TETRA TECH

Pilot Testing for Indirect Potable Reuse in Florida:

Clearwater's Groundwater Replenishment Progam Takes the Next Step

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& Planning Conference
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Southwest Florida Water Management District

CITY OF Clearwater

LBG

Outline

- Project Background and Objectives
- Treatment Approach
- Treatment Results
  - Water Purification
  - Groundwater Recharge Conditioning
- Conclusions

Project Background and Objectives

Mission - Clearwater Public Utilities

- To provide high-quality water, wastewater & reclaimed water services while protecting the public health and natural environment of the City through cost-effective management, operation, and maintenance of the City's infrastructure sustaining these essential services.

Integrated Water Management Tactics

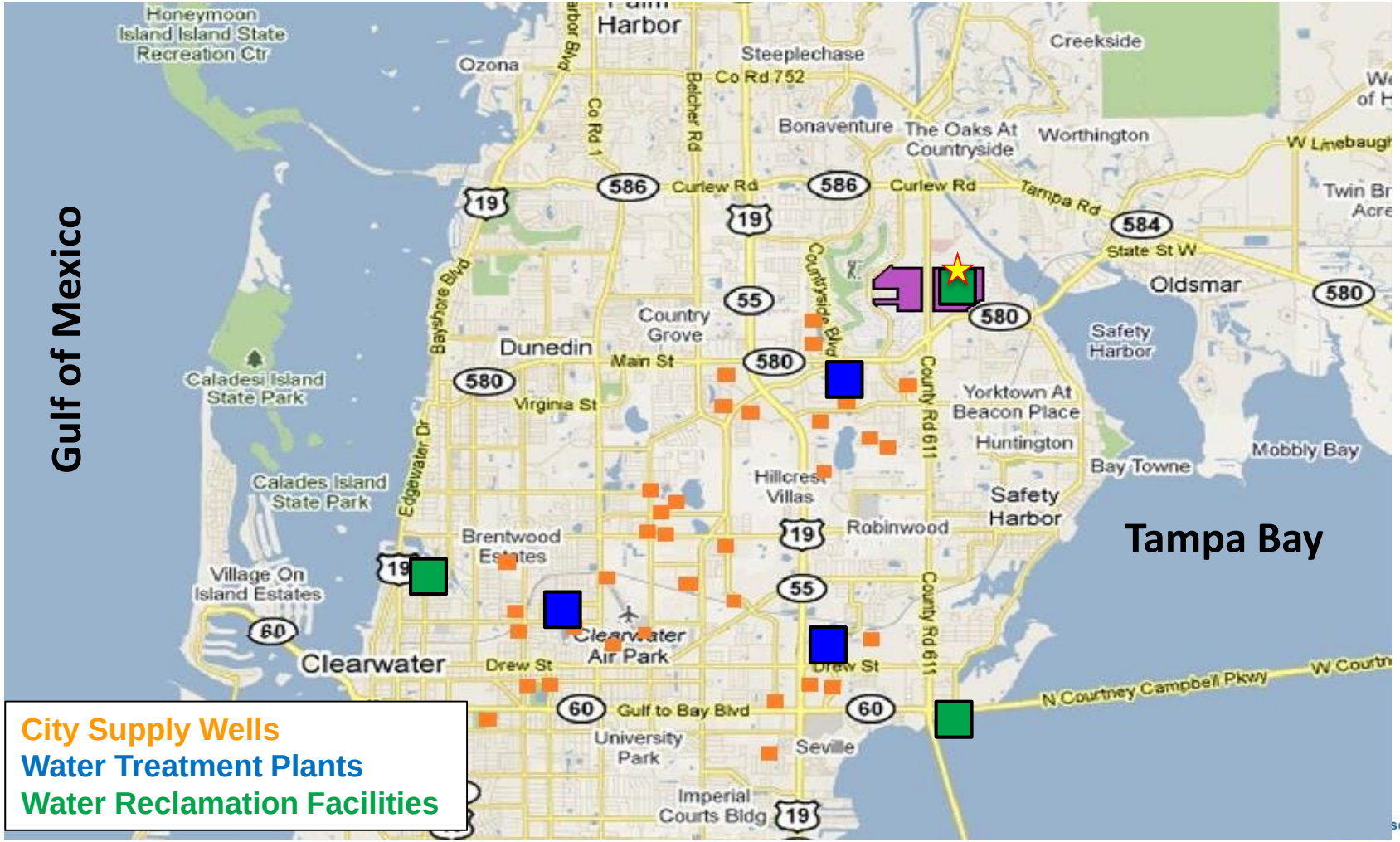
- Conserve Limited Water Supplies
- Preserve Drinking Water Sources
- Protect Coastal Environment
- Produce More Water Locally
- Manage the Rising Cost of Water

Project Objective

- ***To construct a water purification plant at the existing Northeast Water Reclamation Facility to supply 3 MGD of highly treated water to recharge lower Zone A of the Floridan Aquifer***

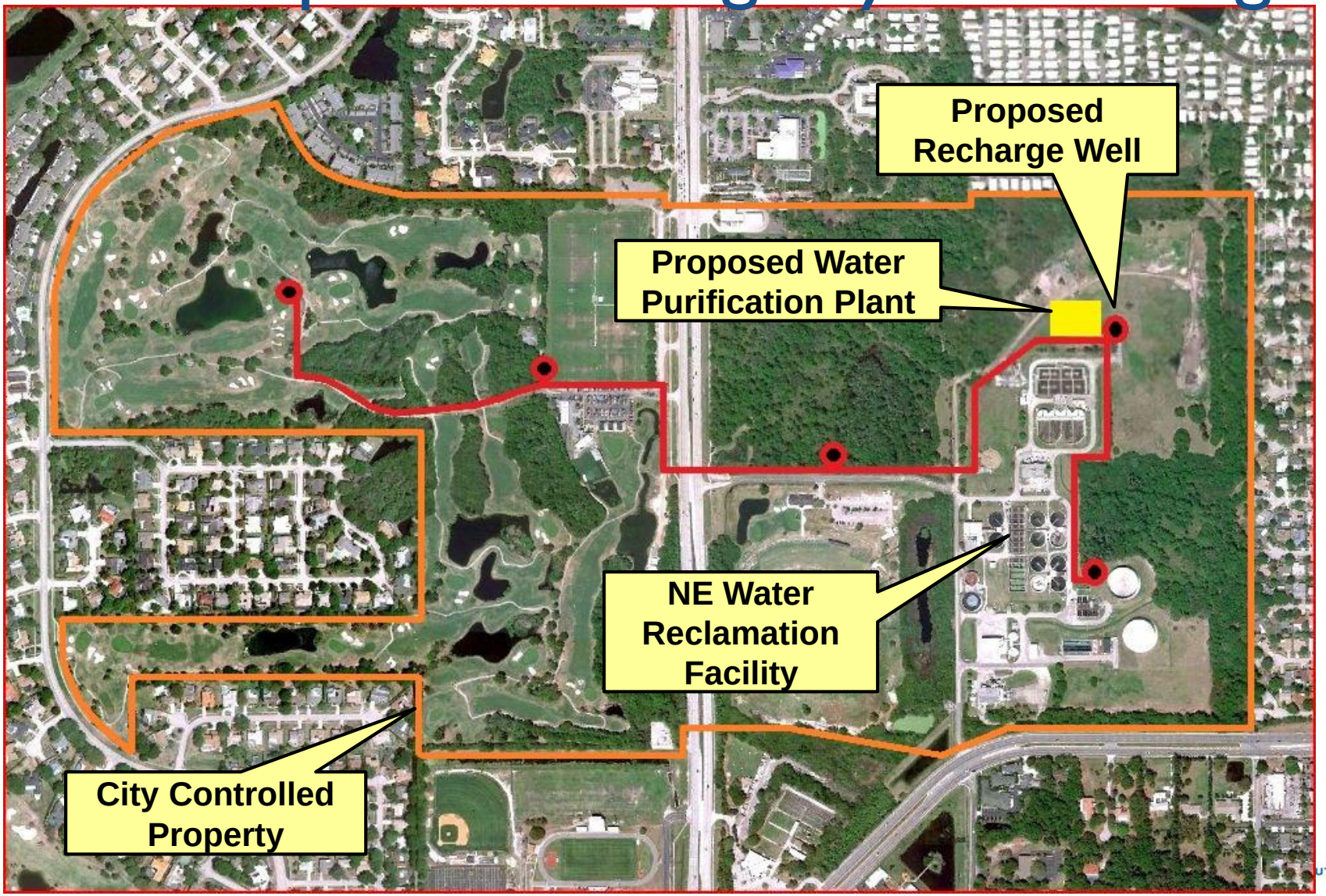
Project Location

Pilot Testing is Being Conducted at the City of Clearwater's Northeast Water Reclamation Facility

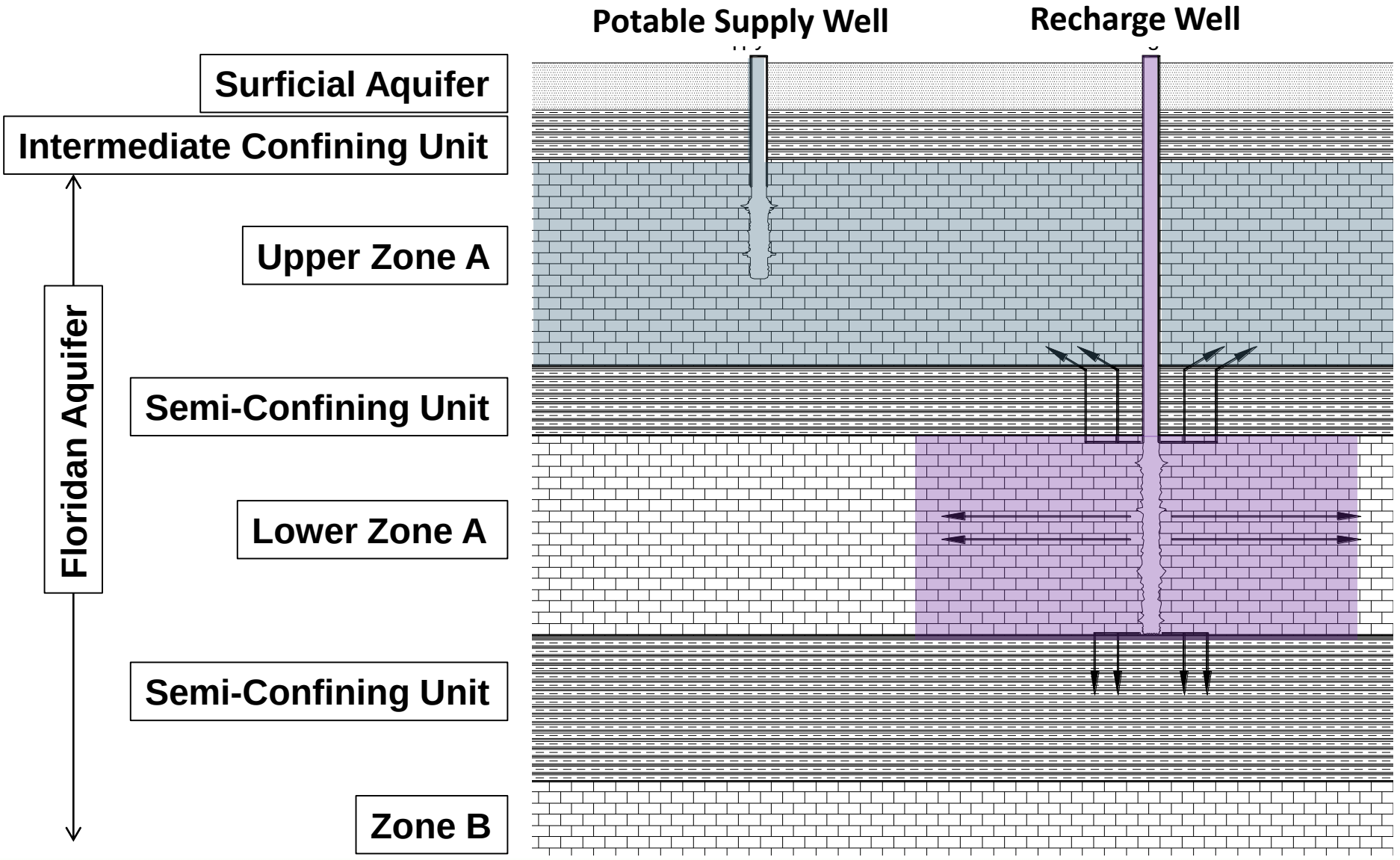


City Supply Wells
Water Treatment Plants
Water Reclamation Facilities

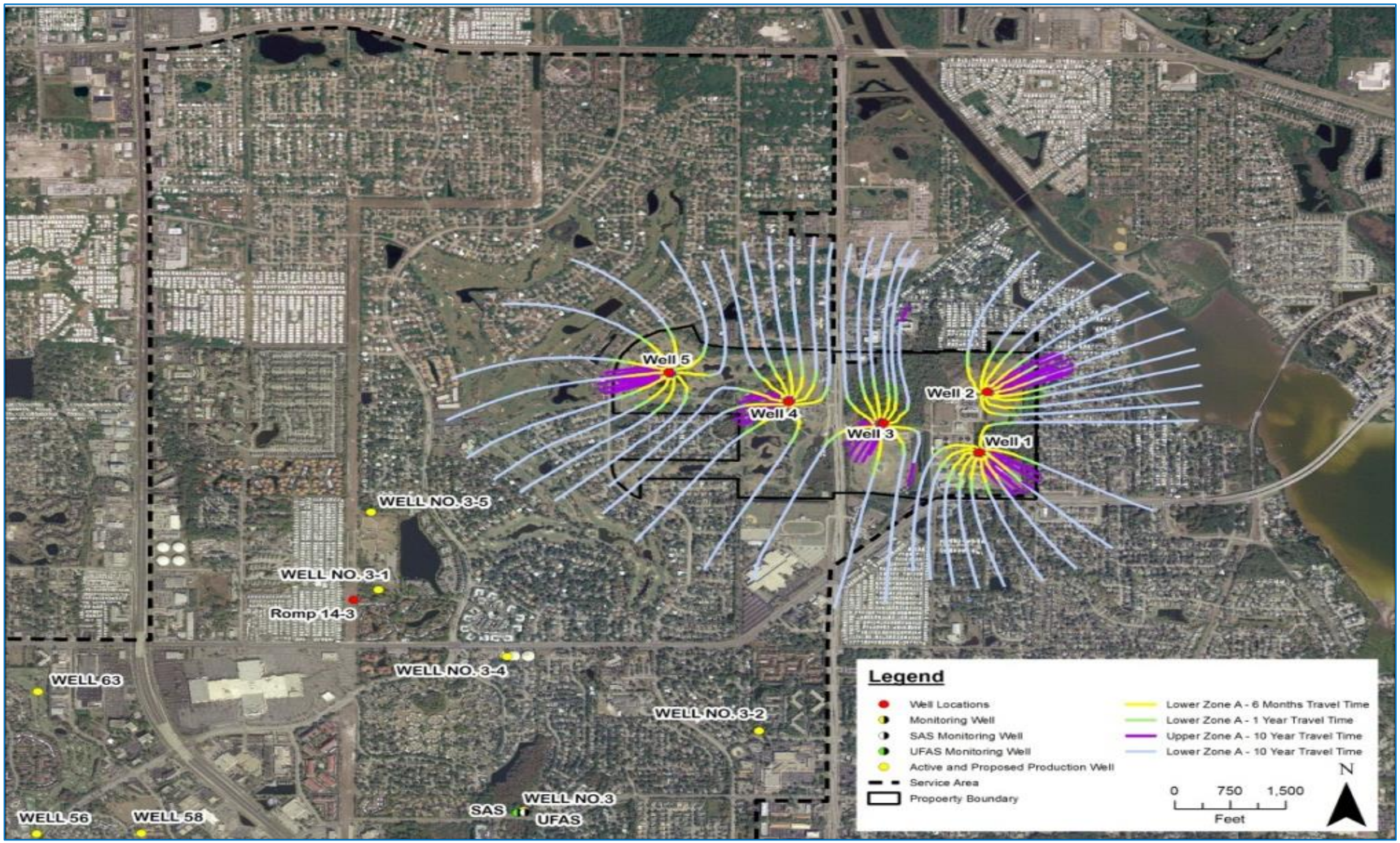
Conceptual Recharge System Design



The Recharge Well Will Inject into Lower Zone A of the Floridan Aquifer



Model Particle Tracks Show the Expected Migration of Water 10 Years from Injection

