

Biological Treatment in Drinking Water Applications

2025 PNWS-AWWA Section Conference

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FACET

Introduction

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Agenda

- Chlorine and Nitrogen Chemistry
- Nitrification and Biological Removal
- Impact on Other Treatments
- Specific Examples

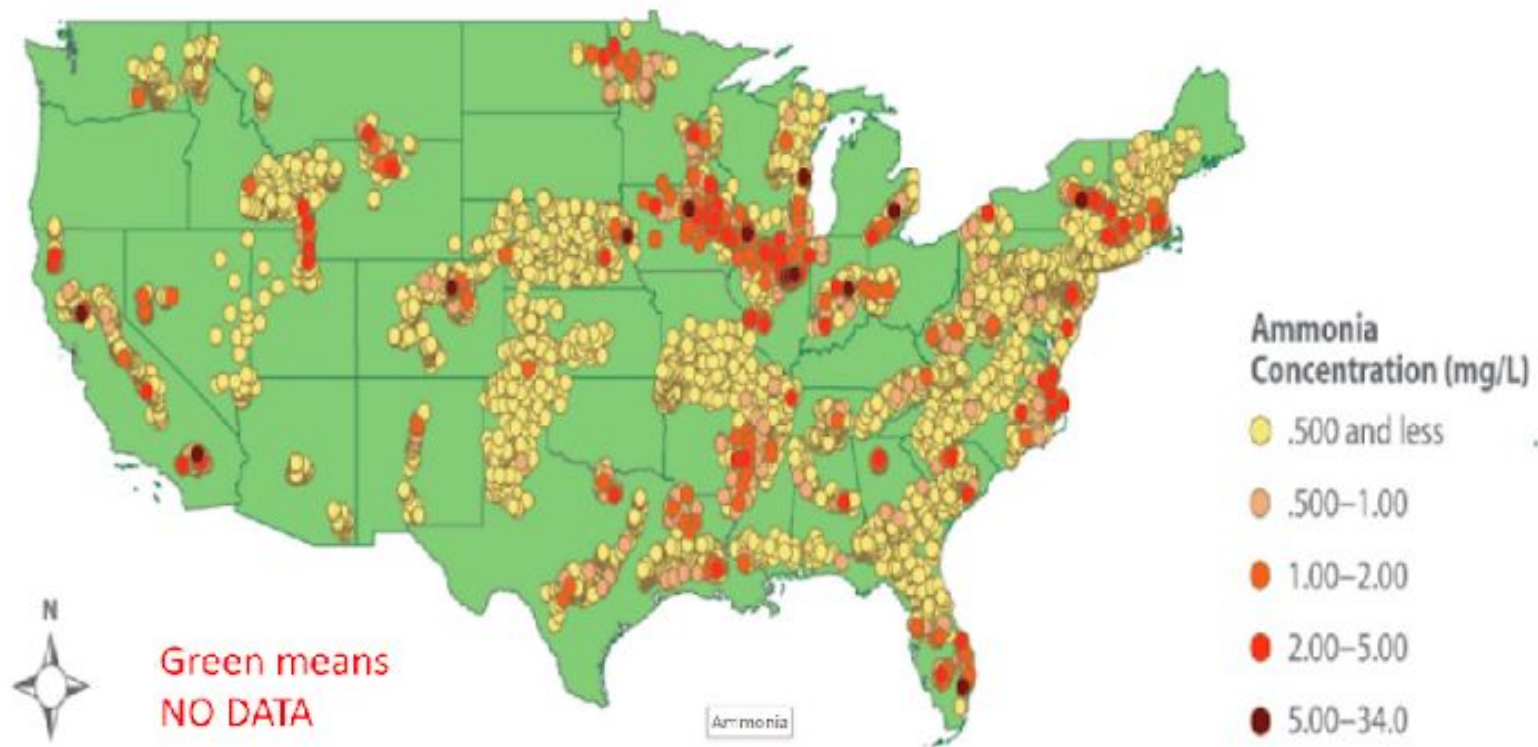


Chlorine and Nitrogen Chemistry

Ammonia

- Naturally occurring across the country
- When the nitrogen present in the well is ammonia, it is not from surface source or activity
 - Surface source is converted (nitrified) to nitrate before it reaches aquifer = nitrate in well, not ammonia
- From Geologists: ammonia is from the mineralization of organic material present from when aquifer was formed
 - Mineralization of organic matter to ammonium by microorganisms in presence of organic carbon sources in an anaerobic (without oxygen) environment

