemical Introduction(s)

- Evaluate CT

- Evaluate Water Age
- Biofilm
- Sediment

Identify the Point of DBP Production in a Water System



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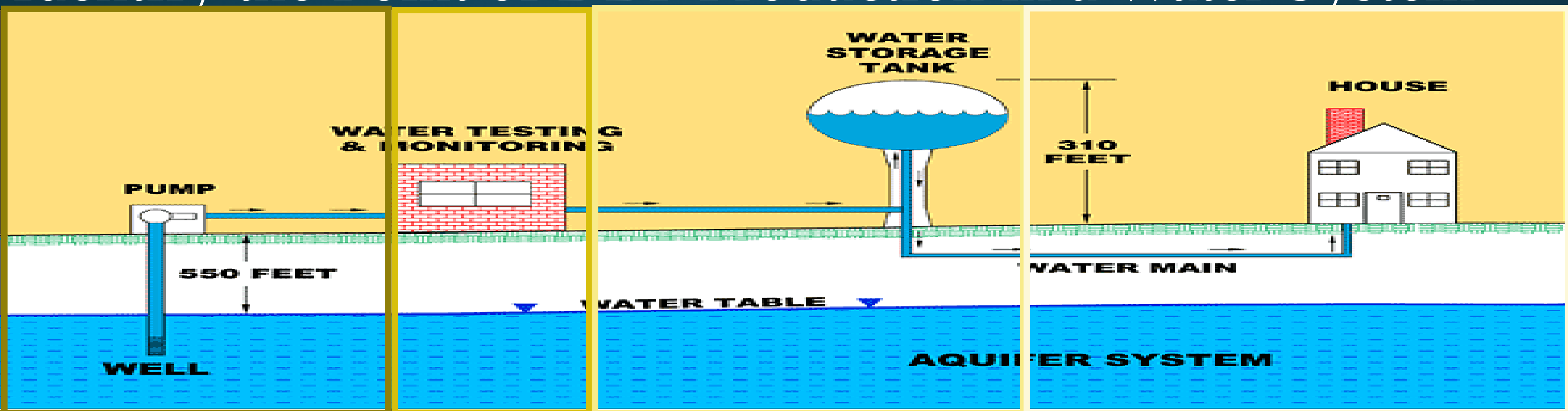


Well(s) & Transmission | Treatment | Storage | Distribution

- Determine Source Water Precursors (TOC):
- Turbidity Concentrations
- Bromates

- Determine Effects of Treatment:
  - TOC
  - TSS
  - DBP
- Evaluate Chemical Introduction(s)

- **Evaluate Water Age/ Residence Time**
- **Biofilm**
- **Sediment**

Managing Water Age

Population	Miles of WM	Min RT	MRT
> 750,000	> 1,000	1 day	~ 1 week
< 100,000	< 400	1 day	~ 2 weeks
< 25,000	< 100	1 day	~ 1 month

AWWA: Water Age for Ave and Dead End Conditions

Determining Water Age with Tracers

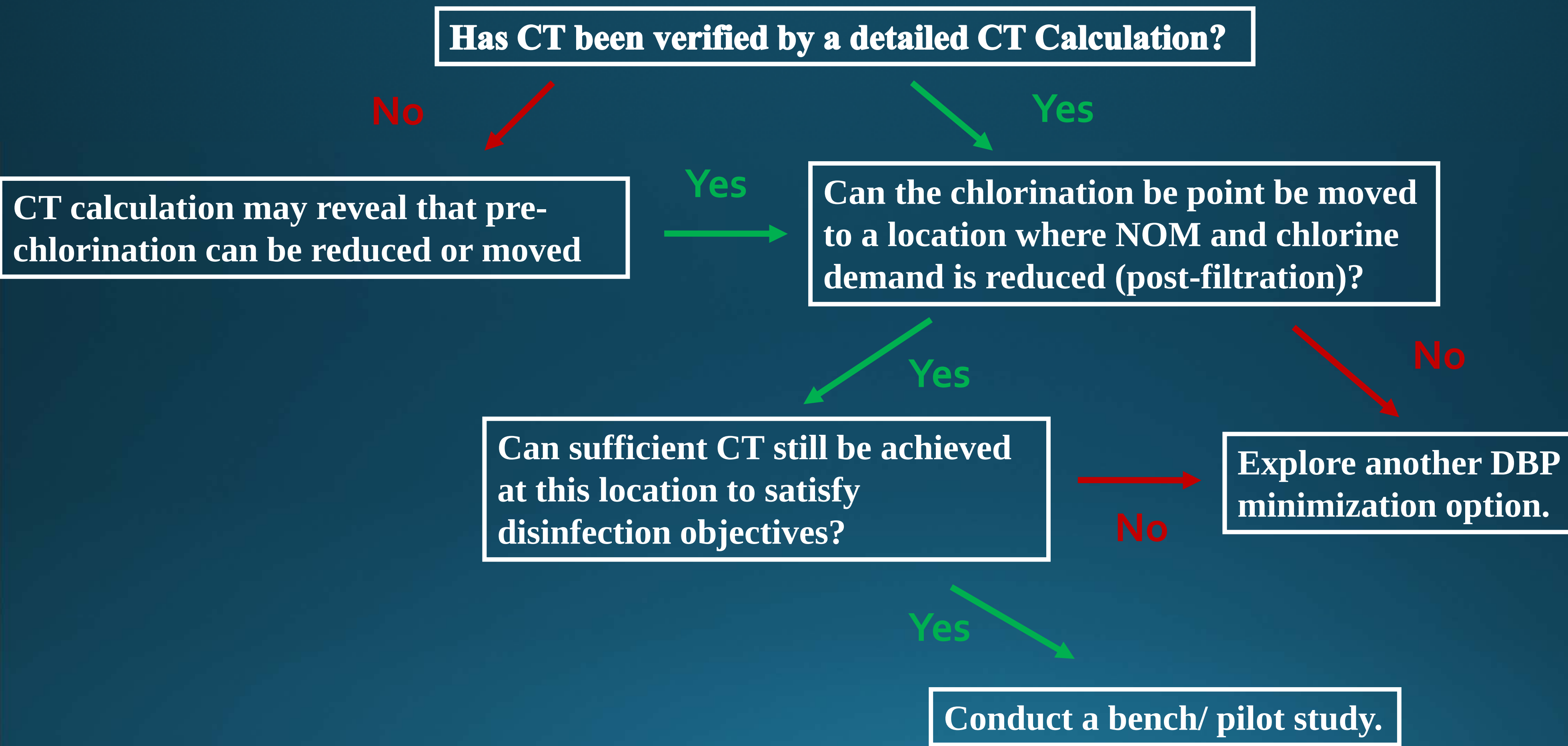
Tracer	Research & Development Needs	Regulatory Issues	Problems/ Comments
Fluoride	Continuous on-line monitor for use in distribution system	Difficulties in adding or shutting off fluoride in some places	May be non-conservative due to pipe wall uptake in systems that do not normally use fluoride
Sodium Chloride	N/A*	N/A*	Requires relatively large volumes of tracer
Calcium Chloride	N/A*	N/A*	N/A*
Lithium Chloride	N/A*	N/A*	Popular in the UK
Coagulants	Possible post-precipitation	N/A*	Utilities may be reluctant to vary coagulant feed (type and quantity)
Chlorine (pulsed)	N/A*	Limits on upper and lower chlorine residuals	Non-conservative and affected by wall demand

