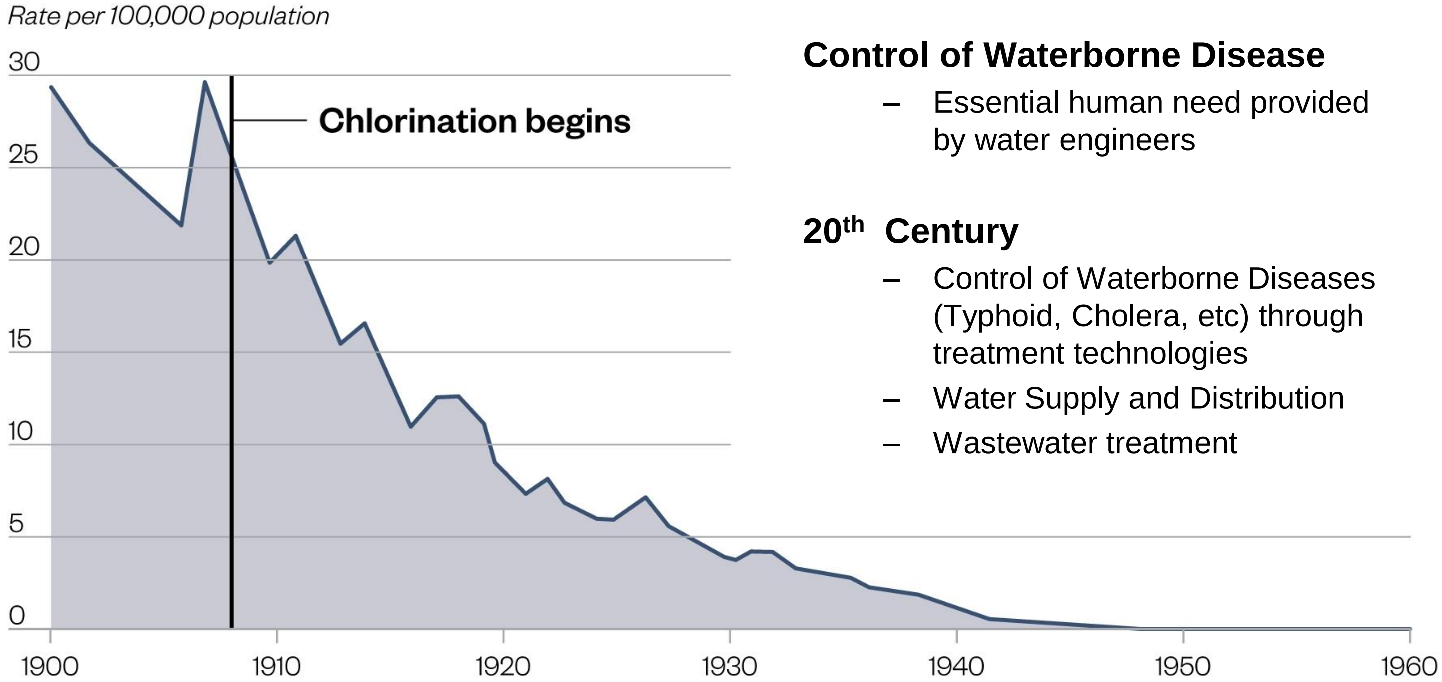
Drinking Water Treatment: *the Basics*

Corpus Christi City Council Meeting | June 14, 2016

LNV | Hazen

Death Rate for Typhoid Fever

United States, 1900-1960



Control of Waterborne Disease

- Essential human need provided by water engineers

20th Century

- Control of Waterborne Diseases (Typhoid, Cholera, etc) through treatment technologies
- Water Supply and Distribution
- Wastewater treatment

Source: U.S. Centers for Disease Control and Prevention, Summary of Notifiable Diseases, 1997.

