Accumulation and Mitigation of Metals on Plastic and Cement-Lined Pipe

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Presentation Overview

- Issue of metals accumulation and release
- Why the focus on cement and plastic pipe?
- Park City's experience
- WaterRF 4509
  - Main Cleaning Evaluation
- Conclusions

Overview of Issue

- **Regulated trace metals can accumulate in DS**
  - Fe/Mn occurrence significantly increases accumulation risk
- **Accumulated metals can be released**
  - Potential for elevated tap concentrations (> MCLs)
  - Releases are not easy to control (or always identify)
- **Ignored by current IOC monitoring & regulatory framework**

Environmental Science & Technology Online News
http://pubs.acs.org/subscribe/journals/esthag-w/2008/jan/science/rr_pipescales.html

Science News –January 23, 2008

Pipe scales release hazardous metals into drinking water

Mobilization of mineral deposits within the distribution system can contaminate treated water before it reaches the tap.

Mineral deposits inside drinking-water pipes can contain high levels of hazardous metals, including arsenic, cadmium, and mercury, and the metals can contaminate tap water when they are disturbed, according to new research published in *ES&T* (DOI: 10.1021/es0702488v). But current water-quality regulations miss such disturbances, because they call for monitoring at the treatment plant before the water enters the distribution system pipes.

Michael Schock et al.

Pipe scales concentrate many different metals.

Pipe Classification Scheme

Scale-Forming	Non Scale-Forming
- Unlined Cast and Ductile iron (19%)	- Cement-lined (34%)
- Steel (4%)	- Plastic (18%)
- Galvanized (<1%)	- Asbestos Cement (15%)

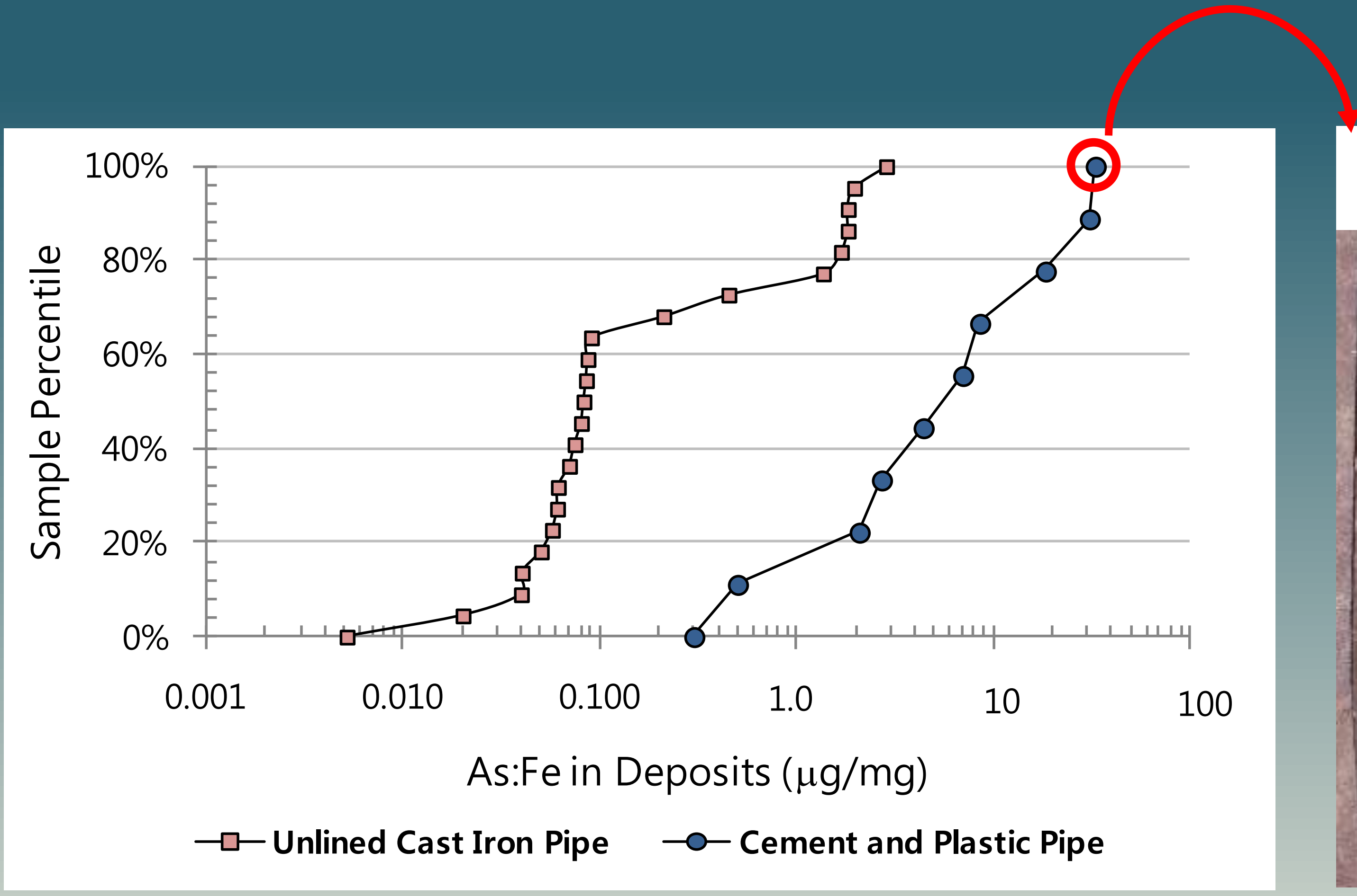
Approx. pipe distributions per USU, 2012

