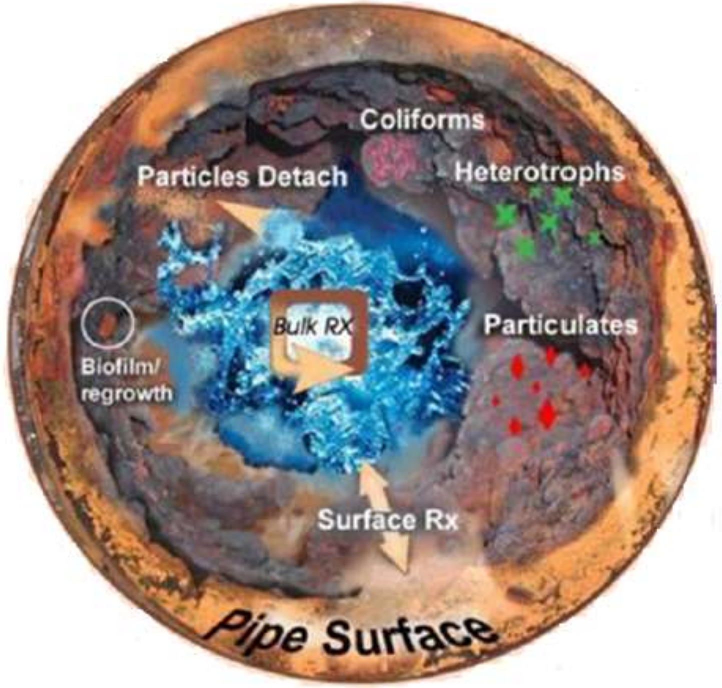
American Water Works Association
Pacific Northwest Section

2018 AWWA-PNWS Conference • Tacoma, WA

Field Evaluation of Flushing Methods for Microbial Water Quality Control



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WRF 4653 Research Project Team

Ensuring Flushing is a Corrective Action Under the RTCR

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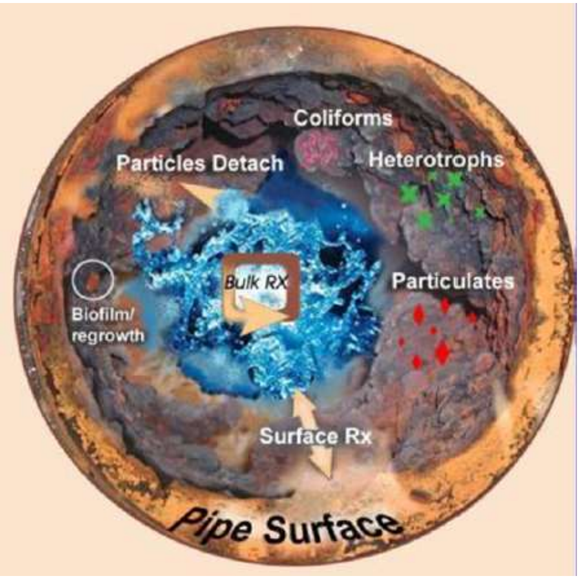
Presentation Overview

- **Project Overview and Objectives**
- **Field Study Approach**
- **Key Findings from Flushing Trials**
  - Portland Water Bureau (PWB)
  - Seattle Public Utilities (SPU)
- **Summary and Recommendations**

Water Quality Impacts of Deposit Accumulation in Distribution Systems

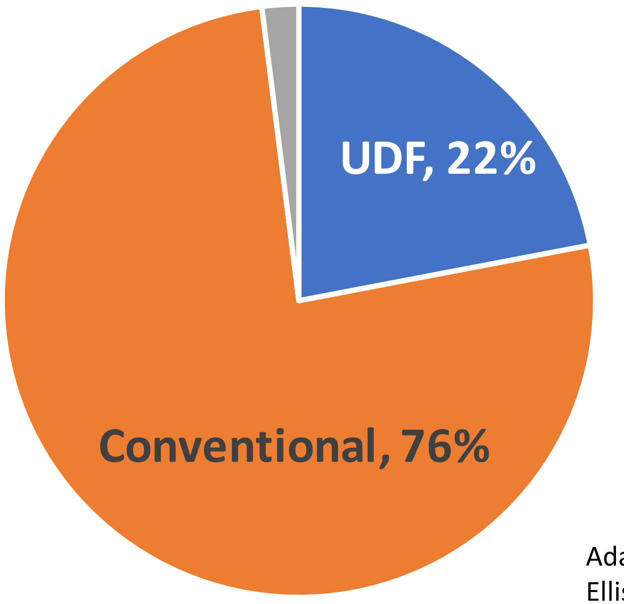
- **Exerts a chlorine residual demand**
- **Substrate for biofilm accumulation**
- **Refuge for coliform and nitrifiers**
- **Aesthetic upsets** (discolored water)
- **Microbially-induced corrosion**



Toolbox of Flushing Techniques

- **Conventional Flushing (CF)**
  - Spot Flushing
  - Dead-End Flushing
  - Automatic Flushing Stations
- **Unidirectional Flushing (UDF)**
  - Area-wide from clean source
  - Spot UDF (i.e., NO-DES)
  - Quasi-UDF

WRF Survey of 500 utilities:
"Use of Flushing for the Purpose of Cleaning Distribution Mains"



Adapted from Ellison et al (2003)

WRF 4653 Research Project

Ensuring Flushing is a Corrective Action under the RTCR

Overall Objective

Develop data-driven industry guidance on the applicability of different flushing methods for preventative, reactive, and corrective forms of microbial control

Specific Research Goals

Technical

- Assess mobilization and removal of microbially-active sediment, biofilm, and nutrients as related to key flushing variables – technique, velocity, and pipe type
- Evaluate bulk water quality response brought about by flushing. Identify *benefits*, *limitations*, and *risks*

Guidance

- Provide a basis for utility investment in preventative flushing for biofilm control (i.e., benefits and costs)
- Provide industry guidance and protocols to ensure that appropriate flushing practices are applied for a given situation

Project Field Study
Small-Scale Flushing Trials

Flushing Conditions Applied			PWB (Mono Cl_2)	SPU (Free Cl_2)
Technique	Pipe Type	Rate		
Area-wide UDF	Unlined iron	3 and 6 fps	X	X
Area-wide UDF	Cement-lined	6 fps	X	
Spot Conventional	Unlined iron	High (600 gpm)		X
Spot Conventional	Unlined iron	Low (300 gpm)	X	

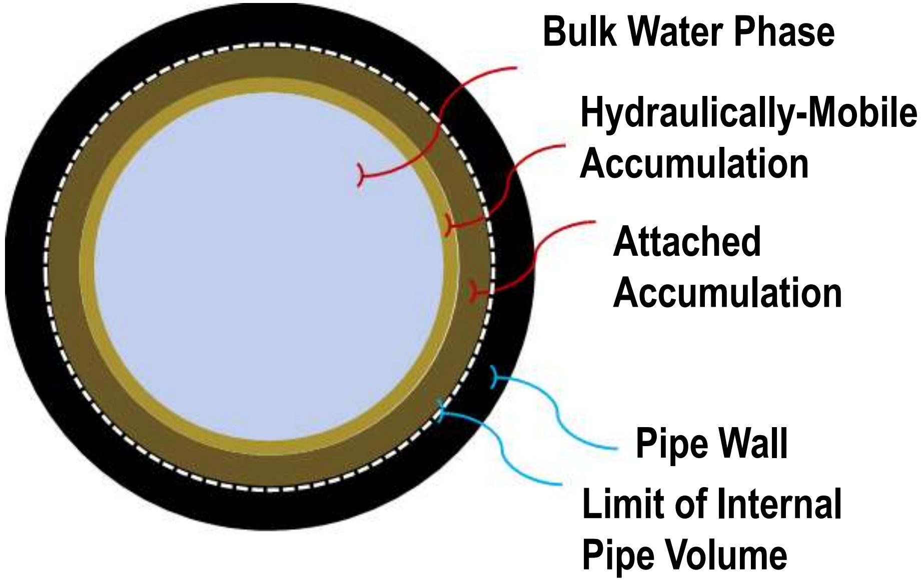
Water Quality Monitoring Strategies
To Characterize Flushing Performance

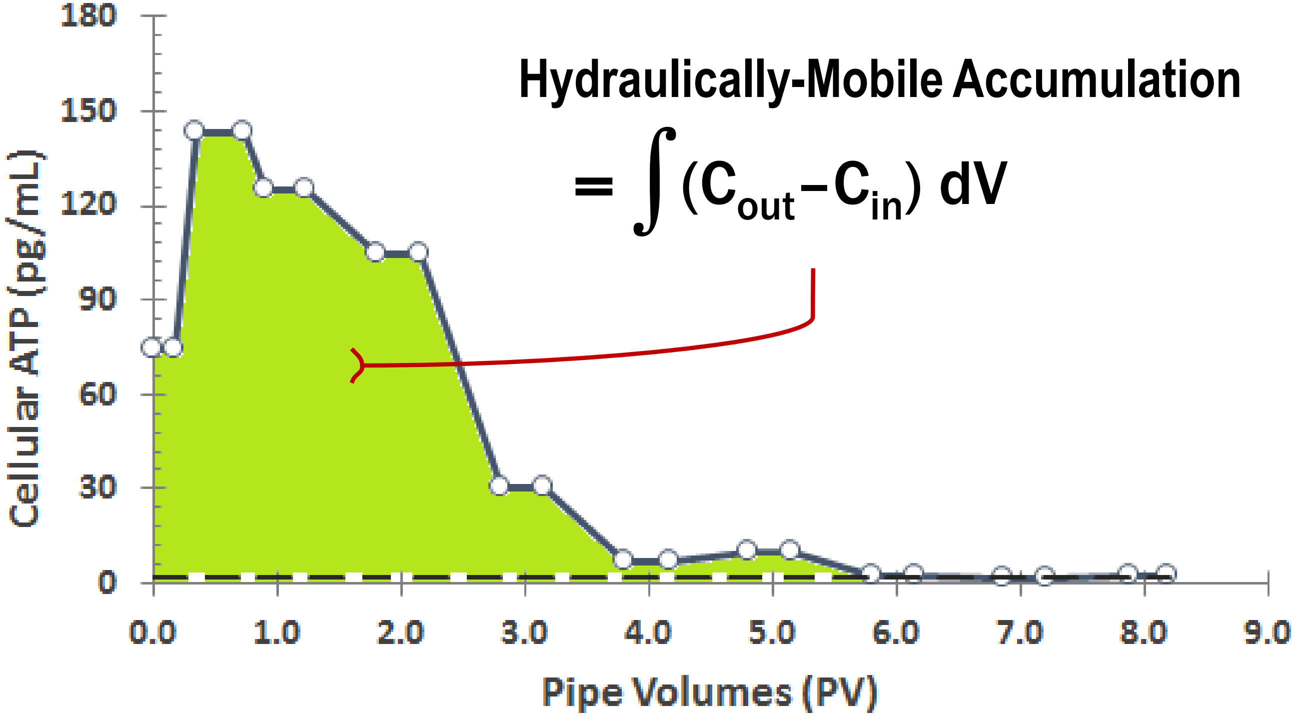
- **Diagnostic Area WQ Monitoring**
  - Clean water inlet (CWI) & several sites
  - Pre-Flush = Baseline (3 wk duration)
  - Post-Flush = Response (6 wk duration)