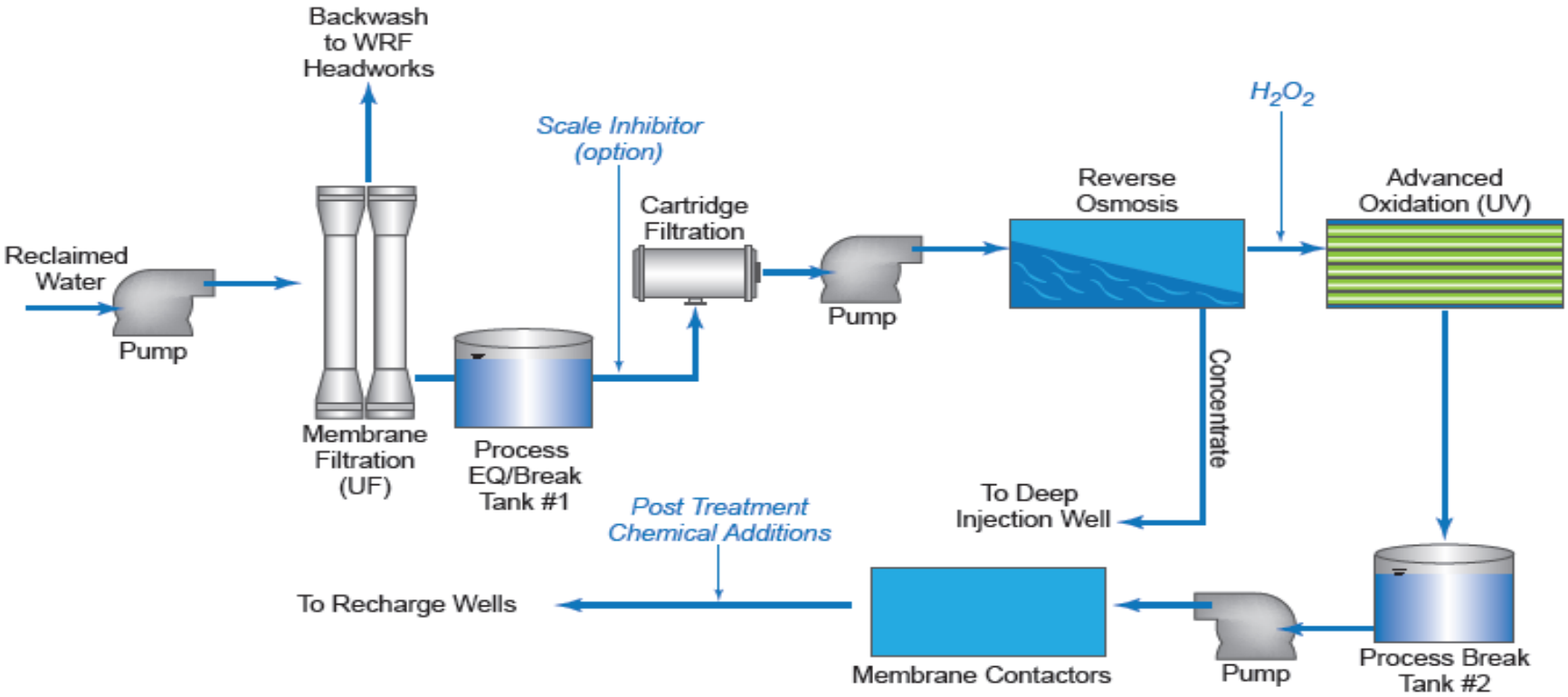


Pilot Testing Process

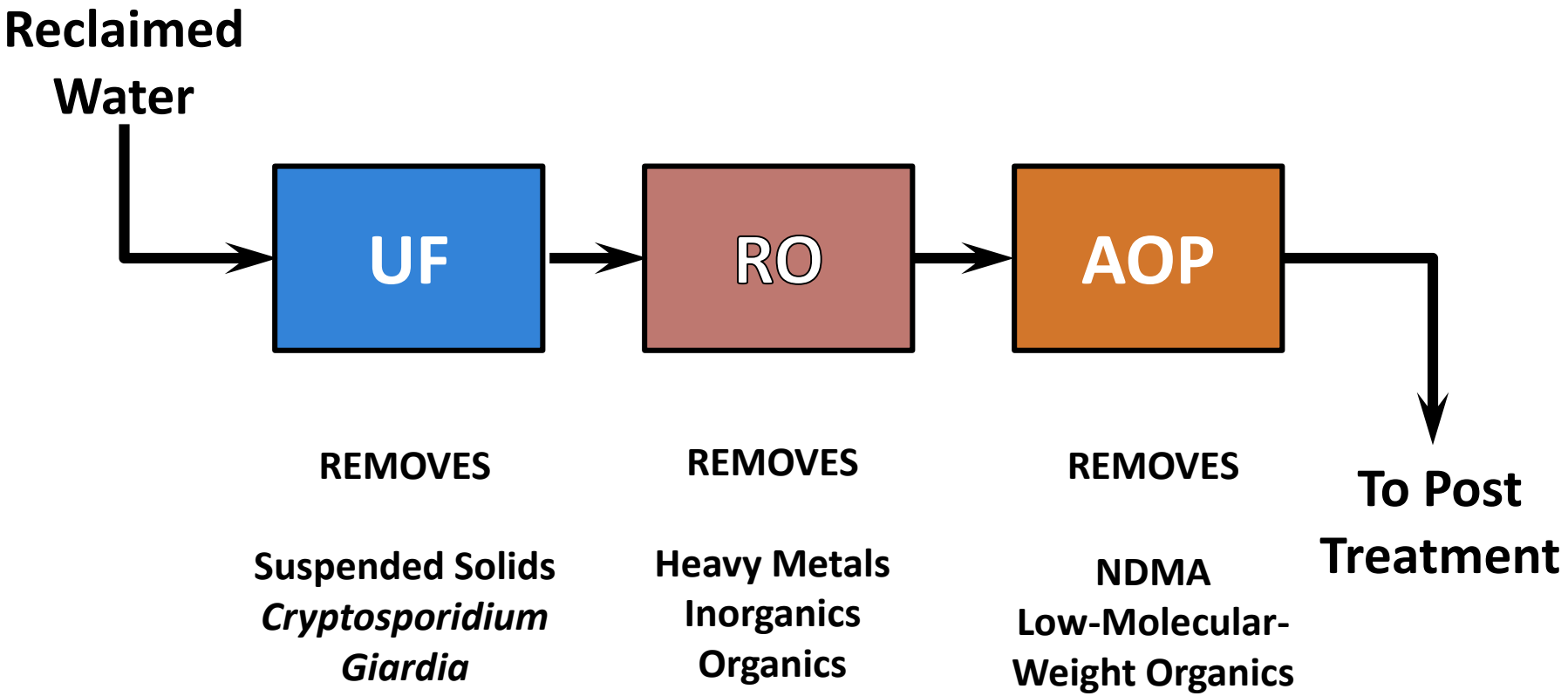
- The full purification and post treatment process is being demonstrated at pilot scale
- Duration of up to 12 months (FDEP, Chapter 62-610)
- Pilot source is the City's Northeast Water Reclamation Facility (tertiary treatment to public access reuse standards)

Treatment Approach

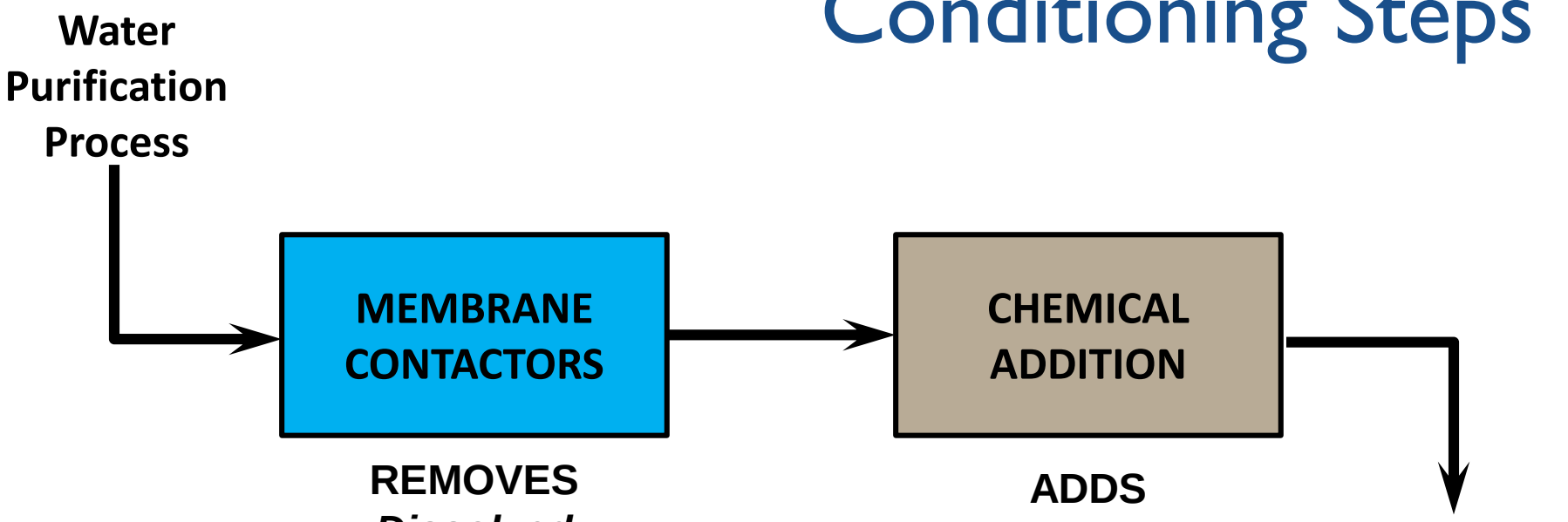
Process Flow Schematic



Water Purification Treatment Steps



Groundwater Recharge Conditioning Steps



REMOVES
Dissolved Oxygen

- **Mitigate Potential for Arsenic Mobilization**

ADDS
Carbon Dioxide
Calcium
Alkalinity
Sodium Bisulfide (Reducing agent)

- **Adjust pH**
- **Adjust LSI**
- **Reduces ORP**

Treatment Results

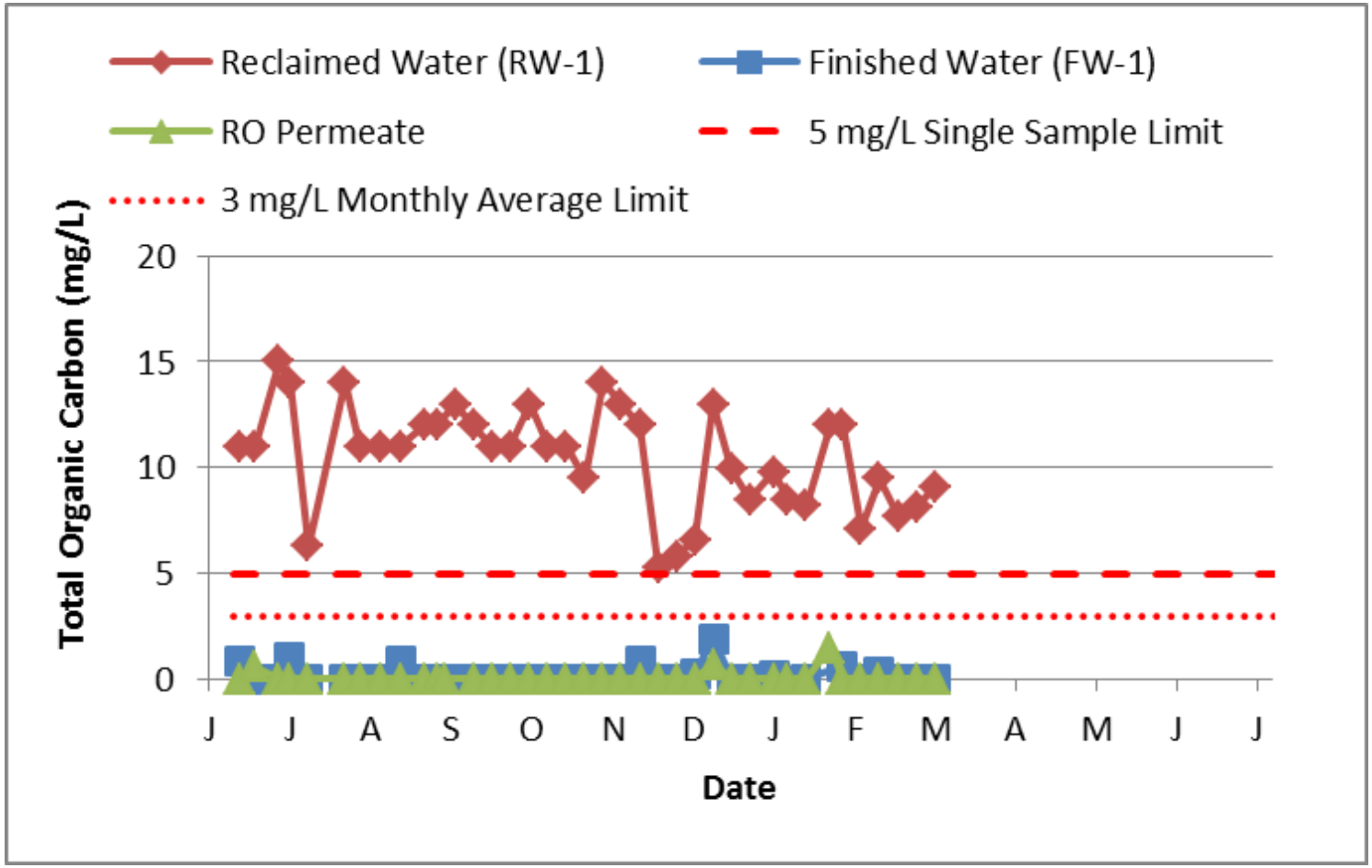
Treatment Performance Monitoring Has Covered A Broad Range of Parameters

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - Mutagenicity
  - Microconstituents
- Groundwater Recharge Conditioning
  - Dissolved Oxygen Removal
  - Calcium stabilization
  - Neutralization of chloramines and peroxide

Purification System Has Shown Effective Performance in Organics Removal

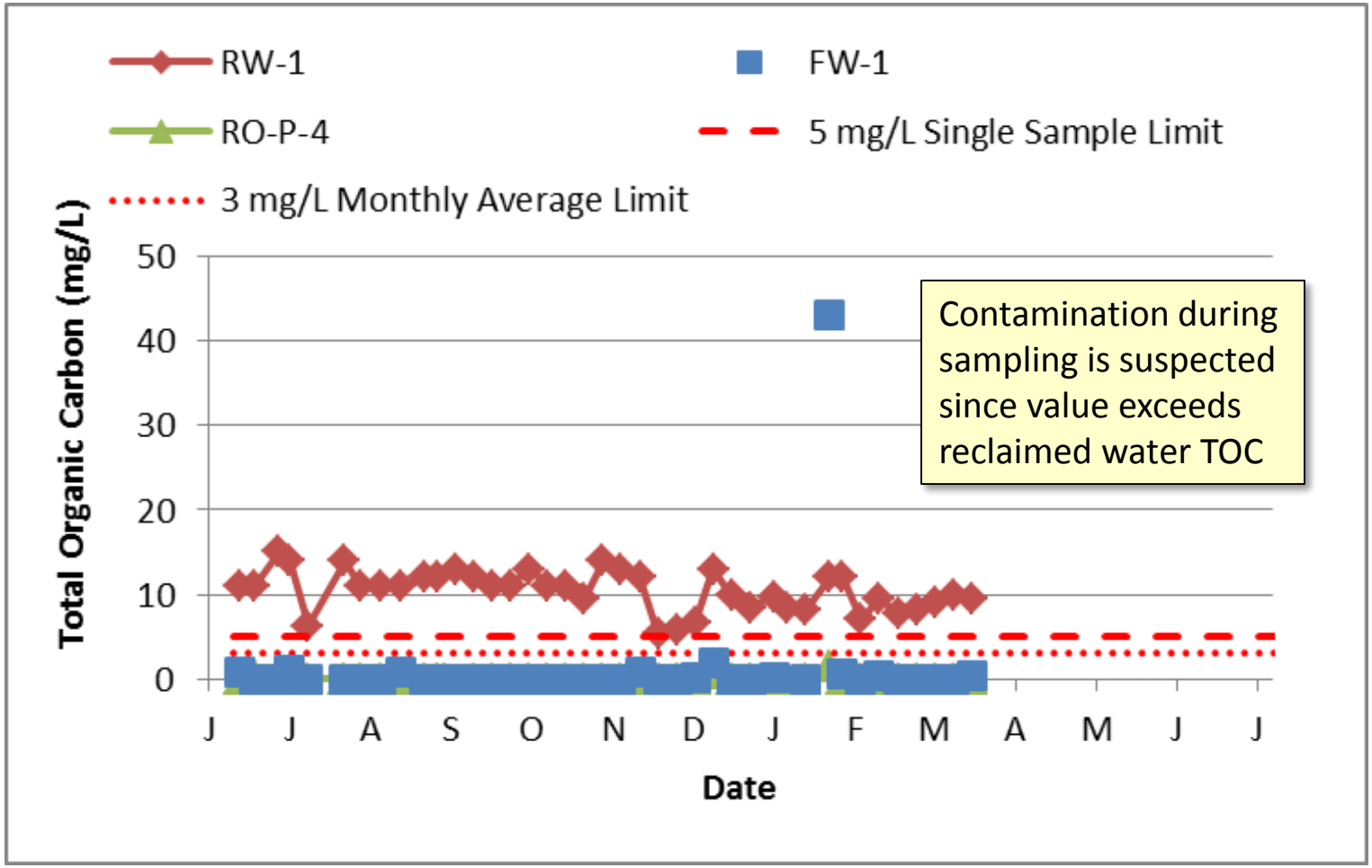
- Water Purification
  - **Organics Removal**
    - **Total Organic Carbon, Total Organic Halides**