Why the focus on plastic and cement-lined pipe?

	Scale-Forming	Non Scale-Forming
Primary Substrate	Corrosion Scale	Settled Precip./Biofilm
Mass Inventory (lb/mile)	High -12,000 lb/mi (UCI median)*	Low -150 lb/mi (median)*
TIC Occurrence (mg/kg = ppm)	Low -Dilution effect of scale -Potentially high at surface	High -Strong relationship to WQ and Fe/Mn loading
Release Potential	Relatively immobile -Adherent -Low interfacial A:V	Relatively mobile -Loose or cohesive -High interfacial A:V

* From WaterRF #3118

Role of Pipe Classification on TIC Occurrence



PVC Pipe Specimen
Arsenic = 13.6 µg/mg

Supporting data and figure from Lytle et al. (2004)

Recent Research

- **WaterRF #4509: Metals Accumulation and Release within the Distribution System: Evaluation of Mechanisms and Mitigation**
- **Tailored Collaboration Project**
    - Park City Municipal Corporation, Utah (PCMC)
    - Confluence Engineering Group, LLC
    - Utah State University (USU)
- **Final Report expected Summer 2015**

Tailored Collaboration Team

- **Research Team**
  - **Park City**: Michelle DeHaan, Kyle McArthur, Ken Mitchell
  - **Confluence**: Melinda Friedman, Andrew Hill, Michael Hallett, Stephen Booth
  - **USU**: Laurie McNeill, Darwin Sorensen, Joan McLean, David Stevens, Tiana Hammer, William Kent
- **WaterRF/PAC**
  - Jian Zhang; WaterRF
  - Brian Lakin; Jacobs Associates
  - Anne Camper; Montana State University
  - John Consolvo; Philadelphia Water
  - Dan Giammar; Washington University

Project Motivation

- **Metals "excursion events" in Park City's distribution system**
  - Dec. 2007 – 10 days
  - Nov. 2010 – 23 days
- **Destabilization of legacy deposits**
- **Event symptoms …**
  - Colored tap water (initially)
  - Elevated Fe and Mn levels
  - Persistent elevated As, Pb, and Tl
    - Even after water cleared up
    - Despite daily zone-wide UDF

