Process Control and Treatment Optimization for Groundwater with Elevated Ammonia and Manganese

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American Water Works Association
Pacific Northwest Section

2022 Section Conference
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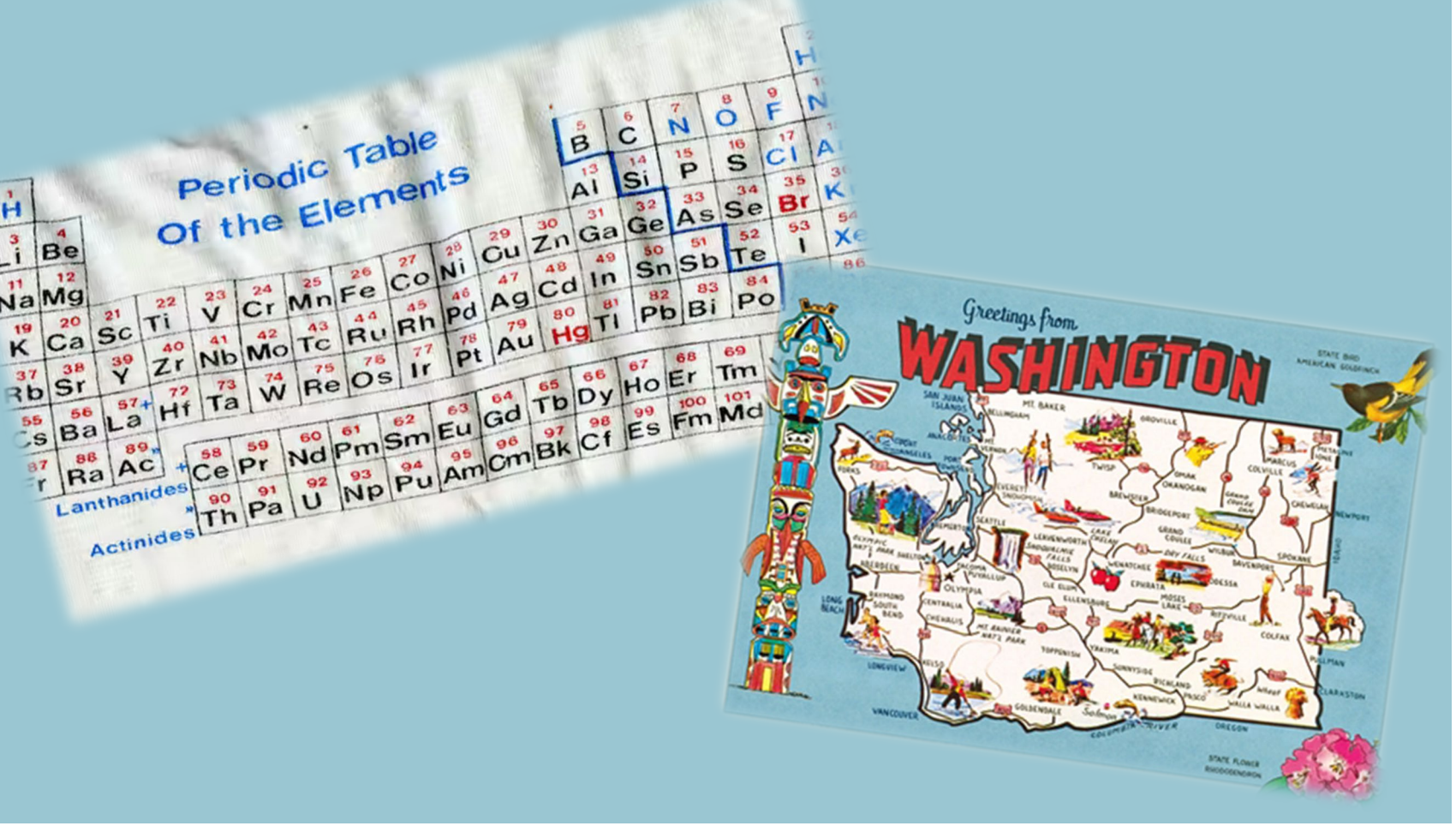
SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1 2

Discussion Topics

1. Background and Introduction Items
2. Bench & Pilot Testing
3. Applying Results to Full-Scale

Al Vetrovs analyzing ammonia and manganese samples
Snohomish PUD Bench & Pilot Testing



Background

Periodic table courtesy of www.theconversation.com
Washington map courtesy www.picklepapers.net

Manganese (**Mn**)

- USEPA Secondary MCL=0.05 mg/L (outdated setpoint from 1962)
  - Industry recommendation is <0.02 mg/L (WRF 4373)
  - 2019 Health Canada MAC = 0.120; Aesthetic Objective = 0.02 mg/L
- "Manganese is Relentless" (Hill et al. 2022)
  - Accumulates at low POE levels and co-accumulates other metals
  - All systems and pipe types impacted; very sticky / difficult to flush off
  - Release events (chlorine/ORP change) can >>>SMCL (w/ or w/o color)

Ammonia (**NH_3**)

- Not regulated, usually not monitored, >>>Cl_2 demand than TOC
- Free NH3 destabilizes Cl_2 residual; exacerbates microbial activity

Mn + NH_3
= varying Cl_2 levels
= pipe scale instability
= ☹

Warm Beach Water System

- 1928 - 1948: Supplied Waterfront Properties Incorporated as an HOA
- 1970 – 1985: Added multiple wells, supplied up to 328 customers

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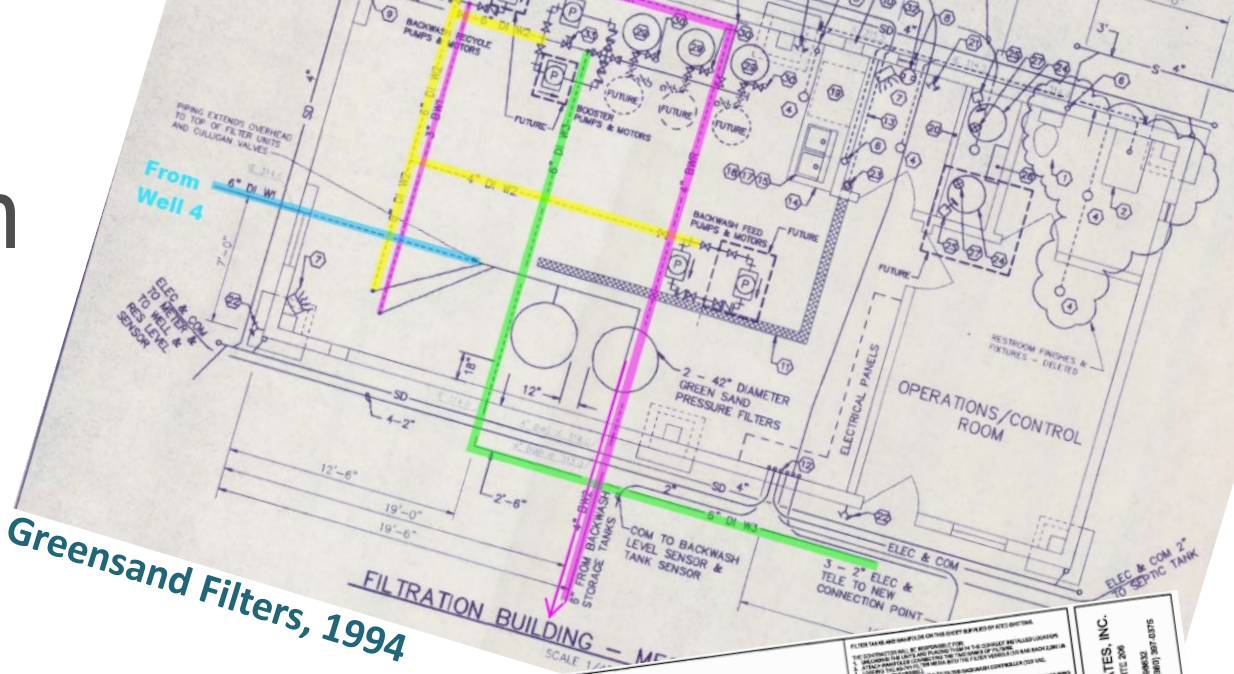
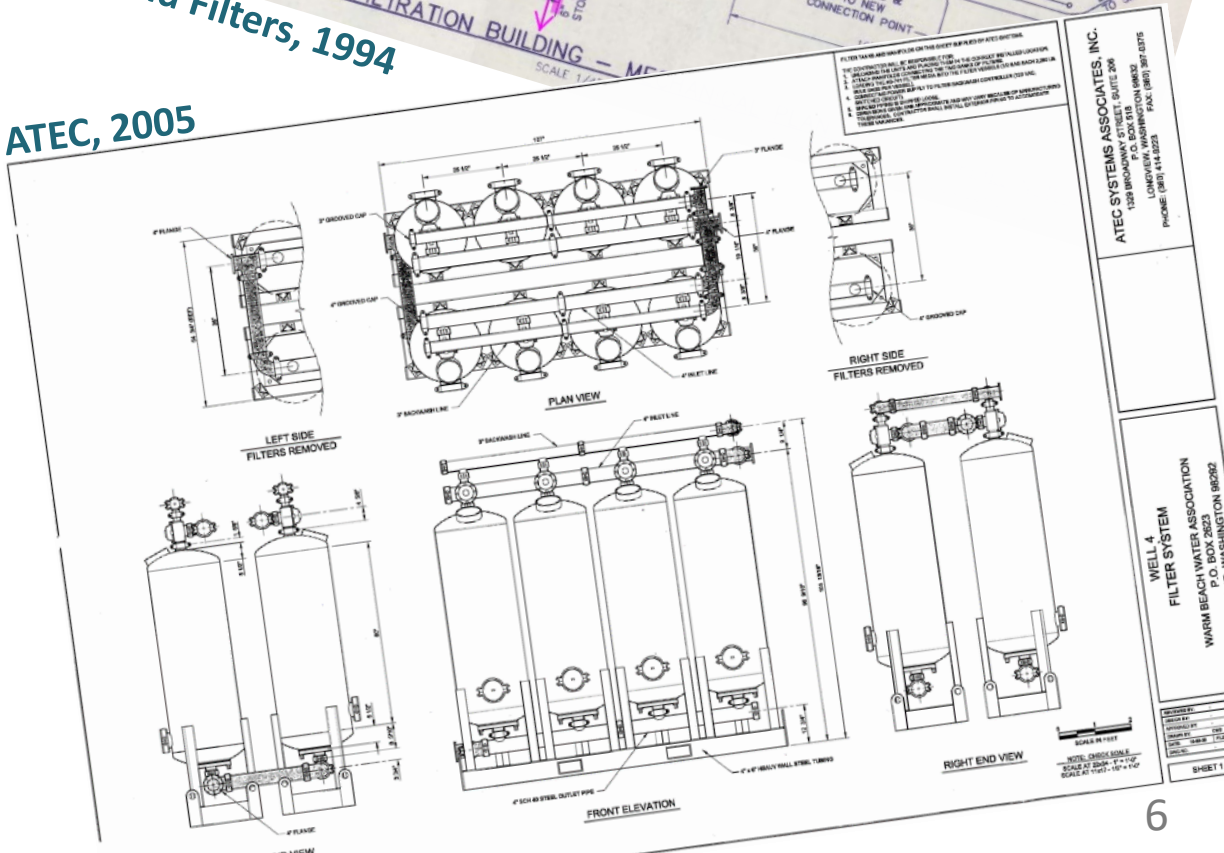
- 1970 – 1985: Added multiple wells, supplied up to 328 customers