TOC has Been Removed to the1 mg/L Reporting Limit



Requirement from Rule 62-610.563

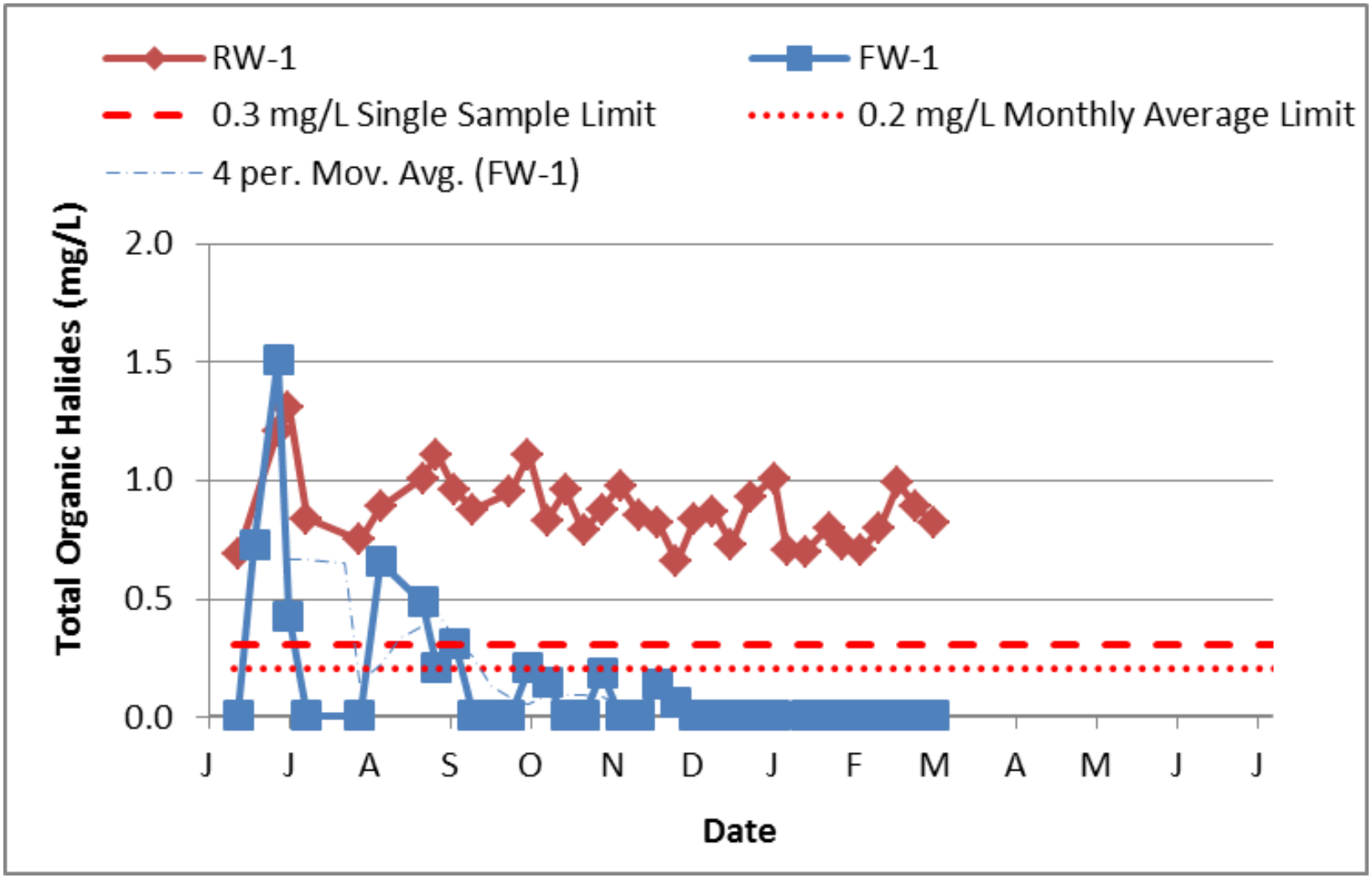
A High TOC Outlier was Observed in The Finished Water on 1/23



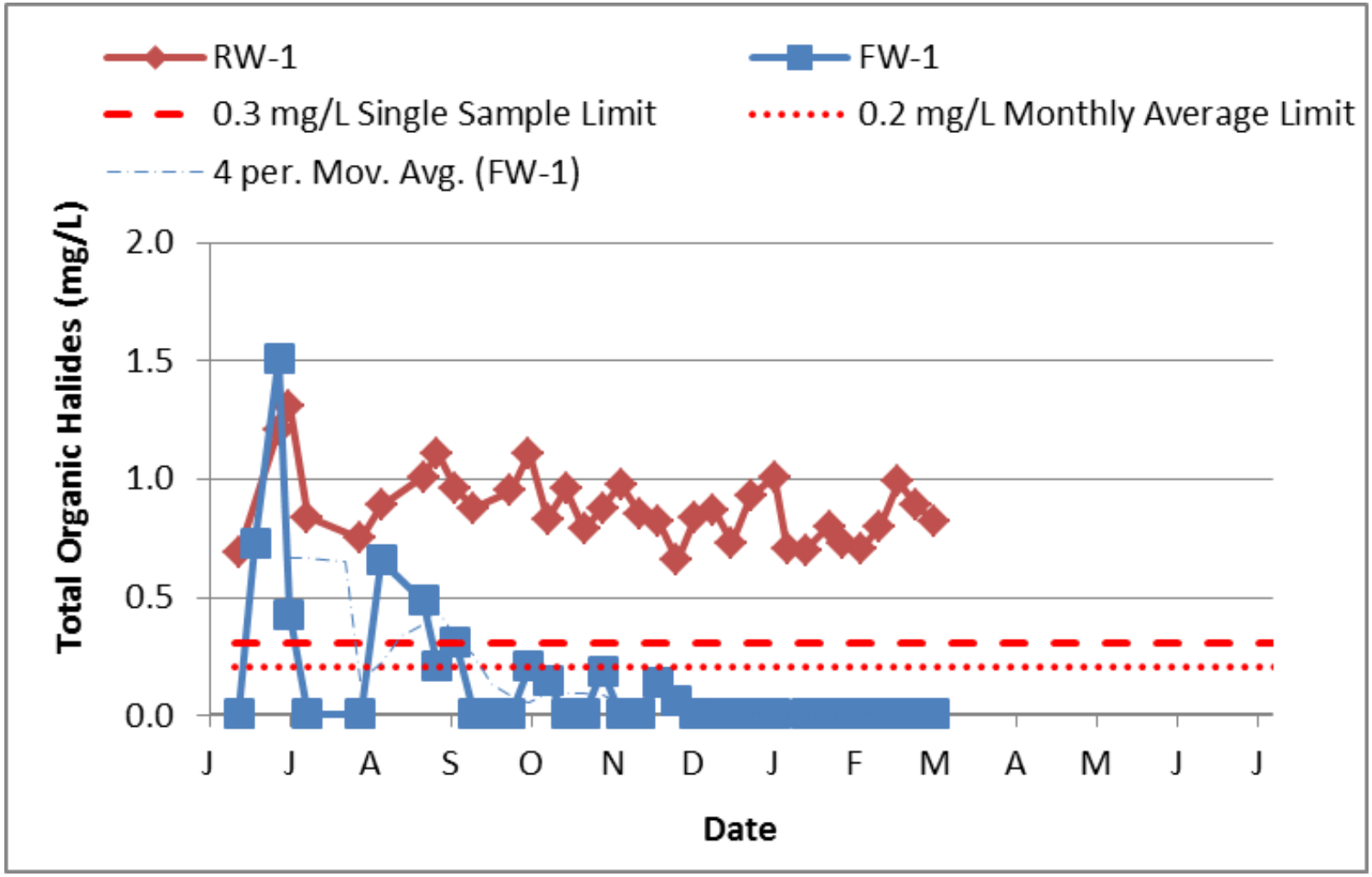
Requirement from Rule 62-610.563

High Value on 1/23

Total Organic Halides Are Within the Limits



Early High TOX Results Ceased After Changes in Sample Tap Chlorination and Flush Practices



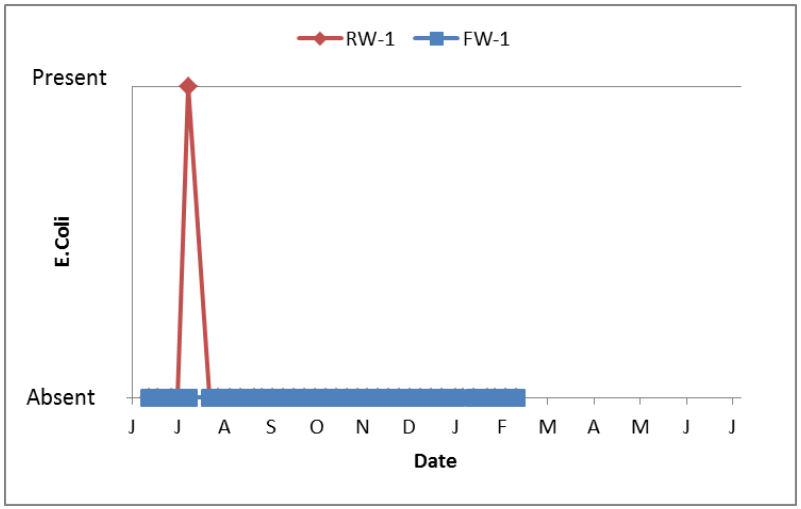
Purification System Has Shown Effective Performance Removing Pathogenic Microorganisms

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - **Microorganisms**

No Coliform Bacteria Have Been Present in the Finished Water

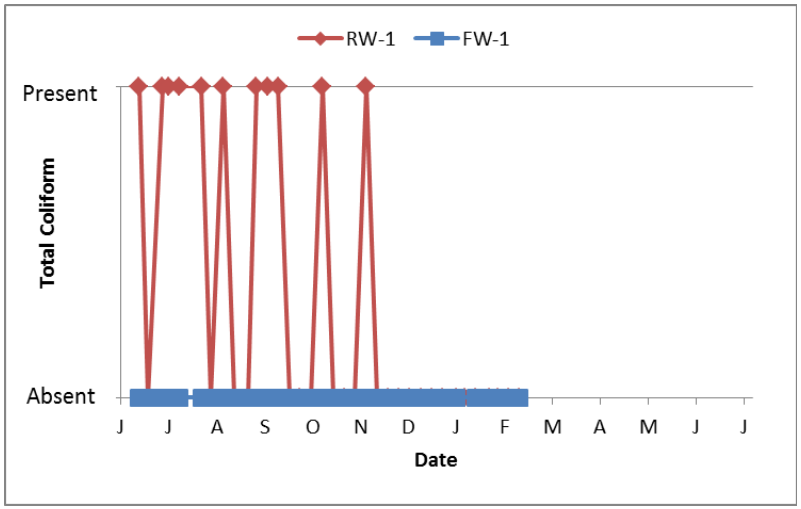
E. Coli

- Present in reclaimed water once



Total Coliform

- Present in reclaimed water several times



Over 40 weekly samples to date

No Viable Pathogens were Detected in the Finished Water

Pathogen	Units	Reclaimed Water				Finished Water			
		7/19/13	10/8/13	12/3/13	2/4/14	7/19/13	10/8/13[1]	12/3/13[1]	2/4/14[1]
Cryptosporidium	Oocysts/ 100L	16.3	14.4	3.2	1.3	-[2]	BDL	BDL	BDL
Enteroviruses	Infectious Units/ 100L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Giardia	Oocysts/ 100L	2.8	12.5	7	22.6	BDL	BDL	BDL	BDL
Helminth Ova	Total ova/L	45	27	26	12	BDL	0.07[3]	0.16[3]	0.07[3]
	Viable ova/L	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Notes: [1]- Sampled from membrane contactor effluent to avoid turbidity interference from lime addition.
[2]- Turbidity interference from lime addition in the finished water interfered with pathogen counts for 7/19/13.
[3]- None of these helminth ova were found to be viable, and therefore do not pose any infection risk.

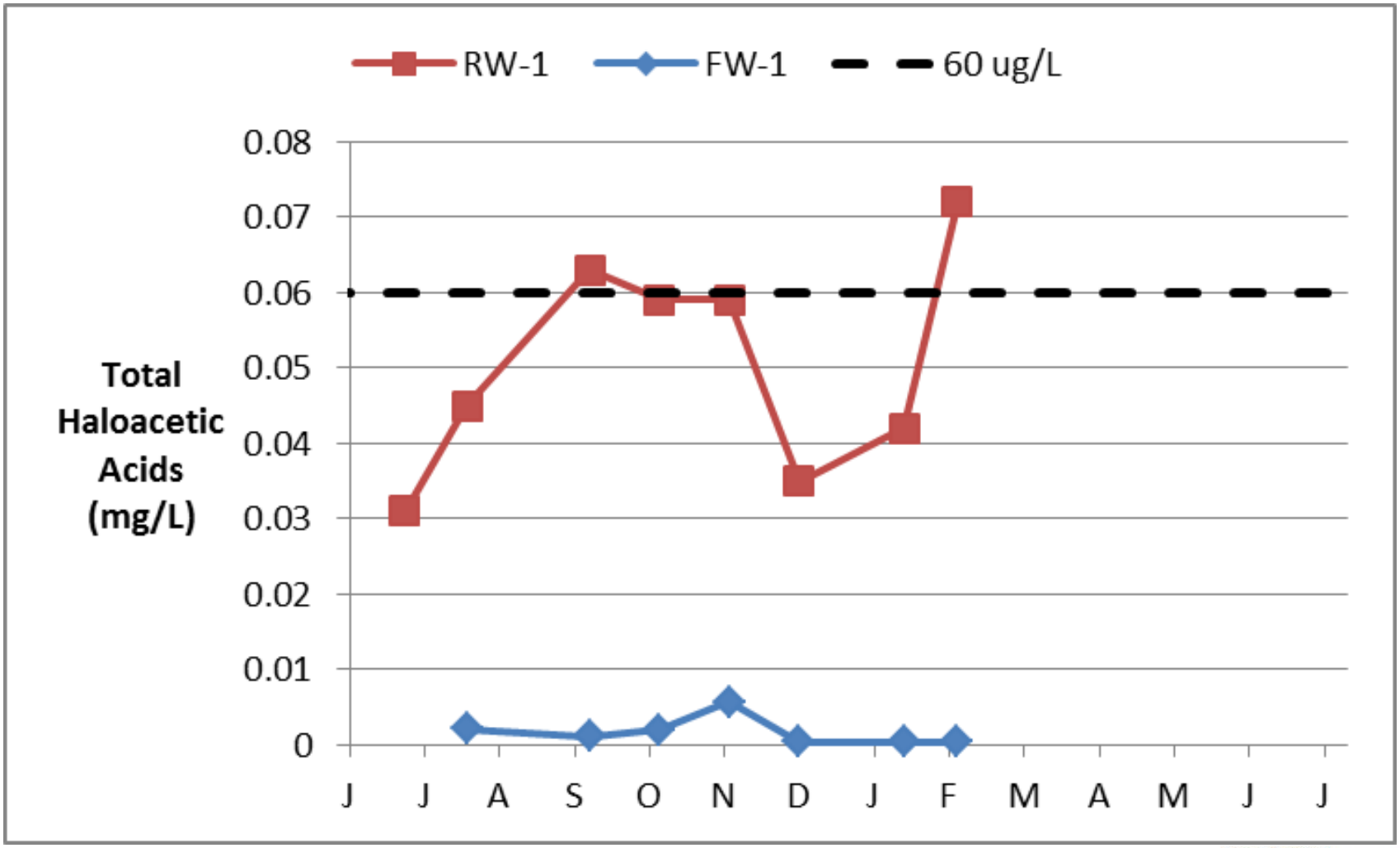
Suspect That Nonviable Helminth Ova Were Introduced Through Return Water Tank

- No helminth ova should be visible after UF and RO
- Return Tank Gets Water at End of Pilot from EQ Tank #1, EQ Tank #2, and Finished Water
- Water back siphoned into EQ Tank #2 when the drain lines into the return tank had no air gap
- EQ Tank #2 cleaned March 2014
- Next samples April 2014