https://www.epa.gov/sites/production/files/2015-09/documents/2007_05_18_disinfection_tcr_whitepaper_tcr_waterdistribution.pdf

Effective Chlorination System Modification Strategies

Disinfection Location	Action	Benefit
Chlorine Feed	Reduce chlorine feed rates while maintaining proper chlorine residuals.	Fewer DBPs formed in the water system. No/ little cost for this option.
Chlorine Injection Point	Change point of chlorine injection to reduce the age of chlorinated water.	Fewer DBPs formed in the water system. Small cost for this option.
Chlorine Injection Boosters	Add chlorine injection point(s) to boost chlorine residuals in the distribution system instead of at the plant.	Lower total chlorine added at the plant site. Fewer DBPs formed in the distribution.
Alternate Disinfection/ Application	use of chloramines in distribution systems with long detention times or selective us o peroxidation or oxidant such as $NaMnO_4$.	Fewer DBPs formed in the water system. Costs for this option could be significant.

Consider Adjusting Pre-Chlorination



https://www.ontario.ca/document/strategies-minimizing-disinfection-products-trihalomethanes-and-haloacetic-acids

Practice Enhanced Coagulation

Collect Monthly data for source water TOC, alkalinity, and specific ultraviolet absorbance (SUVA) and treated water SUVA, THMs, and HAA5s. Also, collect data on coagulation pH and coagulant doses.

↓

Conduct jar tests to investigate optimal pH, coagulant dose, and/or coagulant aid dose to achieve maximum TOC removal.

↓

If possible, conduct a pilot test under the optimum jar test conditions.

↓

Calculate the impact on residual management and recycle streams and make necessary capacity increases where necessary.

↓

Implement the enhanced coagulation conditions at full-scale monitor treated water TOC, SUVA, DBPs, turbidity, and pH.

https://www.ontario.ca/document/strategies-minimizing-disinfection-products-trihalomethanes-and-haloacetic-acids

Effectiveness of Chlorination of Different pH Levels

Is the pH at the point of primary chlorination in the optimum acidic range to ensure disinfection effectiveness?

No

Consider adjusting pH to improve chlorine effectiveness and reduce the necessary chlorine dose. Consult CT tables for the chlorine dose required at the new pH.

Yes

Has the pH of the coagulation process been optimized for DBP precursor removal?

No

Implement enhanced coagulation (previous slide).

Yes

No further pH adjustment necessary. Consider other DBP minimization strategies.

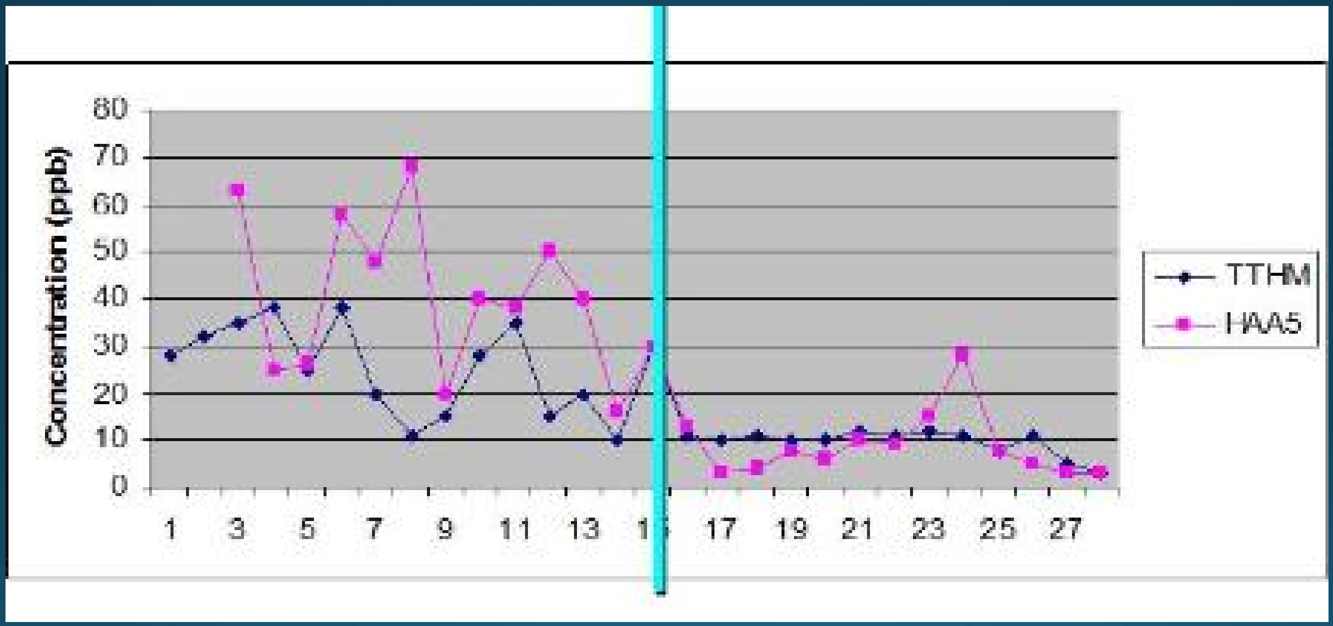
Switch to Chloramination

Benefits and Drawbacks of Chloramination of the Distribution System			
Benefits	**Degree of Importance**	**Drawbacks**	**Degree of Importance**
Significant Reduction of DBPs	Major	Need to maintain optimum chlorine: ammonia ratios to prevent taste, odor and nitrification	Major
Increased disinfectant stability in the distribution system	Major	Less protection in the event of intrusion	Minor
Better biofilm control	Unknown	Possible formation of chloramine-specific DBPs	Minor
		Greater level of care to manage environmental releases	Minor