Project Motivation

- **Excursion events occurred despite…**
  - Dedicated Fe/Mn filtration process (20 years)
  - Low (but measurable) TIC levels at zone POE
  - Proactive semi-annual UDF program
    - UDF conducted 2 months prior to the 2010 event
    - Flush discharge visually clear and metals levels similar to background = flushing is at its limit

Source: Park City Municipal Corporation

Stubborn Legacy Deposits

- **Pipes are cement-lined, AC, and plastic**
- **Thin, slimy films with cohesive "sludge"**
  - Legacy Fe/Mn precipitates
  - Co-precipitated trace metals
  - Biofilm (organic carbon)

Source: Park City Municipal Corporation

Field Investigation of Mitigation

Task Objective

Develop guidance on effectiveness and costs of main cleaning techniques for removal of legacy deposits and contaminants

Task Approach

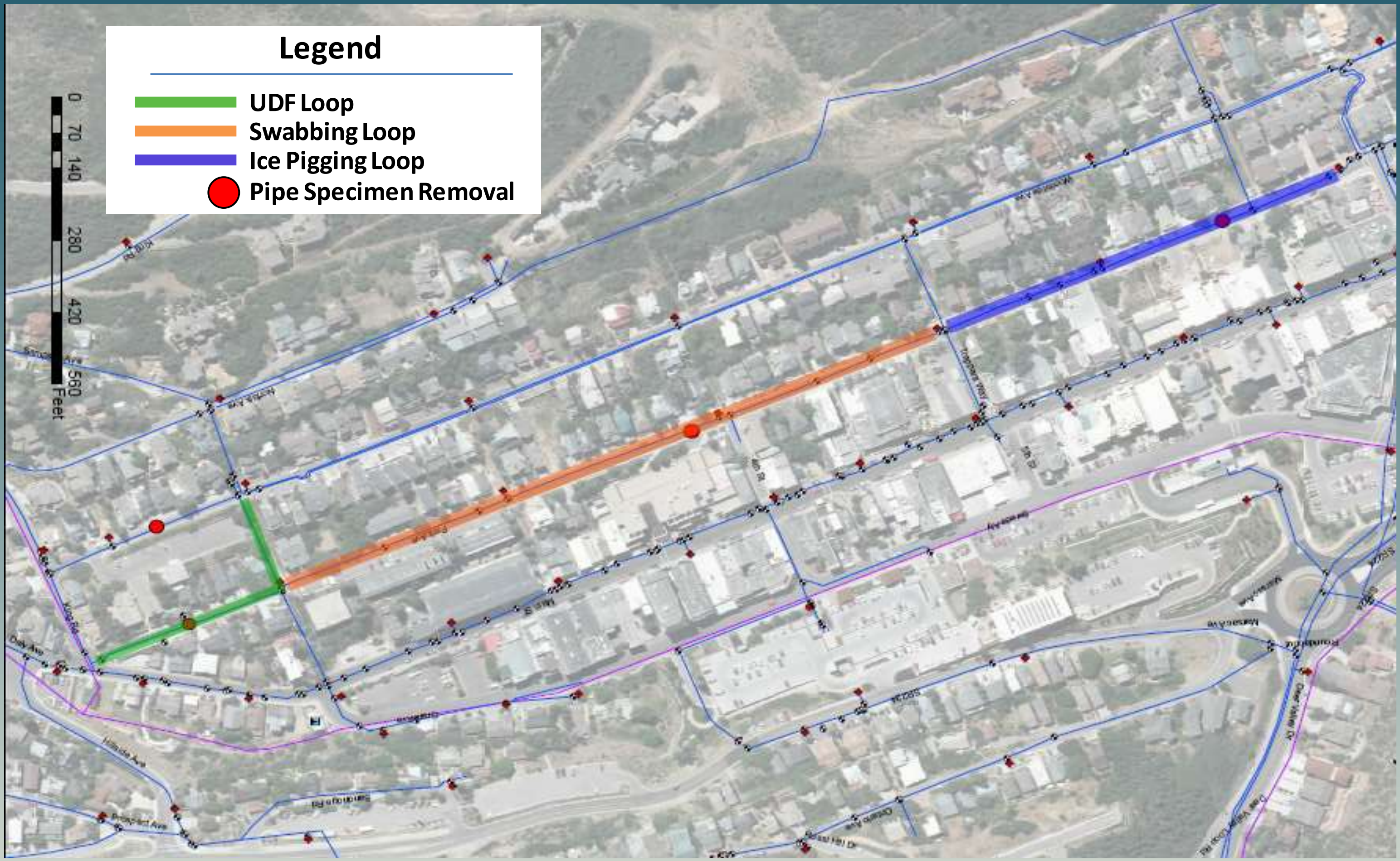
Conduct full-scale main cleaning demonstrations