Disinfection By-products (DBPs)

By-products of reactions between disinfectant (chlorine, ozone, etc.) and natural organic matter and/or bromide present in source water

Disinfectant + Natural Organic Matter → DBPs

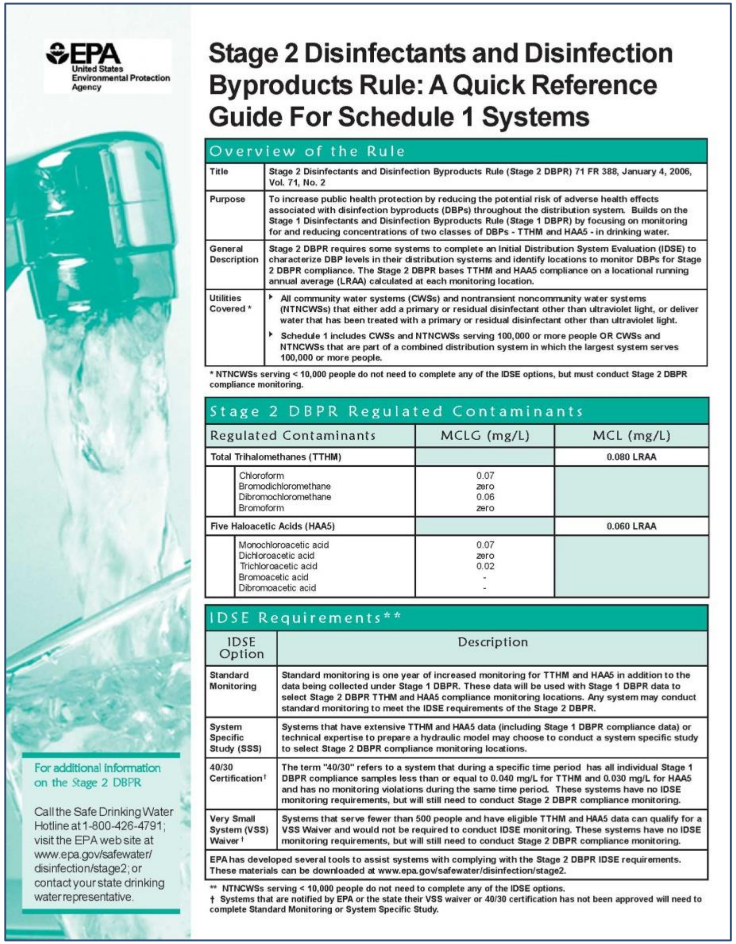
Potential health impacts of DBPs

- Cancer
  - Bladder, colon and rectal
- Reproductive?

All disinfectants form disinfection byproducts!!!

Stage 2 D/DBP Rule

- DBPs of concern:
  - Trihalomethanes (THMs)
  - Haloacetic acids (HAAs)
- Intended to reduce risk and address localized concerns
- Promulgated 2006
- DBP Control Options
  - Limit natural organic matter
  - Adjust disinfection practices
  - Remove after formation



EPA United States Environmental Protection Agency

Stage 2 Disinfectants and Disinfection Byproducts Rule: A Quick Reference Guide For Schedule 1 Systems

Overview of the Rule

Title	Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) 71 FR 388, January 4, 2006, Vol. 71, No. 2
Purpose	To increase public health protection by reducing the potential risk of adverse health effects associated with disinfection byproducts (DBPs) throughout the distribution system. Builds on the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) by focusing on monitoring for and reducing concentrations of two classes of DBPs - TTHM and HAA5 - in drinking water.
General Description	Stage 2 DBPR requires some systems to complete an Initial Distribution System Evaluation (IDSE) to characterize DBP levels in their distribution systems and identify locations to monitor DBPs for Stage 2 DBPR compliance. The Stage 2 DBPR bases TTHM and HAA5 compliance on a locational running annual average (LRAA) calculated at each monitoring location.
Utilities Covered *	‣ All community water systems (CWSs) and nontransient noncommunity water systems (NTNCWSs) that either add a primary or residual disinfectant other than ultraviolet light, or deliver water that has been treated with a primary or residual disinfectant other than ultraviolet light. ‣ Schedule 1 includes CWSs and NTNCWSs serving 100,000 or more people OR CWSs and NTNCWSs that are part of a combined distribution system in which the largest system serves 100,000 or more people.

* NTNCWSs serving < 10,000 people do not need to complete any of the IDSE options, but must conduct Stage 2 DBPR compliance monitoring.