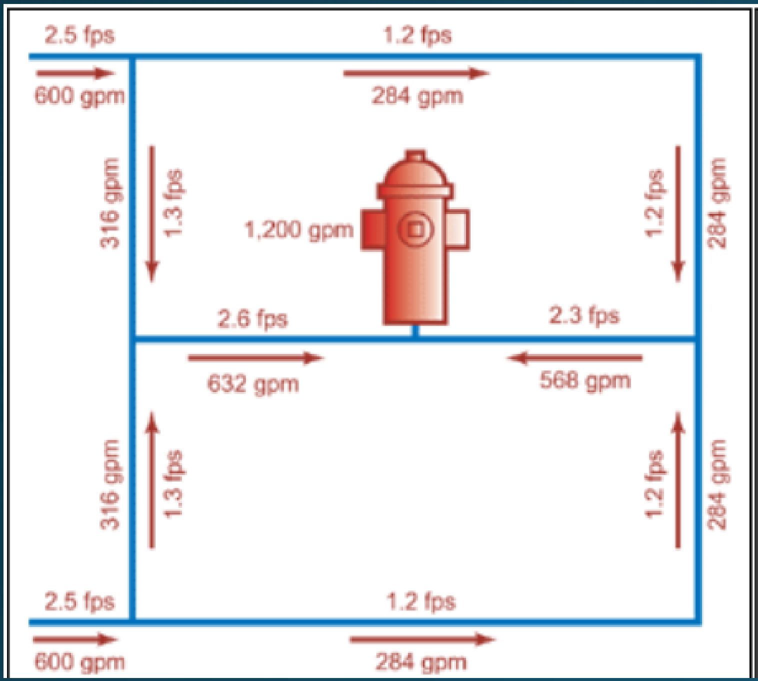
Alternative DBP Minimization Strategies

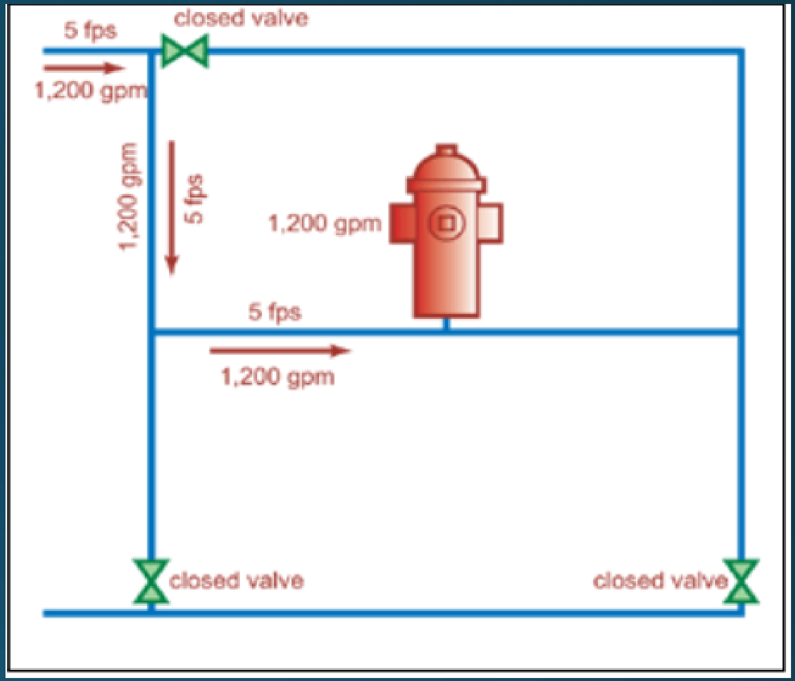
- **UV Disinfection**
- **Granular Activated Carbon (GAC)**
- **Membrane Filtration**
- **Magnetic Ion Exchange (MIEX)**

Removal of Pre-Chlorination



Flushing Objectives Used in Water Distribution Systems





Conventional Flushing (< 2.5 fps)

- **Reduces Water Age**
- **Re-introduced Disinfectant Residual**
- **Expels Some Color/ Turbidity**
- **Remedies Taste/ Odor**

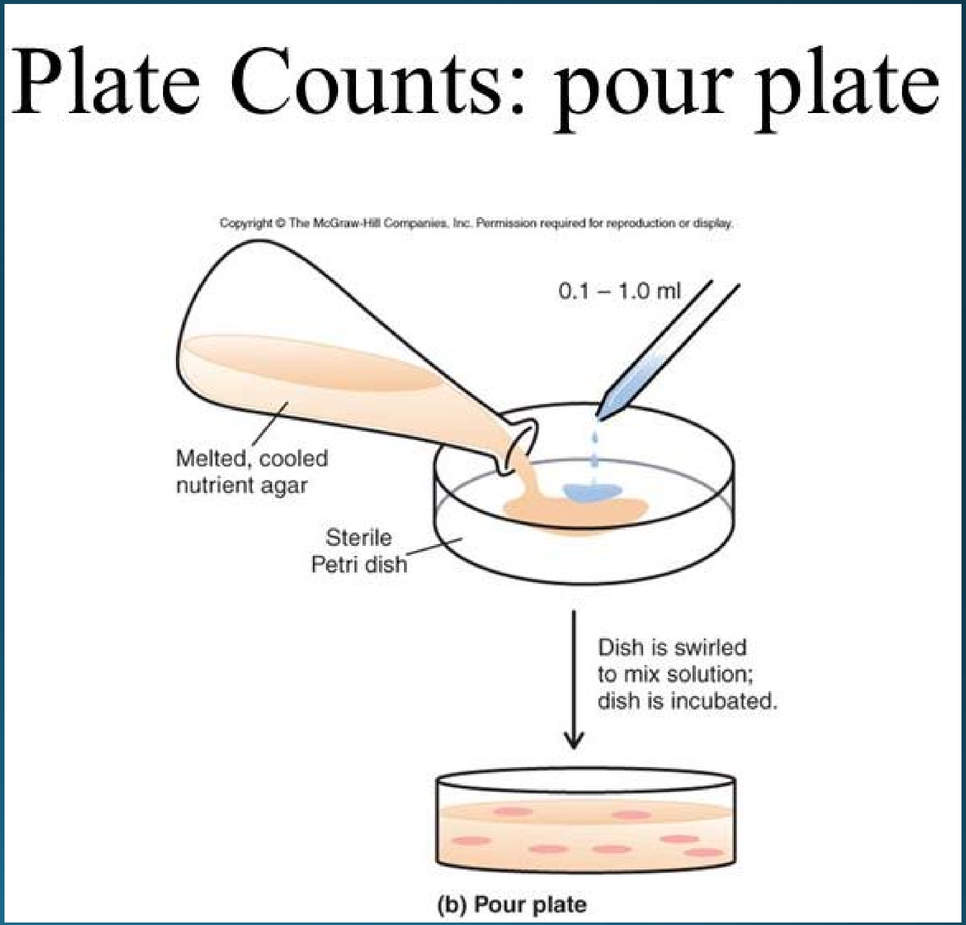
&

Unidirectional Flushing (> 2.5 fps)