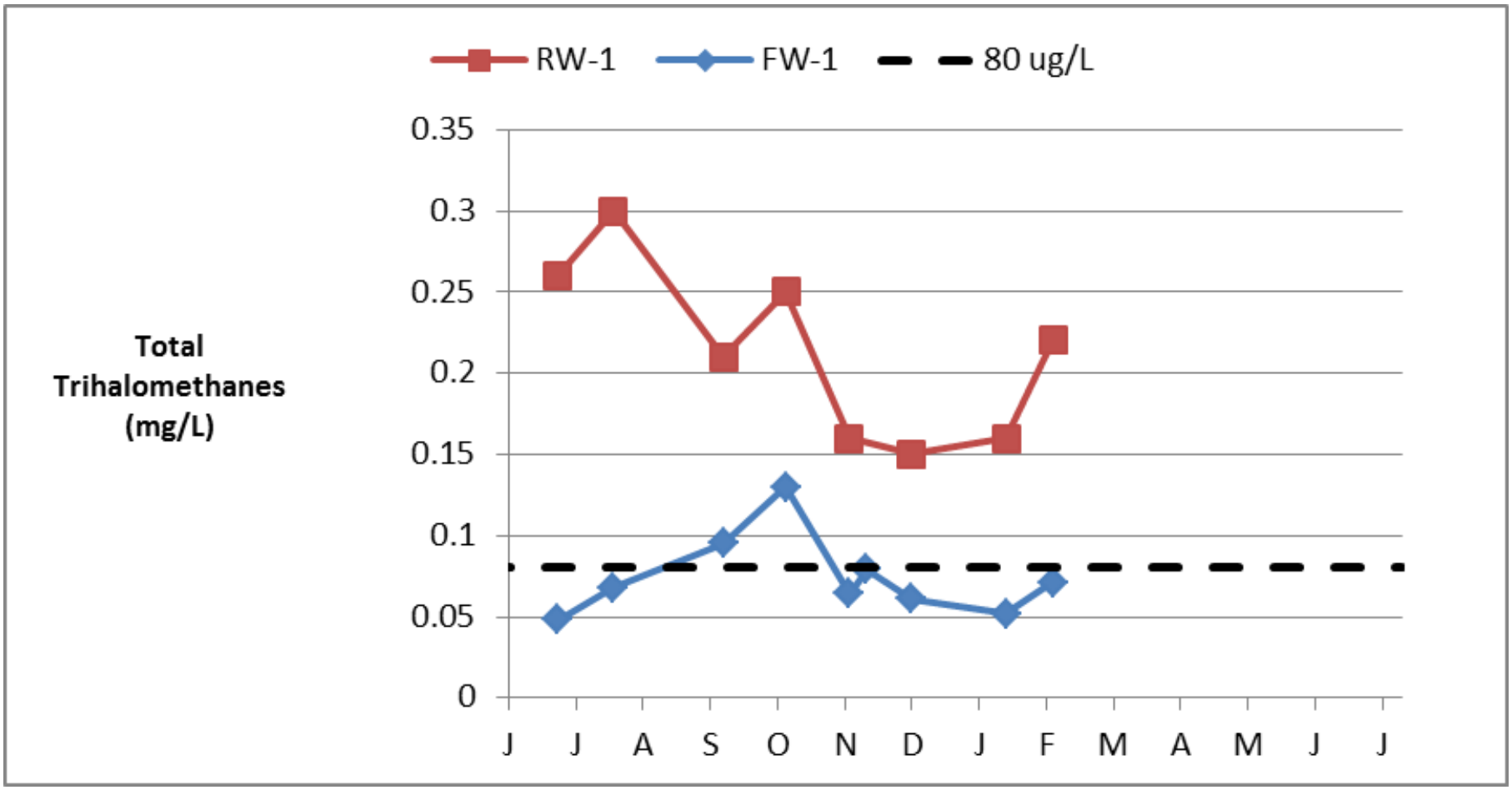
Purification System Has Shown Effective Performance Reducing Disinfection Byproduct Levels

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
    - Microorganisms
  - **Drinking Water Standards**
    - **Disinfection byproducts**

HAAs in Finished Water Are Below the 60 µg/L Drinking Water MCL



TTHMs in Finished Water Are Near the 80 µg/L Drinking Water MCL



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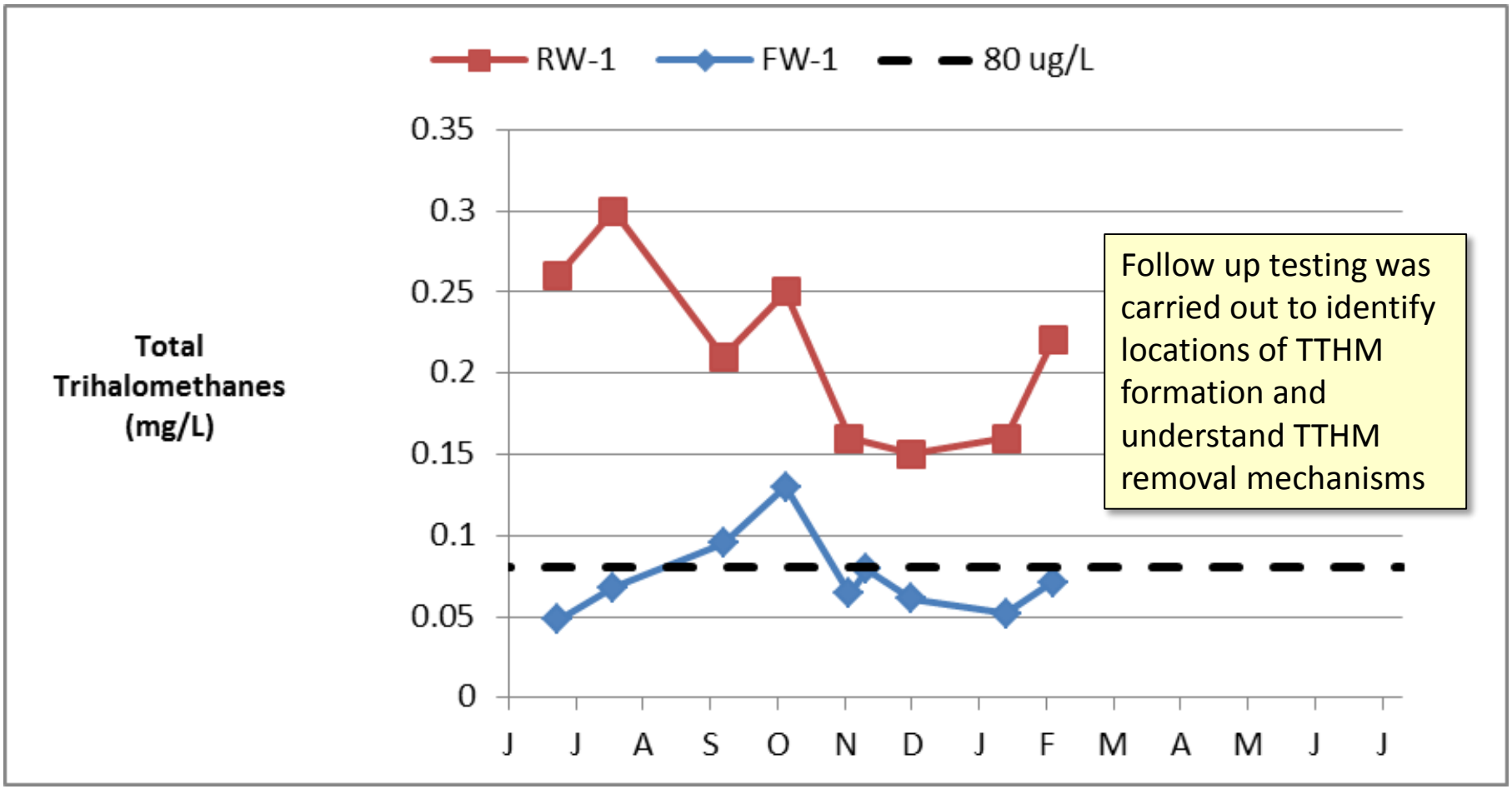
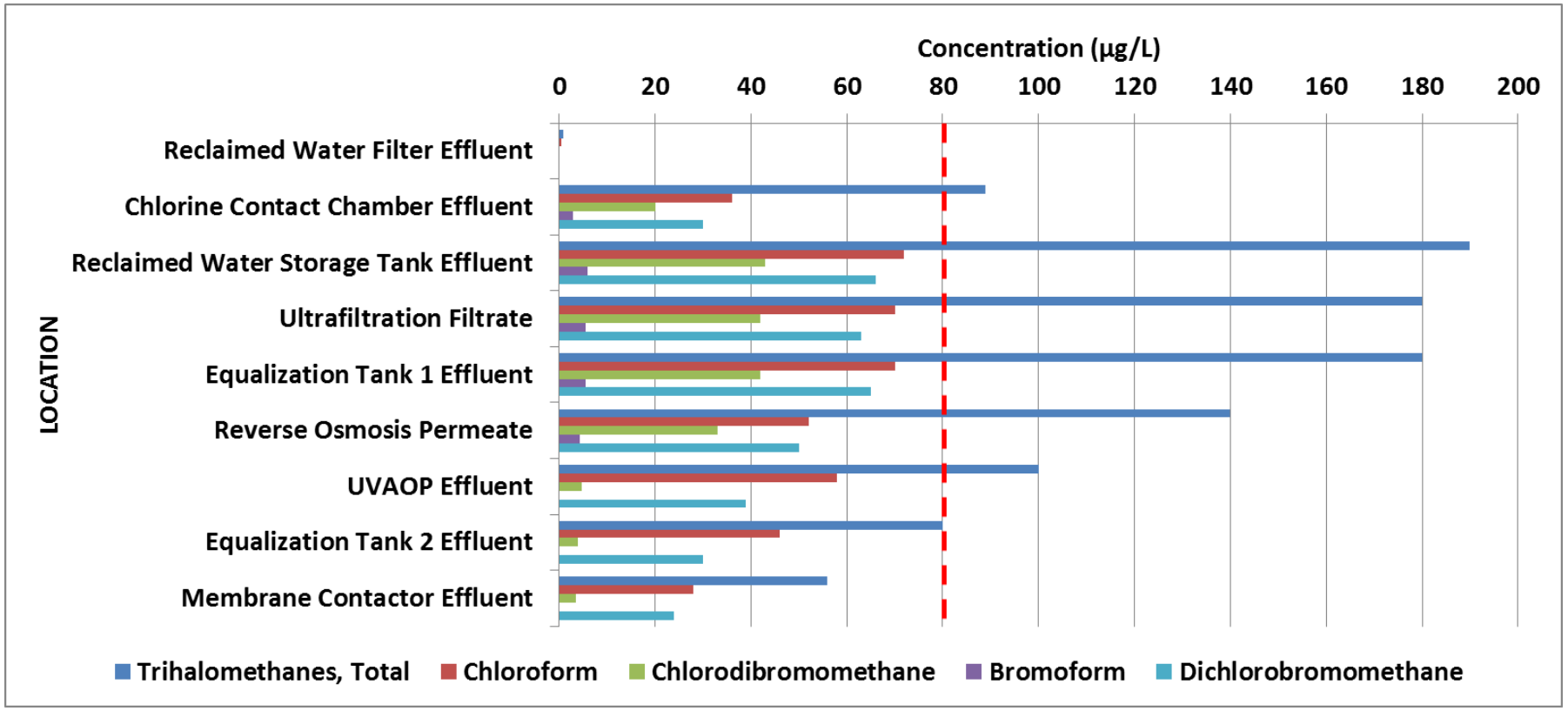
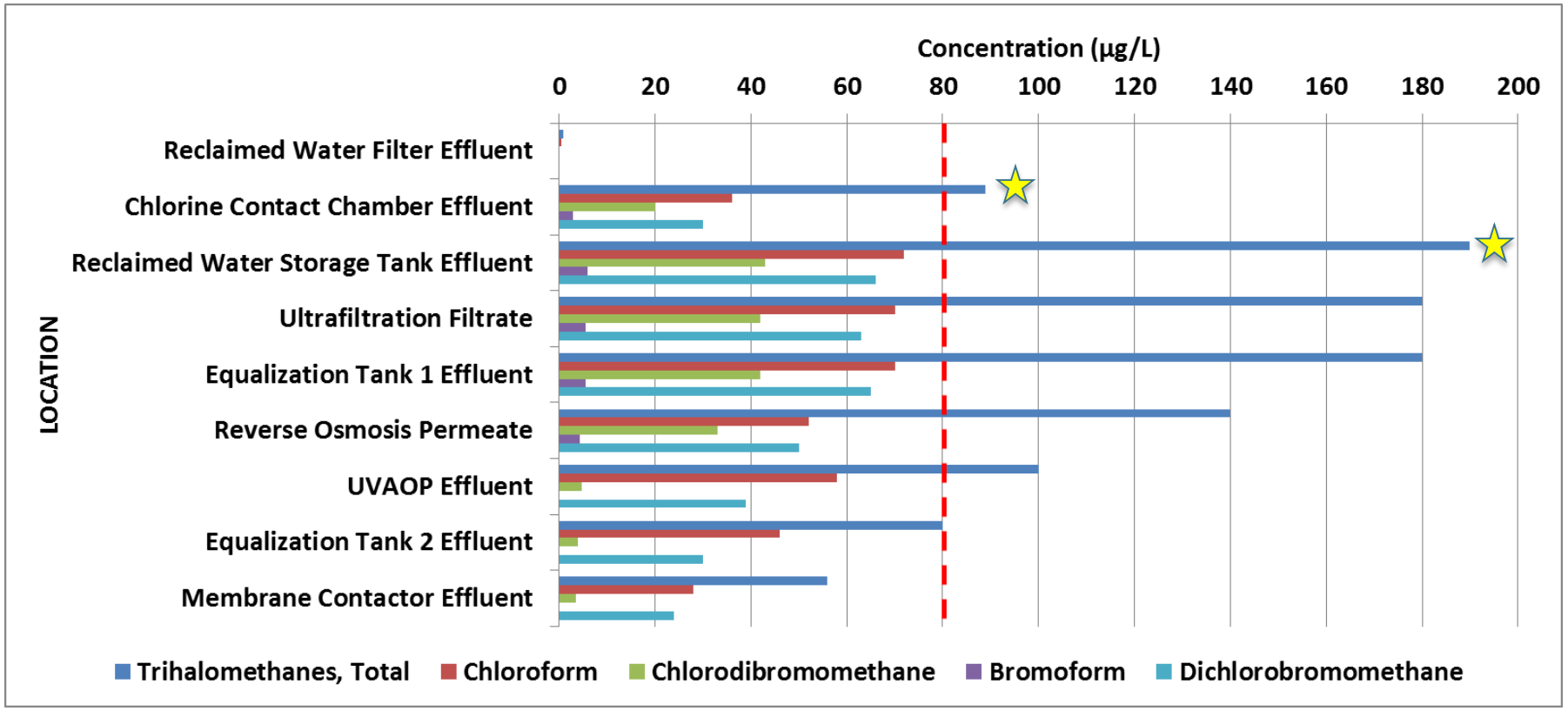


A System Profile Was Carried Out for TTHMs



Moving the Source Water Location from the Reclaimed Water Storage Tank to the Chlorine Contact Chamber Could Reduce TTHMs by More than 50%

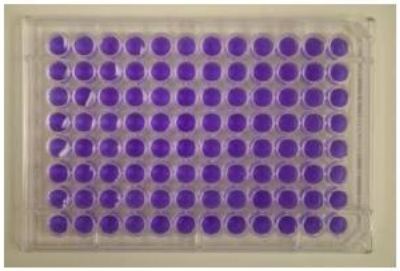


Treatment Performance Monitoring Has Covered A Broad Range of Parameters

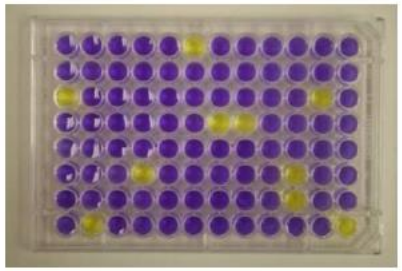
- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - **Mutagenicity**

Mutagenicity Tested Using the Ames' Test Method

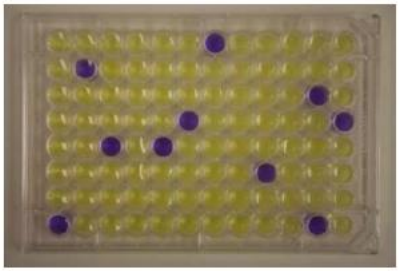
- Altered strains of *salmonella* or *e.coli* bacteria, with known mutations disabling production of yellow protein, are exposed to water and incubated in test wells for 5 days
- Mutagenic substances can mutate DNA back to native state, reactivating production of yellow protein
- More yellow test wells = more mutagenic activity



Sterility Check



Background



Strong Mutagen

Positive Control
(Very strong mutagen)

Image Courtesy: Test Supplier EBPI

Mutagenicity Tests Have Shown That the Treatment Train is Capable of Producing Water Without Significant Mutagenic Effects

Sample Date	Reclaimed Water					Finished Water				
	Bacterial strain					Bacterial strain				
	TA100	TA1535	TA97	TA98	WP2	TA100	TA1535	TA97	TA98	WP2
8/22/13										
10/8/13										
11/19/13										
1/14/14										

Strong Mutagenic Effects Observed

Weak Mutagenic Effects Observed

No Significant Mutagenic Effects Observed

Note: Peroxide residuals were present on 8/22/13 and 10/8/13

Incomplete Quenching of Peroxide was Identified as a Potential Cause of Mutagenicity in the Finished Water

Sample Date	Reclaimed Water					Finished Water				
	Bacterial strain					Bacterial strain				
	TA100	TA1535	TA97	TA98	WP2	TA100	TA1535	TA97	TA98	WP2
8/22/13										
10/8/13										
11/19/13										
1/14/14										

Strong Mutagenic Effects Observed

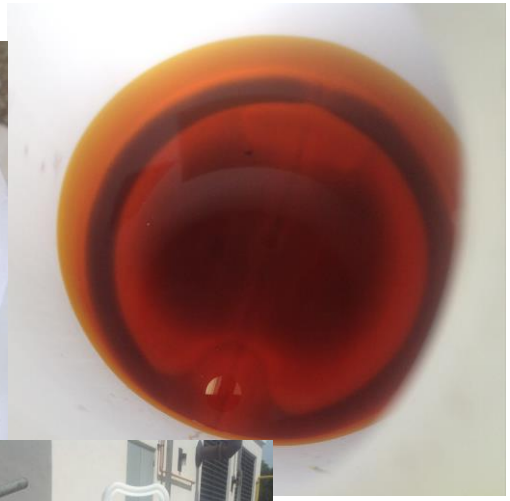
Weak Mutagenic Effects Observed

No Significant Mutagenic Effects Observed

-After 10/8/13, the sodium bisulfide dosage was increased to fully quench peroxide