- 1990: Added Well 4
  - Taste and odor issues (Fe, Mn)
  - 1994: Added $KMnO_4$ + Green Sand
  - 2005: Added Cl_2 feed + ATEC for Fe/Mn

- 2018: Water System Acquired by PUD (started investigations to optimize)



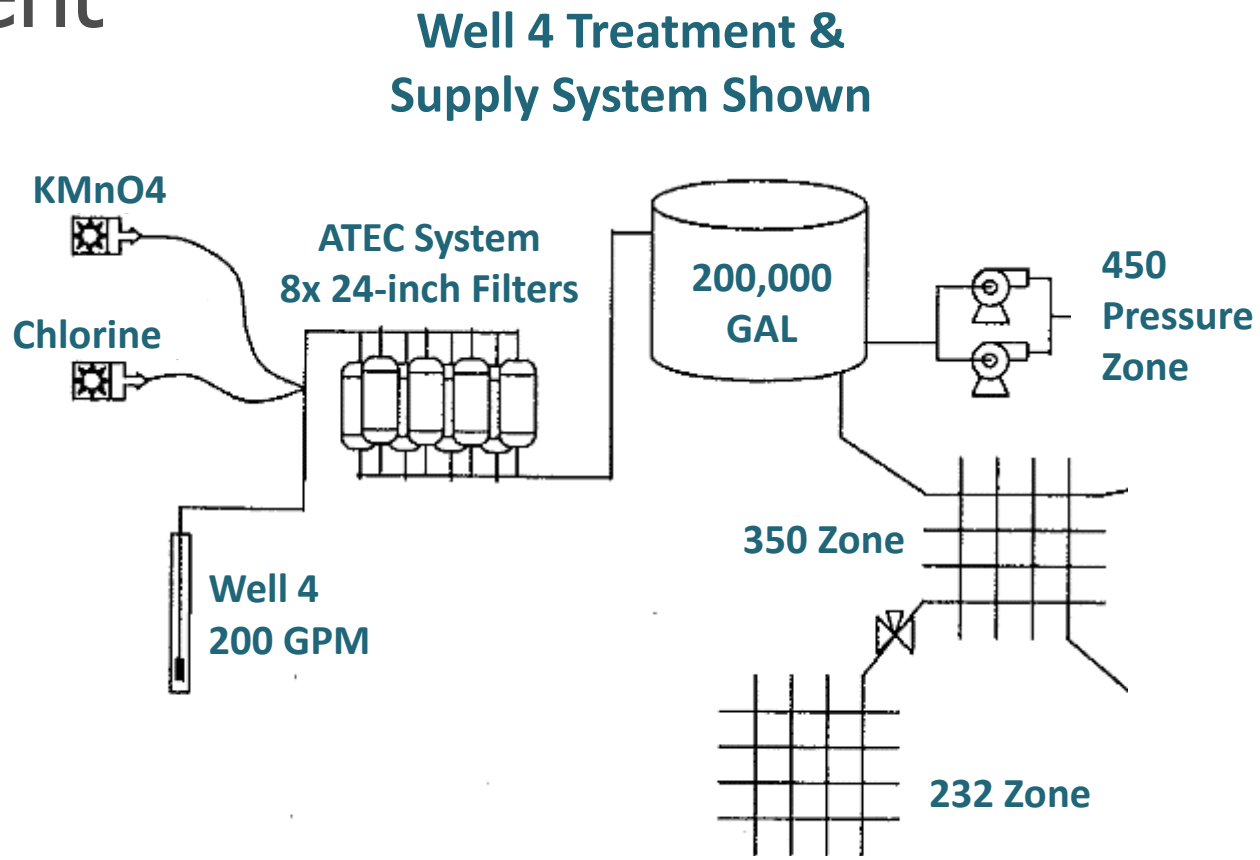
Greensand Filters, 1994



ATEC, 2005

SnoPUD Well 4 Assessment

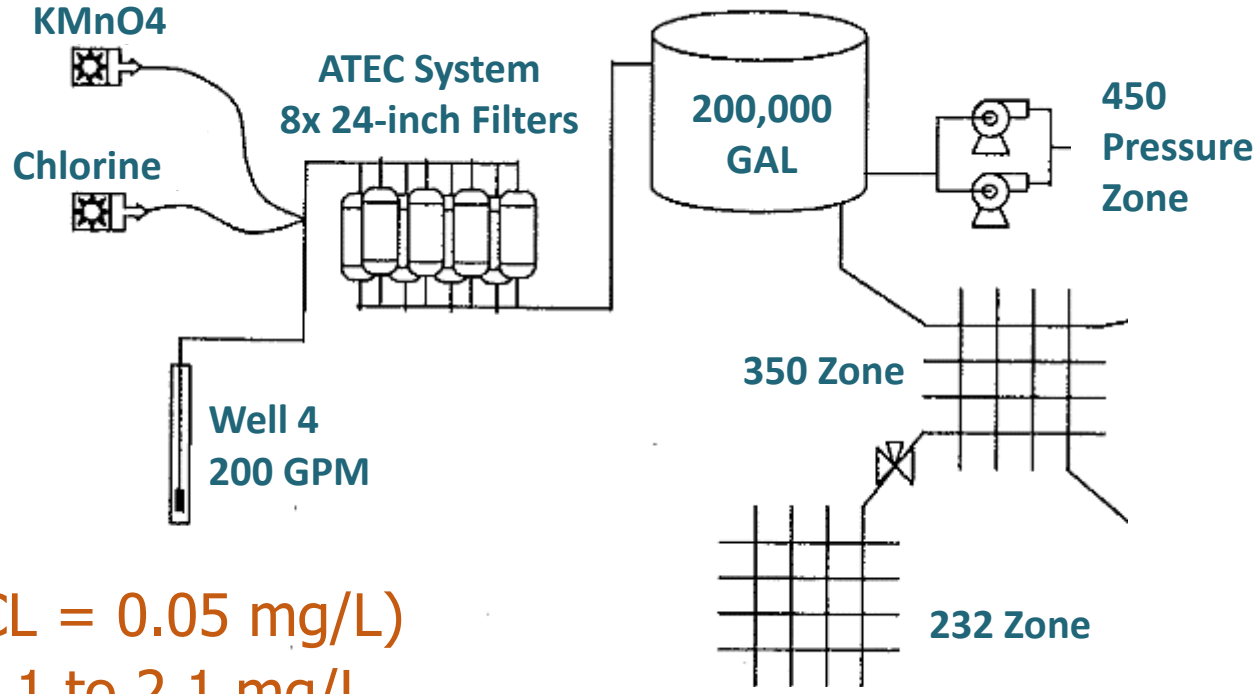
- Well 4 Supplies ~1,500 Residents
  - Cl_2 and $KMnO_4$ feed
  - ATEC Filtration
  - 200,000 Gal Storage
  - Multiple Pressure Zones