- **Scours Solid Deposits from Pipe Lining**
- **Dislodges Biofilm from Pipelines**
- **Expels Most Sediment**

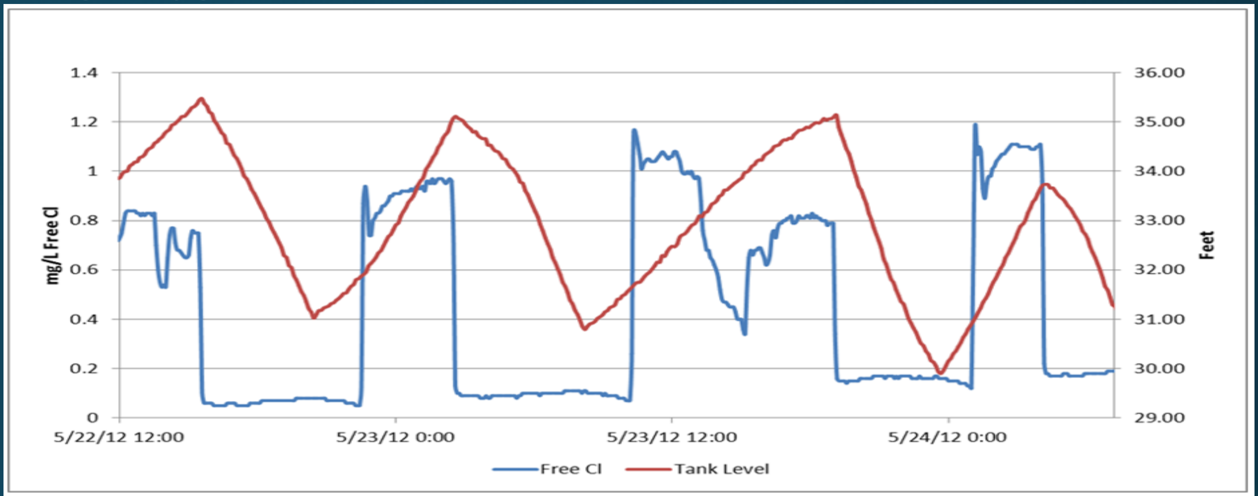
Heterotrophic Plate Count & Biofilm in Distribution

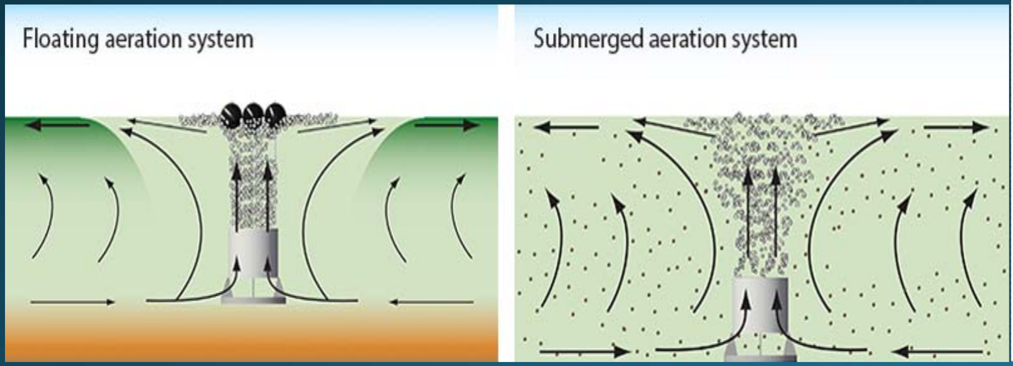
- **Plate Counts of 350-500 Colonies is OK.**
- **Plate Counts > 500 Colonies Indicates Excessive Biofilm.**