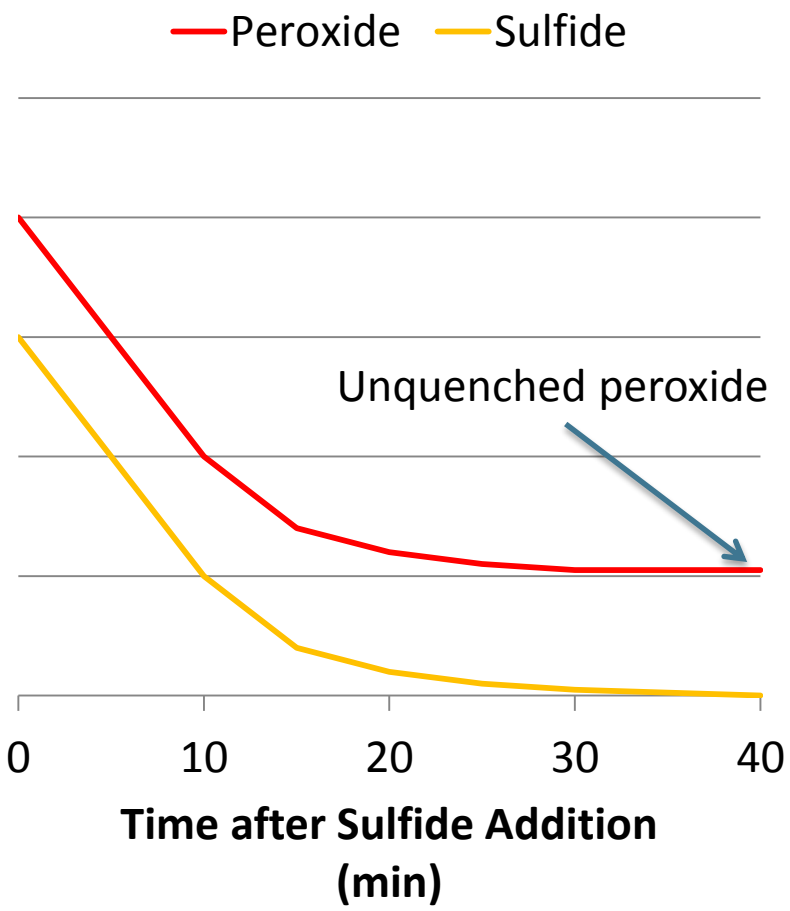
-The cause of the positive result on 8/22 in the reclaimed water is not definitive

Sodium Bisulfide Degrades Over Weeks and the Feed Rate Must Be Adjusted to Avoid Underfeeding Sulfide

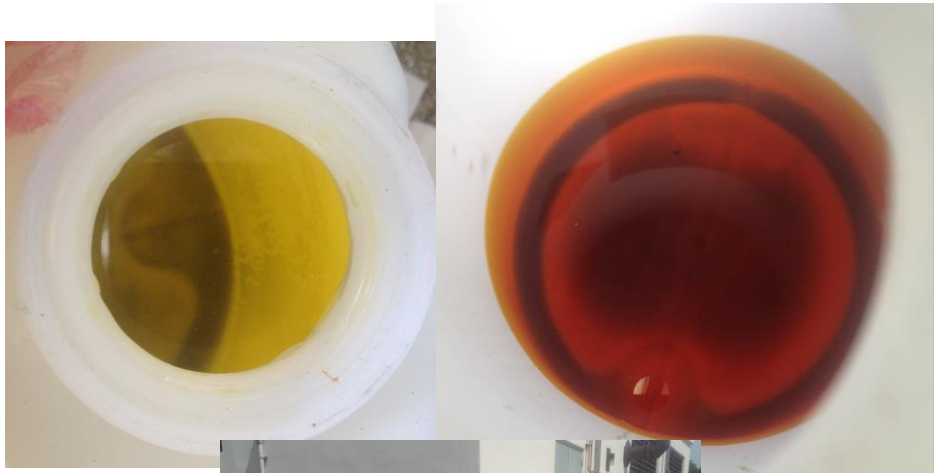


Fresh NaHS

Aged NaHS



Sodium Bisulfide Feed was Adjusted to Maintain a Slight Sulfide Residual



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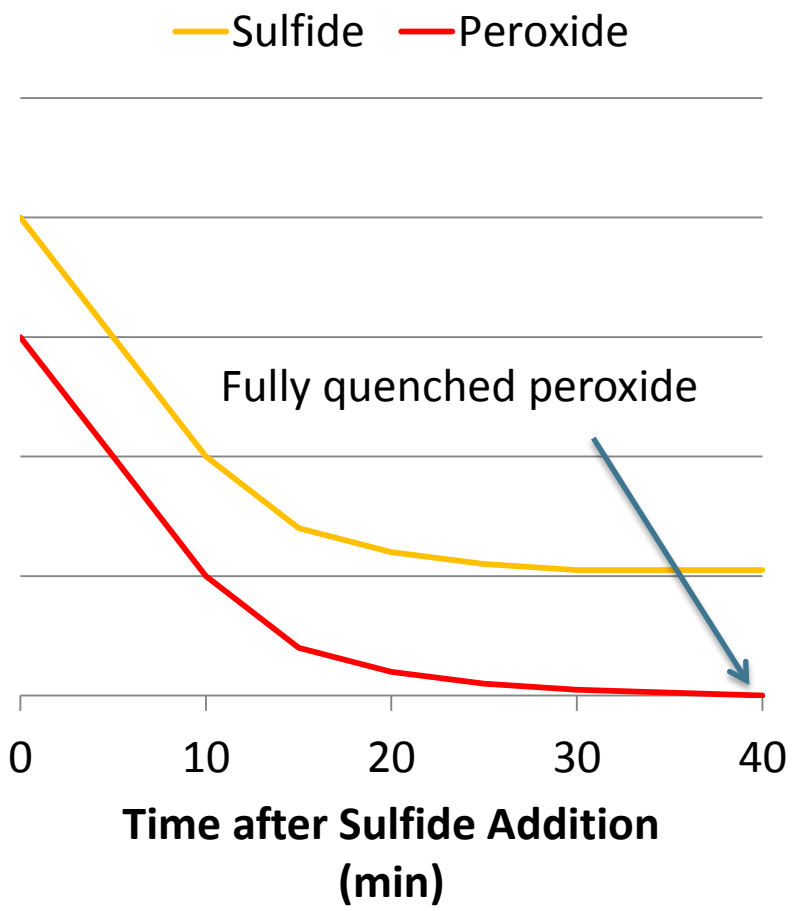


Purification System Has Shown Effective Removal of Microconstituents

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - Mutagenicity
  - **Microconstituents**

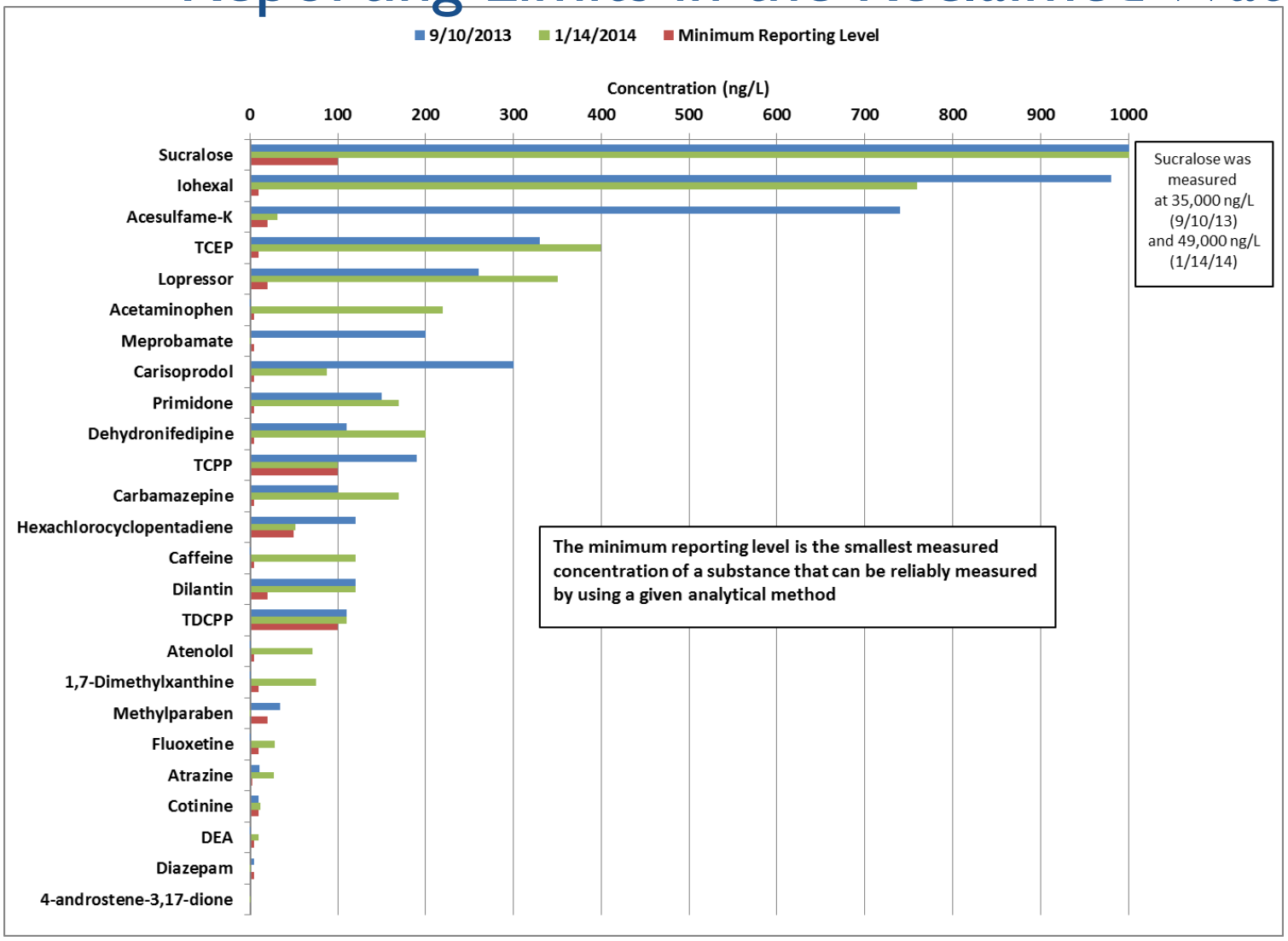
Reclaimed Water and Finished Water Were Screened for 175 Microconstituents

- 25 microconstituents were above the minimum reporting level in the reclaimed water
- 1 microconstituent was above the minimum reporting level in the finished water
- UV/AOP microconstituent spike test results have met California Department of Public Health (CDPH) Draft guidelines

The Following Microconstituents were Above Reporting Limits in Reclaimed Water

Microconstituent	Description
1,7-Dimethylxanthine	Byproduct of caffeine
4-androstene-3,17 dione	Hormone
Acesulfame-K	Artificial sweetener
Acetaminophen	Analgesic (pain-reliever) medication (Tylenol)
Atenolol	High blood pressure medication
Atrazine	Herbicide
Caffeine	Central nervous system stimulant
Carbamazepine	Anti-convulsant and mood-stabilizing drug
Carisoprodol	Muscle relaxant
Cotinine	Tobacco byproduct
DEA	Byproduct of atrazine pesticide, diethyl atrazine
Dehydronifedipine	Byproduct of Nifedipine, high blood pressure medication
Diazepam	Anti-anxiety medication (Valium)
Dilantin	Anti-convulsant (Anti-seizure) medication
Fluoxetine	Anti-anxiety medication (Prozac)
Hexachlorocyclopentadiene	Pesticide precursor
Iohexal	Contrast agent for heart scans
Lopressor	High blood pressure medicication
Meprobamate	Tranquilizer (Anti-anxiety) medication
Methylparaben	Anti-fungal agent often used in a variety of cosmetics and personal-care products
Primidone	Anti-convulsant (Anti-seizure) medication
Sucralose	Artificial sweetener (Splenda)
TCEP	Reducing agent frequently used in biochemistry and molecular biology applications
TCPP	Flame-retardant
TDCPP	Flame-retardant

Microconstituent Concentrations Above Reporting Limits in the Reclaimed Water



Of the 25 Microconstituents, Only Atenolol was in the Finished Water Above Reporting Limits

Microconstituent	Description
1,7-Dimethylxanthine	Byproduct of caffeine
4-androstene-3,17 dione	Hormone
Acesulfame-K	Artificial sweetener
Acetaminophen	Analgesic (pain-reliever) medication (Tylenol)
Atenolol	**High blood pressure medication**
Atrazine	Herbicide
Caffeine	Central nervous system stimulant
Carbamazepine	Anti-convulsant and mood-stabilizing drug
Carisoprodol	Muscle relaxant
Cotinine	Tobacco byproduct
DEA	Byproduct of atrazine pesticide, diethyl atrazine
Dehydronifedipine	Byproduct of Nifedipine, high blood pressure medication
Diazepam	Anti-anxiety medication (Valium)
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TDCPP	Flame-retardant

Purification System Removed 79% or 0.67 Log of Atenolol

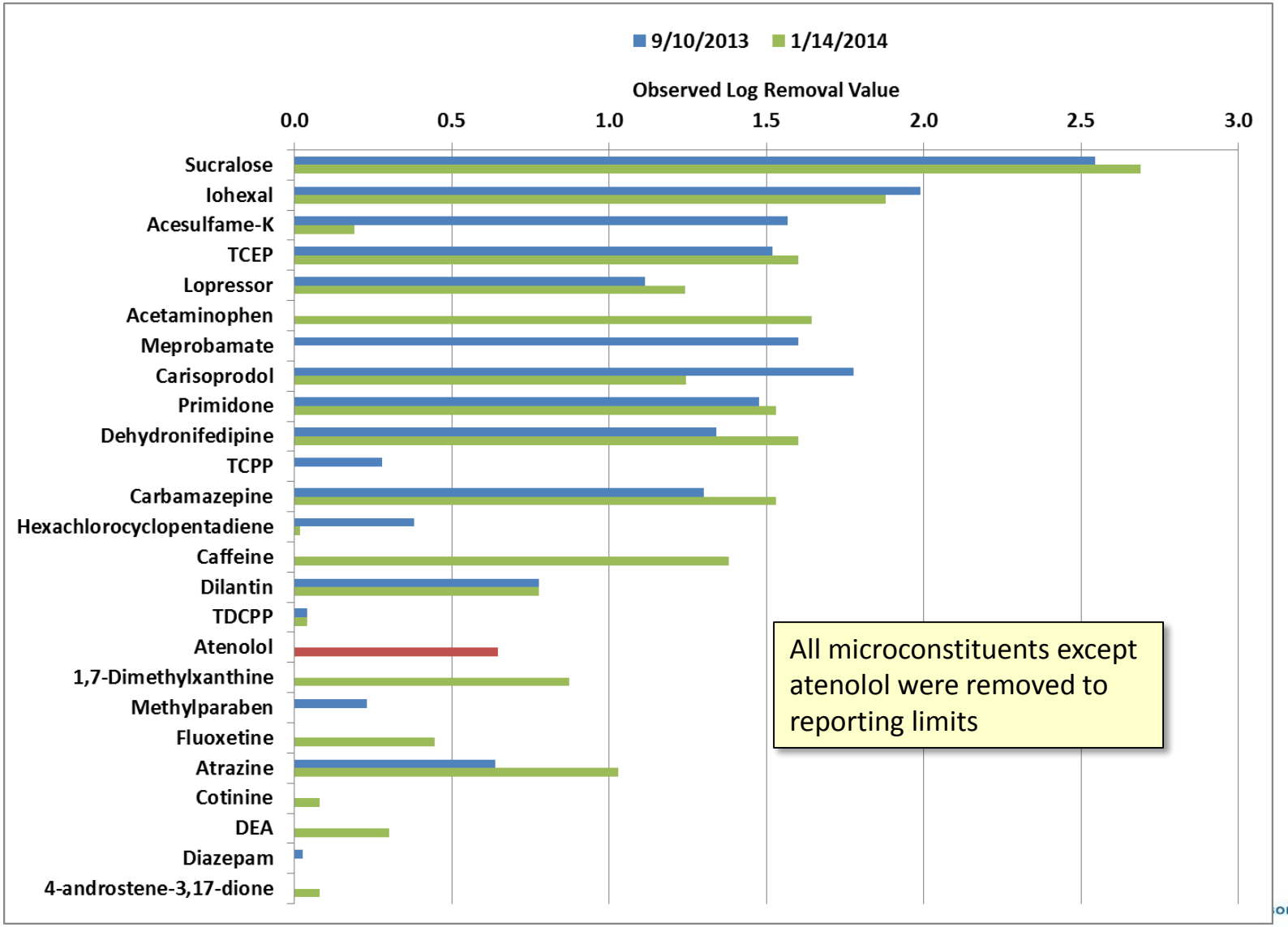
- Atenolol – A prescription drug, “beta blocker,” taken for blood pressure control
- Reclaimed water – 75 ng/L (January 2014)
- Finished water – 16 ng/L (January 2014)
  - 1 of 175 microconstituents tested for found in FW-1
- Reporting Limit – 5 ng/L
- Tested at a peroxide dose of 2 mg/L
- Follow up spike testing of UV/AOP system completed with atenolol in March 2014, results pending

Atenolol Concentration was 250,000x below the Minimum Therapeutic Dose

- Minimum therapeutic dose for prescriptions = 4 mg/L
- Ratio= $\frac{\text{Minimum Therapeutic Dose}}{\text{Observed Value}}$
- Ratio= $\frac{4{,}000{,}000\ ng/L}{16\ ng/L} = 250{,}000$
  - 16 ng/L is 0.00004% of 4,000,000 ng/L

- To ingest the atenolol in the minimum daily therapeutic dose of atenolol, someone would need to drink **33,000 gallons** of finished water in one day!