SnoPUD Well 4 Assessment

- Well 4 Supplies ~1,500 Residents
  - Cl_2 and $KMnO_4$ feed
  - ATEC Filtration
  - 200,000 Gal Storage
  - Multiple Pressure Zones
- Water Quality Information
  - Raw water NH_3-N = 1.7-2.4 mg/L
  - Raw water Mn = 0.6 mg/L
  - System Mn = 0.02-0.09 mg/L (SMCL = 0.05 mg/L)
  - System Free Cl_2 is ND; Total Cl_2= 0.1 to 2.1 mg/L

Well 4 Treatment & Supply System Shown



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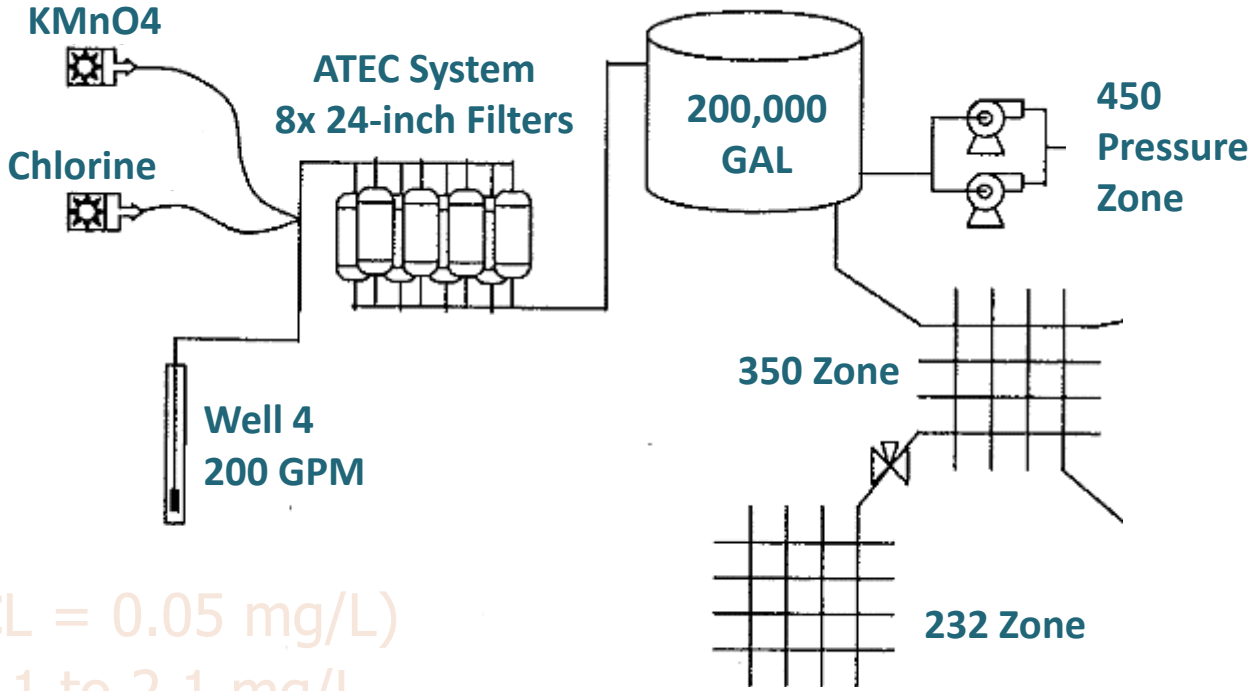


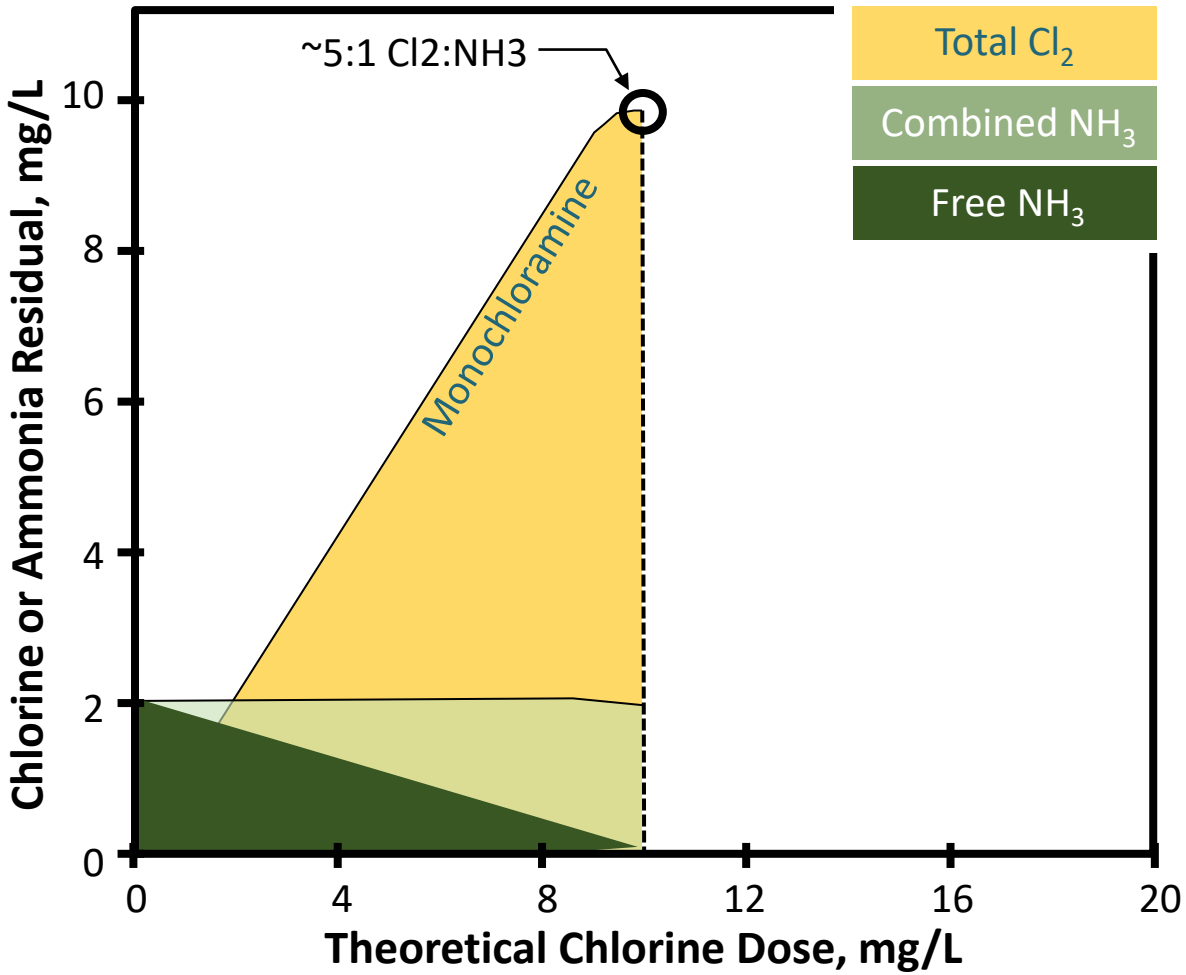
Assessment Result: Implement breakpoint chlorination and optimize filtration

(Breakpoint operations can start quicker than biological treatment; possibly at lower anticipated cost)

Bench & Pilot Testing

Ammonia (NH_3) Oxidation Theory (at 2 mg/L NH_3)

- Ammonia Gives Chlorine (Cl_2) "Demand"
- Up to ~5x Ratio of Cl_2:NH_3-N
  - All Cl_2 is combined with NH_3 (no free Cl_2)
  - Total Cl_2 increasing with dose
  - Negligible NH_3 drop
  - Mix of free NH_3 and NH_3 combined w/Cl_2