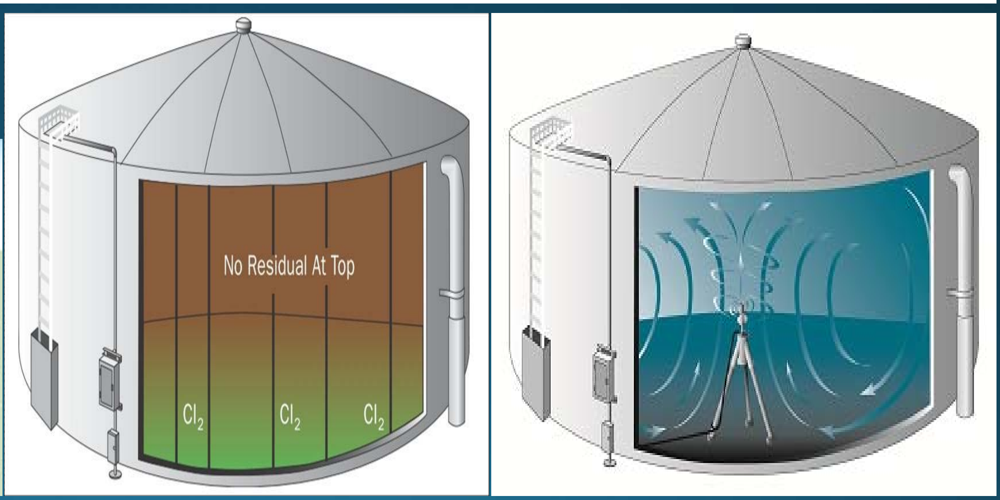


Storage Tank Assessments

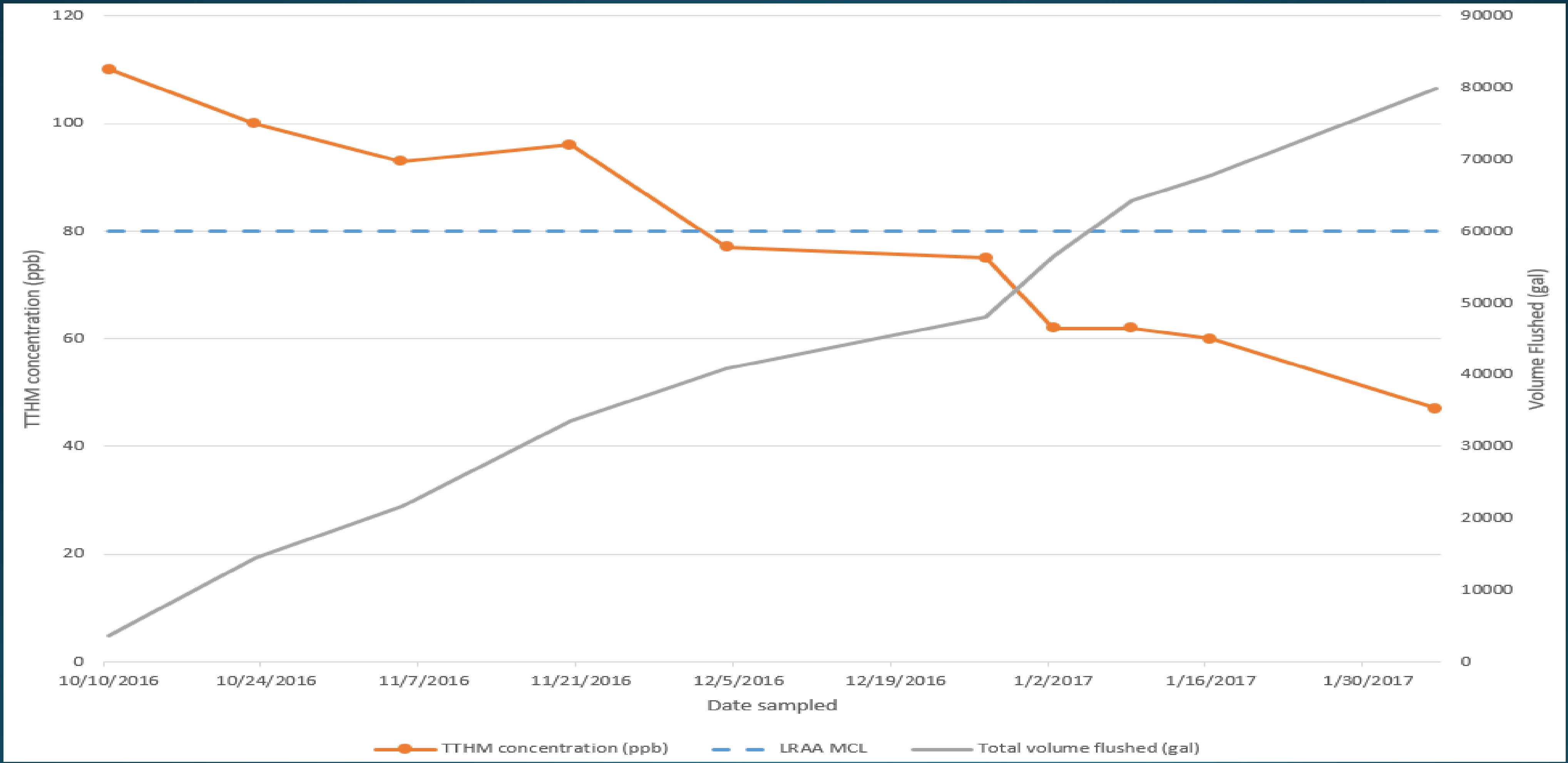
- Tank Level Data
- Water Quality Data
- Physical Characteristics