Stage 2 DBPR Regulated Contaminants

Regulated Contaminants	MCLG (mg/L)	MCL (mg/L)
Total Trihalomethanes (TTHM)		0.080 LRAA
Chloroform	0.07	
Bromodichloromethane	zero	
Dibromochloromethane	0.06	
Bromoform	zero	
Five Haloacetic Acids (HAA5)		0.060 LRAA
Monochloroacetic acid	0.07	
Dichloroacetic acid	zero	
Trichloroacetic acid	0.02	
Bromoacetic acid	-	
Dibromoacetic acid	-	

IDSE Requirements**

IDSE Option	Description
Standard Monitoring	Standard monitoring is one year of increased monitoring for TTHM and HAA5 in addition to the data being collected under Stage 1 DBPR. These data will be used with Stage 1 DBPR data to select Stage 2 DBPR TTHM and HAA5 compliance monitoring locations. Any system may conduct standard monitoring to meet the IDSE requirements of the Stage 2 DBPR.
System Specific Study (SSS)	Systems that have extensive TTHM and HAA5 data (including Stage 1 DBPR compliance data) or technical expertise to prepare a hydraulic model may choose to conduct a system specific study to select Stage 2 DBPR compliance monitoring locations.
40/30 Certification†	The term "40/30" refers to a system that during a specific time period has all individual Stage 1 DBPR compliance samples less than or equal to 0.040 mg/L for TTHM and 0.030 mg/L for HAA5 and has no monitoring violations during the same time period. These systems have no IDSE monitoring requirements, but will still need to conduct Stage 2 DBPR compliance monitoring.
Very Small System (VSS) Waiver †	Systems that serve fewer than 500 people and have eligible TTHM and HAA5 data can qualify for a VSS Waiver and would not be required to conduct IDSE monitoring. These systems have no IDSE monitoring requirements, but will still need to conduct Stage 2 DBPR compliance monitoring.
EPA has developed several tools to assist systems with complying with the Stage 2 DBPR IDSE requirements. These materials can be downloaded at www.epa.gov/safewater/disinfection/stage2.	

** NTNCWSs serving < 10,000 people do not need to complete any of the IDSE options.
† Systems that are notified by EPA or the state their VSS waiver or 40/30 certification has not been approved will need to complete Standard Monitoring or System Specific Study.

For additional information on the Stage 2 DBPR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/disinfection/stage2; or contact your state drinking water representative.

Regulatory Challenges

Disease Control

- disinfection requirements -- CT
- particle removal

Disinfection Byproduct Control

- Further control of THM and HAA levels
- other DBPs

Types of Disinfectant Systems

Chemical agents

- chlorine (Cl_2)
- chloramines (NH_2Cl)
- chlorine dioxide (ClO_2)
- ozone (O_3)

Physical agents

- UV light irradiation
- membranes

Sources of Natural Organic Matter

DBPs

Disinfectant + Bacteria → Dead Bacteria
Disinfectant + Virus → Dead Virus
Disinfectant + *Giardia* cyst → Dead *Giardia* cyst

Disinfectant + Natural Organic Matter → DBPs

All disinfectants form disinfection byproducts!!!