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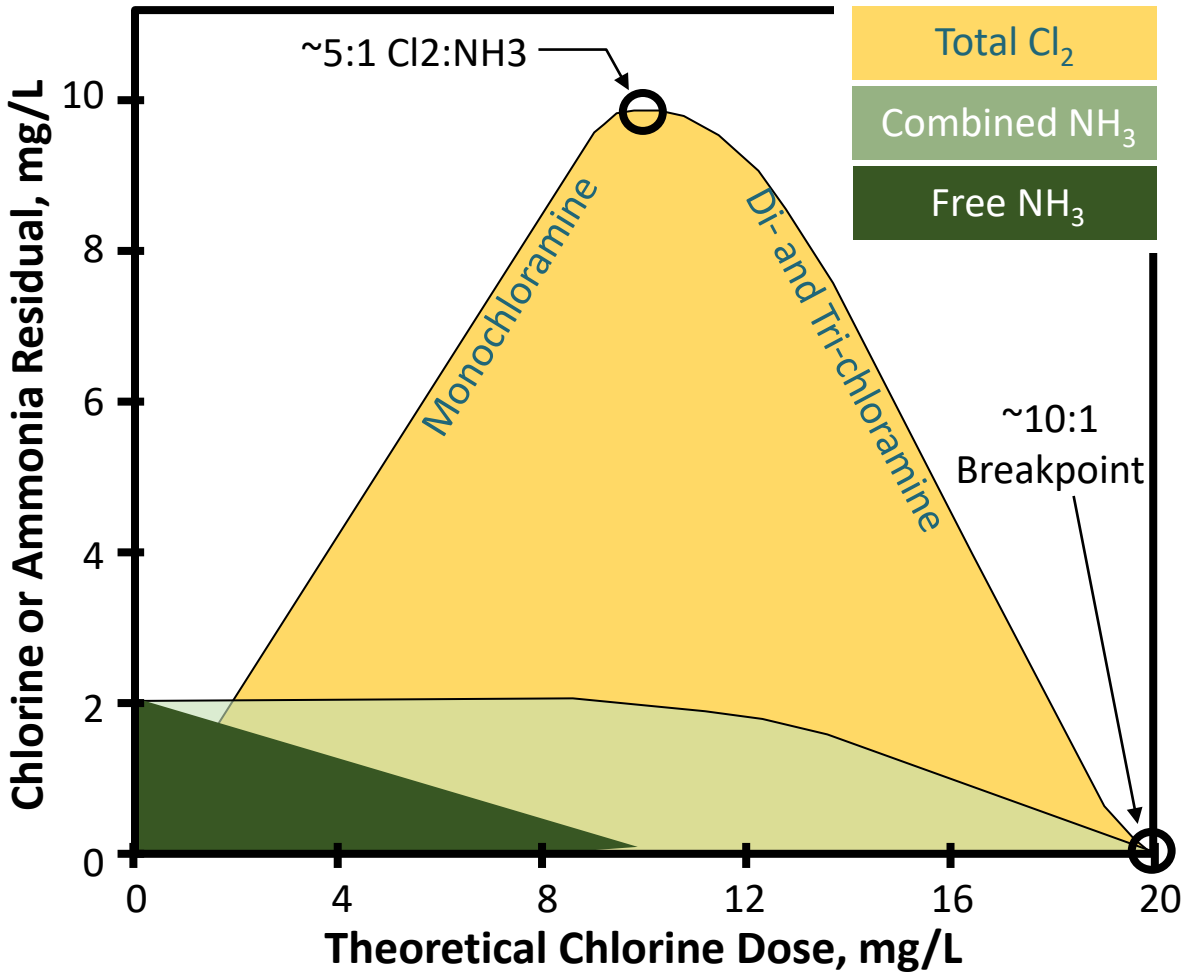
  - Total Cl_2 increasing with dose
  - Negligible NH_3 drop
  - Mix of free NH_3 and NH_3 combined w/Cl_2
- Between ~5x to ~10x ratio
  - All Cl_2 is combined with NH_3 (no free Cl_2)
  - Total Cl_2 decreasing as Cl_2 dose increases
  - NH_3 decreasing with Cl_2 dose
- ~10x Ratio = Breakpoint: No Cl_2 or NH_3
- >10x Ratio: The 'Demand' is Met and Free Cl_2 Residual is Established



Well 4 Bench & Pilot Testing

- ~2 Week Pilot Testing to Optimize Treatment
- Determine Cl_2 dose for NH_3 control & free residual
  - Demand and decay kinetics
  - Disinfection by-product (DBP) formation
- Additional ATEC Filtration Improvements
  - Filter run time
  - Backwash optimization
  - Media health
  - Optimize $KMnO_4$ feed
  - Backwash recovery possible?

Michael Hallett installing Confluence filter pilot testing equipment

Cl_2:NH_3 Testing

- Breakpoint Reaction Stoichiometry
  - NH_3 ranged from 1.8 to 2.6
  - Cl_2:NH_3 breakpoint ratio
    - Ranged from 7.7 to 9.0
    - Average ~8.5

Bench-Scale Data			Pilot-Scale Data		
Chlorine Demand* (mg/L)	Ammonia Depleted (mg/L)	Breakpoint Ratio Calculated	Chlorine Demand (mg/L)	Ammonia Depleted (mg/L)	Breakpoint Ratio Calculated
17.4	1.96	8.9	20.3	2.4	8.7
17.8	1.99	9.0	20.4	2.4	8.7
17.2	1.99	8.6	20.5	2.4	8.7
17.0	2.00	8.5	20.7	2.6	8.1
16.1	1.94	8.3	21.4	2.6	8.4
17.1	1.99	8.6	21.2	2.6	8.3
17.2	2.00	8.6	21.4	2.6	8.4
14.5	1.83	7.9	20.9	2.6	8.2
16.2	1.94	8.3	14.5	2.1	8.4
16.8	1.98	8.5	18.7	2.1	8.9
17.2	2.00	8.6	19.5	2.3	8.7
17.6	2.00	8.8	20.1	2.3	9.0
14.0	1.83	7.7	17.7	2.3	7.9
15.5	1.91	8.1	17.8	2.3	7.9
16.2	1.95	8.3	18.8	2.3	8.6
16.5	1.95	8.5	20.3	2.3	9.0
16.7	2.00	8.3	17.6	2.1	8.4
			18.3	2.1	8.7
			18.4	2.1	8.8
Average bench ratio =		**8.4**	**Average pilot ratio =**		**8.5**