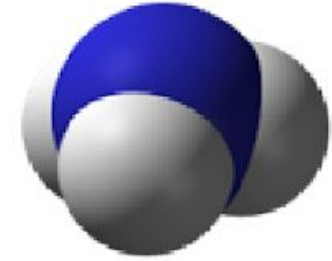
USGS Data for Ammonia Levels



Ammonia

- Levels of 1 to 5 mg/L common in GW
- Levels as high as 11 mg/L
- Levels fluctuate
 - Seasonally in both groundwater and surface waters

Ammonia is **NOT** regulated in drinking water



NH₃
Ammonia Molecule
3 hydrogen and
1 nitrogen atoms

Why is this important

- Ammonia has a huge chlorine demand
 - 10 – 12 mg/L of chlorine per 1 mg/L of ammonia
- Need to know what form of disinfectant you are using
- Taste and odor issues
- Nitrification
- Disinfection byproducts violations or issues
- Water quality impacts
- Ammonia interferes with treatments that require oxidation such as iron, manganese, & arsenic removal

It's important to know the ammonia level in each source and in the system

Chlorine Demand

Water Quality Parameter	Free Chlorine Demand Multiplier x (Factor)
Iron	0.64 mg/L
Manganese	1.3
Hydrogen Sulfide	0.2 - 2.5
Nitrite (as N)	5
Ammonia (as N)	10 to 12
Organic Nitrogen	1
TOC	0.1

Chlorine Compounds

- Monochloramine, NH_2Cl
- Dichloramine, NHCl_2
- Trichloramine, NCl_3
- Free Chlorine, OCl^- (hypochlorite) or HOCl (hypochlorous acid)
 - Dependent on pH
 - Free Chlorine = Free Available Chlorine
 - Total Chlorine = Free + Combined
 - Chlorine Residual = Dose - Demand