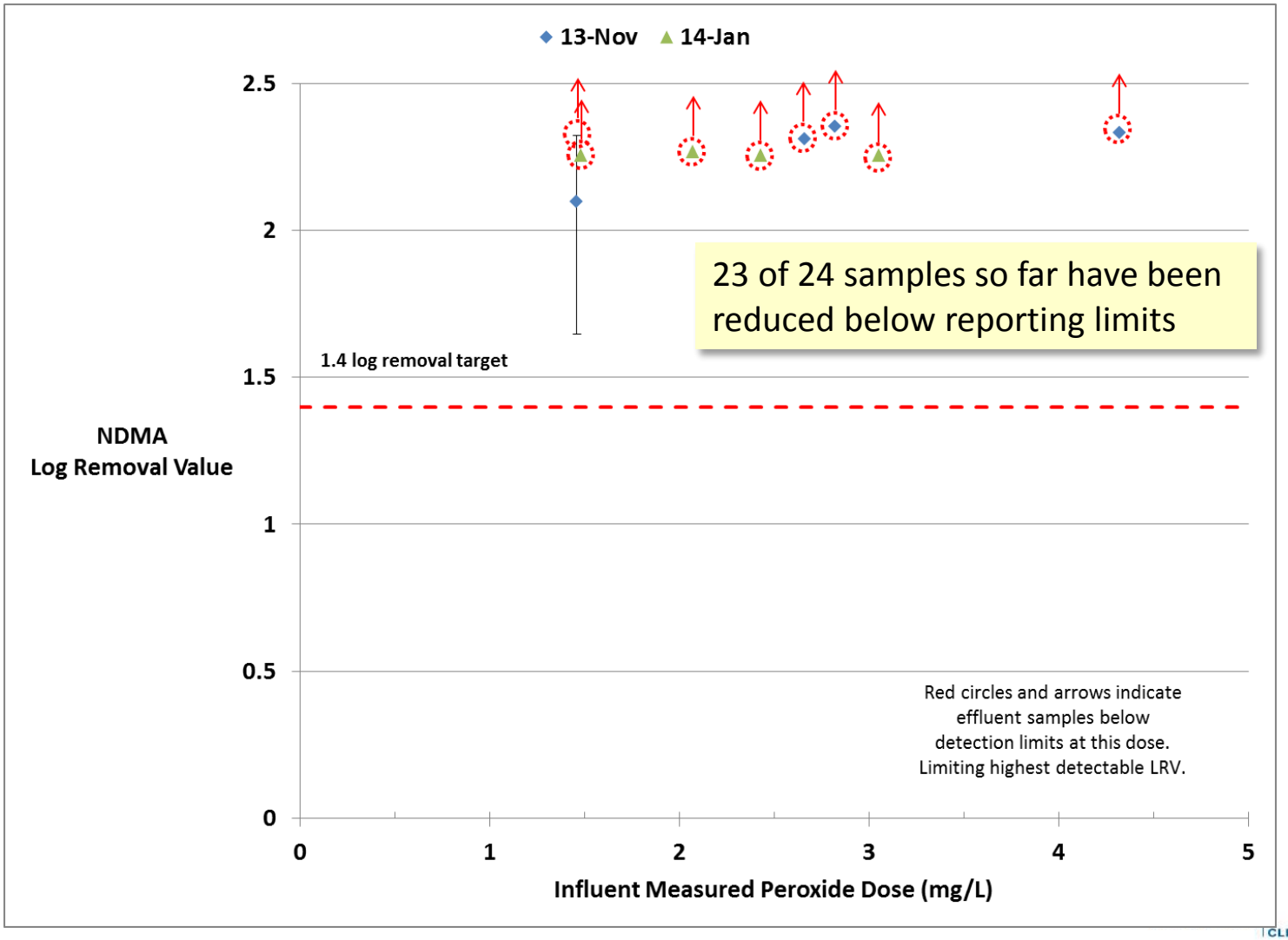
Observed Removal of Microconstituents Ranged from 0.0 to 2.7 Log Removals



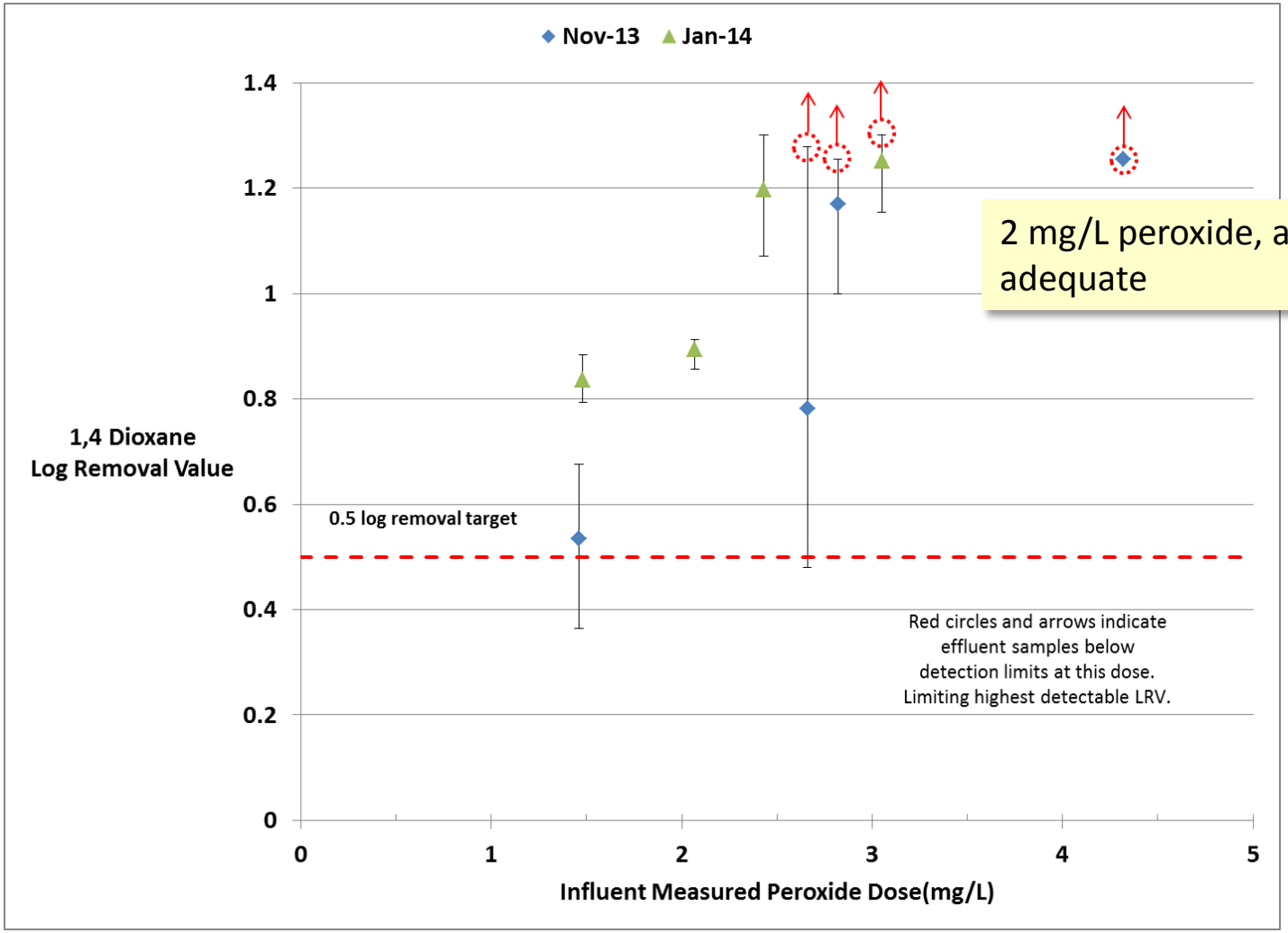
UV/Advanced Oxidation Process was Challenged with a Spiked Solution of NDMA and 1,4-Dioxane

- **NDMA** is destroyed by UV photolysis, and does not require peroxide addition
  - Log Removal Goal: 1.4
- **1,4-dioxane** is destroyed by hydroxyl radicals, which form when peroxide is added
  - Log Removal Goal: 0.5
- Log removal goals selected based on draft CDPH Recharge Regulations

NDMA Removal Target Achieved at All Peroxide Doses Tested



1,4-Dioxane Removal Target Achieved at Higher Peroxide Doses

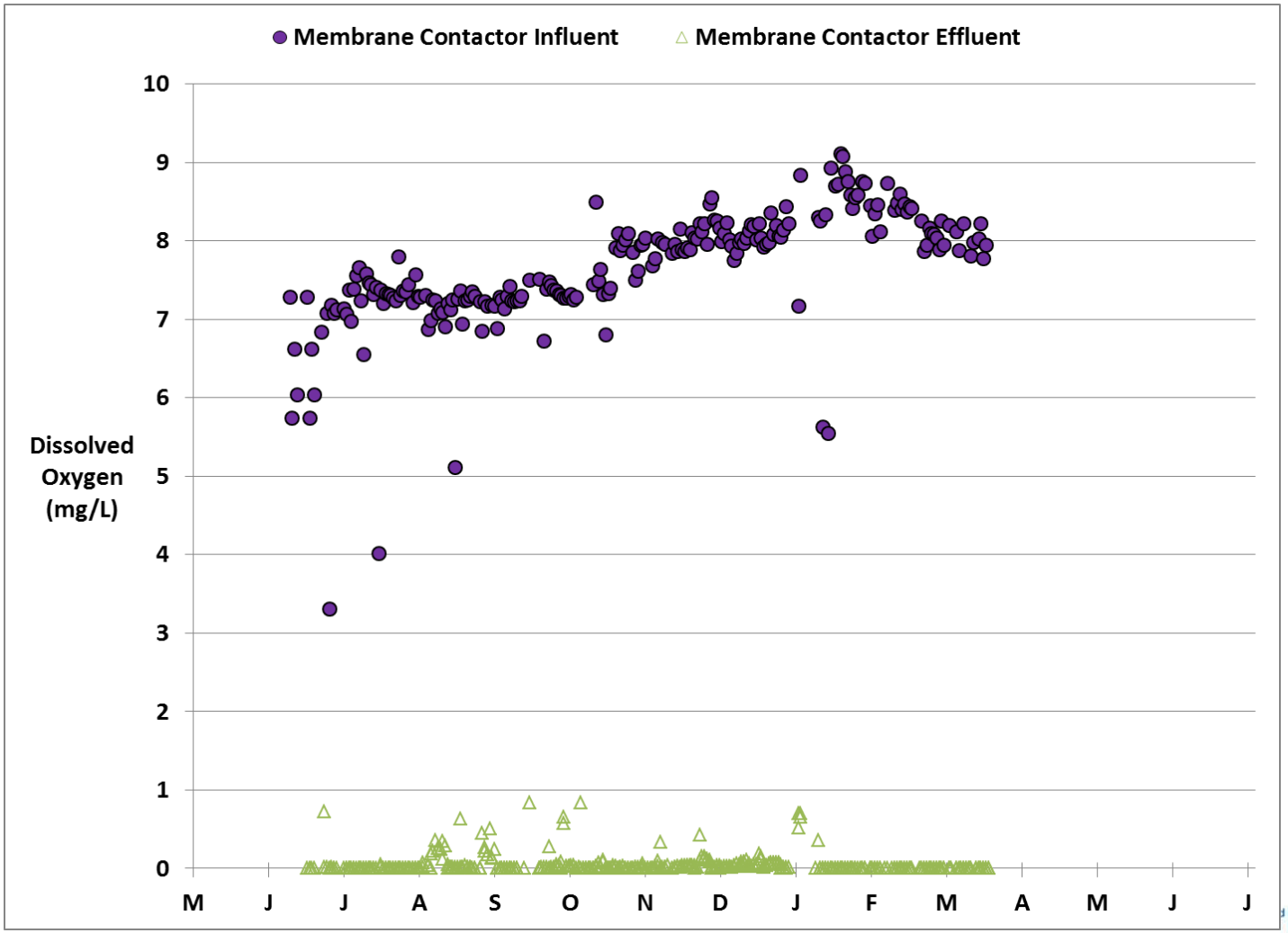


2 mg/L peroxide, appears adequate

Membrane Contactors Have Effectively Removed Most Dissolved Oxygen

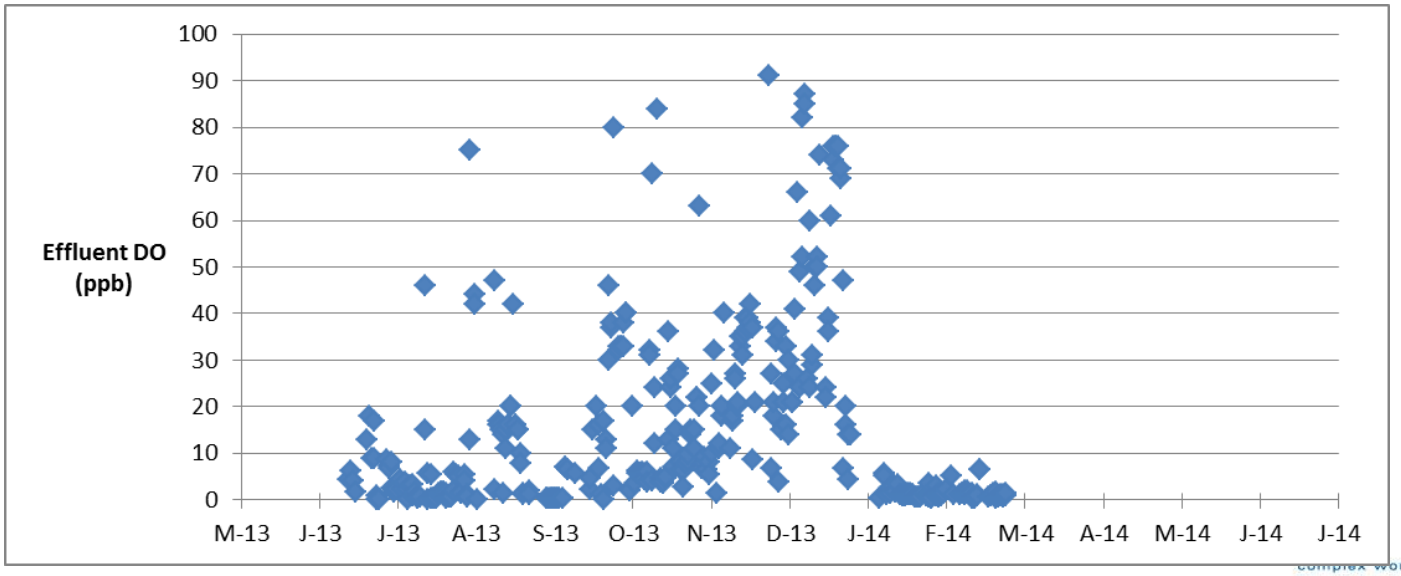
- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - Mutagenicity
  - Microconstituents
- **Groundwater Recharge Conditioning**
  - **Dissolved Oxygen Removal**

Membrane Contactors Have Consistent Removed Most Dissolved Oxygen from the Finished Water



Shifting DO Inline Measurement from the Finished Water to the Contactor Effluent Improved Sensor Stability