Cl_2:NH_3 Testing, continued

- Breakpoint Reaction Stoichiometry
  - NH_3 ranged from 1.8 to 2.6
  - Cl_2:NH_3 breakpoint ratio
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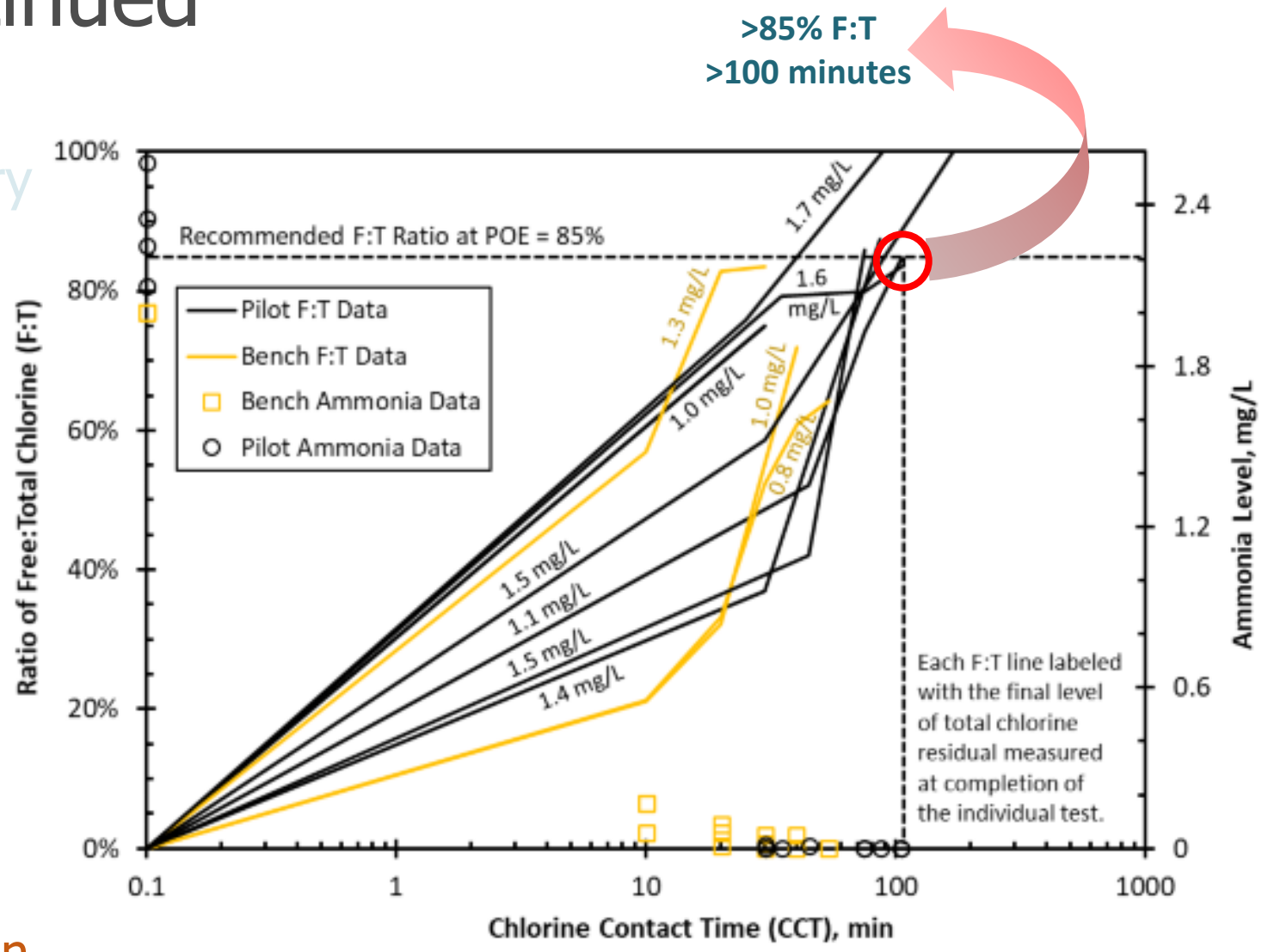
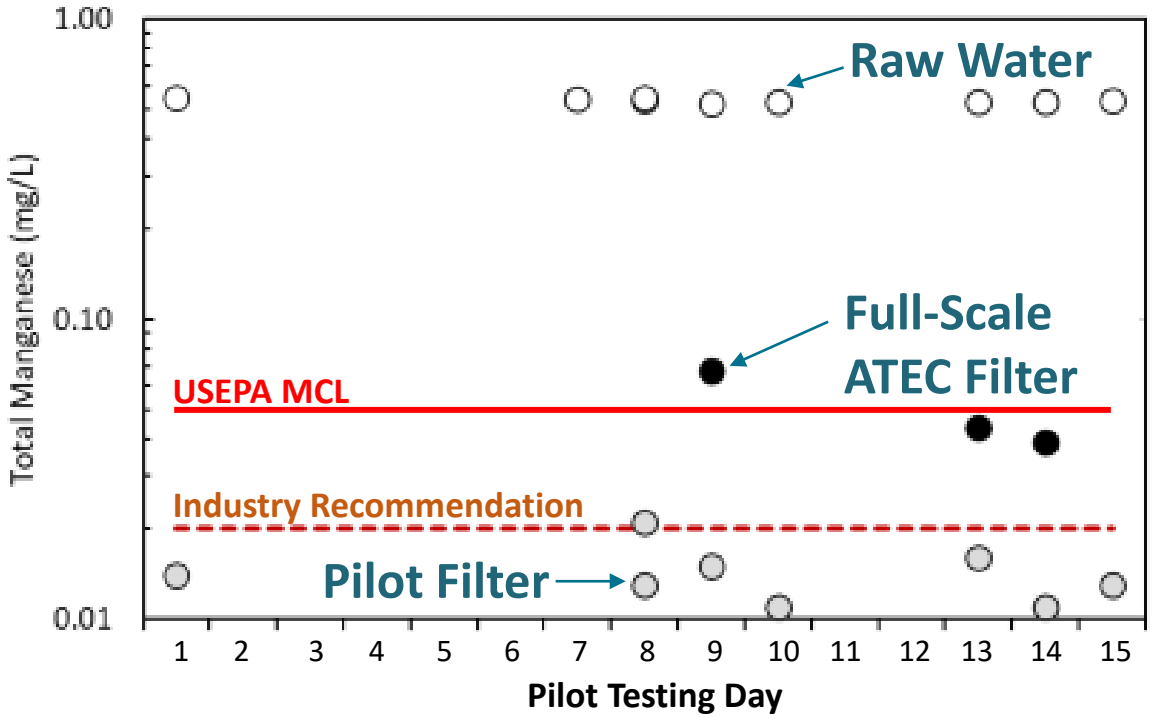
    - Average ~8.5

- Breakpoint Reaction Kinetics
  - NOTE: These are "short-term" reactions (not long-term demand & decay)
  - Reactions NOT instantaneous
  - Time to consistently achieve 85% F:T chlorine ratio = 100 min.



Mn Removal Pilot Testing

- Full-Scale ATEC Filter Not Optimized
- Confirm Difference Between Pilot and Full-Scale Performance…….
  - Years of suboptimal Cl_2 (and/or $KMnO_4$) dosing and possible biofouling?
  - Can $KMnO_4$ dosing be improved at full-scale prior to implementing pilot findings?



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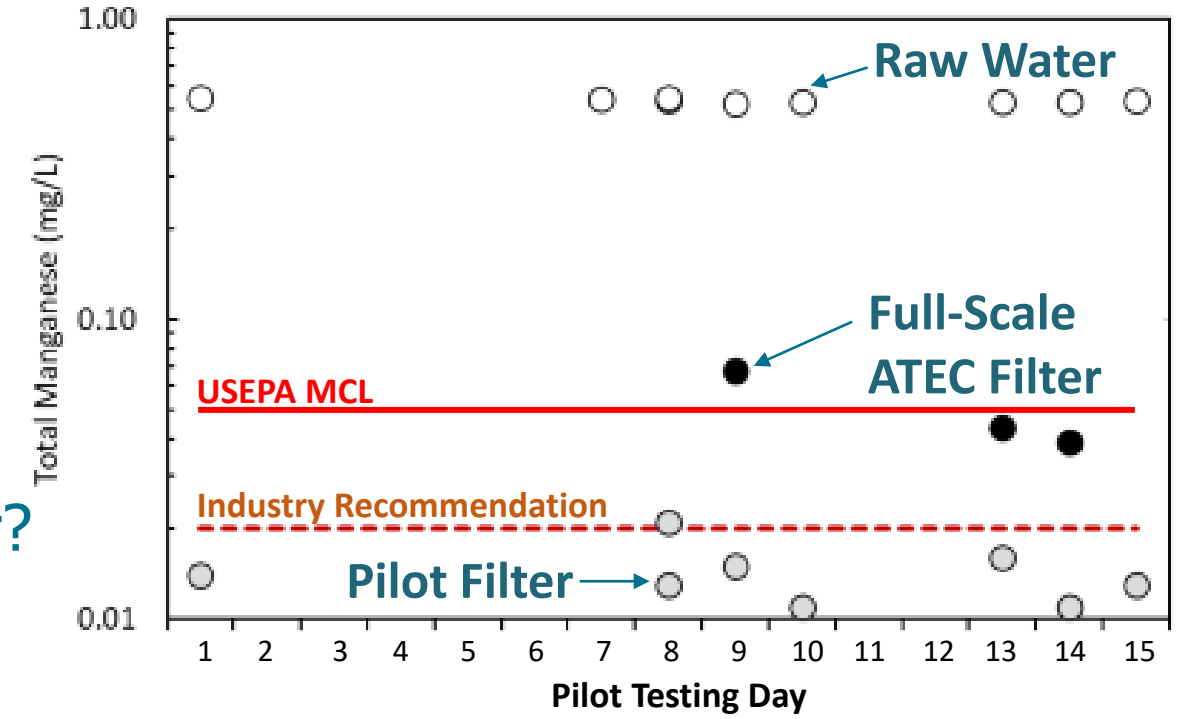
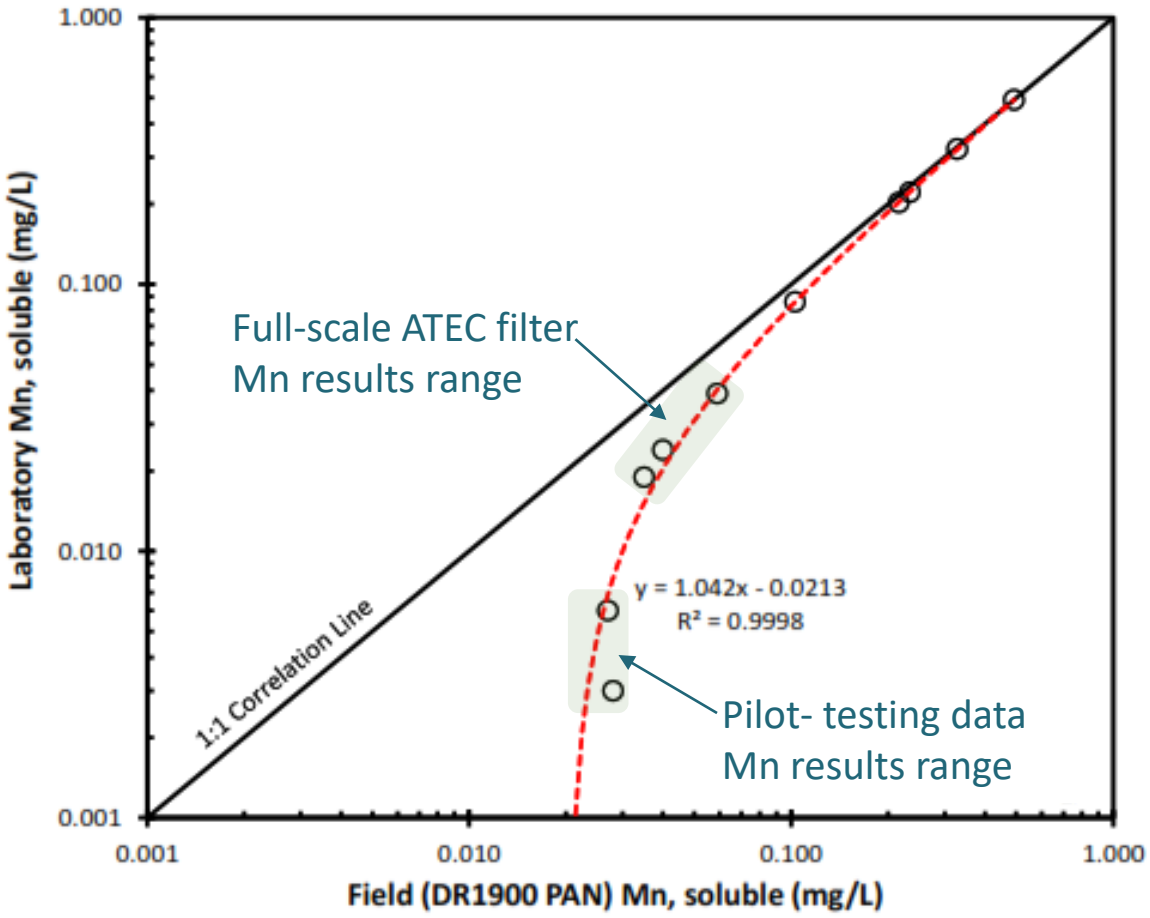
  - Can $KMnO_4$ dosing be improved at full-scale prior to implementing pilot findings?
- In Reality, Is Pilot Mn Data Actually Lower?
  - New pyrolox filter media
  - Chlorine dosing optimized
  - Same potassium permanganate ($KMnO_4$) dose as full-scale
  - Answer is…… (yes ☺ see next slide)