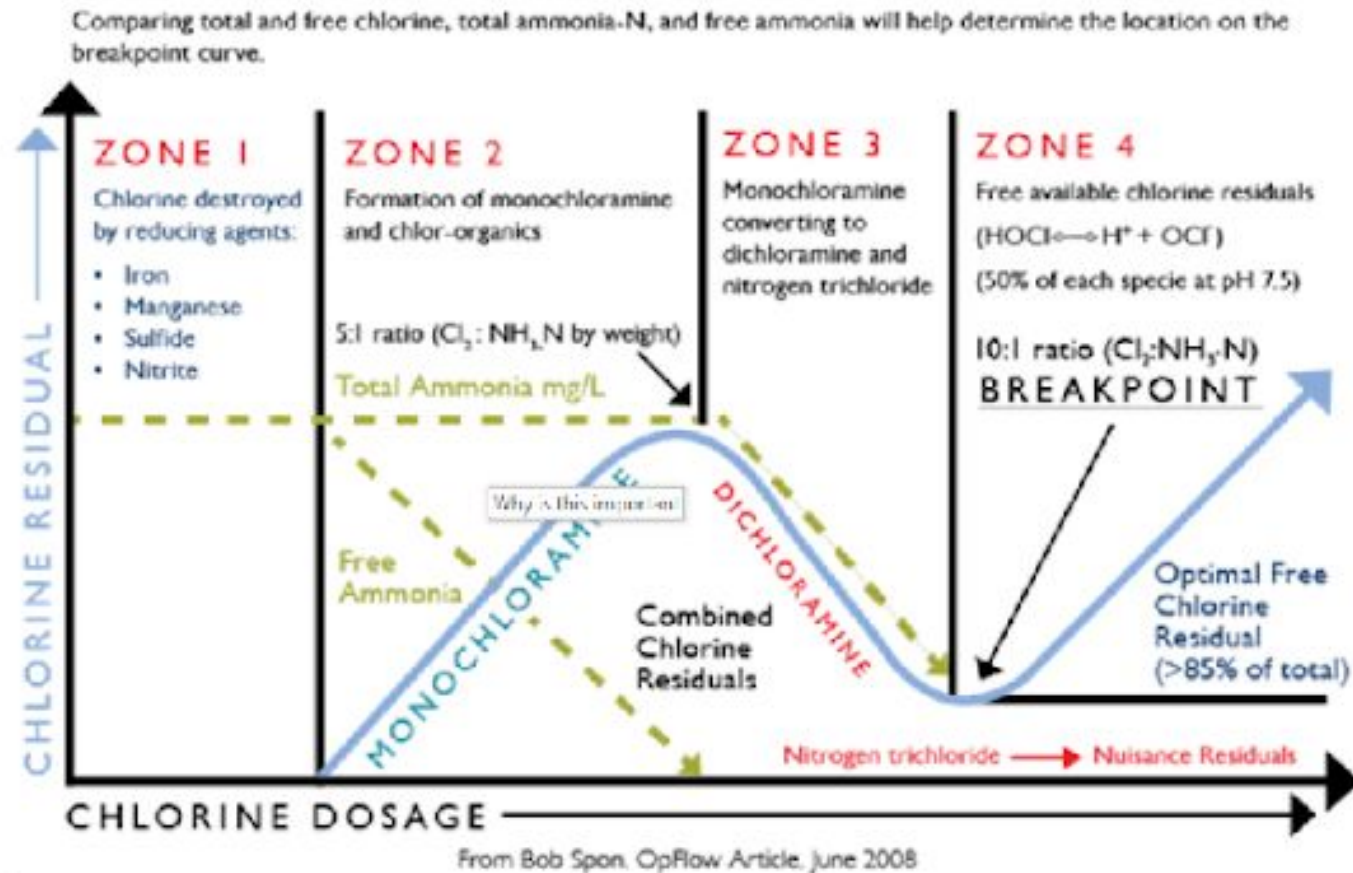
Combined Chlorine

Do you know which
are present in your
system?

Nitrogen Forms of Concern

- Ammonia, NH_3 or Ammonium ion, NH_4
 - In neutral or acidic natural waters, ammonia is present as ammonium ion
- Nitrite, NO_2
- Nitrate, NO_3
- Kjeldahl Nitrogen, TKN
 - $\text{TKN} = \text{Organic nitrogen} + \text{ammonia}$
- For systems adding ammonia
 - Ammonium sulfate (LAS), ammonium hydroxide, or others

Breakpoint Chlorination Curve Interpretation



Chloramination

- For typical, traditional chloramination, the system adds chlorine and ammonia
 - The system can control both chlorine feed rate and ammonia feed rate
 - Typically, chlorine is added first, then ammonia
- In systems with naturally occurring ammonia, chloraminating due to ammonia in source water
 - System can control chlorine feed rate BUT have no, to limited ability to change or control ammonia level