Photo Credit: Portland Water Bureau

- **Discharge Profiling During Flush**
  - Flushing Hydrants: to assess hydraulically-mobile accumulation
  - At Nearby Sites (spot only): to assess un-mitigated release risks

Hydraulically-Mobile Accumulation
Determined from UDF Discharge Profiling





Source: Confluence Engineering Group LLC

Monitoring Parameters

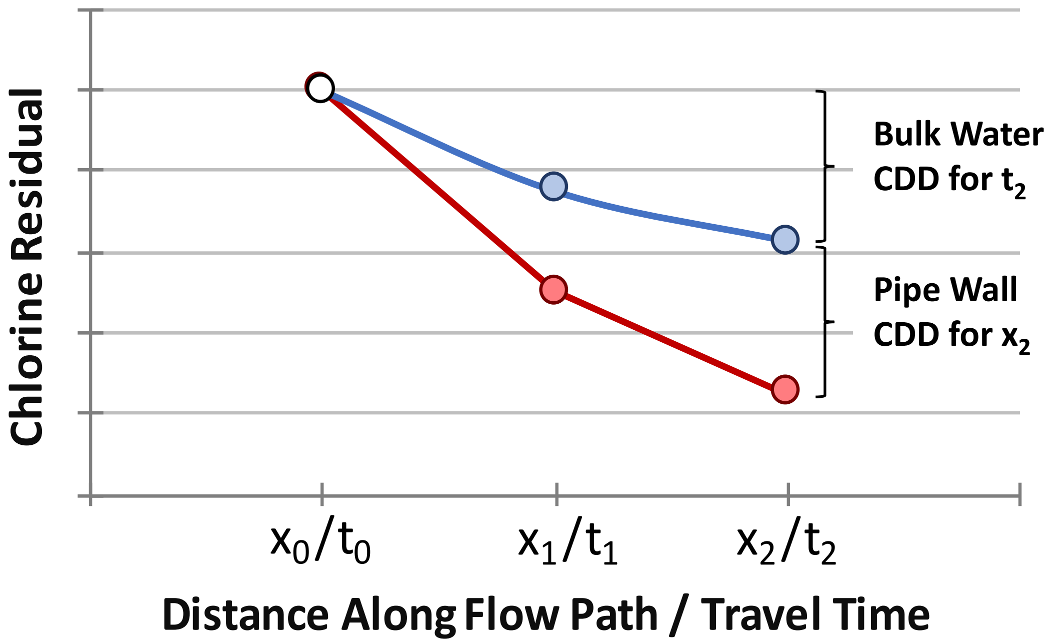
Primary

- Chlorine Demand/Decay (CDD)
- Total Coliform
- HPC-R2A
- Cellular ATP
- Flow Cytometry

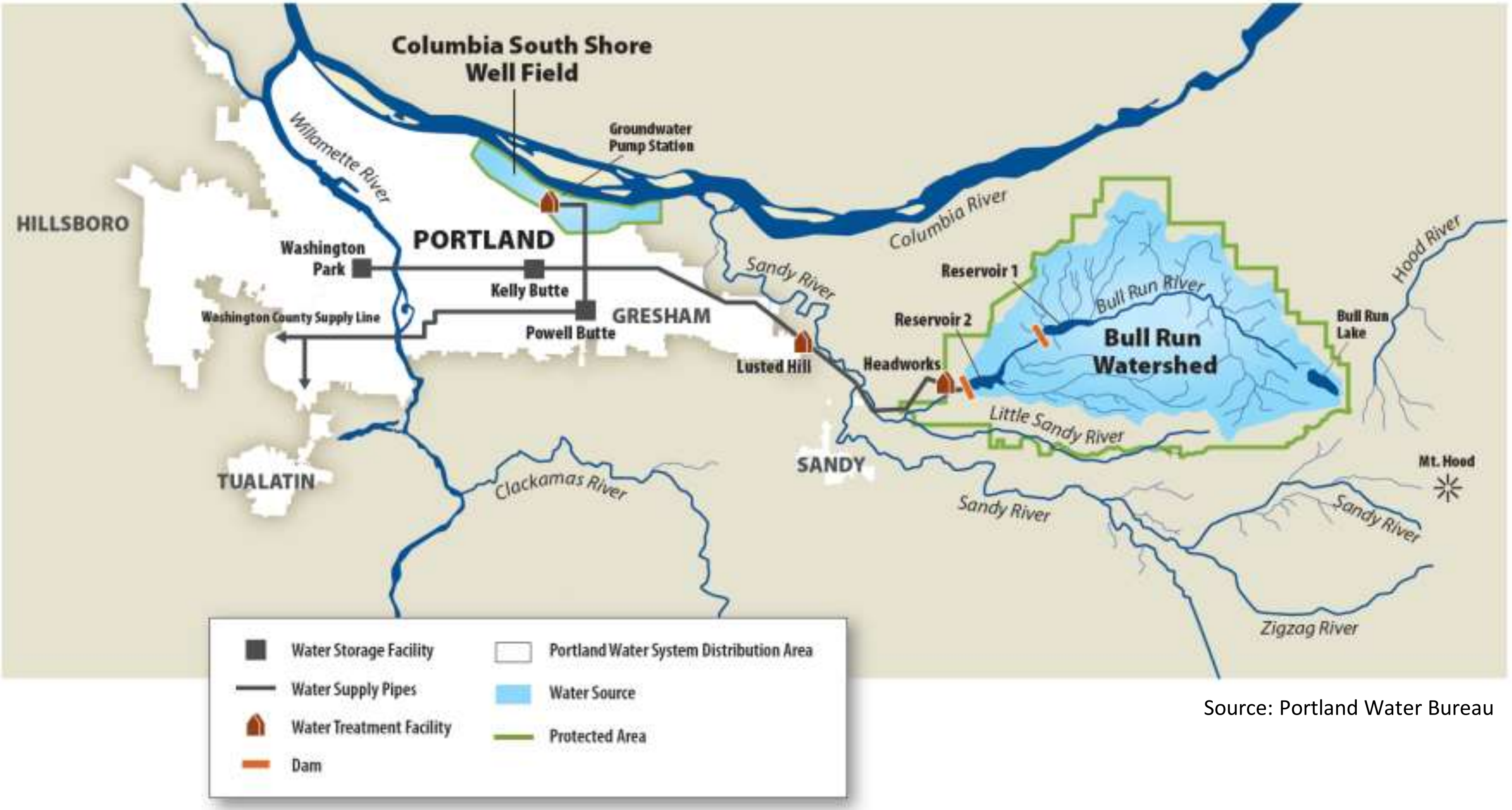
Secondary

- Metal Substrates (Fe/Mn)
- General Water Chemistry
- Nutrients
- Particulate Solids

Source: Confluence Engineering Group LLC



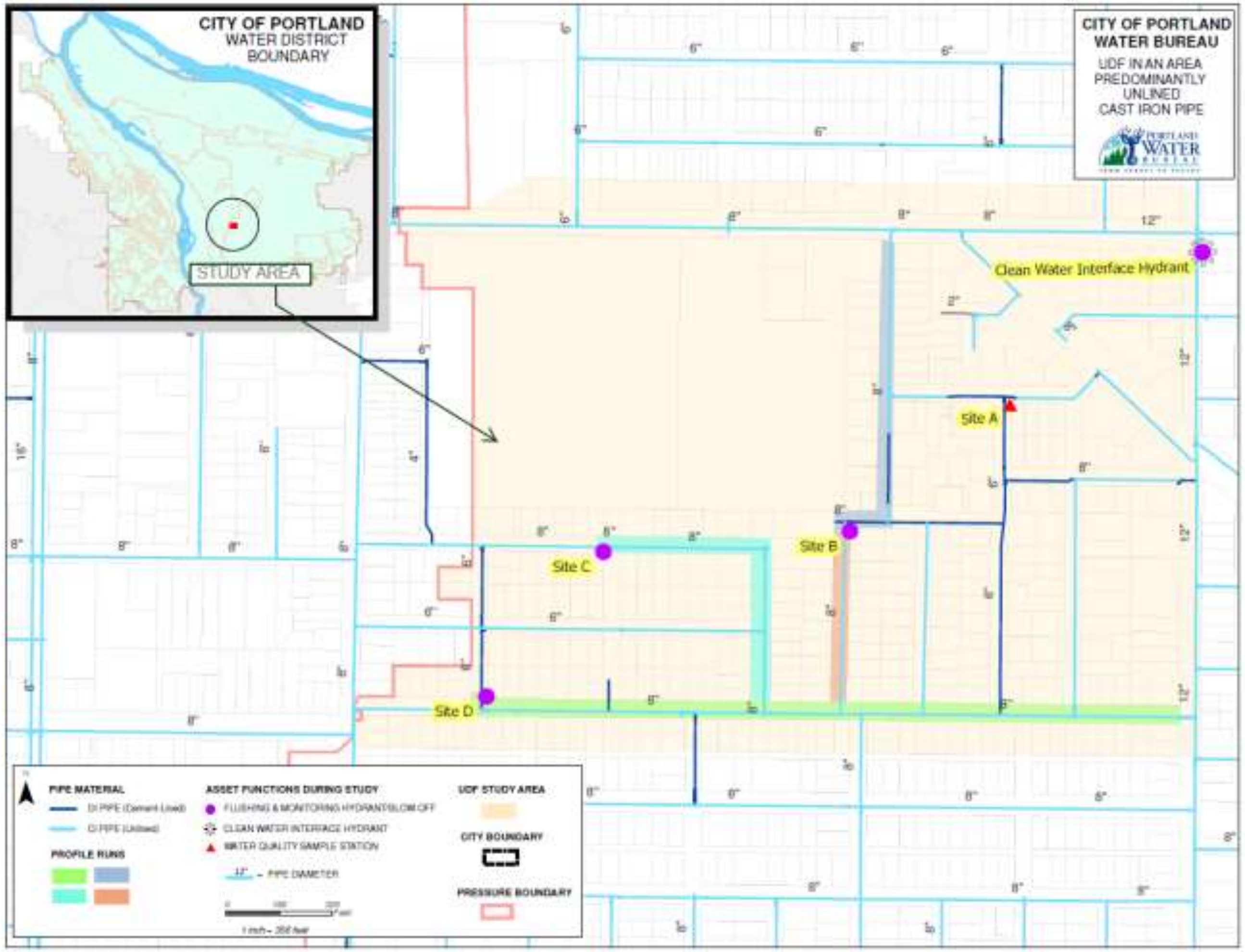
Portland Water Bureau System Overview



Source: Portland Water Bureau

- **Serves over 950,000 people – approximately 25% of Oregon**
- **Surface source is unfiltered**
- **Secondary disinfection with chloramines**
- **Large distribution system**
  - ~200 pressure zones
  - Over 2,200 miles of distribution pipeline