Results Bias: HACH PAN Method (Field Mn Measure)

- Observed during Multiple Confluence Projects (and LaTorre et al. 2019)
- Paired Samples Collected, Analyzed
  - Laboratory: Method 200.8
  - Field: HACH DR 1900 PAN
- When Mn is actually (lab) < 0.1 mg/L
  - Bias can reach up to 0.02 mg/L
  - Difficult to confirm in the field
  - Need to confirm results with paired laboratory samples
- Result: Field Pilot Data ≤0.02 mg/L (PAN) actually correlate to <0.01 mg/L (lab)



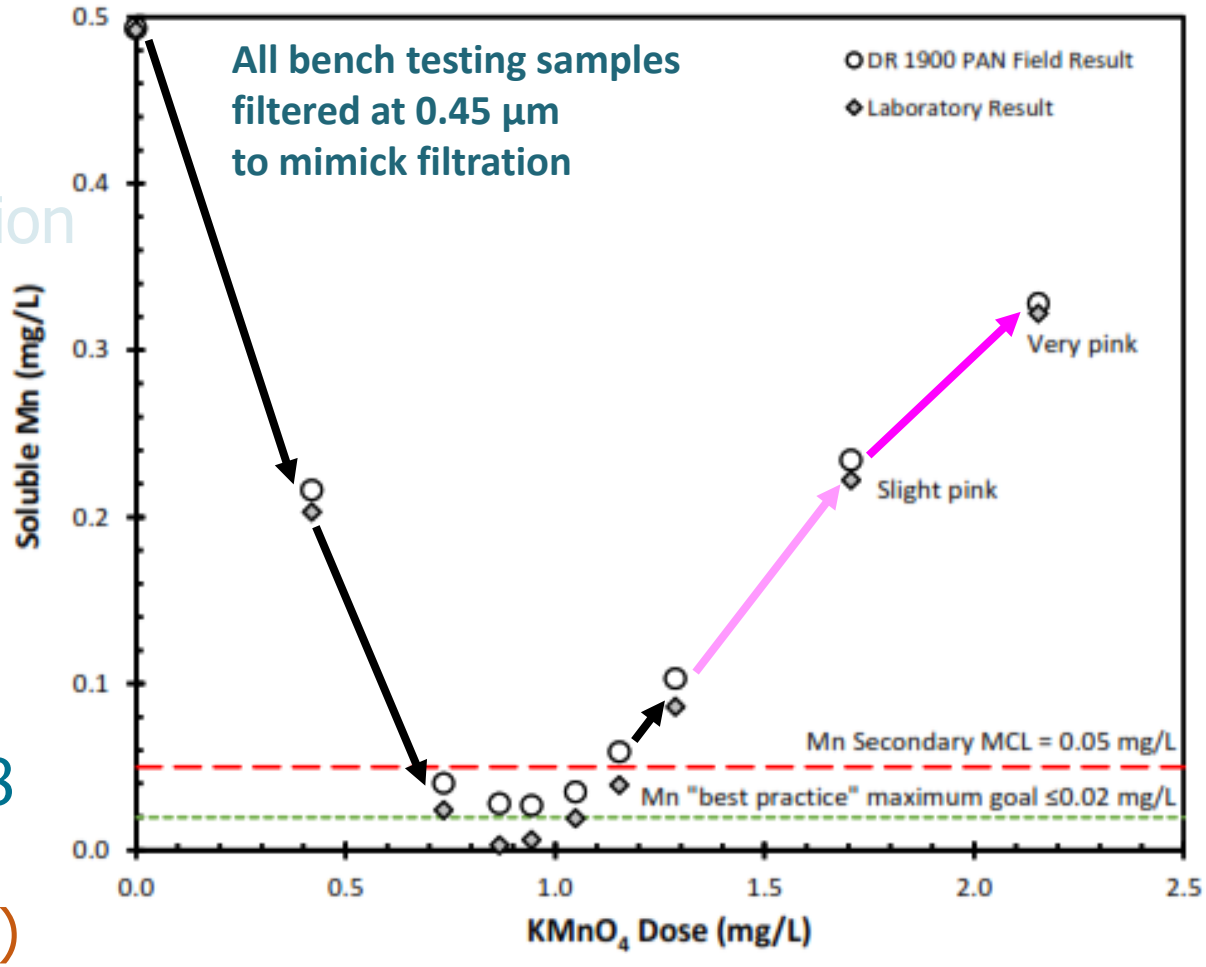
PAN = 1-(2-Pyridylazo)-2-Naphthol indicator solution

Optimize $KMnO_4$

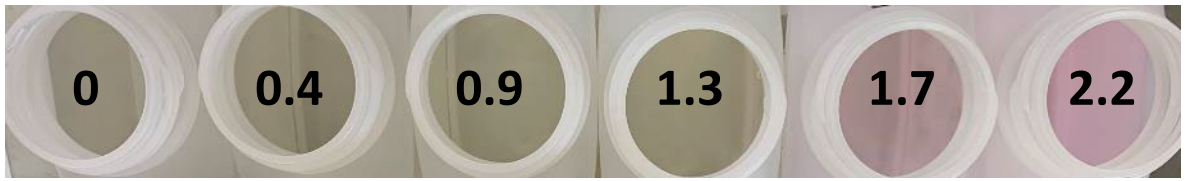
- <1 day Filter Soak; Partial Media Regeneration
  - 100 mg/L $KMnO_4$ with 100 mg/L Cl_2
  - Bled filters; Extended backwash after soak

Optimize $KMnO_4$, continued

- <1 day Filter Soak; Partial Media Regeneration
  - 100 mg/L $KMnO_4$ with 100 mg/L Cl_2
  - Bled filters; Extended backwashing
- Bench Tests to Optimize $KMnO_4$ Dose
  - Too little = Soluble Mn(II) passes filter
  - Too much = Soluble Mn(VII) passes filter (unreacted $KMnO_4$ = pink water)
- Results w/ Field HACH PAN & Lab EPA 200.8 Confirmed ~0.9 mg/L optimum dose
  - Up to 1.3 mg/L added w/o color (visual only)



$KMnO_4$ Dose (mg/L):



Predicting Distribution System Cl_2 Decay & DBPs

- Current System is Not Experiencing Free Cl_2
  - Groundwater w/ ~2 mg/L NH_3 & ~1.6 mg/L TOC
  - Chloramines are longer-lasting; form fewer DBPs

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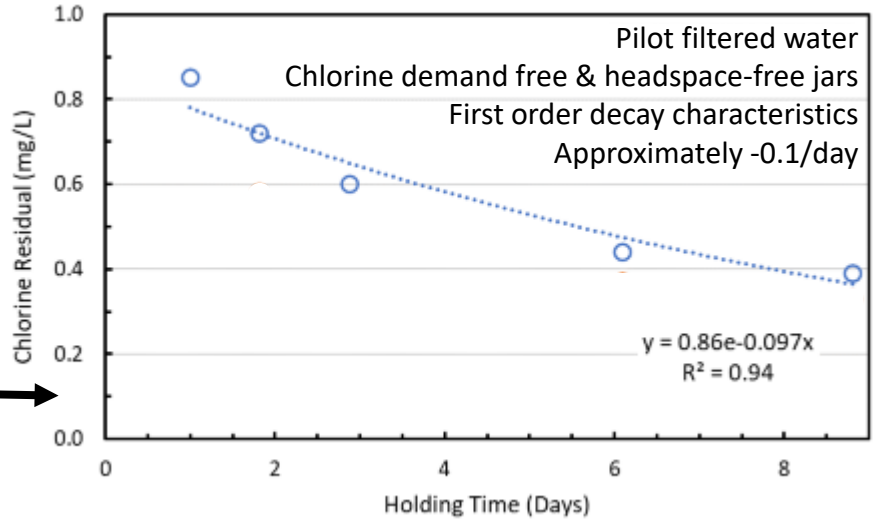
- Long-Term (Days) Decay
  - Ammonia, TOC, others cause Cl_2 demand
  - Time 0 after pilot filter & free Cl_2 achieved
  - Target of 1 mg/L free residual Cl2
  - Decay of ~0.5 mg/L after 1 week