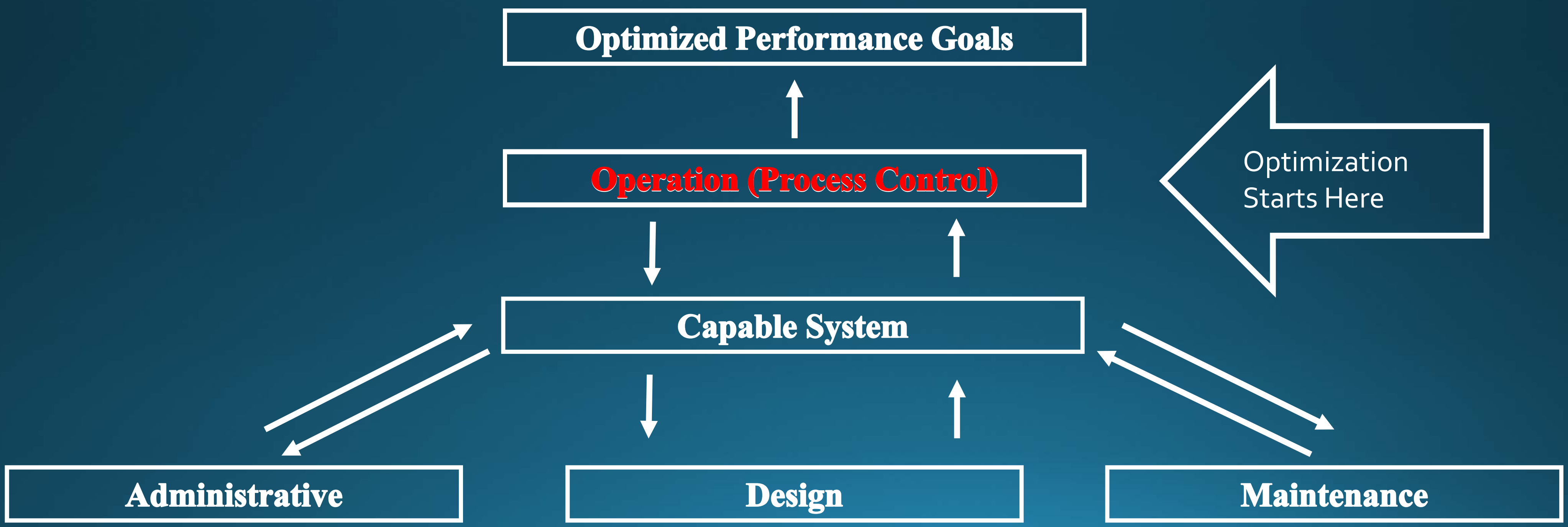


Storage Tank Assessments

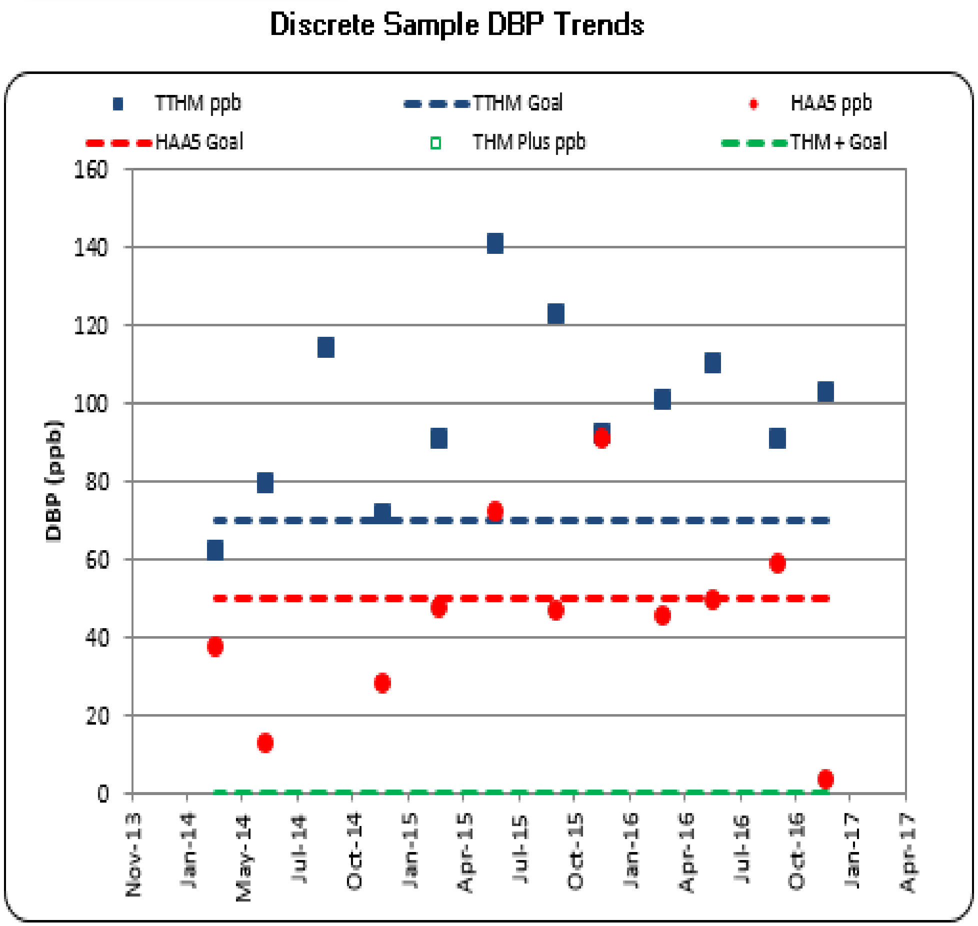


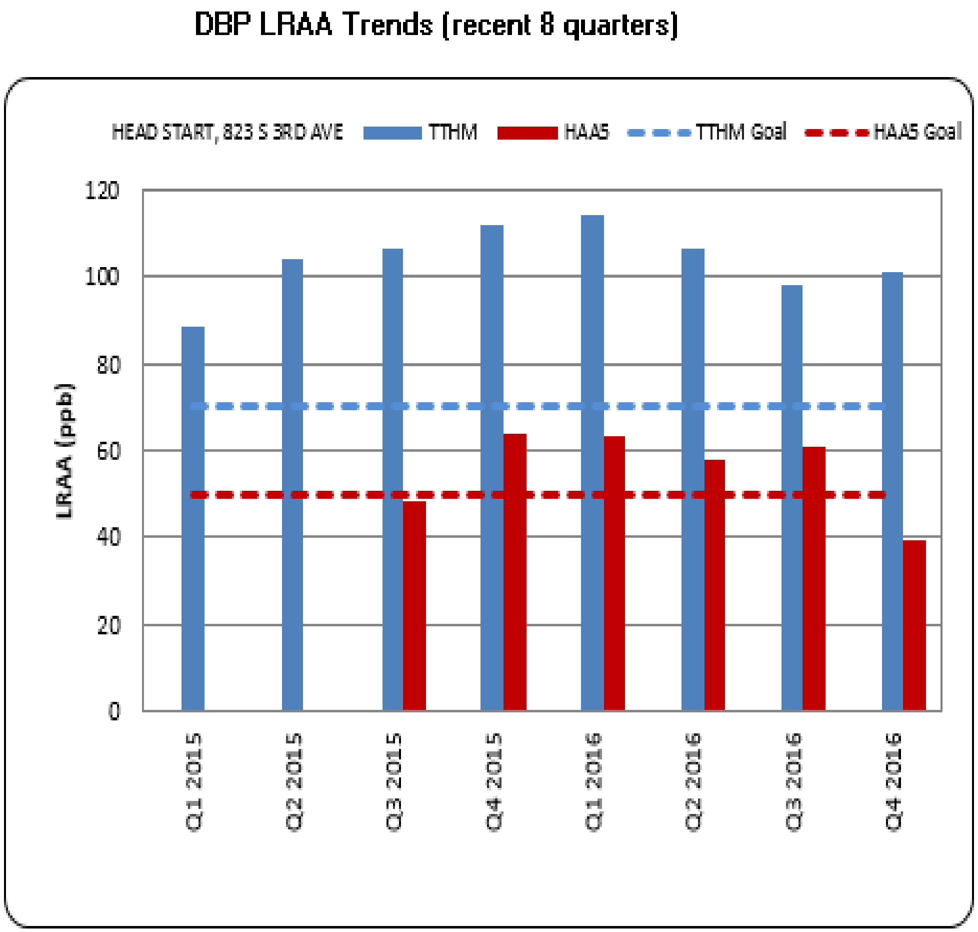
D/DBP Optimization Steps

1. Data Development and Trending
2. Special Studies
3. Prioritization



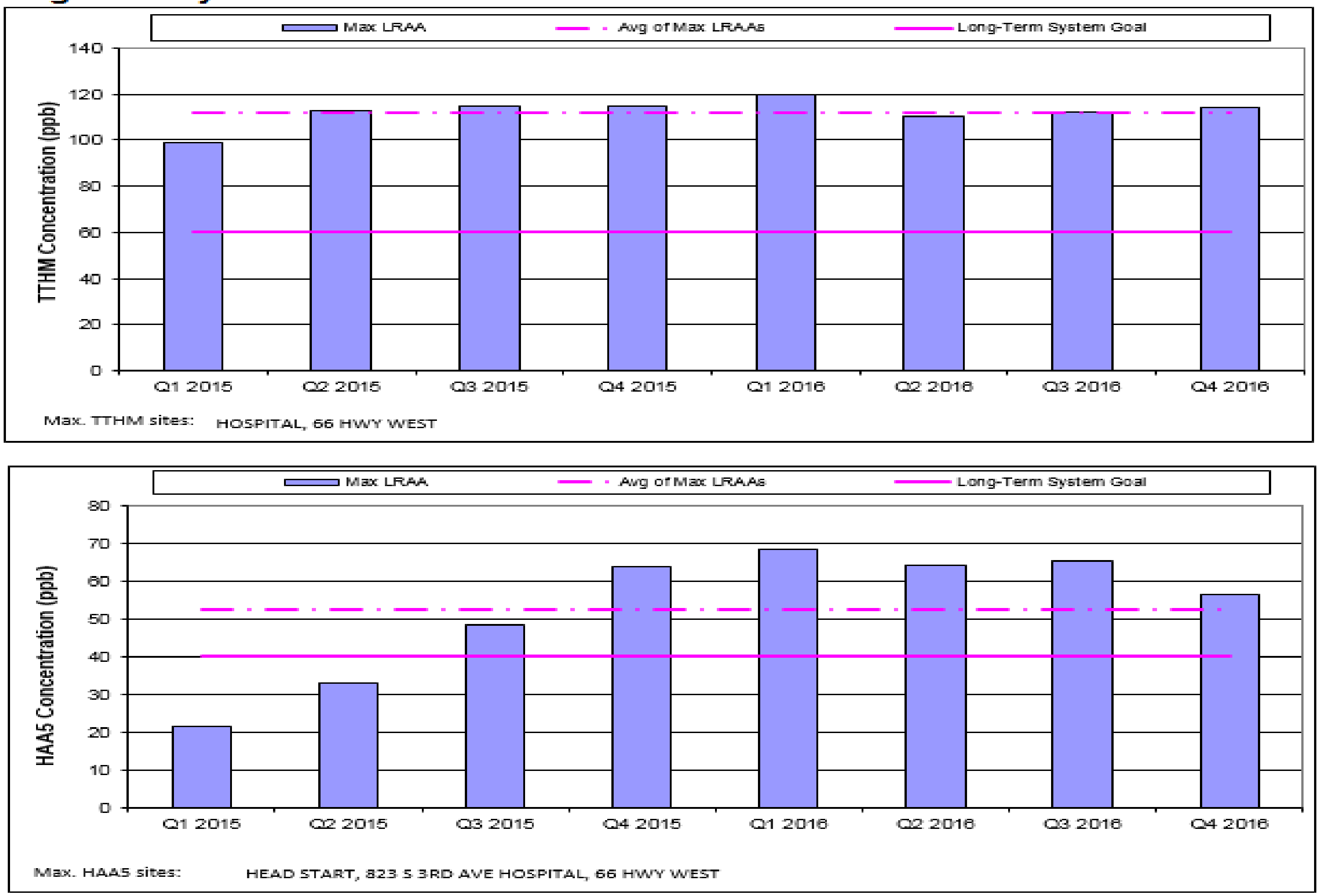