PWB UDF Flushing Study Area



Source: Portland Water Bureau

- **UCI pipe, mostly 8-inch diameter, installed between 1910 and 1931**
- **Small residential area (< 4 miles of pipe)**
- **Nitrification and low Cl_2 challenges Sept thru Nov**
- **Conventionally flushed multiple times per year**

PWB Study Conditions

Important Caveat

Timeframe for project monitoring and flushing (Jun-Jul) did not coincide with season when water quality challenges (nitrification) are experienced in the UDF areas (Sep-Nov)

- **Excellent WQ conditions during baseline period (~ 1.5 mg/L Cl_2)**
- **Limited opportunity for WQ improvement in the 6-wk response monitoring period**
- **But, UDF could be evaluated on usefulness as a preventative maintenance practice heading into nitrification season**

PWB Monitoring Summary
Baseline Water Quality in UDF Area

	Parameter	Units	CWI	Area Median
Chemistry	Total Cl_2 Residual	mg/L	1.8	1.5
	Redox Potential	mV	350	330
Microbial	HPC-R2A	cfu/mL	4	25
	ATP	pg/mL	0.5	0.8
Metals	Iron	mg/L	0.05	0.08
	Manganese	mg/L	0.004	0.01

PWB Flushing Performance
Accumulation Removed with UDF

Source: Portland Water Bureau

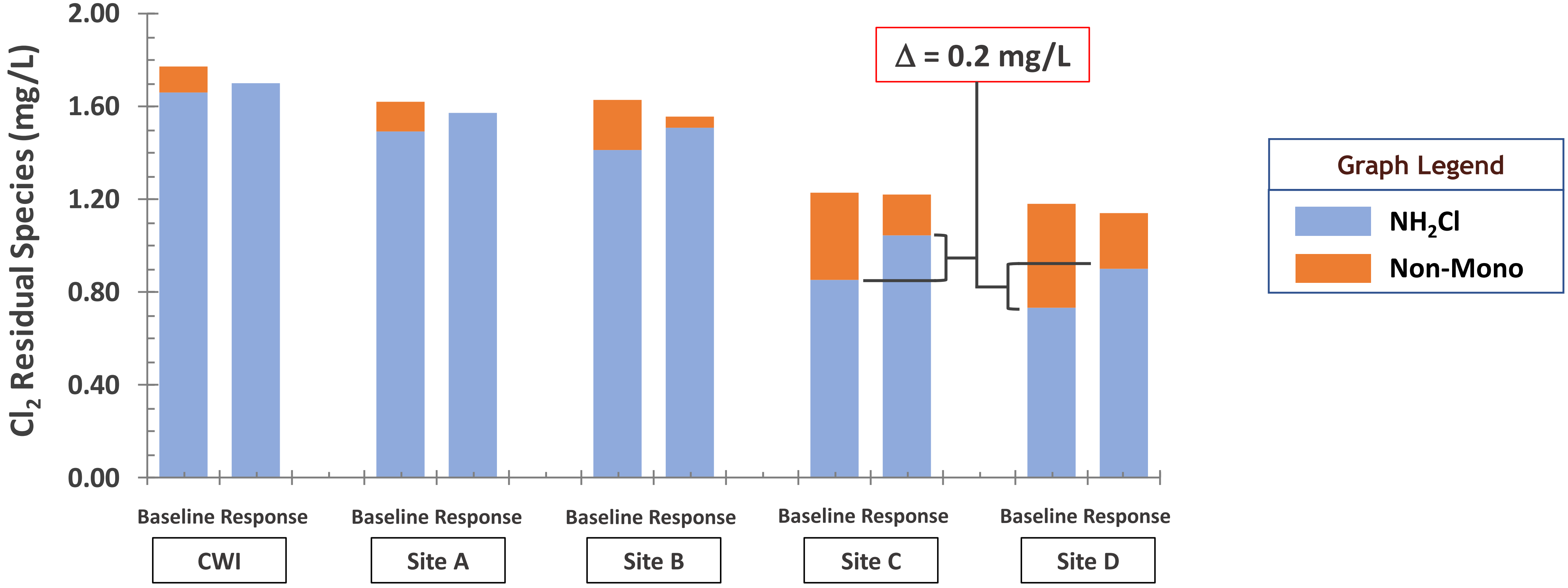
PWB Flushing Performance

Accumulation Removed with UDF

Parameter	Units	Accum. Removed	Baseline WQ	Bulk Water Fraction
Iron	mg/L	15.9	0.08	0.5%
Manganese	mg/L	0.6	0.01	1.6%
cATP	pg/mL	12	0.8	6%
HPC-R2A	cfu/mL	1,700	25	1%
TOC	mg/L	2.8	0.8	23%

Note: all values are based on area-wide median

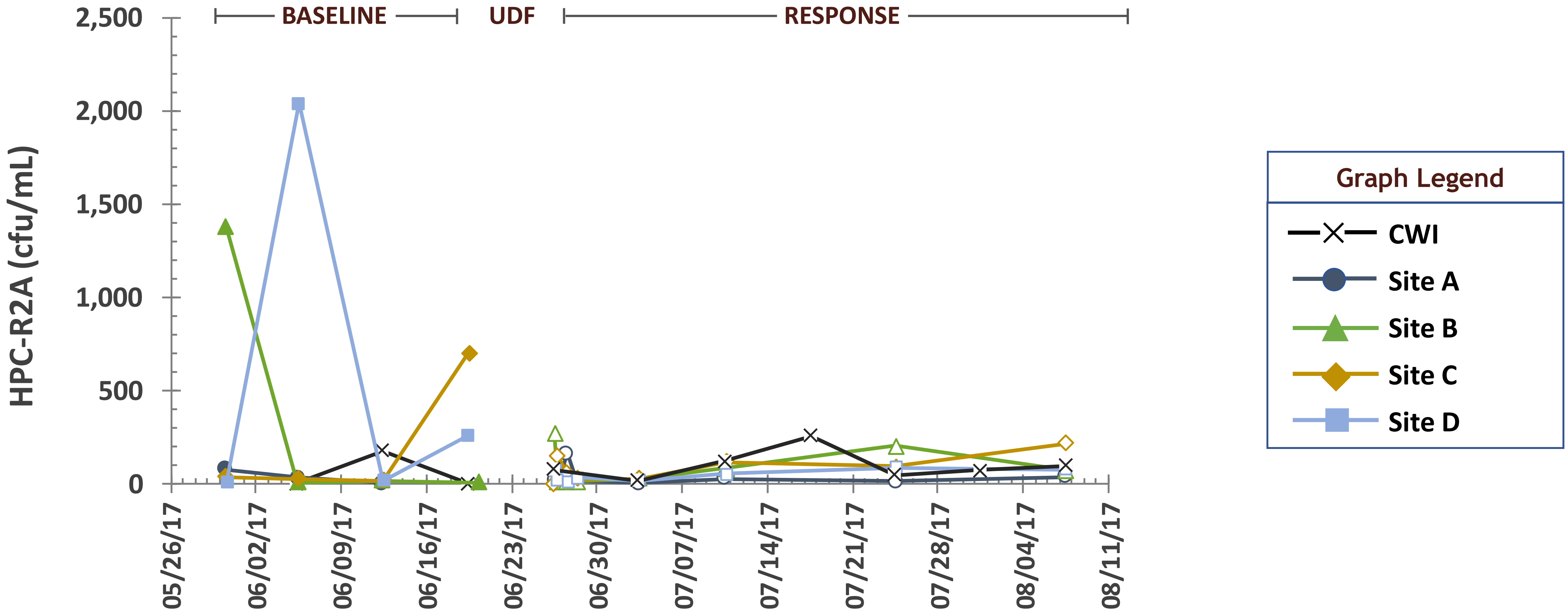
PWB Flushing Results
Disinfectant Residual Speciation



Non-monochloramine likely represents undesirable organochloramines

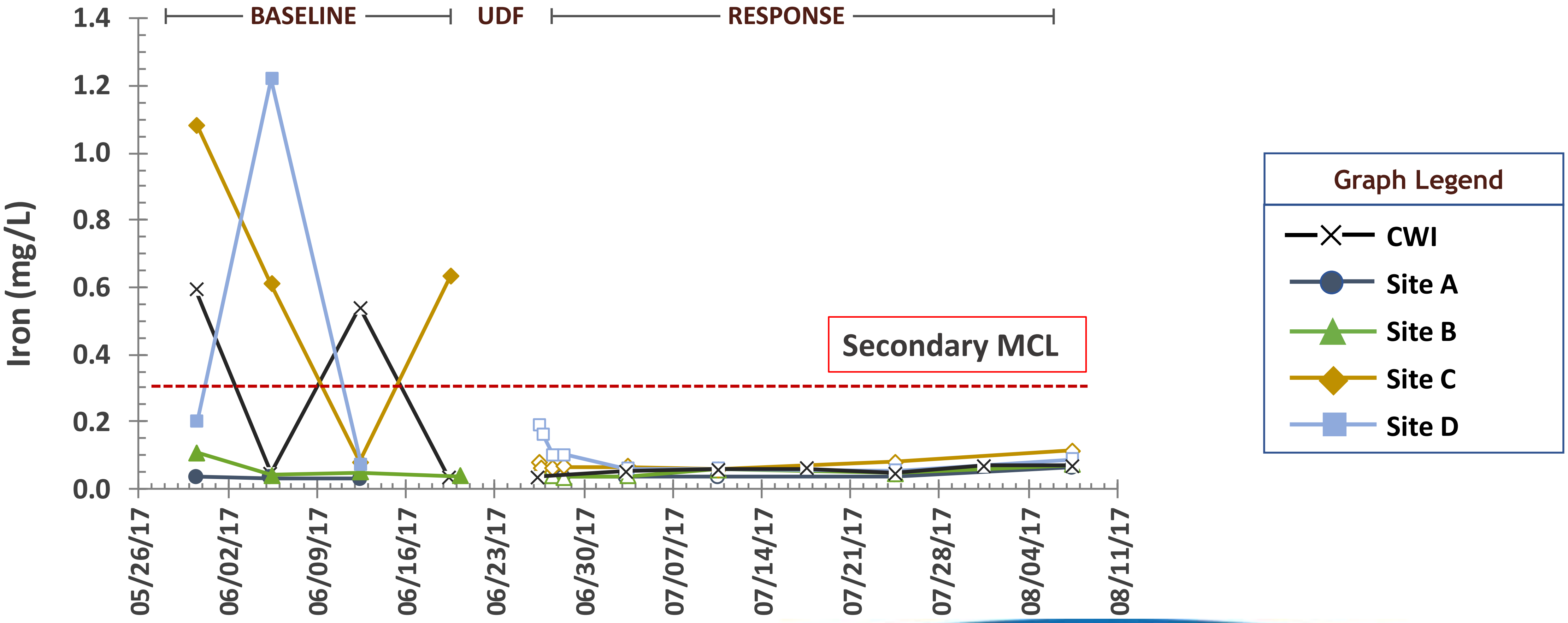
- **Formed by reaction with organic nitrogen in biofilm**
  - $NH_2Cl + RNH_2 \longrightarrow RNHCl + NH_3$ (Westerhoff et al, 2010)
    monochloramine *organic nitrogen* *organochloramine*
  - Total Cl_2 is constant… but speciation changes
- **UDF lessens impact of this reaction by removing biofilm from the scale–water interface**