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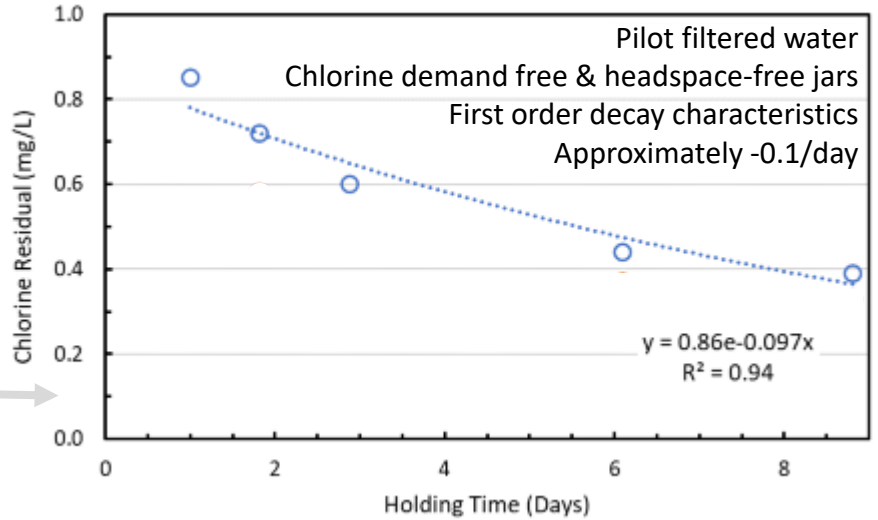
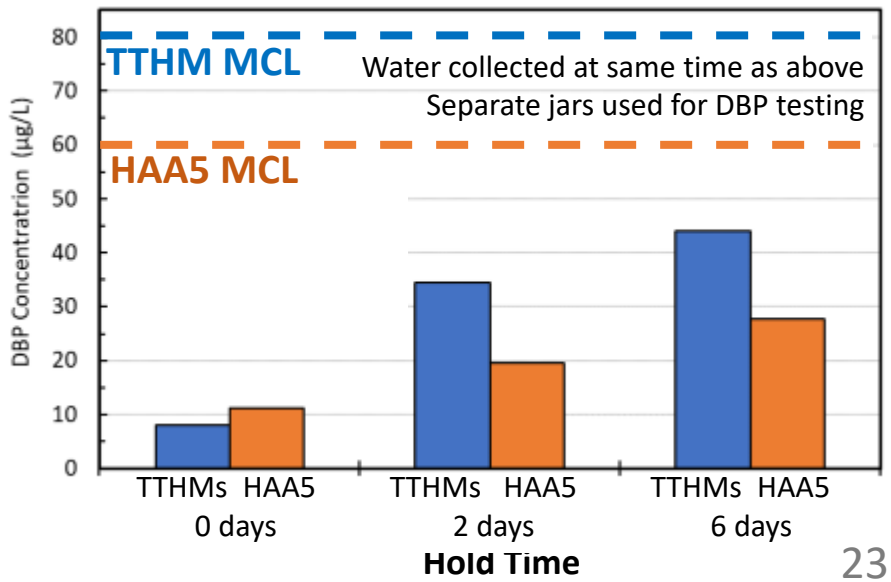
  - Decay of ~0.5 mg/L after 1 week
- Simulated DBP Testing
  - After approximately 1 week
  - DBPs ~50% of THM and HAA5 MCLs





Applying Results

Full-Scale Activities

- Recommendations Turning into Capital Improvements (Murraysmith completing facility retrofit designs)
  - Chemical storage and feed improvements
  - Building and site improvements
  - Filter backwash recycle to be added
  - After retrofit, Confluence to confirm optimized operations
- Operations Improvements Continuing
- $KMnO_4$ Dose Optimized
  - Filters performance acceptable
  - Conduct another filter soak before summer
  - Replacement of filter media being considered
- Automate Chlorine Feed for NH_3 Control & Sustained Filter Performance….

Automating the Cl_2 Dose

- NH_3 Analyzer: Select, Procure, Complete Testing
  - Reviewed available equipment
  - Completed multi-criteria analysis (accuracy/reliability, purchase/O&M costs, etc.)
  - Purchased ChemScan UV/spectrometer
  - Completing acceptance tests (data in review)

ChemScan NH_3 analyzer installed at end of 2021

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- Installed Free & Total Chlorine Analyzers

HACH Cl_2 analyzer installed at beginning of 2022

Automating the Cl_2 Dose

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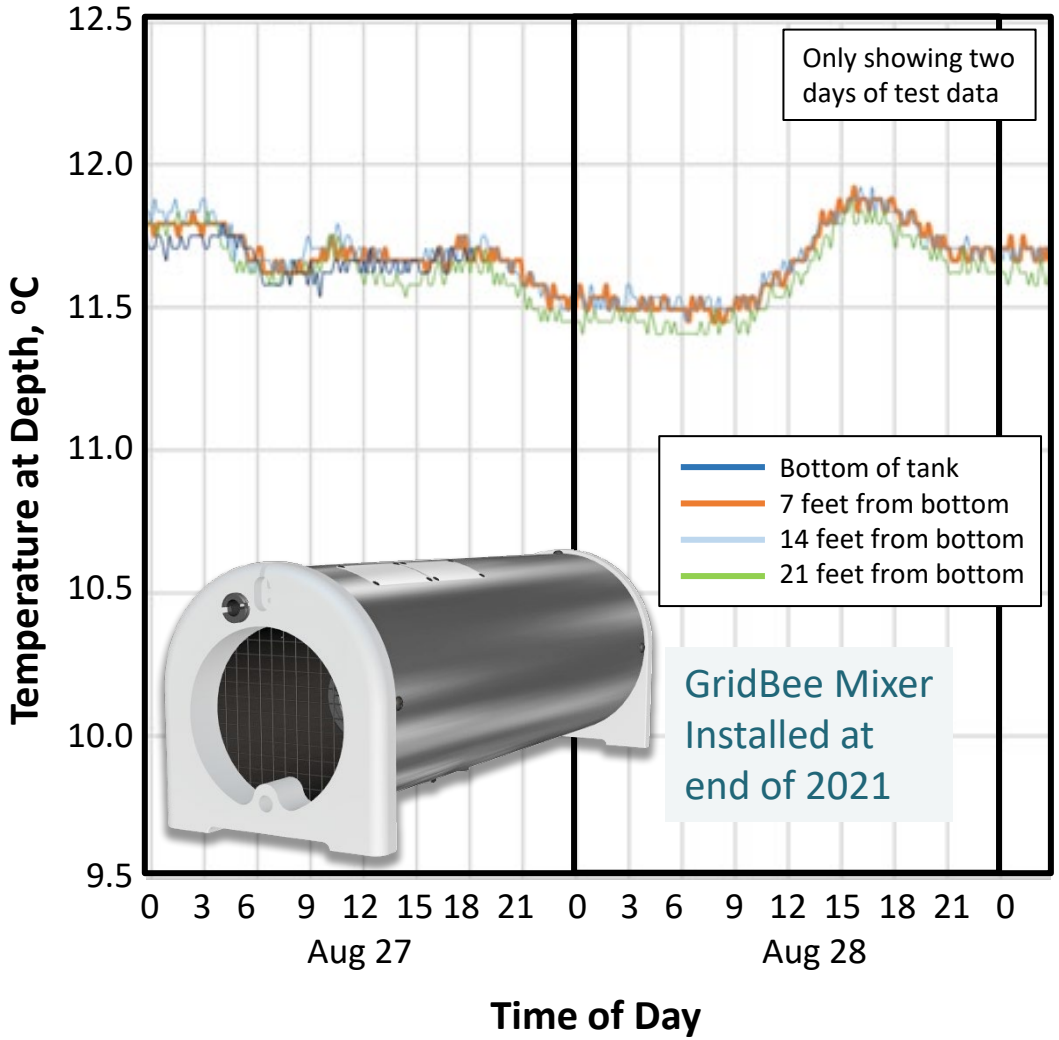
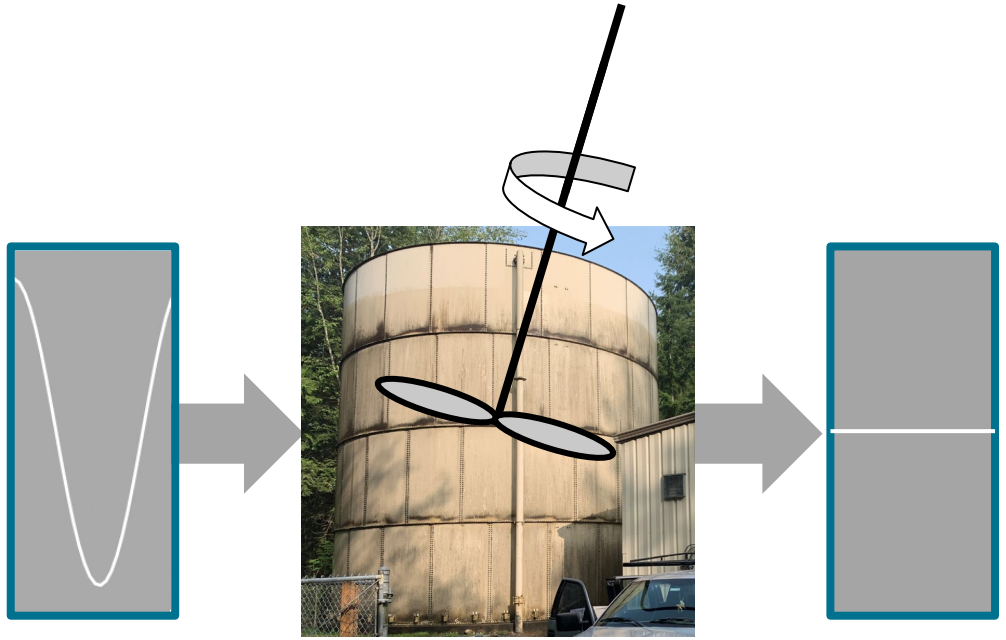
  - Purchased ChemScan UV/spectrometer
  - Completing acceptance tests (data in review)
- Installed Free & Total Chlorine Analyzers
- Reservoir Mixer: Prevent Tank Short Circuiting
  - Complete F:T Cl_2 reactions in the tank
  - Mixer purchased and installed
  - All depths well mixed (+/- 0.2 °C)