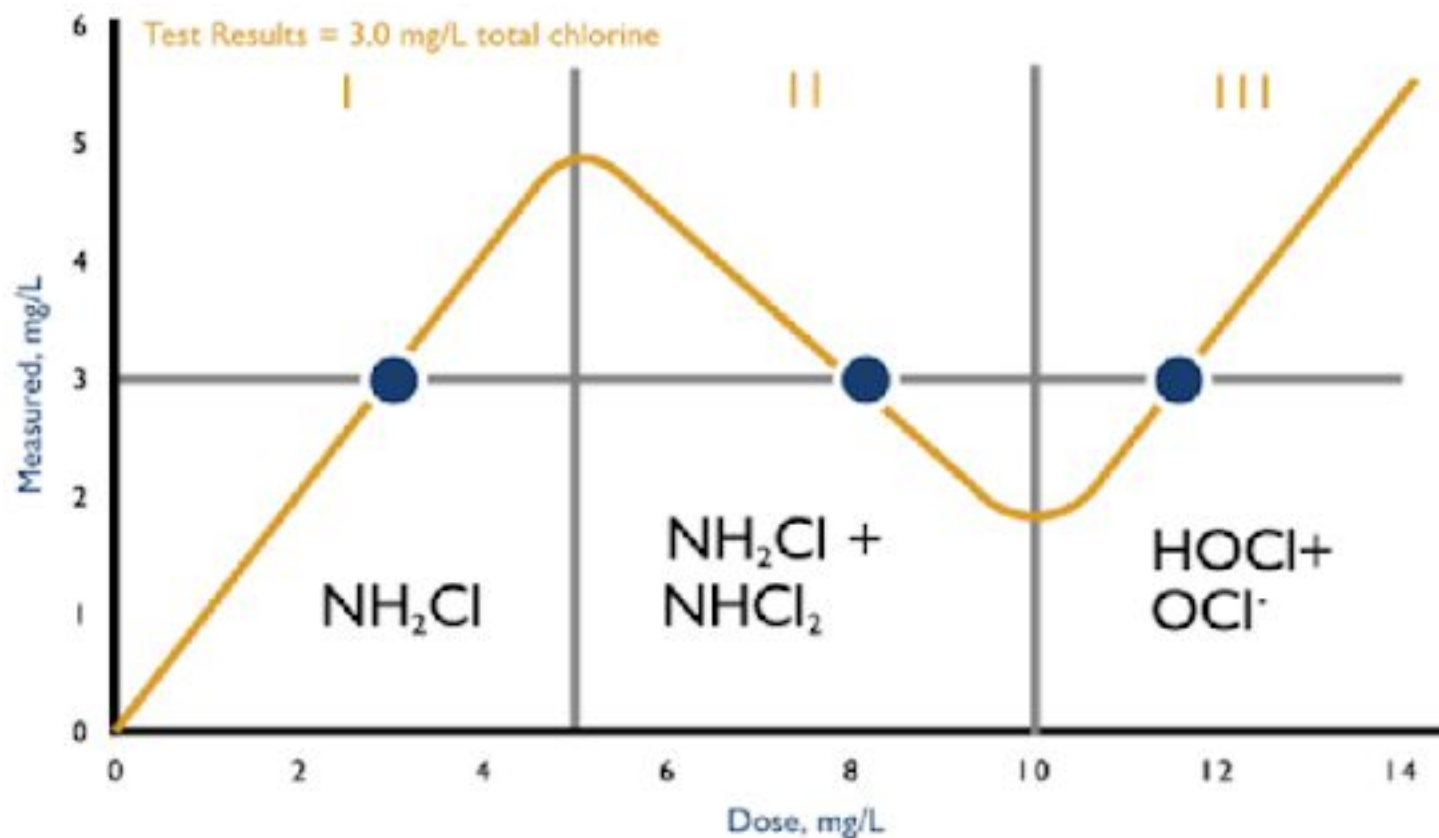
Chlorine + Ammonia Reaction

- Ammonia reacts with chlorine to form monochloramine, dichloramine, and trichloramine
- Formation is dependent on the pH and chlorine to ammonia ratio
- Monochloramine, dichloramine, and trichloramine are measured as a part of the total chlorine residual and are weak disinfectants
- Trichloramine = Nitrogen trichloride

Chemical Reaction

- Monochloramine and dichloramine exist together at pH of 6.5 – 7.5
- Chlorine to ammonia ratio determine which is formed
- Dichloramine and trichloramine cause taste and odor problems
- Small amounts of trichloramine (nitrogen trichloride) may exist past the breakpoint and may also cause taste and odor problems

Where are you on the chlorine curve?



Courtesy of Hach disinfection series
<http://www.hach.com/DisinfectionSeries06>

Chloraminating Systems

- All chloraminating Systems
 - Monochloramine (NH_2Cl) at the target
 - Total Chlorine = Monochloramine (NH_2Cl)
 - Other factors
 - Mixing energy and reaction time
 - pH
 - Temperature

Free Chlorine Systems

- Free Chlorine Systems
 - The key is to always stay on the free chlorine side of the curve (past breakpoint)
 - Free chlorine residuals are stable
 - Free chlorine residuals within 80% of the total residuals throughout the system

Chloramination vs Free Chlorine

- Chloramination
 - Monochloramine is equal to Total Chlorine
 - Free Ammonia of 0.04 to 0.10 mg/L
- Free Chlorine
 - No remaining ammonia
 - True free chlorine residual (reading does not increase)
 - Free chlorine is at least 80% of total
 - Optimal is > 85%

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Nitrification and Biological Removal



Nitrite + Nitrate

- Can be a result of surface activities or contamination
 - When you find nitrite or nitrate in raw water samples (directly from well or surface water) indicates it is a result of surface activity
- Can be a result of bacterial nitrification of ammonia within the water system
 - Often find ammonia, nitrite and nitrate present in the same SEP or system sample if nitrification is incomplete

Nitrite

- Result of contamination from surface activities
 - When found in raw water samples (directly from well) indicates close source of contamination or recent contamination
- Result of bacterial nitrification of free ammonia
 - Conversion within transmission line, treatment plant, storage or distribution system
 - Up to one nitrite formed for each ammonia
 - 1 mg/L of ammonia can form 1 mg/L of nitrite
- MCL in drinking water of 1.0 mg/L – **ACUTE** health concern