PWB Flushing Results
Microbial Response

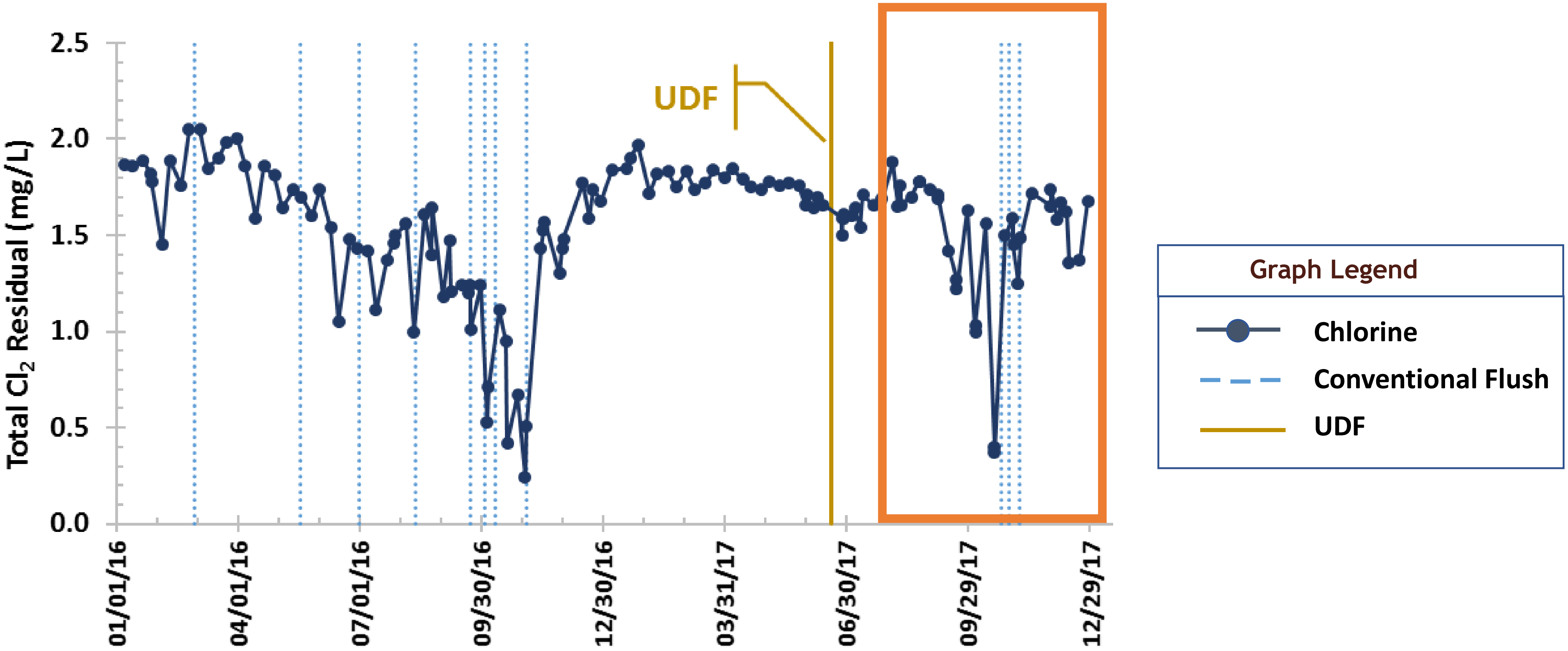


PWB Flushing Results

Metals Response



UDF as a Preventative Technique
Leading into Nitrification Season



Year-Over-Year Analysis of Nitrification Control Benefits

Parameter	2016 Nitrif. Season	2017 Nitrif. Season	YOY Change
Total Cl_2 (mg/L) (5th percentile)	0.5	0.8	+0.3 (+60%)
HPC-R2A (cfu/mL) (95th percentile)	158	35	–123 (–78%)
No. of Response Flushes Needed to Address WQ	7	3	–4 (–57%)

Note: Data are associated with nitrification season of July thru November each year

Seattle Public Utilities System Overview

- **Serves approx. 1.4 million people in Seattle and surrounding area from Cedar and Tolt watersheds**
- **Area selected for WRF study served by Cedar Water Treatment Plant (unfiltered source)**
  - Cedar treatment consists of ozonation, UV disinfection and free chlorine to maintain residual in distribution system
  - Wells used during drought/emergencies (last used in 2015)
- **Direct Service Area has approx. 1,470 miles of pipe**
  - ~ 37% is unlined cast iron

SPU UDF Study Area

Source: Seattle Public Utilities

- Small residential area
- Pumped zone from a standpipe (CWI)
- UCI pipe, mainly 8-inch dia., installed from 1910 to 1918
- No historical Cl2 data but canvassing showed low Cl2
- Frequent customer complaints (discolored water)
- Last flushed in 1990s

SPU Monitoring Summary
Baseline Water Quality in UDF Area

	Parameter	Units	CWI	Area Median
Chemistry	Free Cl_2 Residual	mg/L	0.8	0.1
	Redox Potential	mV	580	305
Microbial	HPC-R2A	cfu/mL	0	165
	ATP	pg/mL	2.5	12
Metals	Iron	mg/L	0.04	0.20
	Manganese	mg/L	0.002	0.01

Baseline Chlorine Demand/Decay

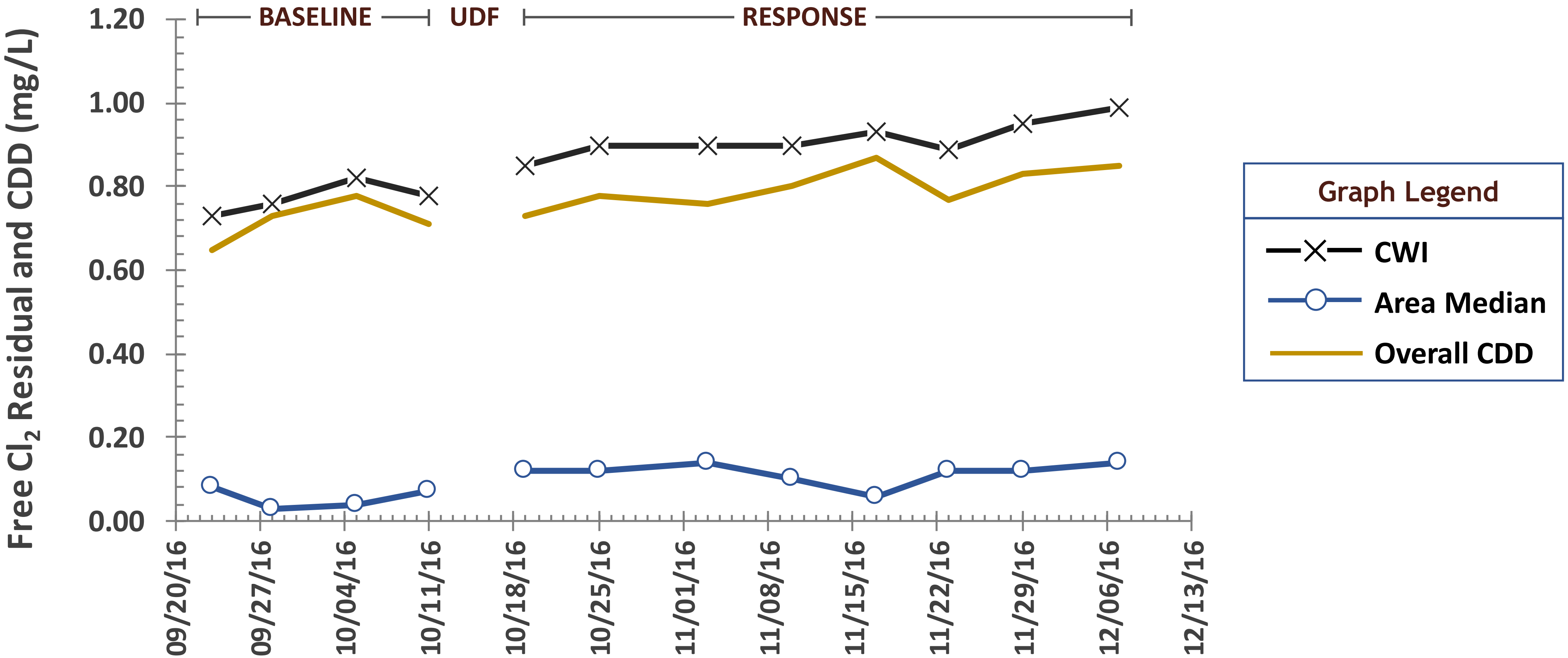
CDD Term	CWI $\rightarrow$ Site E (travel t = 43 hr)
Bulk Water CDD (From Jar Tests)	**0.11 mg/L** (17%)
Pipe Wall CDD (Calculated)	**0.55 mg/L** (83%)
Total CDD (Field Monitoring)	**0.66 mg/L** (100%)

SPU Flushing Performance
Accumulation Removed with UDF

Parameter	Units	Accum. Removed	Baseline WQ	Bulk Water Fraction
Iron	mg/L	154	0.20	0.1%
Manganese	mg/L	19.7	0.01	0.1%
cATP	pg/mL	380	12	3%
HPC-R2A	cfu/mL	6,800	165	2%
TOC	mg/L	3.2	0.8	20%