D/DBP Optimization Steps



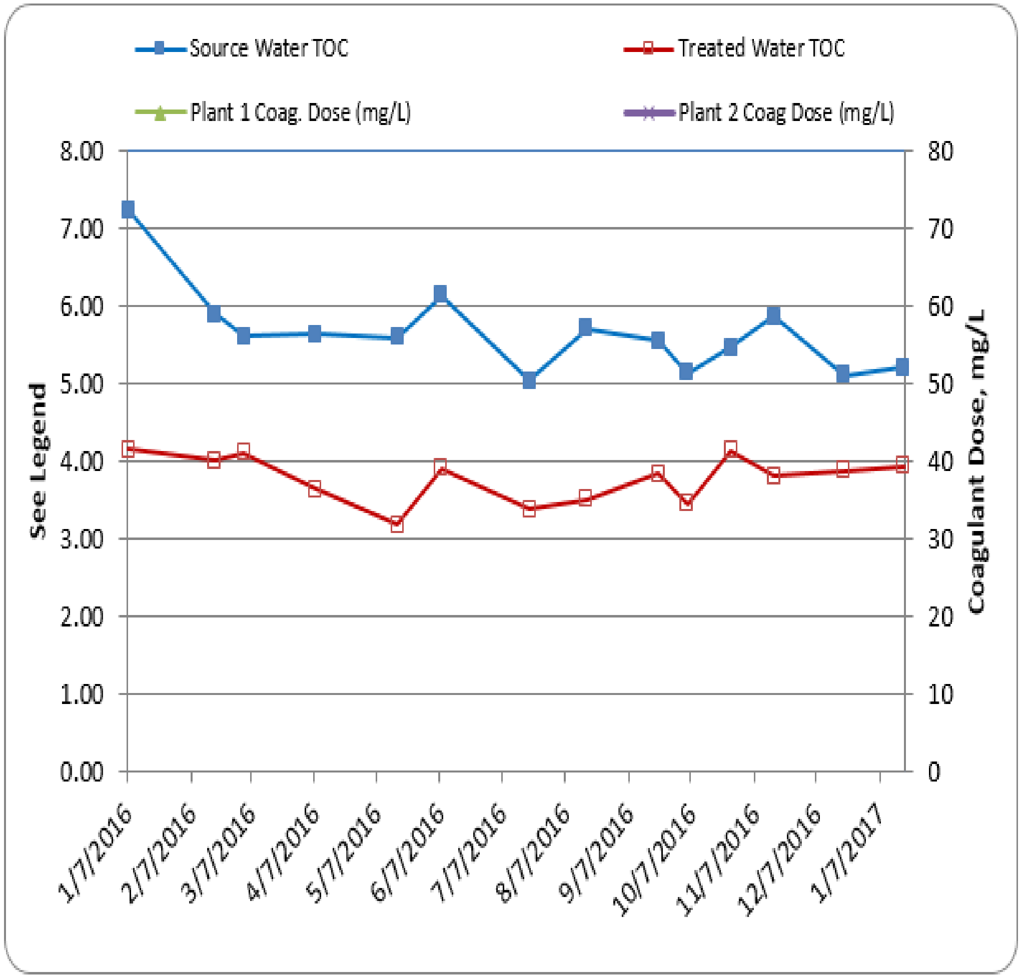


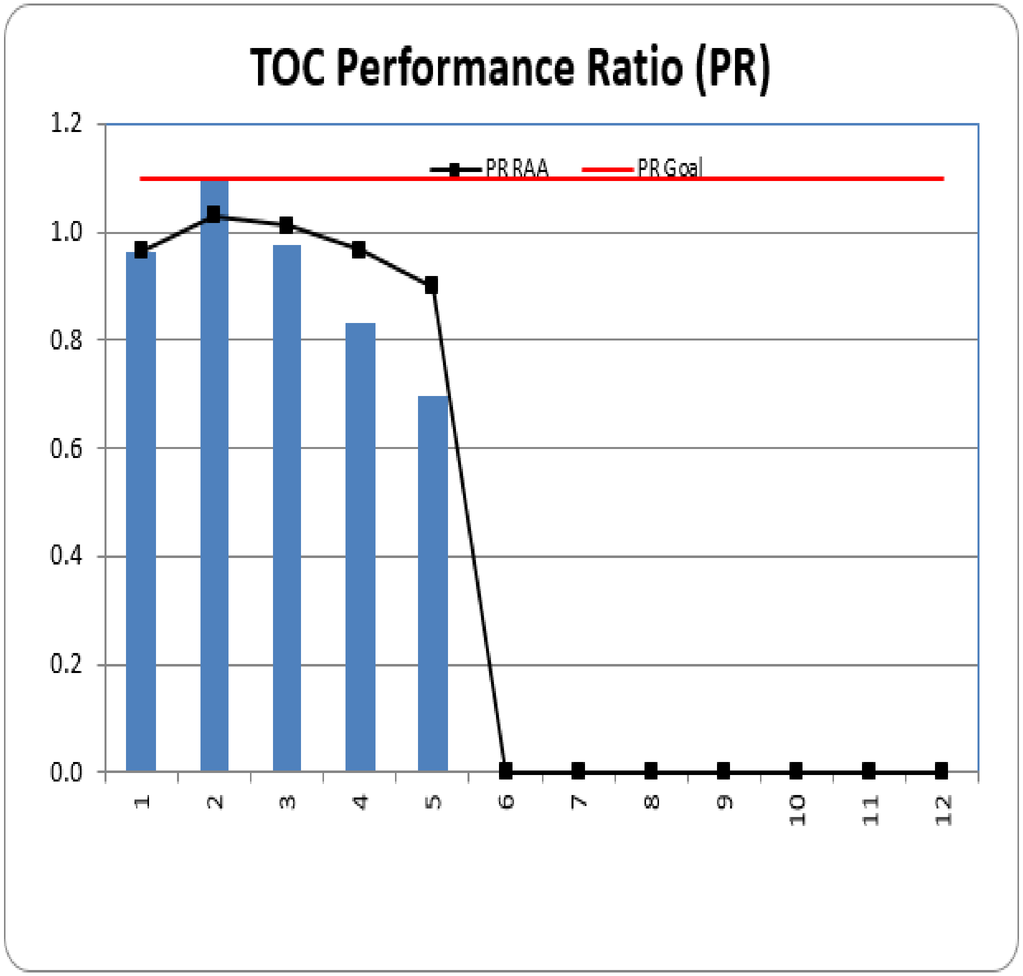
D/DBP Optimization Steps

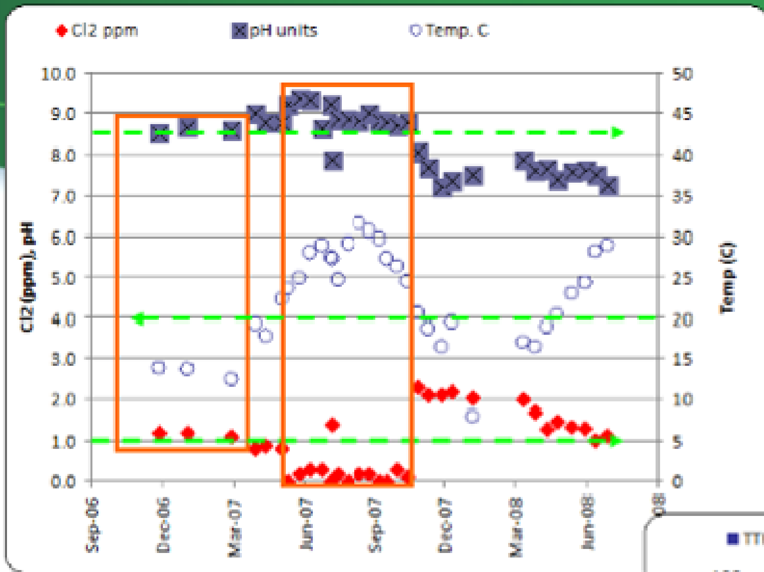
Long-Term System Goal Assessment



D/DBP Optimization Steps

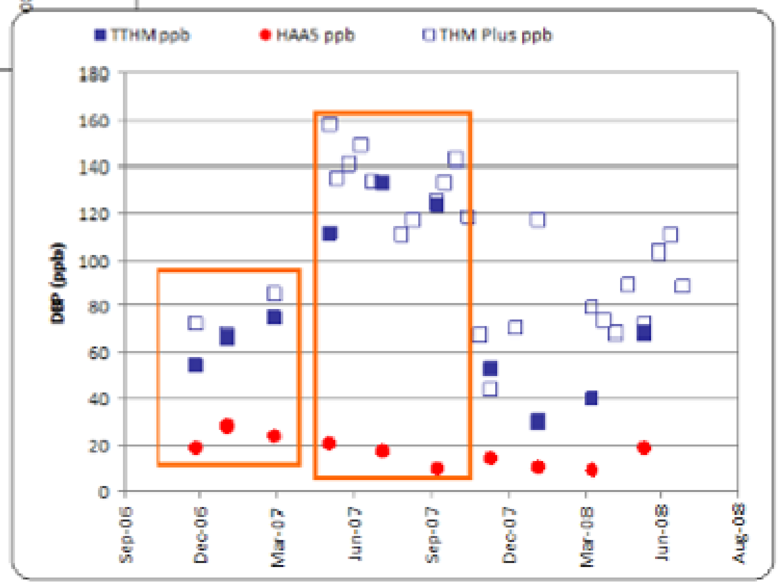






➔ High residual + normal pH suggests lower DBP formation

➔ Low residual + high pH + temp suggests elevated DBP formation (time to optimize DS flushing!)



<u>(System Specific) Action Levels:</u>

Residual < 1.0 ppm +
pH > 8.5 + elevated temp +
THM Plus > 100 ppb =>
TTHM ≥ 80 ppb

Questions?