Nitrate

- Result of contamination from surface activity
 - Find nitrate in raw water samples
- Result of bacterial nitrification of nitrite
- MCL of 10 mg/L – **ACUTE** health concern

Nitrifying Bacteria

- Nitrosomonas
 - Convert ammonia to nitrite (1:1)
- Nitrobacter
 - Convert nitrite to nitrate (1:1)
- Present in treatment plants & transmission lines, storage, etc (biofilm)
- Common in soil and environment
- NOT detected as part of total coliform test
- NOT always detected as part of HPC (heterotrophic or other total plate count)

Nitrifying Bacteria

- Nitrosomonas
 - Convert ammonia to nitrite (1:1)
 - Resistant to chloramines
 - Less sensitive to chlorine
 - If established, can protect themselves in presence of high chlorine residuals
 - First to establish when starting nitrification
 - Hardy and easy to get started

Nitrifying Bacteria

- Nitrobacter
 - Convert nitrite to nitrate (1:1)
 - Very sensitive to ammonia
 - Any ammonia not consumed by Nitrosomonas will inhibit Nitrobacter
 - Very sensitive to chlorine and chloramines
 - Will be dormant (hibernate) in presence of chlorine or chloramines, usually will not be killed except at high levels
 - Thrive in narrow pH range – 7.6 to 7.8
 - Have to have nitrite present (food source)
 - Finicky and much more sensitive than Nitrosomonas

Factors in the Biological Conversion

Factor	<i>Nitrosomonas</i>	<i>Nitrobacter</i>
pH	5.8 – 9.5	5.7 – 10.2
Optimum pH	7.5 – 8.0	7.6 – 7.8
Temperature	5 – 30 C	5 – 40 C
Optimum Temperature	30 C	28 C
Chlorine	Less Sensitive	Very Sensitive
Ammonia	Consume	Very Sensitive

Factors in the Biological Conversion

- Amount of dissolved oxygen (DO)
- Chlorine residuals
- Temperature
- Detention/retention time
- Amount of free ammonia present
- pH
- Light
- Microbial community composition
- Alkalinity
- Phosphate level
- Carbon or TOC levels
- Type of filter media
- Backwash water – chlorinated or nonchlorinated
- Others

Oxygen + Alkalinity Levels

- For complete nitrification (conversion of ammonia to nitrate), 4.57 mg/L of oxygen is consumed per each 1 mg/L of ammonia
 - This is in addition to the oxygen needed for oxidation of iron and other contaminants
 - Often this is the limiting factor – conversion stops at nitrite leading to nitrite MCL violations
- For complete nitrification, 7.1 mg/L (as CaCO₃) of alkalinity is needed for each 1 mg/L of ammonia
 - Used to build cell walls by nitrifying bacteria

Nitrification as a bad thing

- This can move your system on the chlorine curve
 - Taste and odor complaints
 - Dirty water complaints
 - Changes in chlorine residuals
 - MCL violations

Nitrification as a **GOOD** thing

- Biological removal of ammonia through nitrification
- Ammonia to nitrite to nitrate
 - No ammonia or nitrite in finished water
 - Free chlorine residuals – breakpoint side of curve
- Typically occurs in filters but may occur in aeration or detention
- No chlorination prior to filters
- Care must be taken during establishing to protect nitrifying bacteria
 - Backwash rate
 - Backwash water – chlorinated or not chlorinated
- Typically takes 8-12 weeks or more to establish

Ammonia Removal as a **GOOD** thing

- Limiting factor
 - Dissolved oxygen
 - If ammonia is greater than ~2 mg/L, there will not be enough oxygen for complete nitrification
 - About 4.5 mg/L of oxygen is needed to completely nitrify 1 mg/L of ammonia
 - Conversion stops at nitrite if not enough oxygen
 - Often have nitrite MCL violations at SEP as not enough oxygen to get from nitrite to nitrate
 - Systems with higher ammonia levels now operating with air injection to get ammonia removal in contactors (new treatment step prior to filters)

Ammonia Removal – Breakpoint Chlorination

- Destroys all ammonia so no “food” for the nitrifying bacteria
 - Ammonia to nitrogen gas
- Disinfection by free chlorine (past breakpoint on free side of curve)
- Requires large dose of chlorine
 - In practice, 10 to 12 mg/L (or more) of chlorine per 1 mg/L of ammonia is common
- TTHM/HAA5 concerns
 - Many systems with raw water ammonia have high raw water TOC levels