DBP Formation

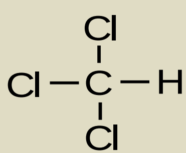
NOM = natural organic matter

Cl_2 + NOM → Chlorinated Organics
- THMs
- HAAs
- many others

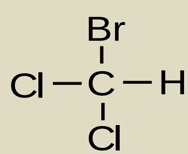
Reduce these to minimize formation

Affected by: chlorine dose, NOM concentration, pH, temperature, time

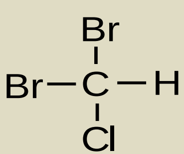
The THMs



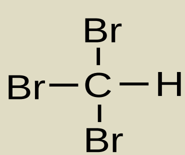
Chloroform



Bromodichloromethane

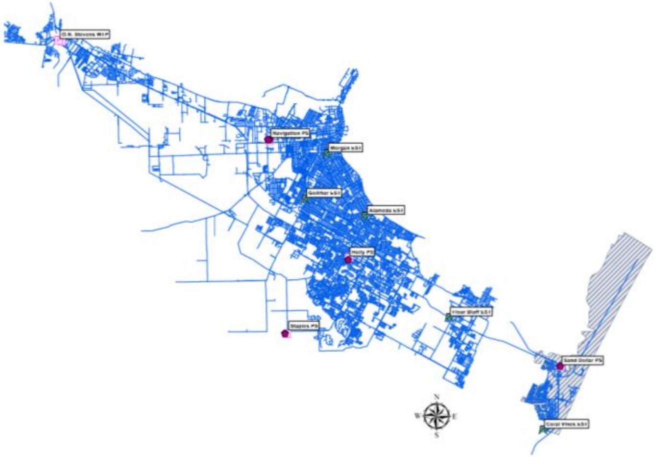


Chlorodibromomethane



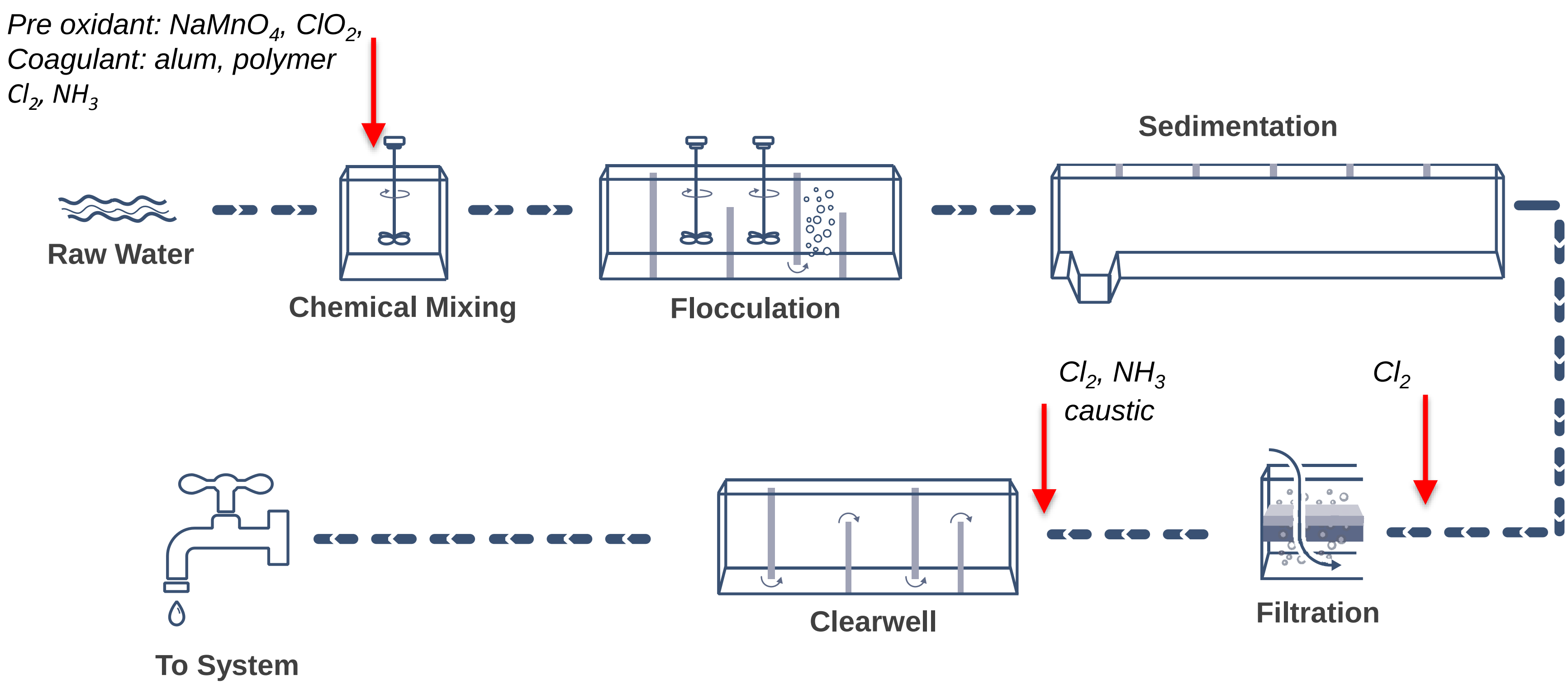
Bromoform

DBP Control:
Understand your water system



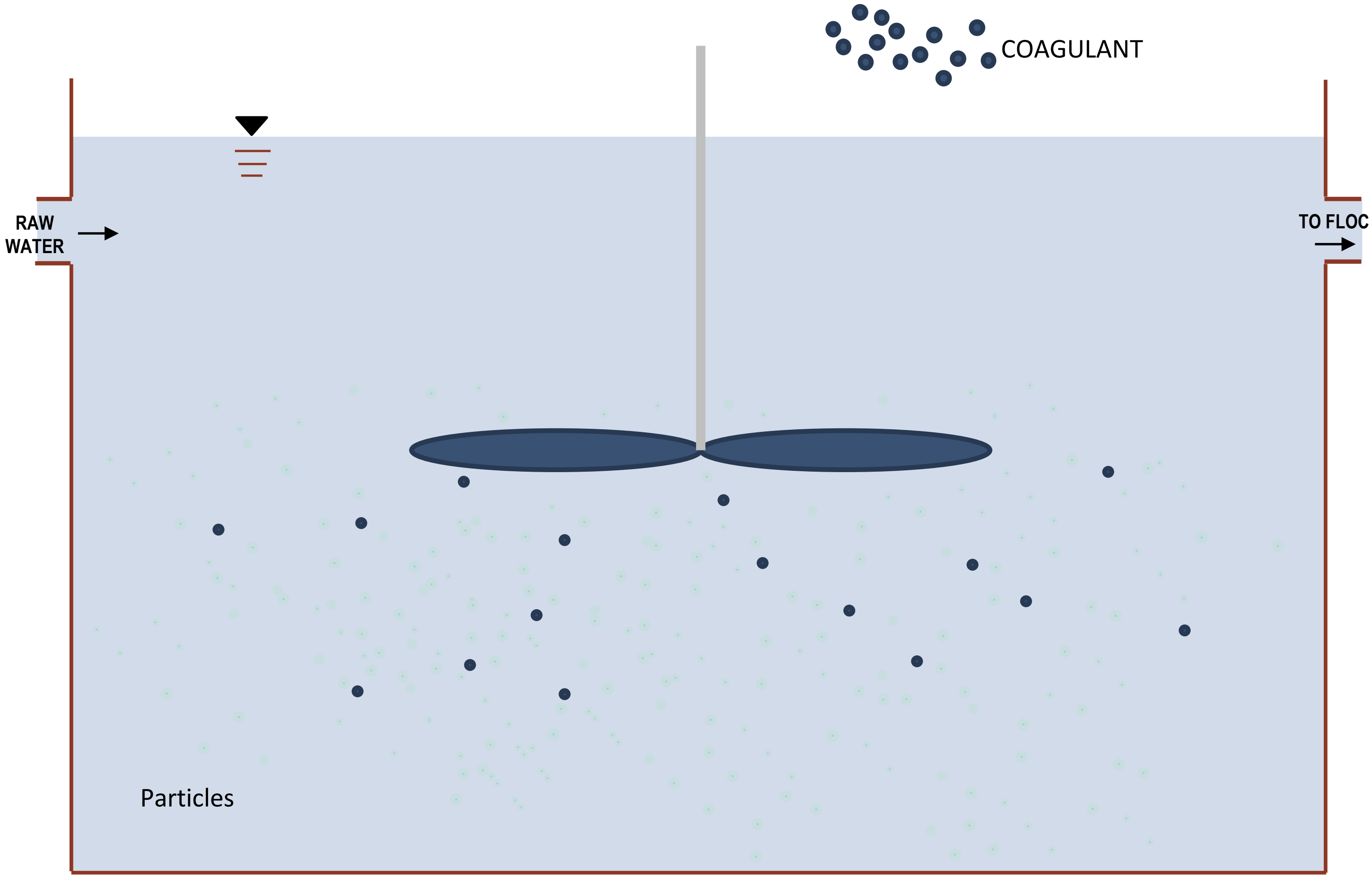
Source **Treatment Plant** **Distribution System**