1. UDF – 3 fps and 6 fps sequentially
2. Foam Swabbing
3. Ice Pigging

Sites for Cleaning Trials

Site	Zone	Rationale for Selection
AST **8” CLDI**	**Thaynes**	▪ **Zone of metals excursion events** ▪ **Low flow, moderate ATP (biofilm)**
UPA **8” CLDI**	**Old Town**	▪ **Historically served from unfiltered mine tunnel source with Fe, Mn, As, and Pb** ▪ **Numerous pipe samples with black slime**

Cleaning Loop Development



- Representative loop lengths of 500 – 1,500 ft
- Mass removed normalized to length (lb/mile)

Unidirectional Flushing (UDF)

Grab samples for AST
Peak TSS = 10 mg/L

Foam Swabbing/Cubing

Grab samples for AST
Peak TSS = 1,000 mg/L

Foam Swabbing/Cubing of Non-Scale Forming Pipe

Ice Pigging

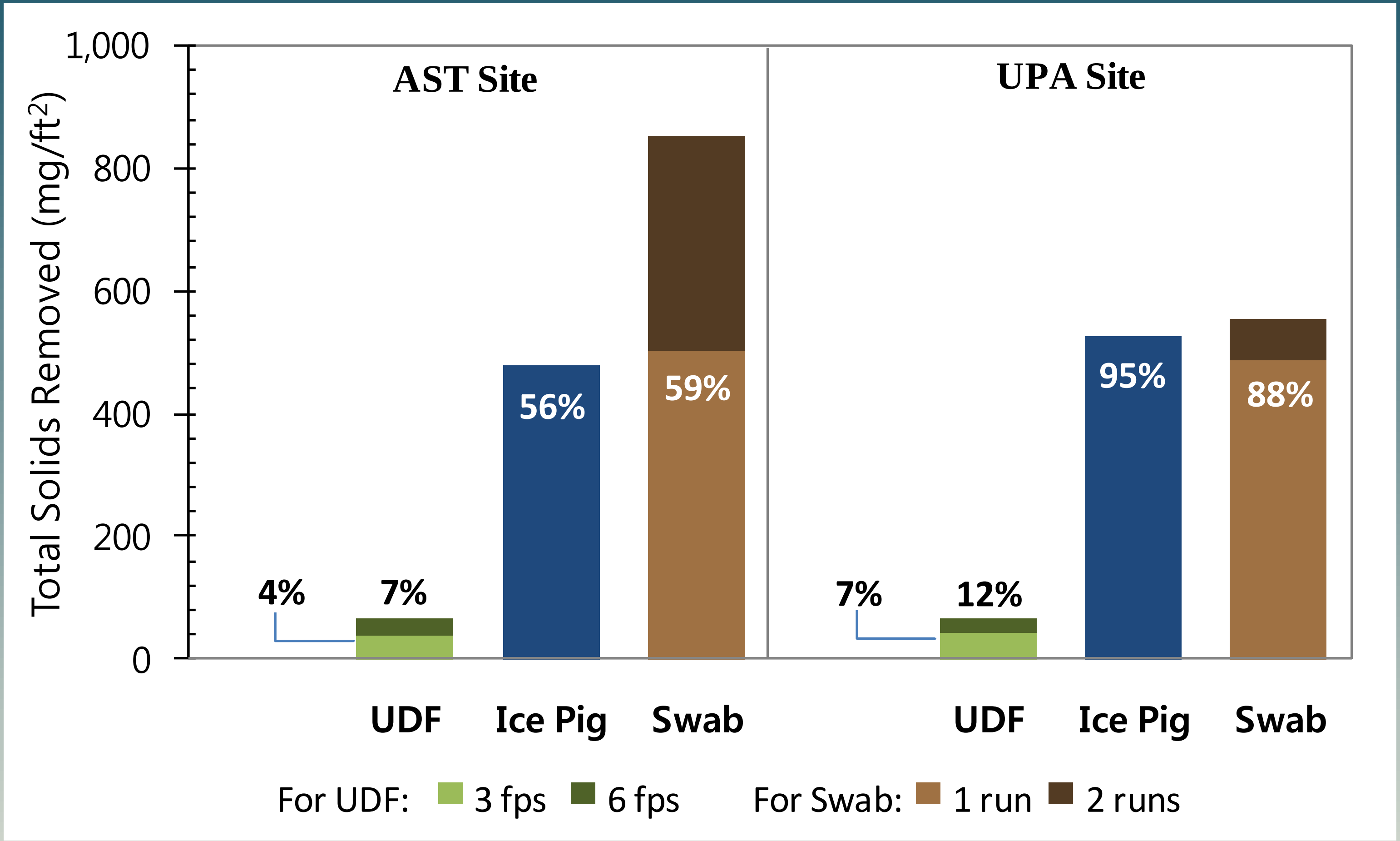
Grab samples for AST
Peak TSS = 900 mg/L