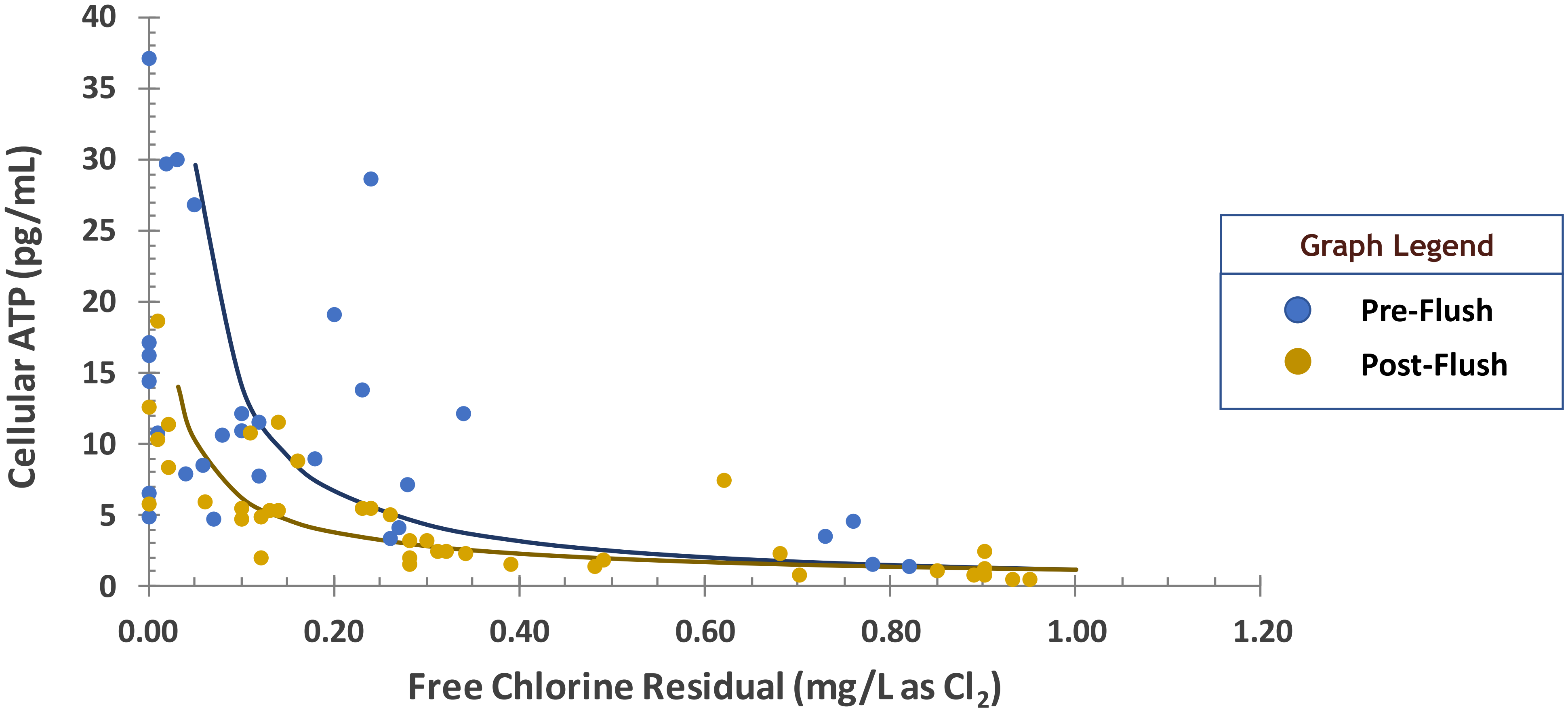
Note: all values are based on area-wide median