Typical Conventional Water Filtration Plant



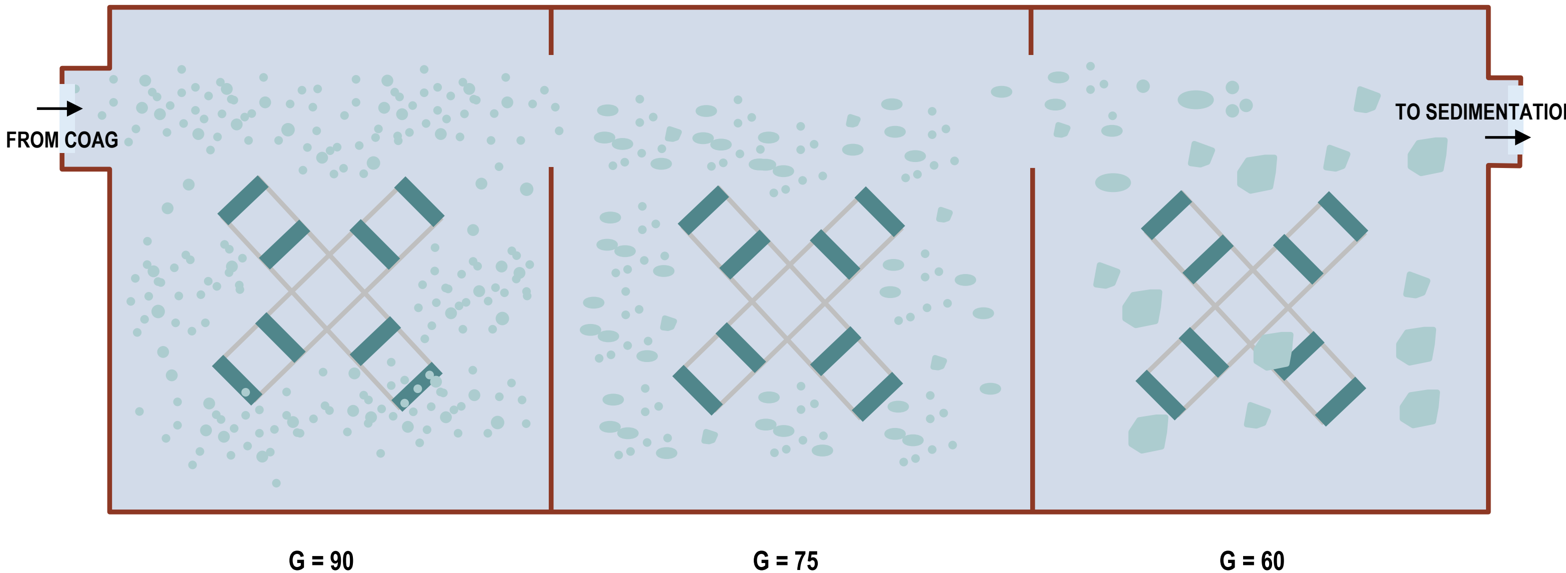
THE COAGULATION PROCESS

Goal: to rapidly disperse chemicals to promote particle aggregation



THE FLOCCULATION PROCESS

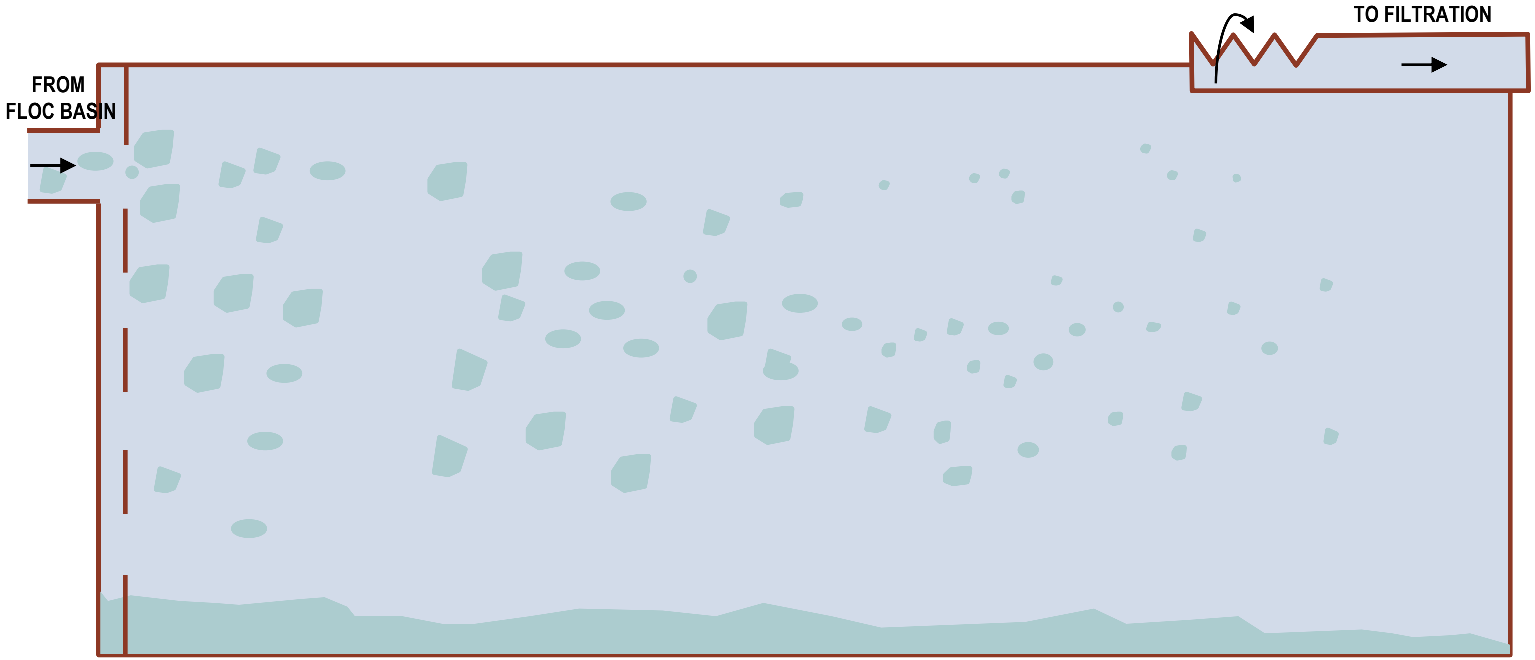
Goal: to impart slow mixing to promote particle-particle collisions