Pre- and Post-Cleaning Pipe Conditions

After UDF at 6 fps

After Ice Pigging

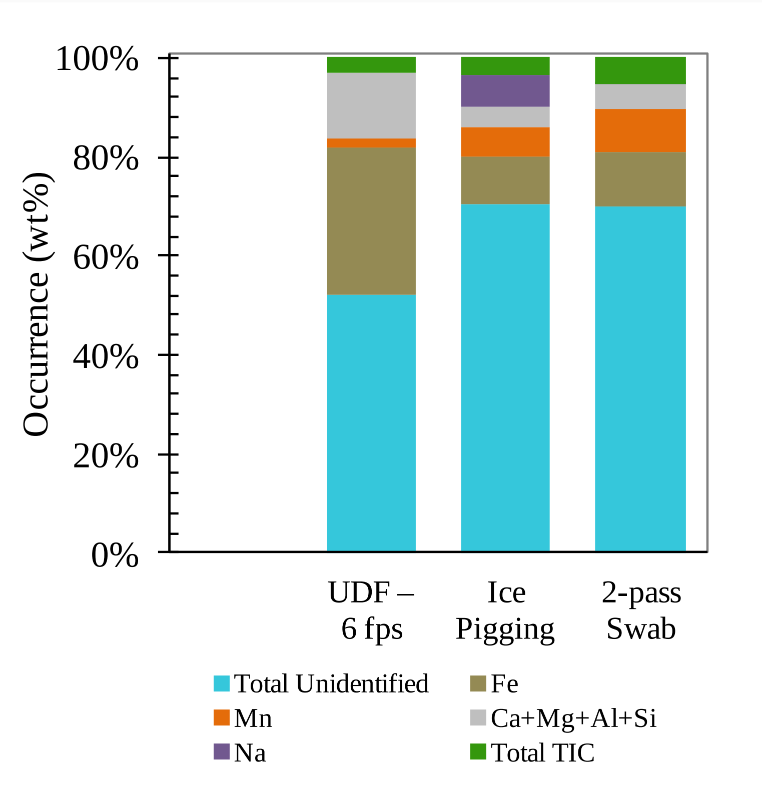
Comparison of Cleaning Performance

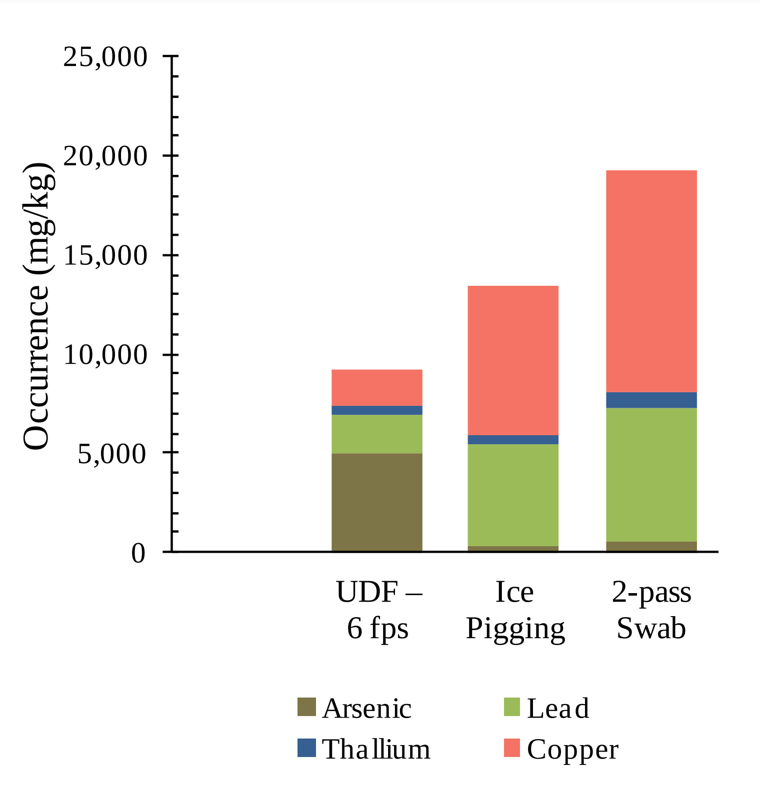


% = Relative Cleaning Effectiveness