SPU Flushing Results
Free Chlorine CDD Response



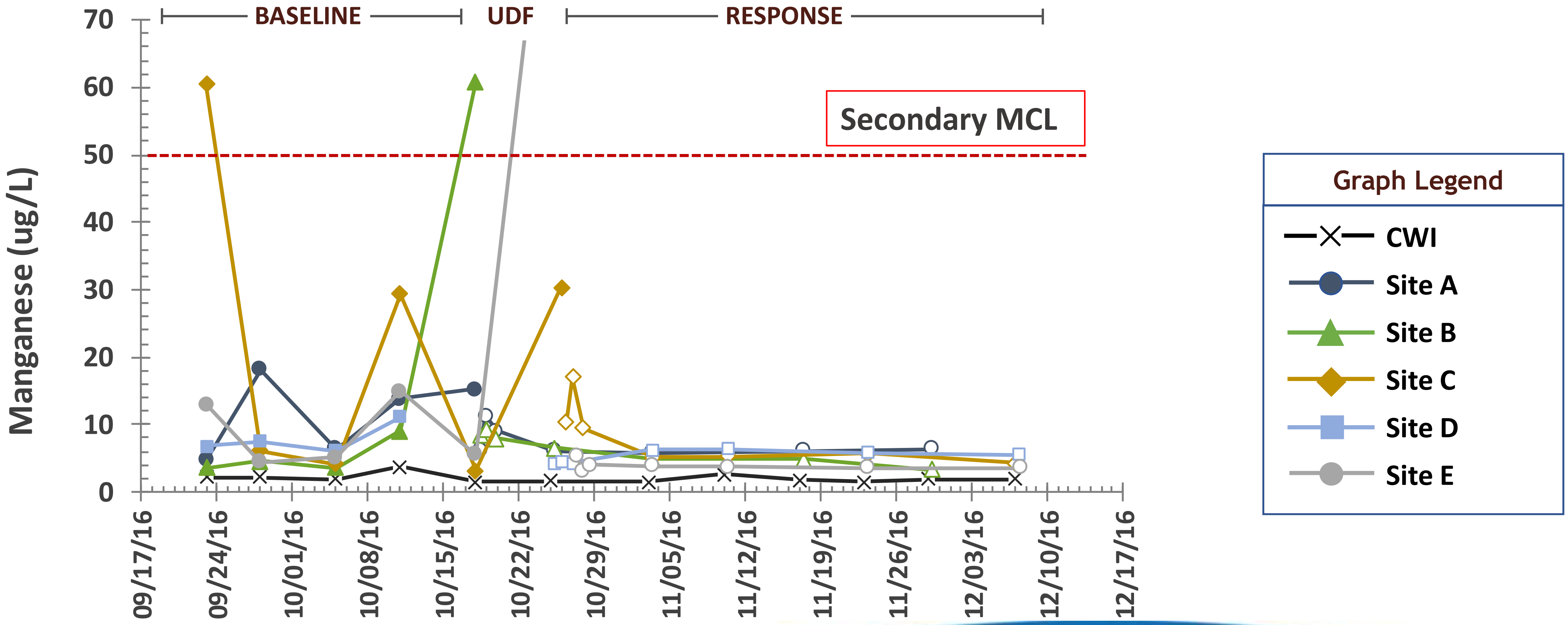
SPU Flushing Results

Microbial Response

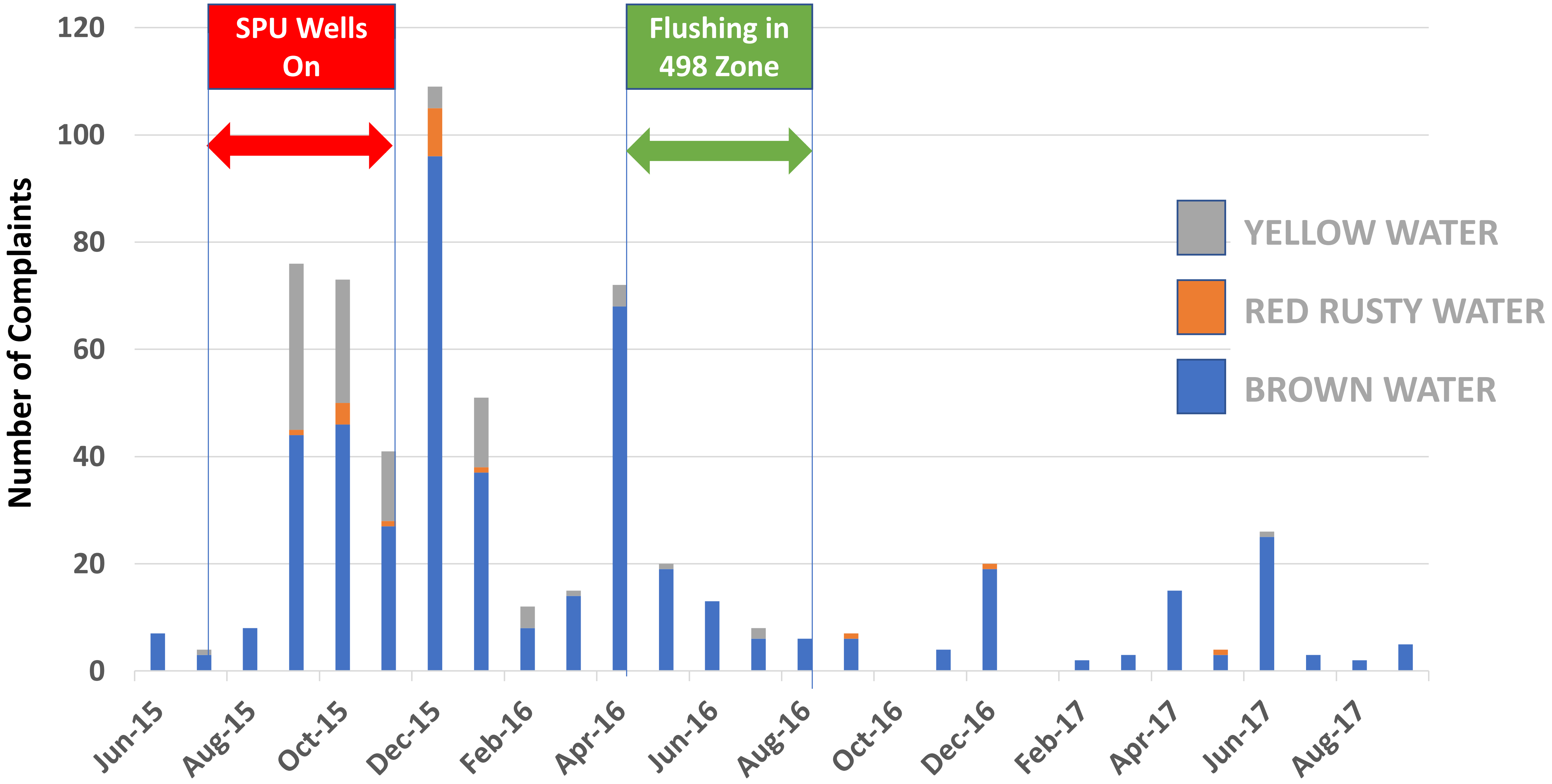


SPU Flushing Results

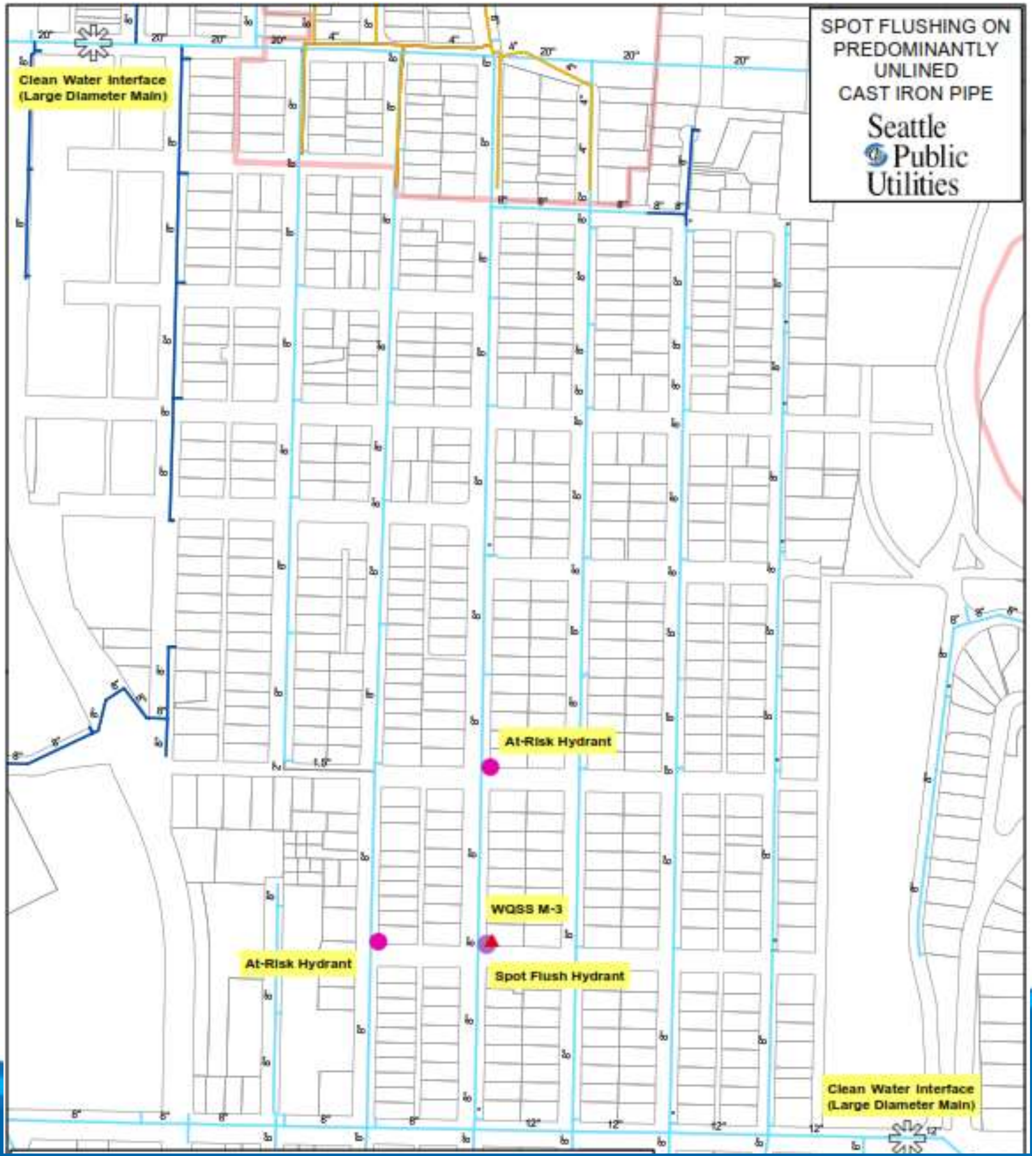
Metals Response



Longer-Term Analysis – Customer Complaints



SPU Conventional Flushing (CF) Trial



- **Small gridded residential area in SE Seattle**
- **Nearby transmission lines with 0.9 mg/L of Cl_2 (CWI)**
- **UCI pipe, mainly 8-inch dia., installed around 1929**
- **Seasonal Cl_2 residual maintenance challenges**

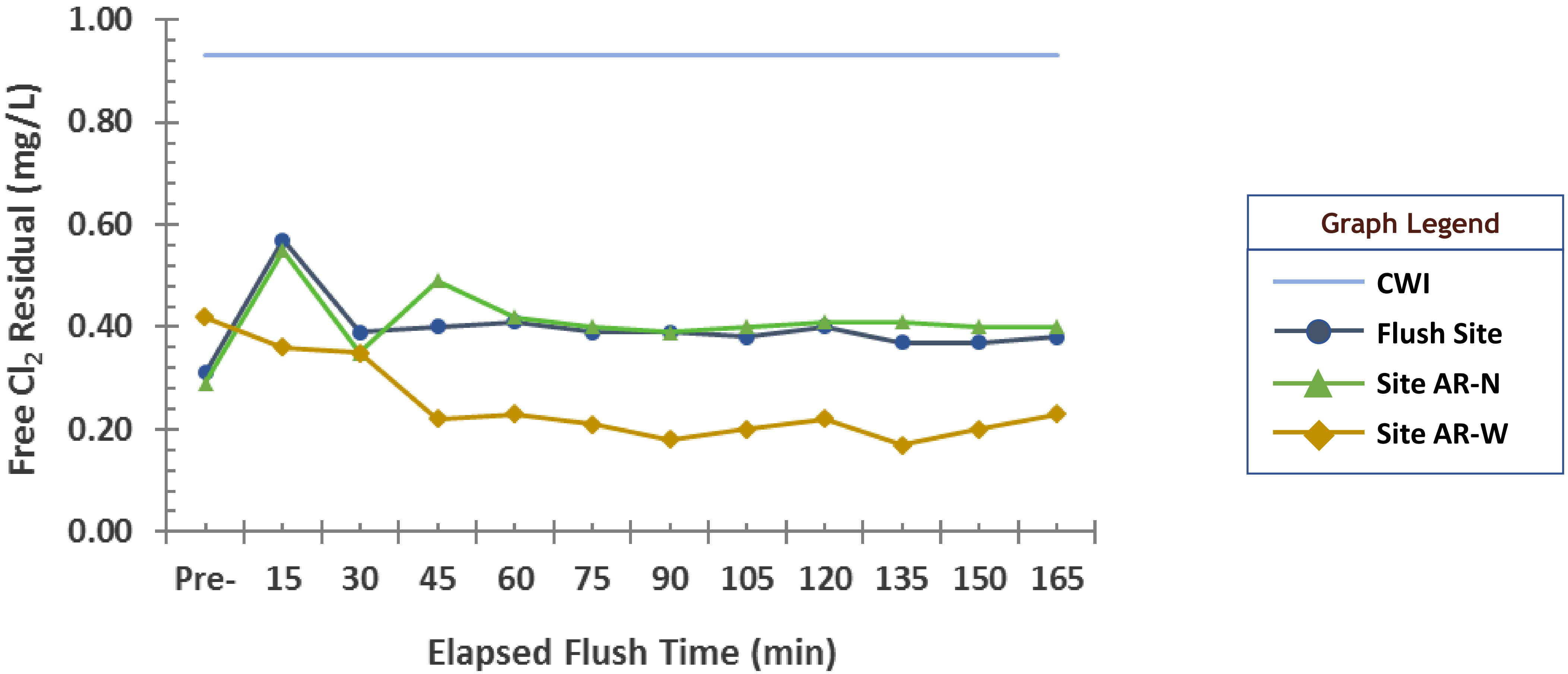
Flushing Conditions Applied

- **Opportunity to evaluate SPU's previous spot protocol**
  - Conventional flush with no valving
  - 600 gpm flow for 3 hour duration
- **Nearby "at-risk" locations also monitored during flush**

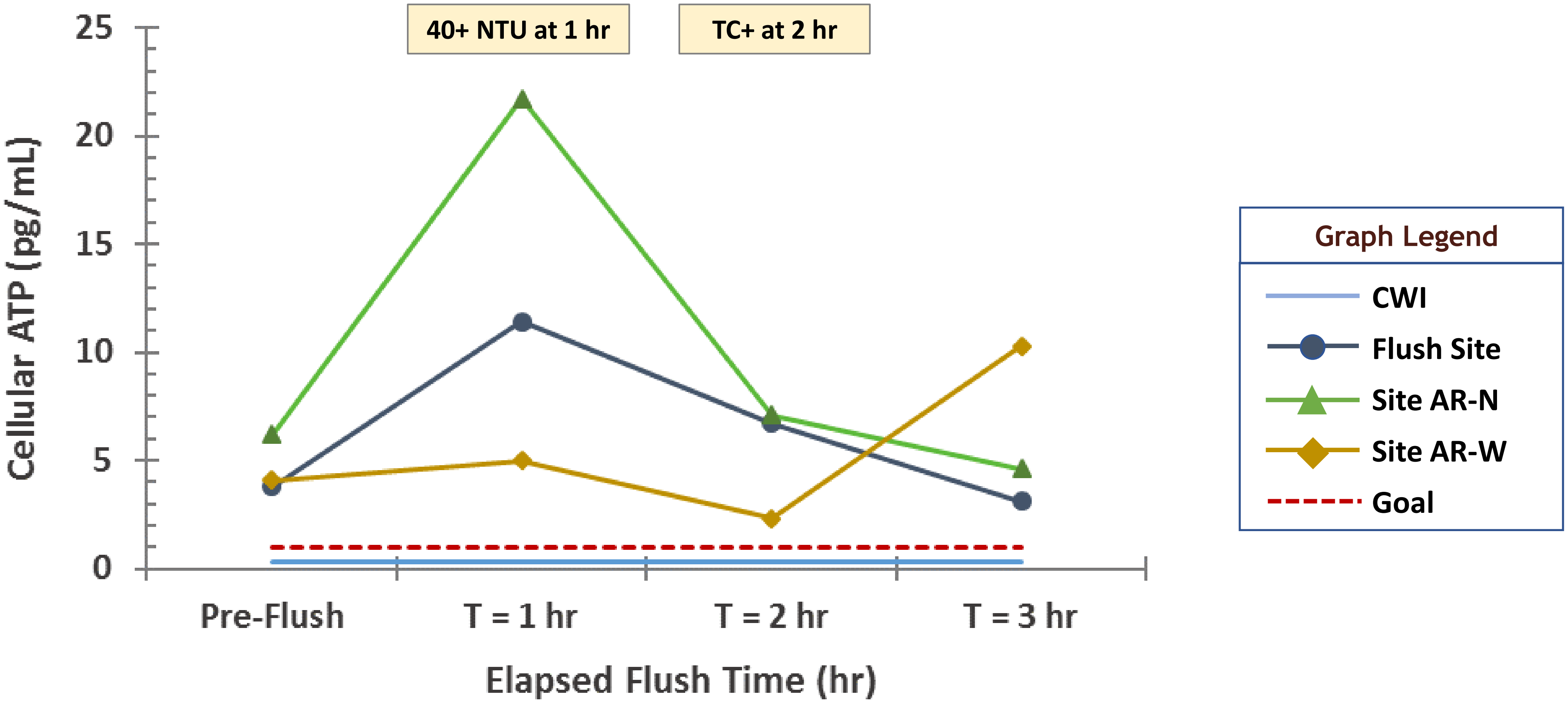
Parameter	Flush Site		At-Risk North (AR-N)		At-Risk West (AR-W)	
	Baseline	CF 630 gpm	Baseline	CF 630 gpm	Baseline	CF 630 gpm
Flow Direction	North	N. and S.	North	South	North	South
Flow Rate Range (gpm)	10-100	100-1,000	10-100	100-1,000	10-100	10-100[a]