TAPERED FLOCCULATION

THE SEDIMENTATION PROCESS

Goal: to allow flocculated particles to settle out



DBP Control

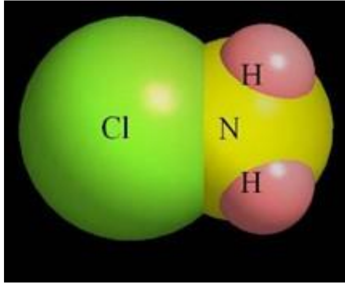
Control options:

- Alter chlorination scheme
  - Reduce chlorine dose
  - Move point of chlorination to downstream of natural organic matter removal
- Optimize natural organic mater removal (e.g., improved mixing, coagulation chemistry, pH, GAC, (MIEX®)
- Use alternative disinfectants
  - Use of ozone, chlorine dioxide typically results in lower concentrations of DBPs
  - UV disinfection
  - Chloramines
- Optimize distribution system operations
  - Reduce travel time in distribution system
  - Change pH
  - Replace aging infrastructure
- Remove DBPs after formation
  - Aeration for THMs; GAC for HAAs

History of chloramines

- First used by Denver in 1917
- Gained popularity through until 1936 due to higher stability, longer lasting residual, and fewer tastes and odors than free chlorine
- Usage dropped during World War II due to ammonia shortage
- Increased after the EPA THM Rule in 1979
- Today roughly 30% of all systems use chloramines (50% in TX, FL)
- EPA estimates up to 57% of all surface water plants will use chloramine to comply with the Stage 2 regulations

Chloramines



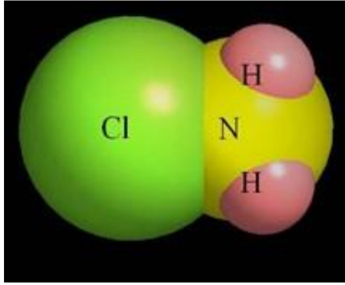
Chloramines are formed when chlorine (Cl_2) reacts with ammonia (NH_3)

- Significantly lower levels of THMs and HAAs than free chlorine
- Better control of *Legionella* in building plumbing systems
- More stable residual than free chlorine

Issues

- Nitrification – loss of disinfectant residual
- harmful sensitivities to dialysis patients
- harmful sensitivities to fish

Chloramines



$NH_3 + HOCl \leftrightarrow NH_2Cl + H_2O$ **monochloramine**

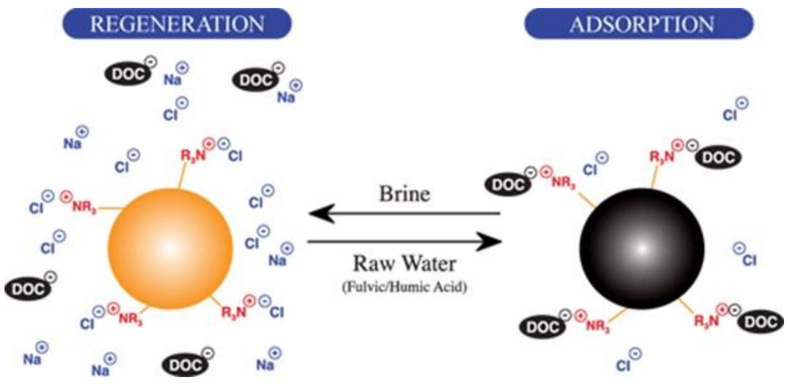
$NH_2Cl + HOCl \leftrightarrow NHCl_2 + H_2O$ dichloramine

$NHCl_2 + HOCl \leftrightarrow NCl_3 + H_2O$ trichloramine

Cl2:NH3-N Ratio	**Dominant Species**
$\leq$ 5:1	**Monochloramine**
5:1 to 7.6:1	Dichloramines
> 7.6:1	Free Chlorine