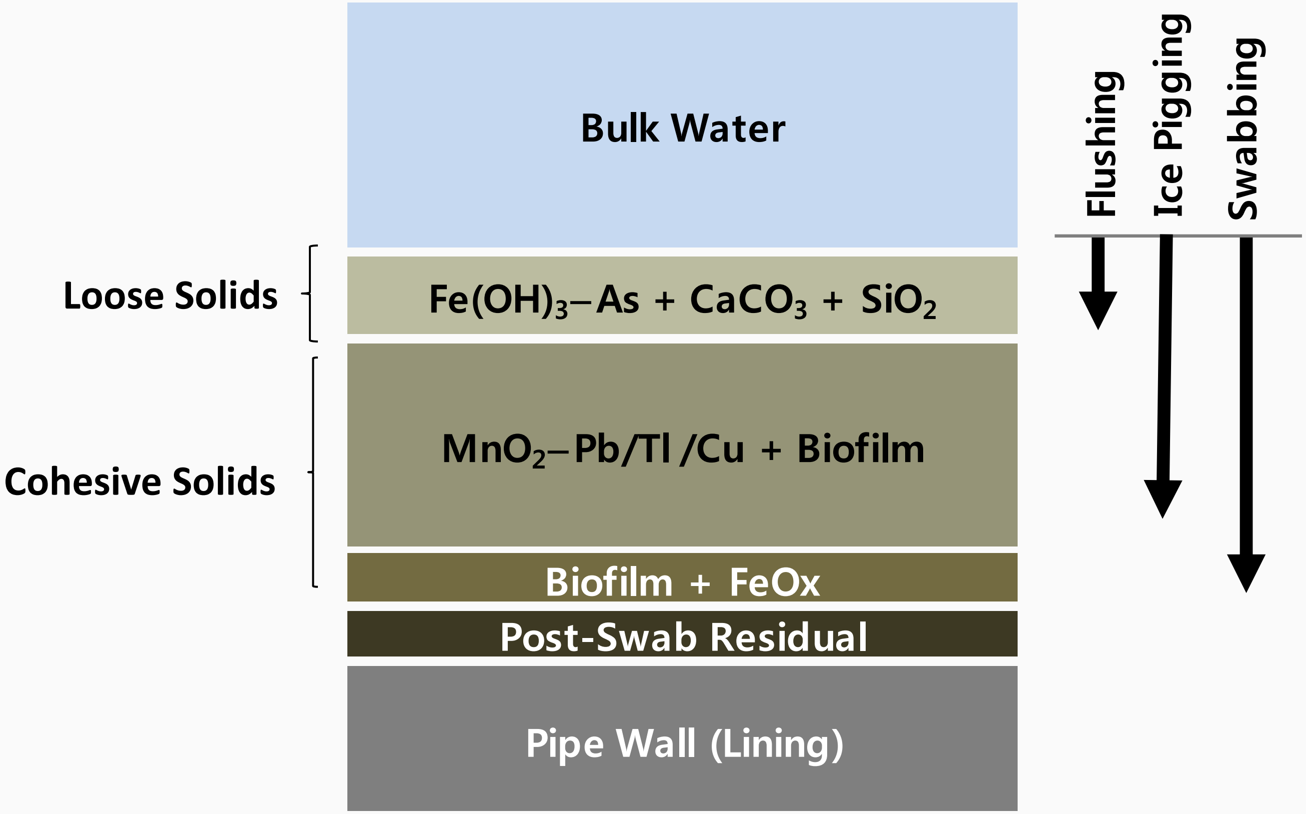
Contaminant Occurrence Trends

- **Composition of solid removed also differs by technique**
  - Preferential vs. impaired removal
  - Flushed mass is not simply a subset of the whole