(a) Flow in upstream line increased to 100-1,000 gpm range

Chlorine Residual Profile During Flushing



Microbial Profile During Flushing

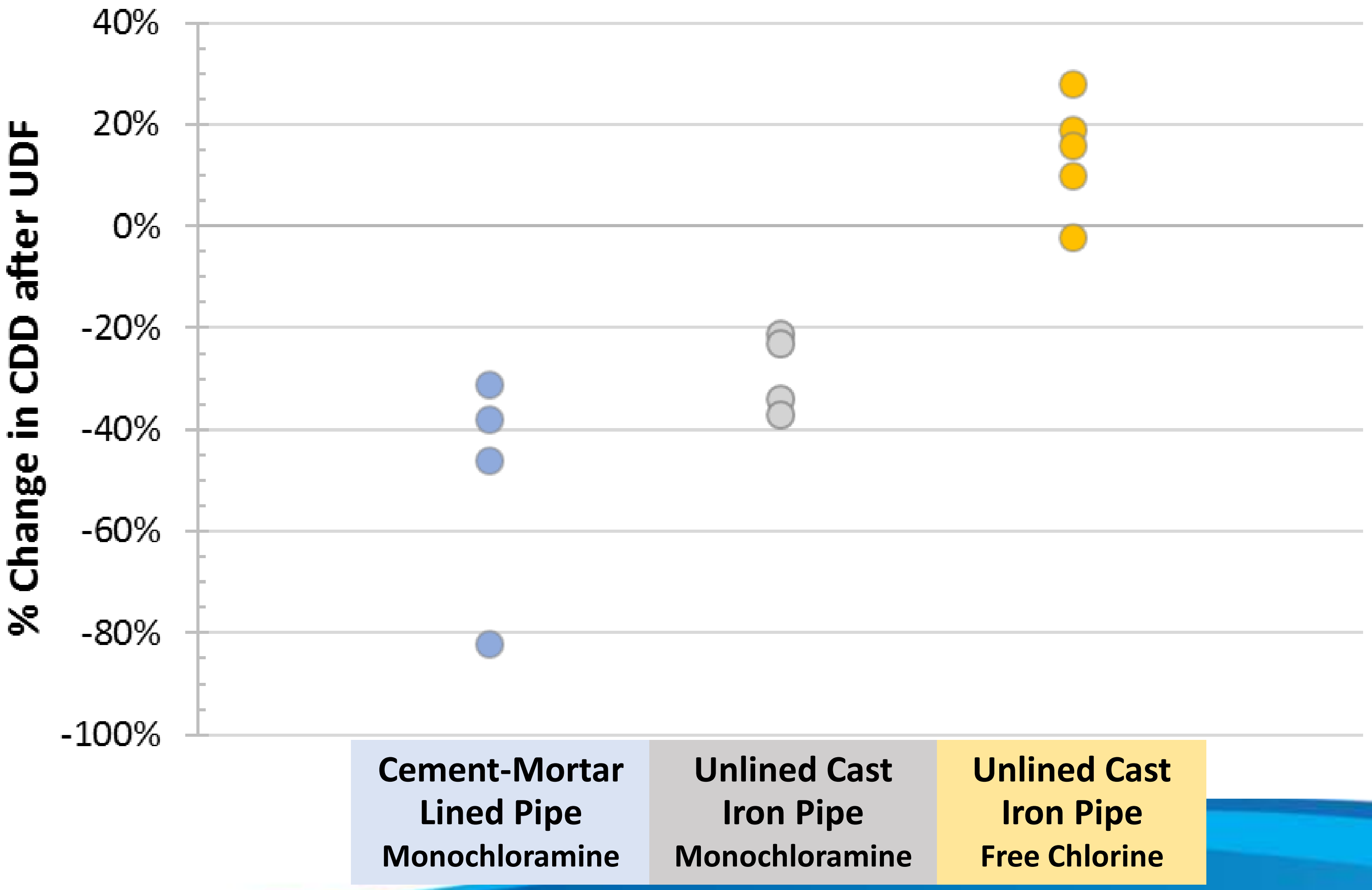


Key Findings from UDF Trials

- **WQ benefits of UDF can take numerous forms**
- **Many aren’t evident with TCR monitoring**
    - Removal of hydraulically-mobile biofilm, coliform, and microbially-active sediment (and other contaminants)
    - Improve water quality stability / avoid releases
    - Reduce pipe wall chlorine demand
    - More sustainable system performance
    - Proactive system management / less reactive O&M
    - Improve public perception / reduced complaints

Key Findings from UDF Trials

Impact of UDF on Pipe Wall CDD



Key Findings from Conv. Flushing Trials

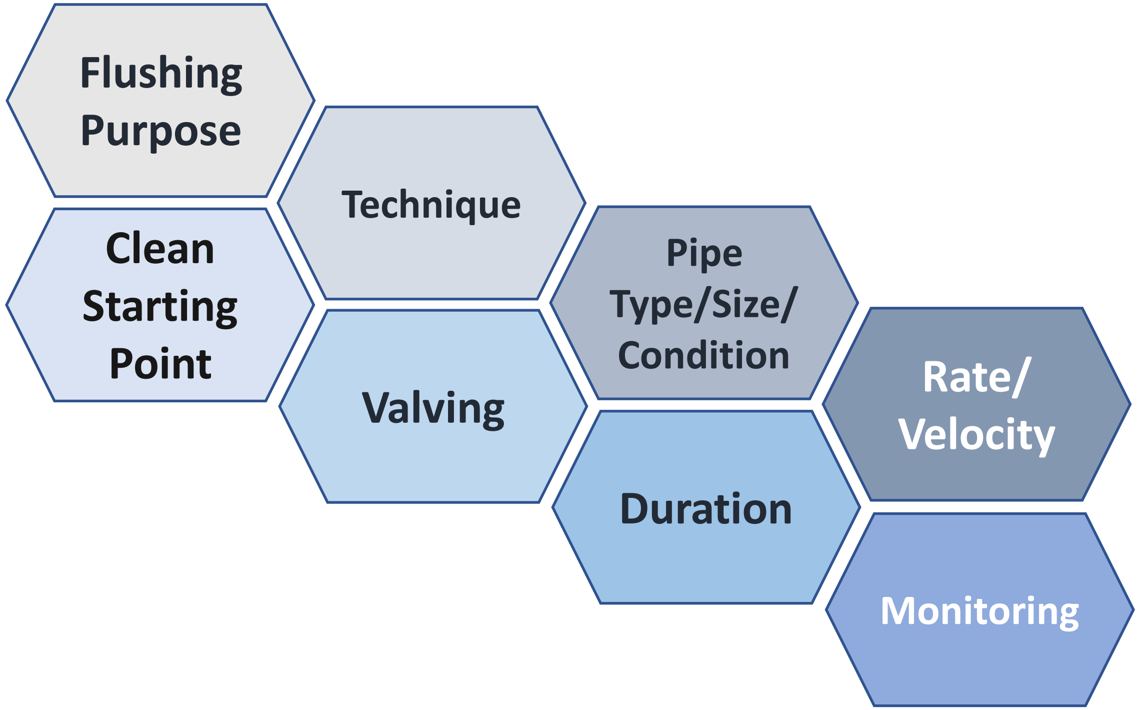
- ***High-rate*** **conventional flushing poses under-appreciated risks**
  - Uncontrolled scouring over a large area
  - Risk of deposit mobilization without removal
    - Spatial WQ variations
    - Water quality could end up worse
    - Could create or exacerbate a coliform event!
  - Can necessitate very lengthy flushes
    - Customer exposure risks
    - Inefficient water use

Recommendations for Utilities

- **Flushing is invaluable tool available to all utilities, but it must be used in a controlled manner**

- **Use of the proper technique and application method are essential to achieve targeted benefits and minimize risks**

- **Appreciate what flushing can and cannot do**



Key Considerations for Utilities

- **Is flushing the most appropriate tool?**

  It cannot sustainably address impacts from…
  - Inadequate treatment
  - High local water age (unless auto-flushing station)
  - Extensive corrosion scale
  - Carryover effects from upstream (e.g., nitrified water)

- **What is the purpose of the flushing endeavor?**
  - Main Cleaning → UDF
  - Turnover → Conventional

- **How should the technique be applied?**

Guidance on Conventional Flushing

- **Quick band-aid**
- **Purpose should be bulk water turnover**
  - Purge undesired water; bring in fresh water; Cl2 ↑
  - Cl2 benefit may be limited & brief (hours to days)
- **Be gentle; avoid disturbing deposits**
  - More Flow ≠ Better
  - Limit to 200-300 gpm for 6 and 8” mains
- **For large areas, use multiple hydrants in sequence and selective valving (quasi-UDF) to accelerate the process**

Guidance on UDF

- Can fulfill multiple purposes
  - Controlled removal of hydraulically-mobile deposits
  - Controlled displacement of poor WQ
- Highly-organized; plan in advance
- Start at a clean water source and work entirely through an area
  - May need to establish CWI with pre-flushing
  - Can use NO-DES for "spot" UDF
- Velocity is an important control variable

Role of UDF Flushing Velocity

- **Velocity is an important control variable**
  - 2-4 fps will remove most loose particles
  - 6-10 fps can mobilize some biofilm
- **Optimal flushing velocity is *site-specific***
  - Goal is to maximize deposit removal while protecting pipe, lining, and corrosion scales
  - Consequences of non-optimal velocities
  - Use step-velocity tests with WQ monitoring

How Should Flushing Be Used to Address Coliform Events?