Treatment Options:
Advanced Natural Organic Matter Removal

- Activated Carbon
- Membranes
- Ion Exchange (MIEX®)

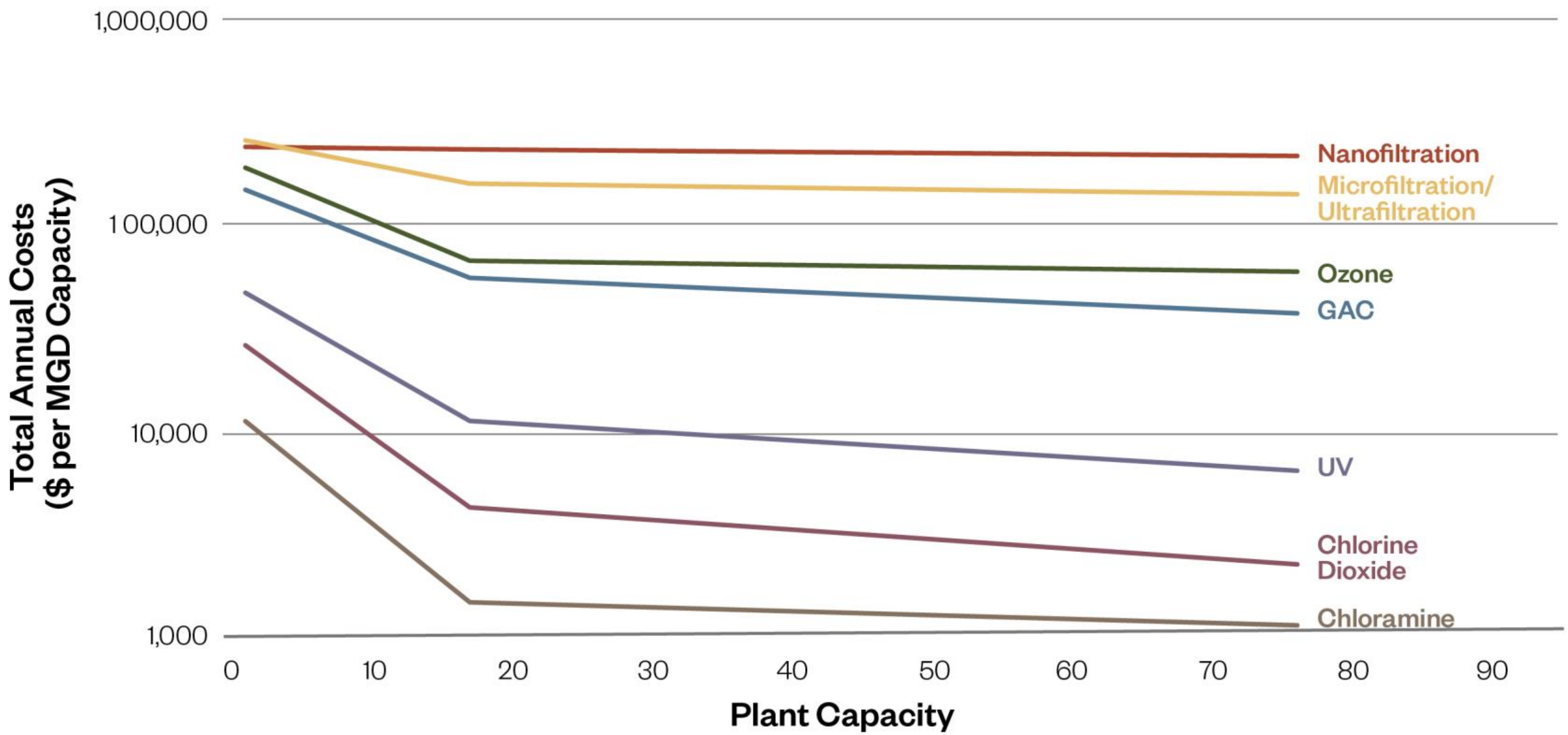


Activated Carbon

- Several options for using activated carbon
  - Pretreatment powdered activated carbon (PAC)
  - Filter adsorbers – Granular activated carbon in place of anthracite
  - Post-Filter granular activated carbon contactors

Annual Cost of Compliance Technology Options

(Roy et al., 2010)



Next Steps

- Source monitoring
- Plant improvements
- Distribution system improvements
- Operational changes
- Consideration of Alternative Treatments