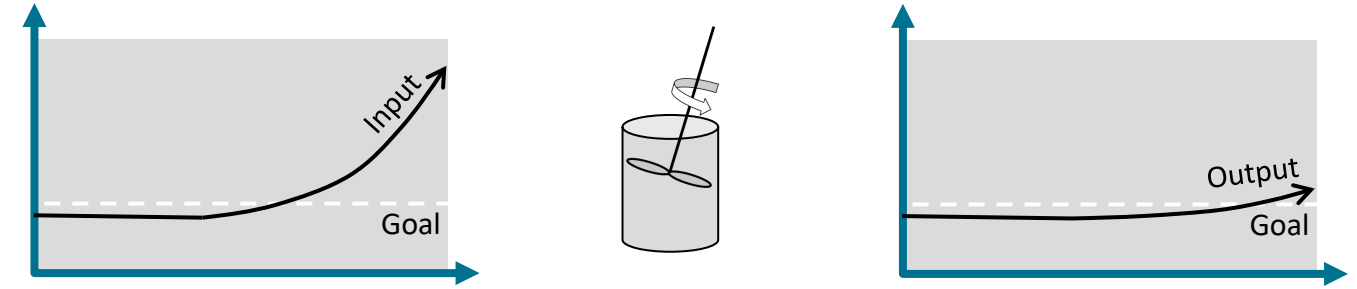


Finished Water Tank: Storage Time is a Benefit

- Characteristics of a Continuously-Stirred Tank Reactor (CSTR)
  - Large, bulk change happens slowly
  - Small changes observed rapidly
  - Promotes stable operations



Therefore:

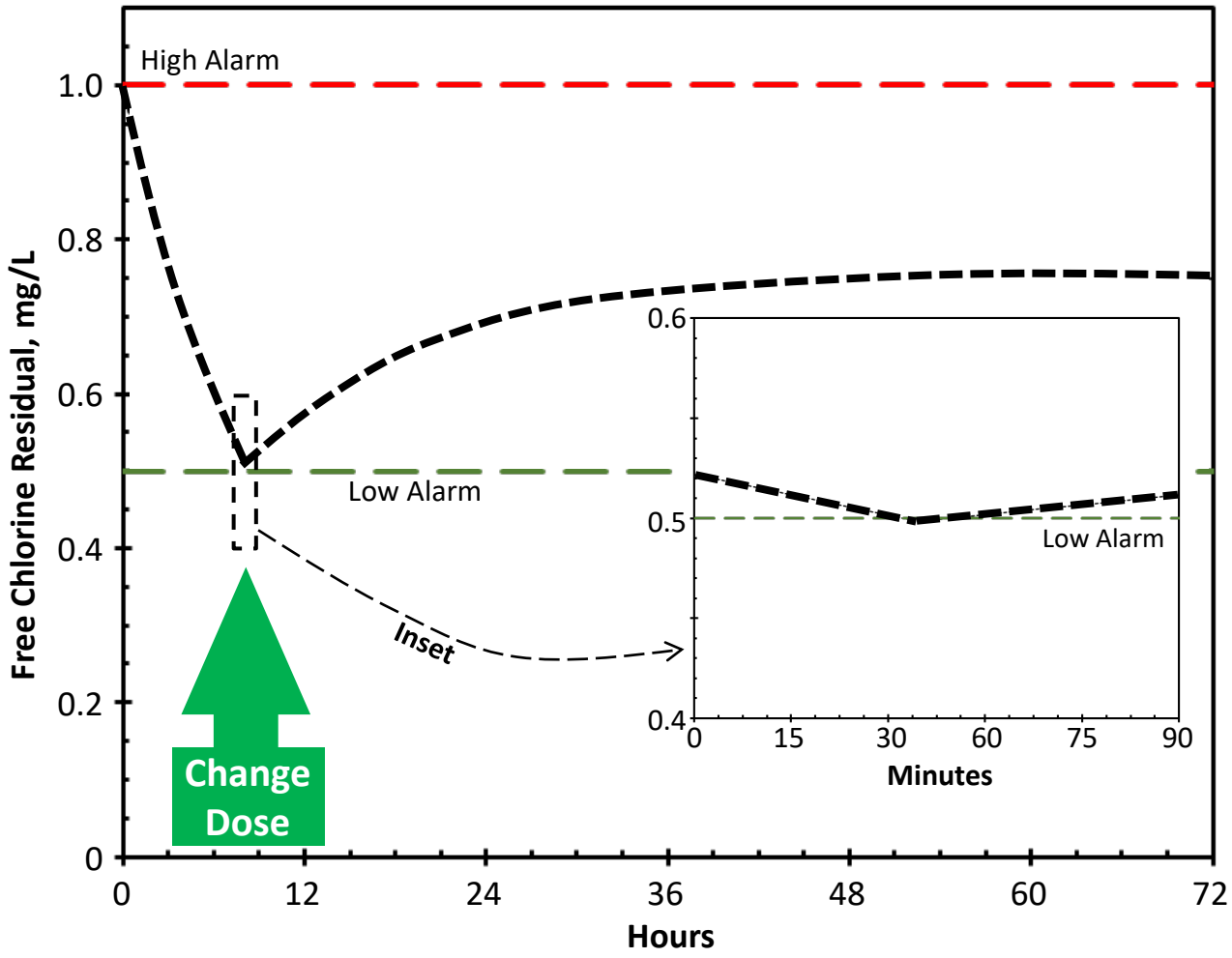


Rapid change of input + CSTR = slow change at output

Sine wave gif: www.stackoverflow.com

Finished Water Tank: Storage Time is a Benefit

- Characteristics of a Continuously-Stirred Tank Reactor (CSTR)
  - Large, bulk change happens slowly
  - Small changes observed rapidly
  - Promotes stable operations
- Theoretical SnoPUD Tank Example
  - "If" Cl_2 feed *stops* (example only)
  - Time to tank outlet = hours
  - Observing a dose change = minutes
- Set SCADA to identify downward or upward sloping trends & respond



Next Steps

- Another Cl_2 + $KMnO_4$ Filter Soak
- Startup Items
  - NH_3 and Cl_2 Analyzer Startup QC and SCADA Upgrades
  - Free chlorine conversion plan & begin optimized dosing
  - Can begin before/during capital improvement activity
  - Sentinel distribution system monitoring and response
- Re-Assess Filter Conditions with Free Cl_2
  - Improved media performance, or new media needed?
  - Are $KMnO_4$ feed changes needed?
  - Impacts from backwash recycling?

Process Control and Treatment Optimization for Groundwater with Elevated Ammonia and Manganese

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Thank You!

American Water Works Association
Pacific Northwest Section

2022 Section Conference
Tacoma, Washington April 27-29

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