Ammonia Removal – Breakpoint Chlorination

- Free chlorination may not be possible
 - Often cannot add enough chlorine to meet demand
- May not be enough reaction time
 - Reaction time dependent on pH and temperature
 - Must go through all reactions to get to free chlorine (past breakpoint)
 - If reaction not complete, unstable water entering the system
 - Taste and odor complaints
 - Colored water corrosion issues common

Ammonia – Chloramination

- Minimize free ammonia as much as possible
 - For systems adding ammonia, target 0.04–0.1 mg/L free ammonia
 - For systems with natural ammonia, target consistent ammonia levels and maximum chlorine to ammonia ratio
- Target disinfectant
 - Monochloramine – total chlorine
- May still have free ammonia present so may have nitrite formation in low use areas, dead-ends, and storage facilities
 - Reversion to ammonia (breakdown of chloramines)

Ammonia Control

- Breakpoint Chlorination
 - DBP's
 - Large chlorine demand
- Chloramination
 - Less volatile
 - Less reactive w/ organic matter
 - Last longer
- Biological Removal
 - Reduced chlorine demand
 - Reduced DBP issues
- Very specific for each system



Impact on Other Treatments



Type of Disinfectant

- Determines minimum residual level requirements
- Disinfection of new media requires free chlorine
- Filter media changeout may impact disinfectant in use
- Biological removal impacts
- Oxidation of iron and arsenic require free chlorine
- Regeneration of catalytic media requires free chlorine
- Zeolite softening may remove ammonia then “dump” ammonia impacting demand

New Media – Free Chlorine

- Factor in ammonia demand for disinfection
- Follow AWWA C653

New Media

- Important to understand what treatment is being done in filters
 - Biological or not
 - Chlorine demand will increase significantly if biological
 - Will take time to bring back
- Greensand or other catalytic media require recharge
 - Must be permanganate or free chlorine
 - Continuous or batch recharge

Iron & Arsenic Oxidation

- Requires free chlorine, not chloramine
 - What is your oxidant?
 - O₂, permanganate, chlorine
 - Verify contact time



Specific Examples



Case Study No. 1

- Groundwater system
- Aeration, detention, potassium permanganate addition, pressure filtration, & chlorine
- Media testing showed media needed replaced
 - Replaced with greensand plus

Case Study No. 1

- Replacement work went fine
- Disinfected, clean bact samples, charged with permanganate
- Filters returned to service and had excellent iron and manganese removal
- Disinfection with chloramines now
- About 6 weeks later, manganese levels started to increase
- Within a few more weeks, SEP manganese levels greater than raw levels

Case Study No. 1

- Recharged the media, manganese levels dropped immediately
- This happened 2 additional times
- What happened???

Case Study No. 1

- Permanganate dose was not high enough to continuously recharge media
- System lost biological removal of ammonia and manganese with media change
- Permanganate dose adjusted to meet demand and recharge media
 - After a few months, dose was back to original and biological ammonia restarted

Case Study No. 2

- Groundwater system
- Aeration, detention, chlorine addition, & pressure filtration
- Full system replacement required due to age
 - Replaced with similar system

Case Study No. 2

- Disinfection wouldn't achieve minimum free chlorine residual (25 ppm)
- Flushed and rechlorinated 2 additional times
- What happened???

Case Study No. 2

- System didn't know they had ammonia naturally occurring in their water
- Chlorine demand for ammonia wasn't factored in
 - Eventually the contractor just got fed up and dumped in a lot of chlorine until it was achieved
 - Proper review prior to disinfection would have saved a lot of heartache

Case Study No. 3

- Groundwater system
- Aeration, detention, chlorine addition, & pressure filtration
- Iron & manganese removal efficiency began to decline

Case Study No. 3

- It was determined that media just needed a batch recharge
- Batch recharged with chlorine, no impact
- Completed several more times
- What happened???

Case Study No. 3

- System didn't know they had ammonia naturally occurring in their water
- They were recharging with chloramines, not free chlorine
 - Chloramines not effective on catalytic media
 - Operator just accepted reduced efficiency and kept fighting feed rate
 - We reviewed, assisted in batch recharge, efficiency increased the next day

Questions?

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