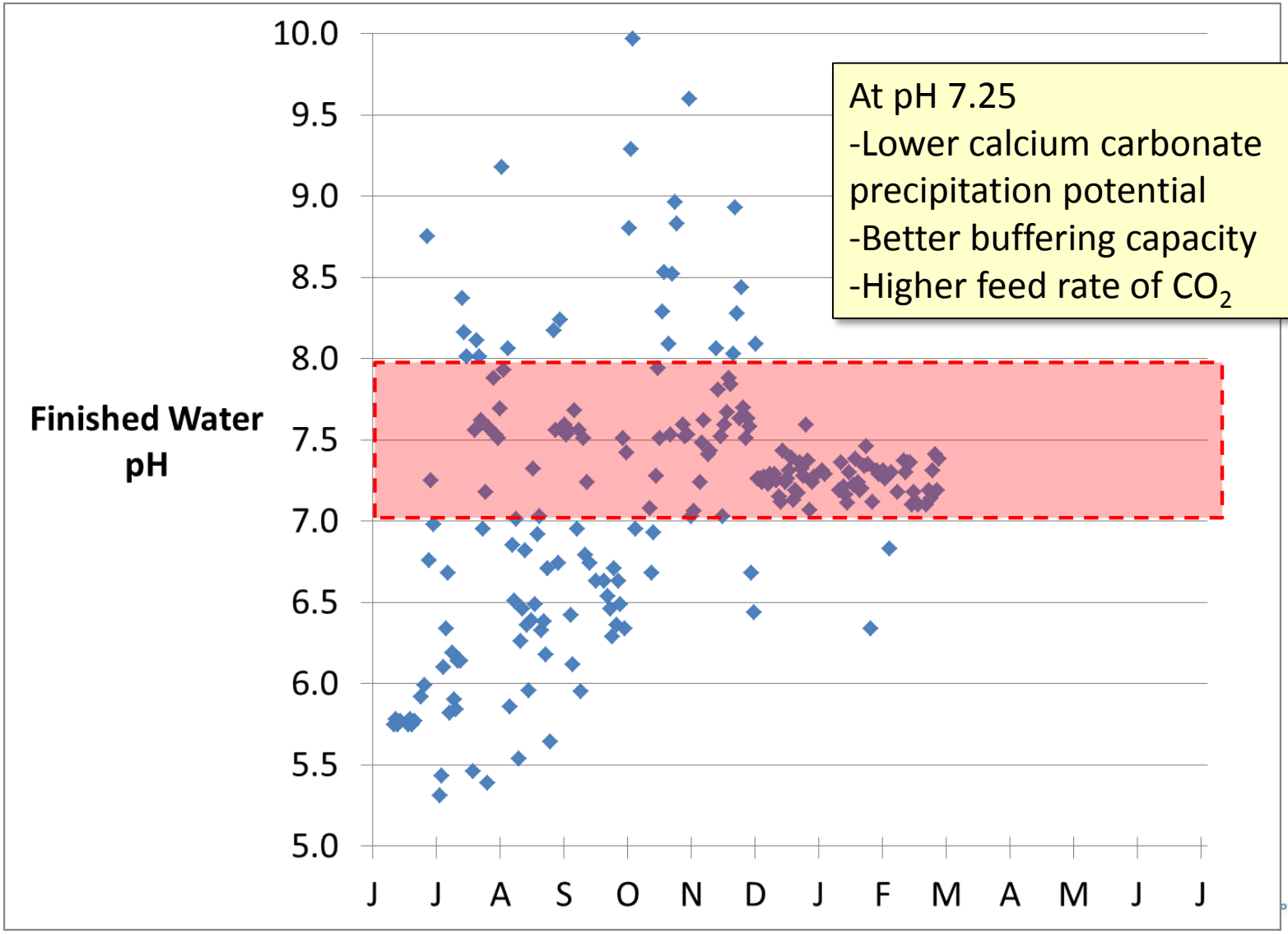
- Precipitation of calcium carbonate and addition of reducing agent appear to have affected stability of DO sensor
- Now effectively measuring consistent 3.5 log removal of DO
- Recommend monitoring membrane contactors with dedicated trace DO sensor, isolated from finished water



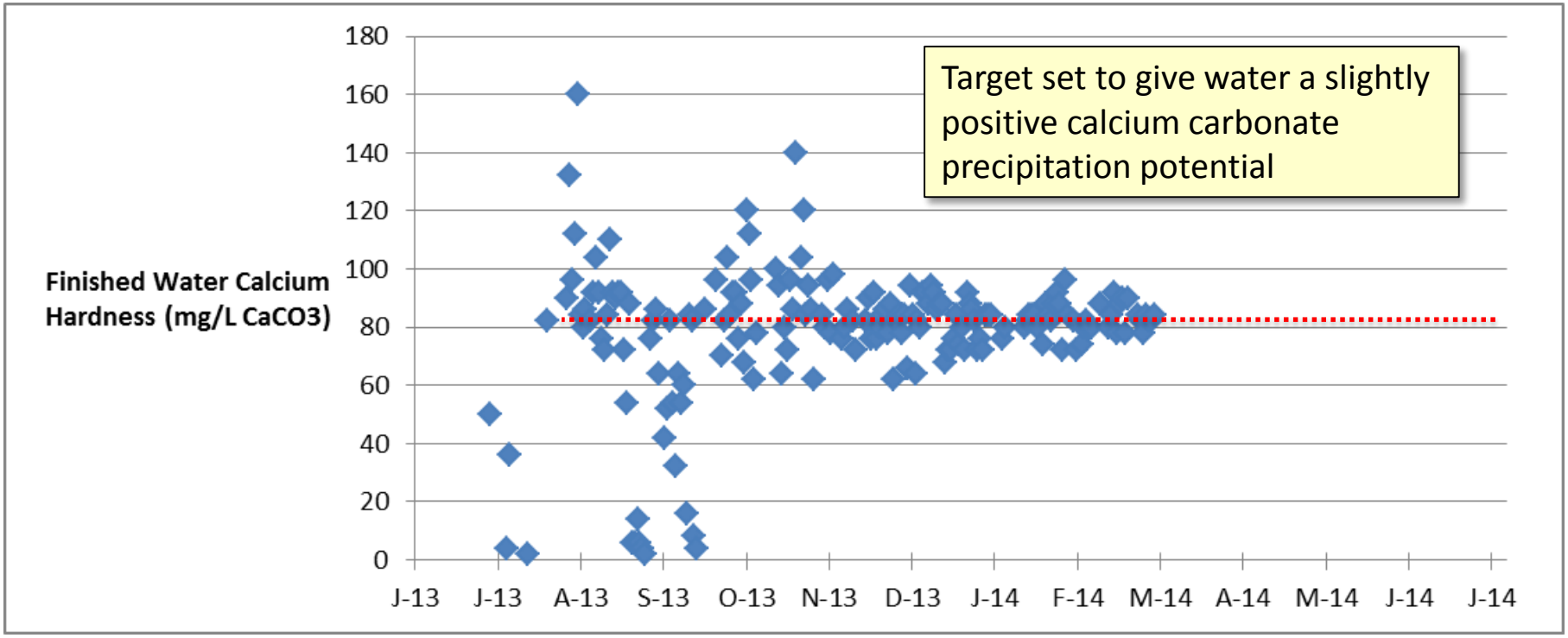
Post Treatment Calcium Addition with Lime has Avoided Calcium Precipitation at Lower pH

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - Mutagenicity
  - Microconstituents
- **Groundwater Recharge Conditioning**
  - Dissolved Oxygen Removal
  - **Calcium stabilization**

Finished Water pH Target was Initially 7.5
A Lower pH of 7.25 was Easier to Maintain



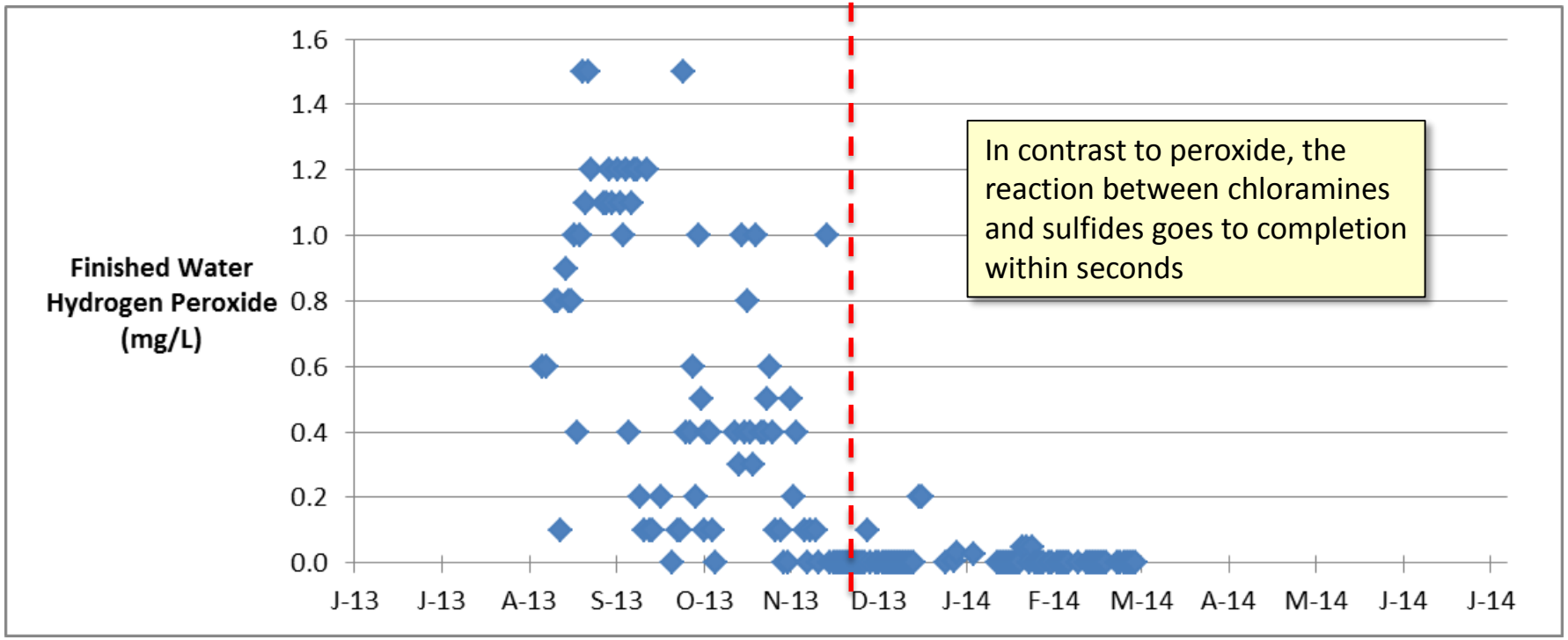
Finished Water Calcium is Being Maintained Close to 80 mg/l as $CaCO_3$ Target



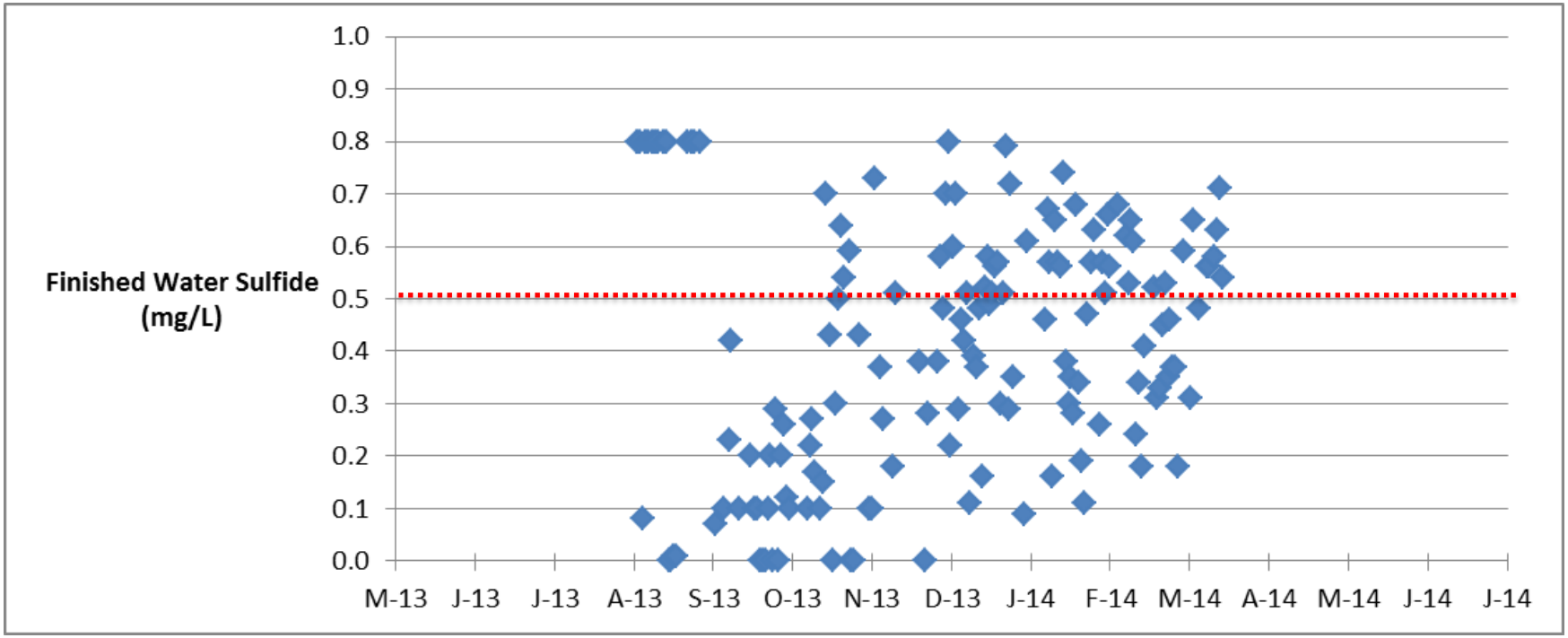
Treatment Performance Monitoring Has Covered A Broad Range of Parameters

- Water Purification
  - Organics Removal
    - Total Organic Carbon, Total Organic Halides
  - Microorganisms
  - Drinking Water Standards
    - Disinfection byproducts
  - Mutagenicity
  - Microconstituents
- **Groundwater Recharge Conditioning**
  - Dissolved Oxygen Removal
  - Calcium stabilization
  - **Neutralization of chloramines and peroxide**

Peroxide Sampling was Changed in December to Include a 30 Minute Hold Time for Complete Neutralization by Sodium Bisulfide



An Operational Target of 0.5 mg/L Sulfide After 30 Minute Hold Time Has Been Set to Reduce Peroxide Breakthrough



Conclusions

Conclusions (1/2)

- The City of Clearwater is pilot testing a purification process for groundwater recharge with highly-treated water.
- The testing program will reach the one-year mark in June 2014.
- System met organics removal requirements for total organic carbon and total organic halides
- Microorganisms were effectively removed, including: coliforms, cryptosporidium, viruses, giardia, and helminths
- Haloacetic acids and total trihalomethanes were effectively removed
- Relocation of source water intake to chlorine contact effluent could reduce trihalomethane levels in finished water consistently below the MCL
- Incomplete neutralization of peroxide appears to have contributed to initial positive mutagenicity results.

Conclusions (2/2)

- 25 out of 175 microconstituents tested for were found in the reclaimed water
- Only 1 out of 175 microconstituents, atenolol, was found in the finished water
- Spike testing of the advanced oxidation process showed that it met CDPH draft guidelines for 1,4-dioxane and NDMA
- Membrane contactors effectively removed 3.5 log's of dissolved oxygen, to below 10 parts per billion
- Placement of trace dissolved oxygen sensors upstream of post-treatment chemical addition enhances sensor stability
- Reducing the pH target from 7.5 to 7.25 improved finished water pH control, and reduced calcium precipitation
- Added sulfide and peroxide require up to 30 minutes to react completely

Reclaimed water can be treated to meet the high standards of groundwater recharge, through a multiple barrier system that removes multiple targeted contaminants.

Acknowledgments

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- Jeff Trommer, P.G., Project Manager
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One Water

Balancing Water Needs …
Protecting Water Resources

City's Integrated Water Management Strategy

- A holistic approach that brings together all facets of the water cycle:
  - Water supply and treatment
  - Sewage collection and treatment
  - Purification
  - Reuse and disposal

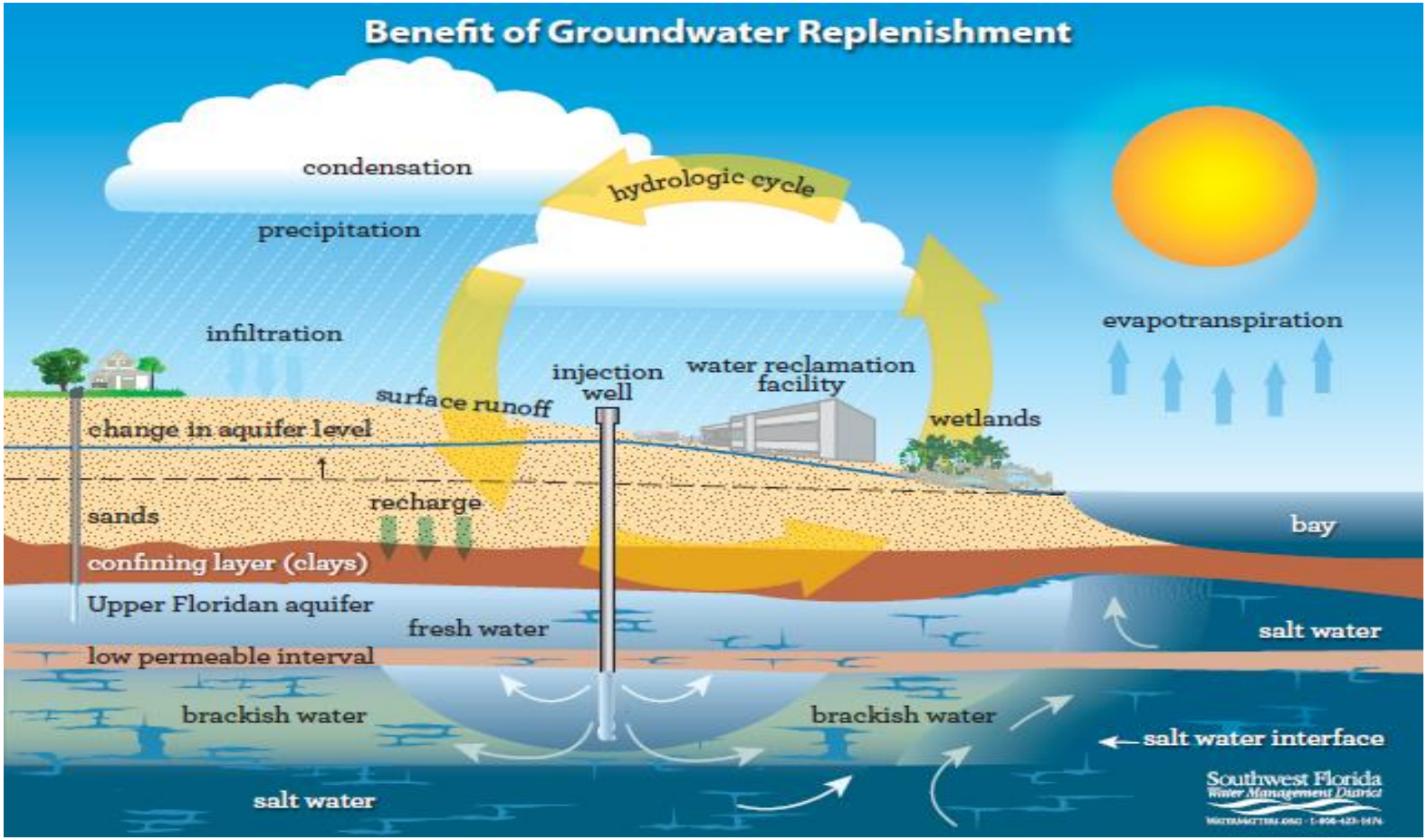
Integrated Water Management Tactics

- Conserve Limited Water Supplies
- Preserve Drinking Water Sources
- Protect Coastal Environment
- Produce More Water Locally
- Manage the Rising Cost of Water