- **Situation-Specific**
- **Start with an Assessment of Probable Cause**

RTCR Guidance in WRF 4653

Step 1.
Conduct Coliform Assessment to Determine Likely Cause

- Treatment/Source Water Breakthrough
- Direct Contamination of Distribution System
- Regrowth
- Other (sampling/analytical)
- Unknown Cause

Step 2.
Consult Table 6.1 to Assess Appropriateness of Flushing

- Compare Flushing Techniques
  - Conventional
  - Unidirectional
- Evaluate Appropriateness of Flushing
  - Corrective Action
  - Response Tool

Step 3.
Consult Table 6.2 to Implement Flushing Properly

- Technique
- Flow Rate/Velocity
- Duration
- Monitoring to Demonstrate Performance

Step 4.
Consult Table 6.3 to Identify Other Potential Corrective Actions

- Breakthrough
- Direct Contamination
- Regrowth
- Sampling or Testing Related

How Should Flushing Be Used to Address Coliform Events? (Continued)

- **UDF can be Preventative, Reactive, or Corrective**
  - Only considered a Corrective Action if cause is biofilm regrowth
  - CF is never a considered a Corrective Action

- **For other causes, flushing can help with response once the underlying cause has been corrected**
  - Replace with clean water
  - Temporarily improve chlorine residual

Importance of Water Quality Monitoring and Data Management

- **Distribution System Surveillance Monitoring**
  - Establish baseline conditions
  - Identify WQ trends & triggers
    - Where, When, and How Often to Flush
    - System-Specific Flushing Performance
- **Monitoring During Flushing**
  - Use to guide flush duration
  - Turbidity, Cl_2 residual, ATP

Typical Surveillance Parameters

pH	Turbidity
Alkalinity	Fe/Mn
Cl2 Residual	ATP
ORP	HPC-R2A
Conductivity	System-specific

Questions?

Final WRF 4653 Report To Be Published in February 2019
"Ensuring Flushing is a Corrective Action Under the RTCR"

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Boneyard Slides

Impact of Conventional Flushing Rate on Water Quality

Parameter (Δ = EOF–Baseline)	Units	CF at 630 gpm			CF at 370 gpm		
		Site M-3	Site AR-N	Site AR-W	Flush Site	Site AR-1	Site AR-2
Δ Cl_2 Residual	mg/L	+0.1	+0.1	–0.2	+0.2	+0.6	+0.06
Δ HPC-R2A	cfu/mL	–7	+1	+17	–25	+10	-10
Δ cATP	pg/mL	–0.7	–1.6	+6.2	–0.1	+0.4	+0.5
Δ Turbidity	NTU	+0.3	0.0	–0.4	–1.6	+0.3	–0.9
Δ Iron	µg/L	+56	+48	+30	–26	+5	–62
Δ Manganese	µg/L	+5.7	+11.3	–2.6	–1.4	+2.8	–10.2

Major Improvement | Minor Improvement | Negligible Change | Minor Degradation | Major Degradation

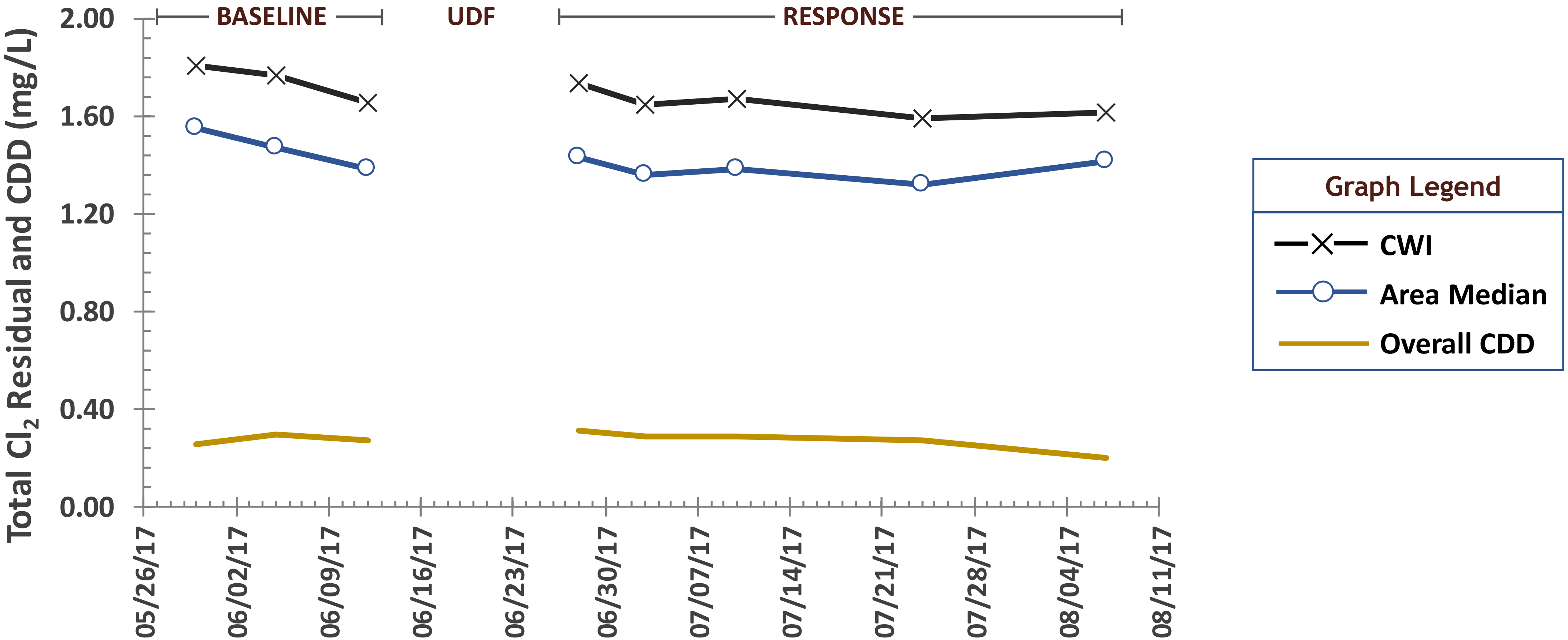
Toolbox of Flushing Techniques

Flushing Technique	Expected Water Quality Response
Automatic Flushing Station Portable device or semi-permanent station operated to regularly purge water.	• Comparable to spot flushing; however, the turnover and water age control benefit is more sustainable because of programmed regular use.
Conventional Spot Flushing One or more hydrants flowed. Flow originates from multiple directions and pipe segments.	• Bulk water turnover to reduce water age. Little-to-no pipe cleaning benefit (when conducted properly). • Localized, limited, and temporary • Highest risk of disturbing sediment and/or spreading contamination.
Dead-end Flushing Similar to conventional spot flushing, but dead-end results in a single flow path for local segment.	• Localized, limited, and temporary although the unidirectional flow may provide local pipe cleaning. • Risk of disturbing sediment upstream .
Quasi-Unidirectional Flushing Hybrid of conventional and UDF. Lacks a true upstream clean water source.	• Specific main segments are cleaned; but the water introduced from upstream is not “clean.” • High flow rates used creates potential for upstream issues (disturbing sediment).
Unidirectional Flushing (UDF) Organized sequential main cleaning from a clean starting point. Requires extensive planning.	• All local and upstream pipes are (at least partially) cleaned; also achieves > 100% bulk water turnover. • Least amount of water used and avoids risk of disturbing sediment without removal.

Chlorine Demand/Decay (CDD)

- **Bulk Water Term**
  - Bulk Water Rxns
  - Blending Effects
  - Nitrification
- **Pipe Wall Term**
  - Reaction with corrosion scale (unlined iron pipe)
  - Reaction with accumulated particles and biofilm

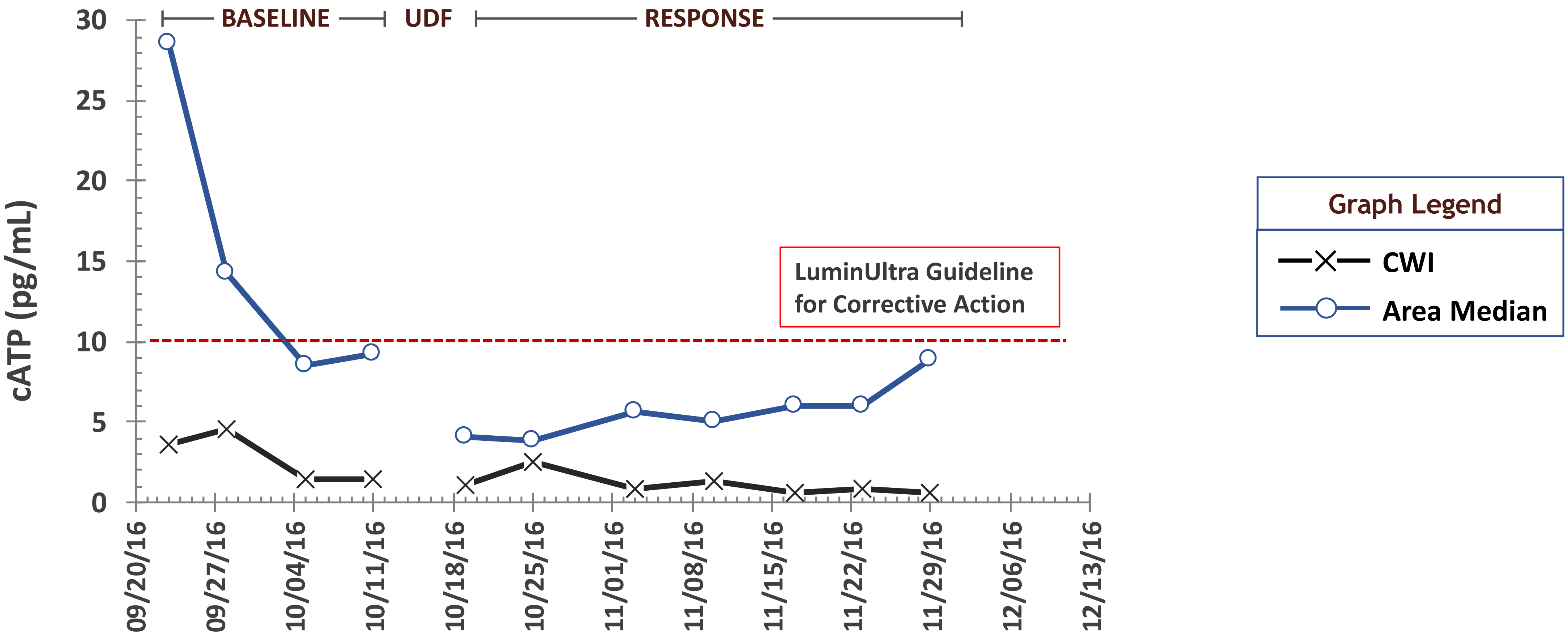
PWB Flushing Results
CDD Response



Why SPU Interested in WRF Project

- **Trying to resurrect flushing/UDF program due to recent events in West Seattle**
- **Compare with current spot flushing practices**
- **Complete WRF in tandem with other flushing projects:**
  - Created and implemented 498 Zone UDF program (2016)
  - NO-DES technology pilot (2016)

SPU Flushing Results
Microbial Response



Results from Step-Velocity Trials