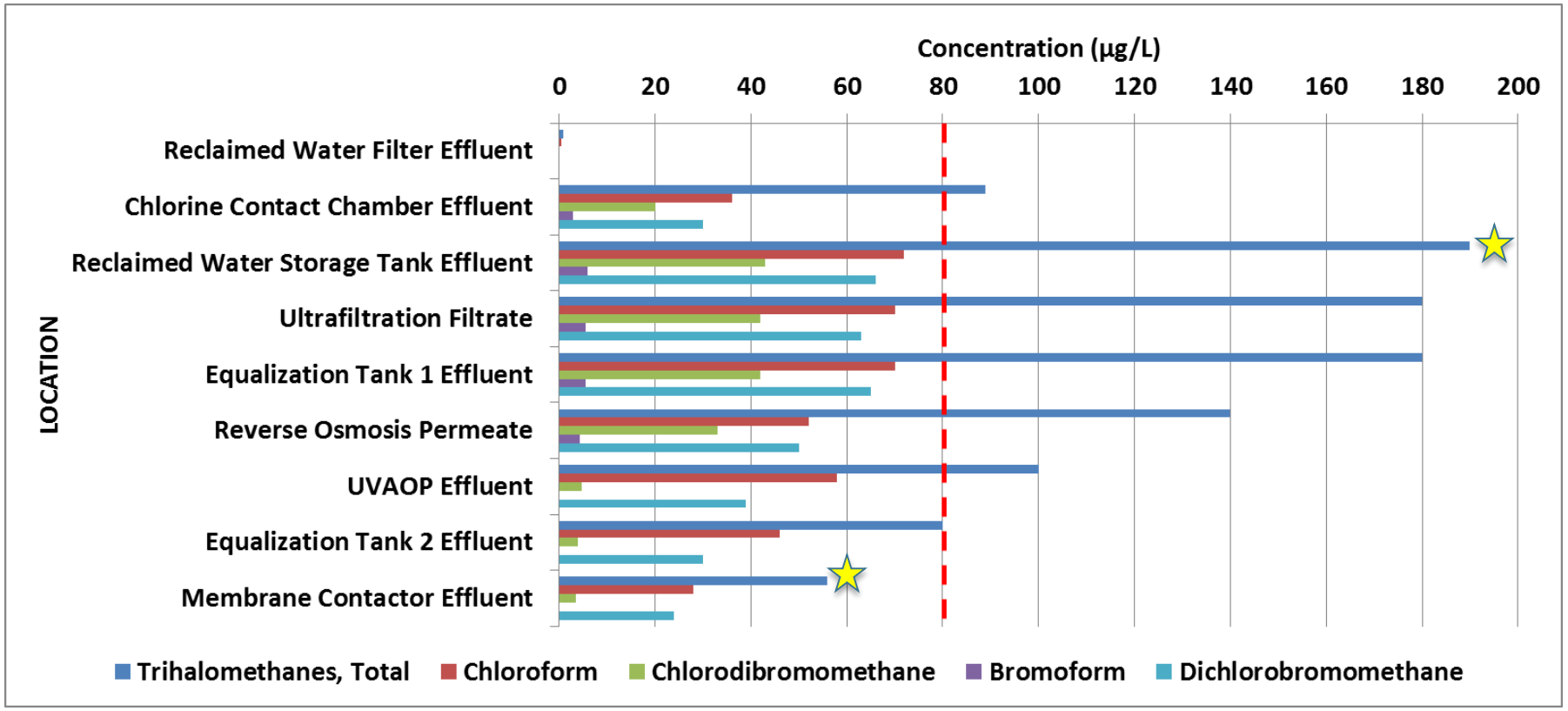
Public Outreach

- City Council and Elected Officials
- Environmental Advisory Board
- Utility Customer Communications
- Homeowners Association Meetings
- Community Groups & Service Clubs
- Professional Society Meetings & Conferences
- USF Graduate Seminar

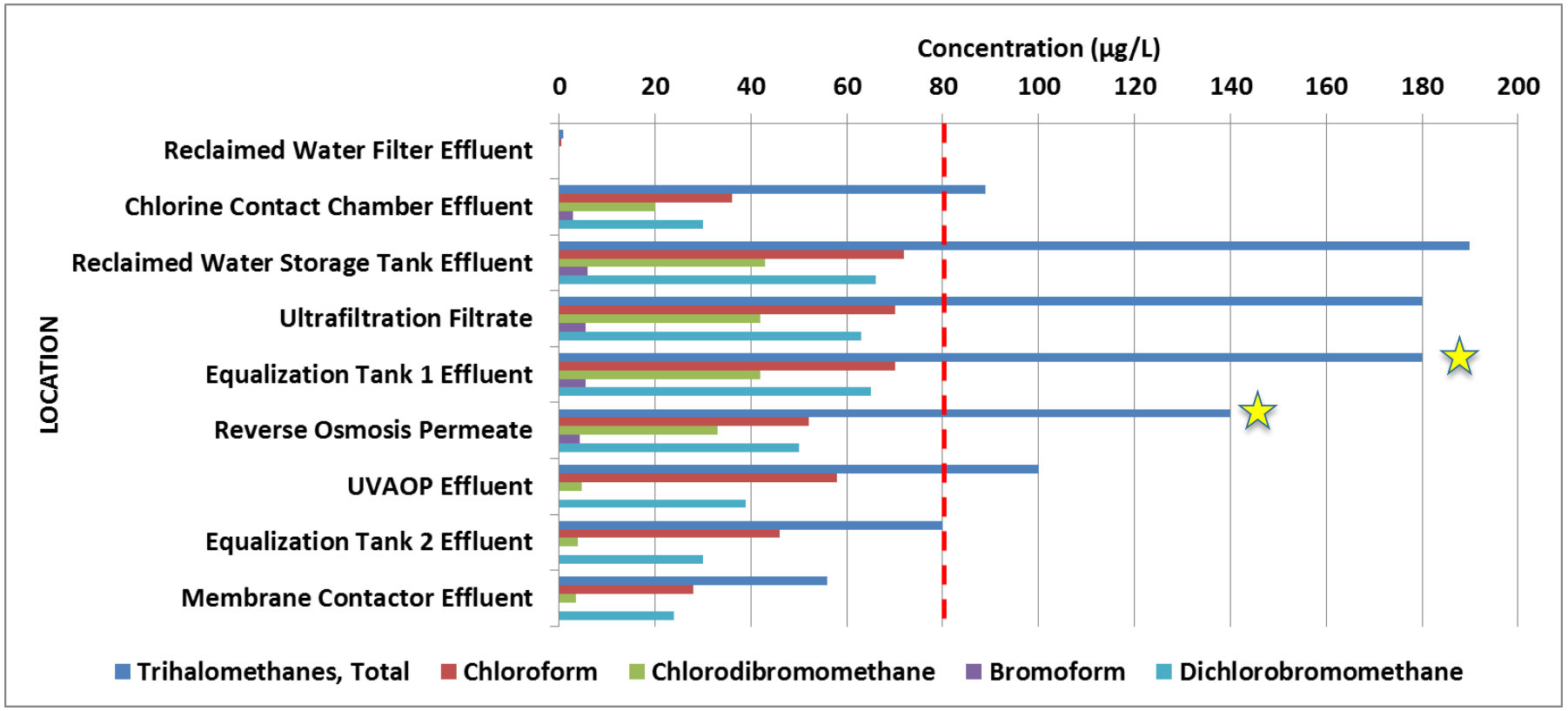
Water Cycle


Benefit of Groundwater Replenishment
condensation
precipitation
hydrologic cycle
infiltration
evapotranspiration
injection well
water reclamation facility
surface runoff
wetlands
change in aquifer level
recharge
sands
bay
confining layer (clays)
Upper Floridan aquifer
fresh water
salt water
low permeable interval
brackish water
brackish water
salt water interface
salt water
Southwest Florida Water Management District

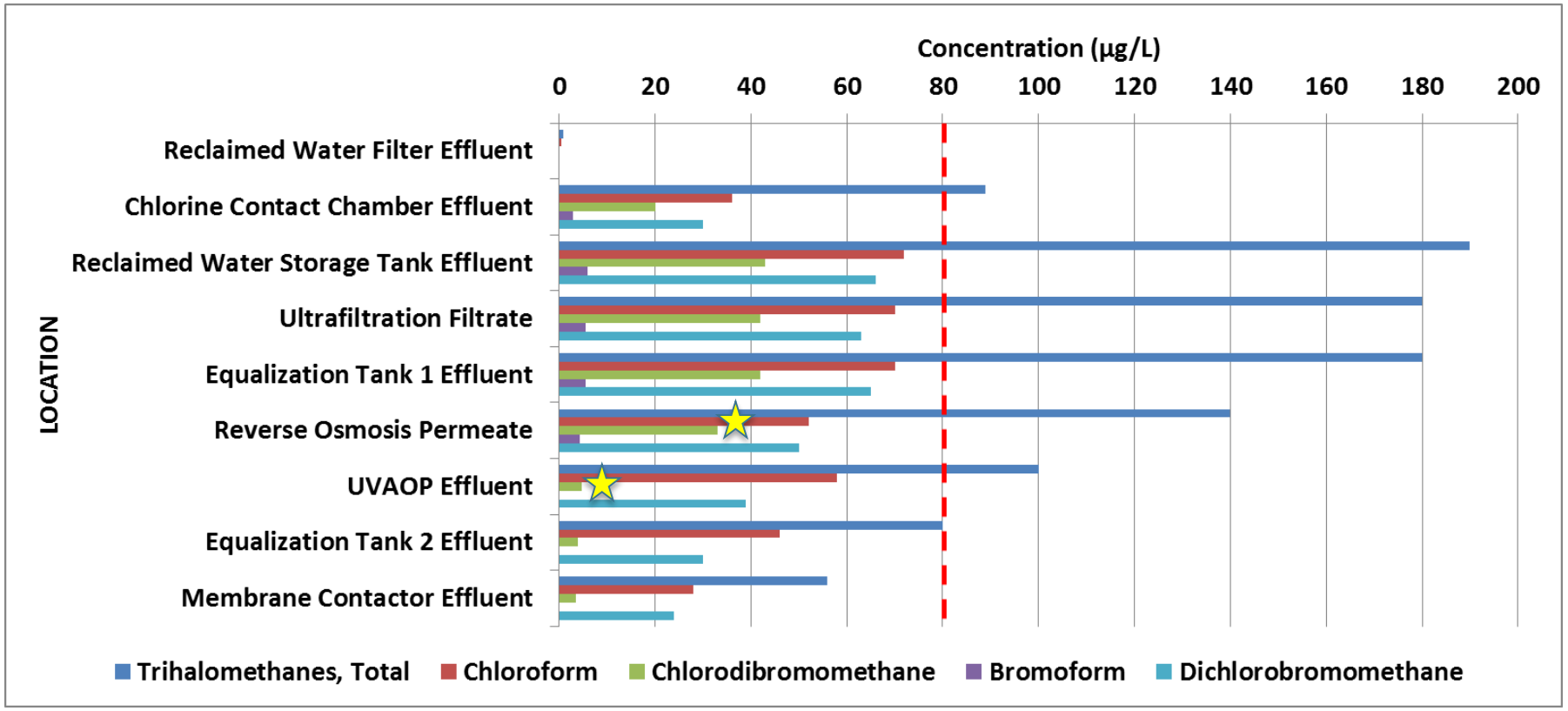
The System Removes More Than 50% of TTHMs Through Multiple Treatment Steps



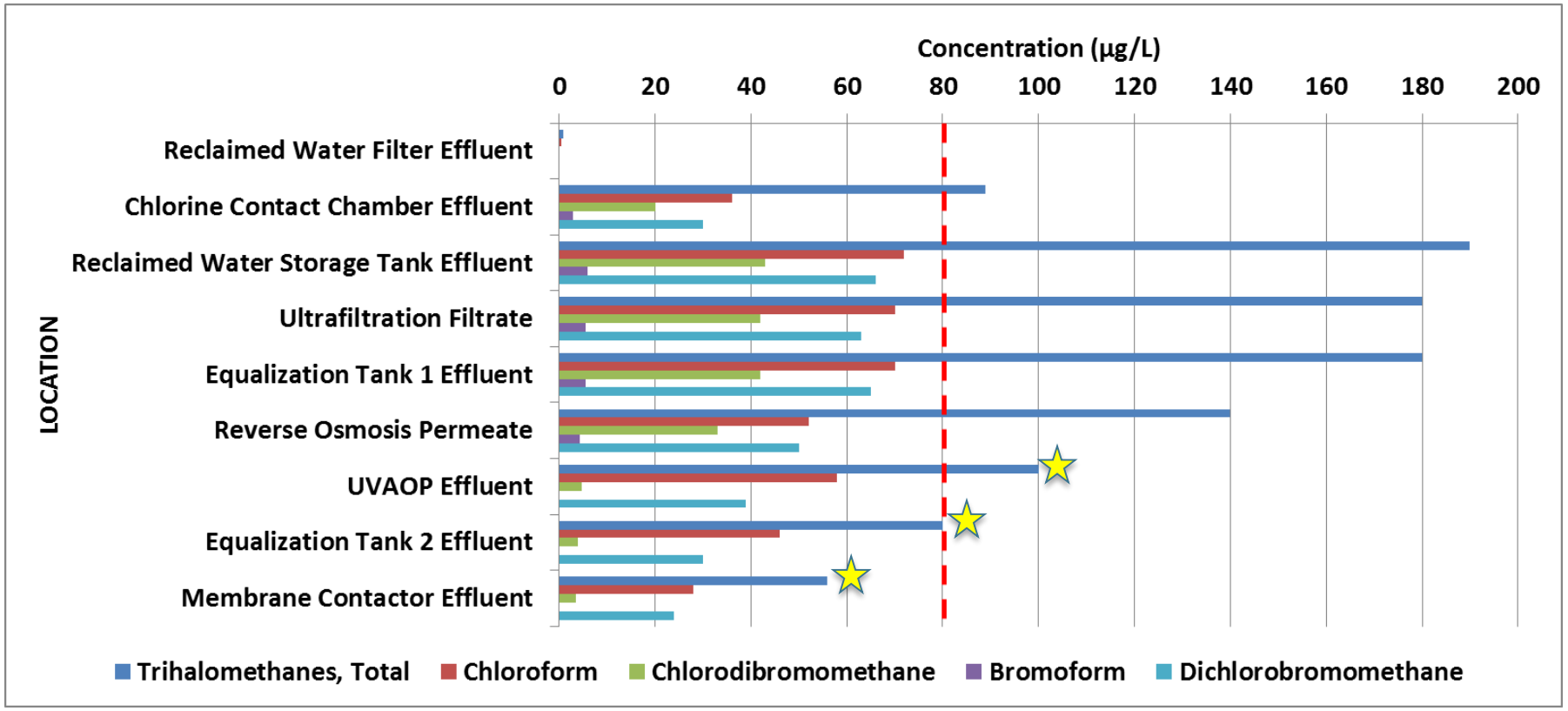
RO Removes about 25% of All THMs



UVAOP Removes Nearly 85% of Chlorodibromomethane and Bromoform



Aeration in Equalization Tank 2 and the Membrane Contactor Reduces Volatile THMs



Atenolol Will Be Included in the Next UVAOP Challenge Test

- Atenolol only microconstituent reported in the finished water
- Purpose of challenge test is to understand how atenolol LRV responds to different levels of peroxide
- Atenolol is destroyed by hydroxyl radicals
- Anticipate atenolol LRV is peroxide dose dependent like 1,4-dioxane
- If reduced from 75 ng/L to 5 ng/L reporting limit, the observed LRV for the pilot would have been >1.1 LRV

Atenolol Concentration was 4,375x below the "Minimum Guideline Value"

- "Minimum guideline value" – corresponds to the LOAEL (lowest observed adverse effect level) according to the EPA standard risk assessment methodology
  - Atenolol Minimum Guideline Value: 70,000 ng/L
  - Based on a cancer study with rats
- Margin of Safety = $\frac{\text{Minimum Guideline Value}}{\text{Observed Value}}$
- Margin of Safety = $\frac{70{,}000\ ng/L}{16\ ng/L} = 4{,}375$
  - 16 ng/L is 0.023% of 70,000 ng/L