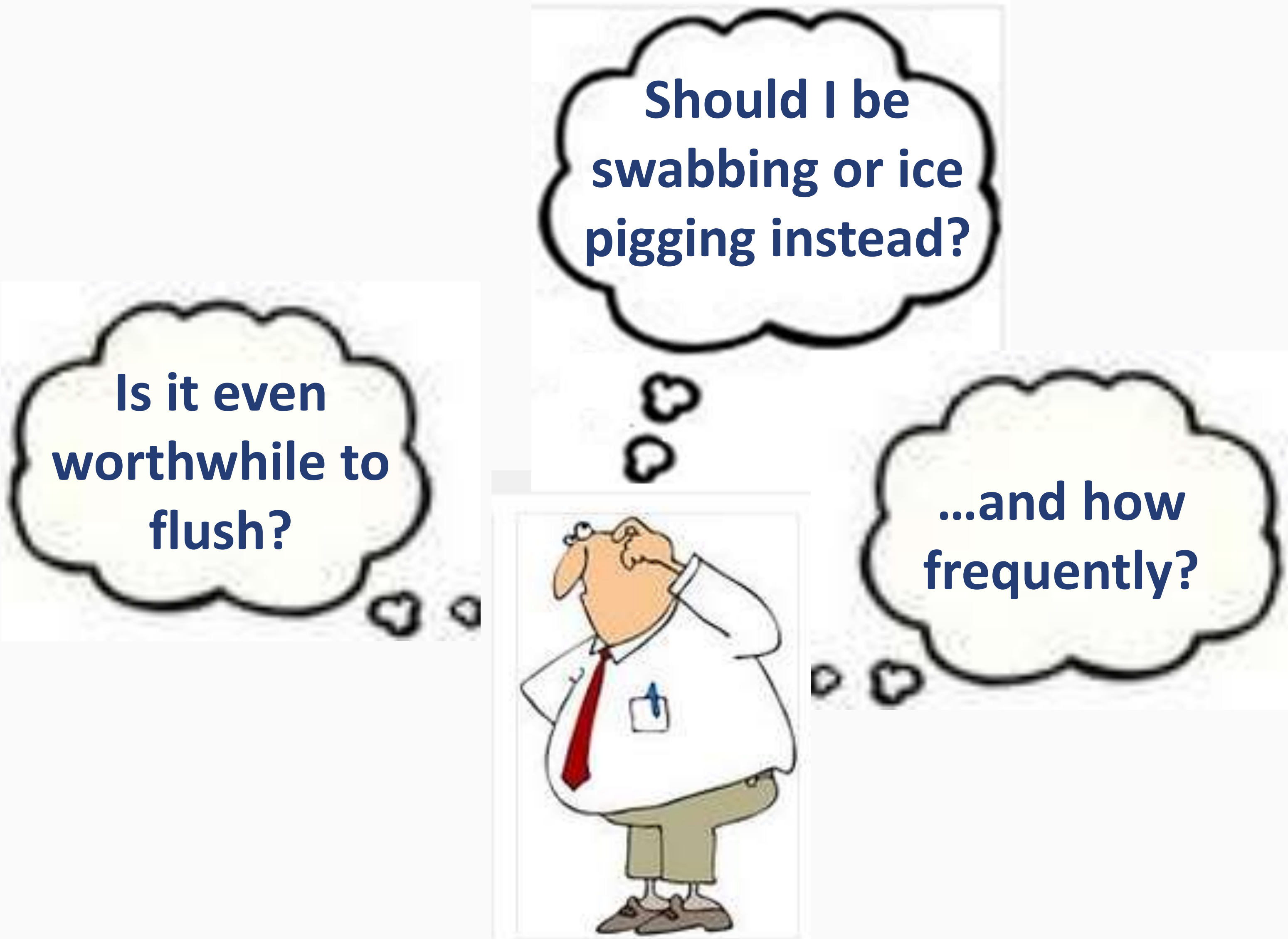




Conceptual Deposit Layering



So What Does This Mean for Utilities?



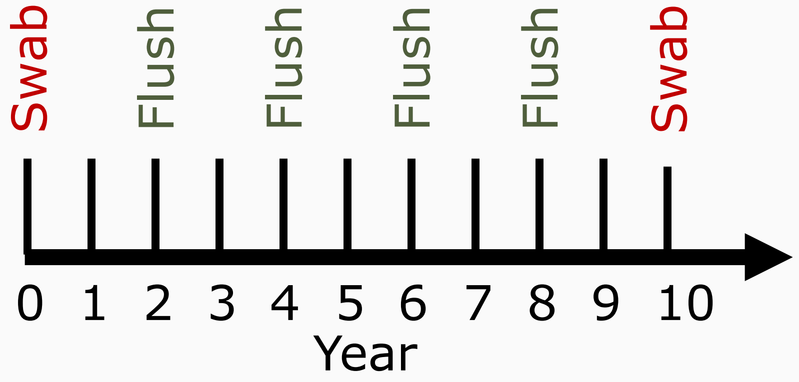
Routine (Unidirectional) Flushing Still Plays a Key Role

- **Preferential removal of certain metals**
  - At AST, flushing removed:
    - 50% of Fe and 40% of As
    - vs. just 7% of total solids
- **Removal of hydraulically-mobile metals**
  - Reduces risk of frequent low-level releases
- **Helps address other system WQ issues**
- **Relatively low application cost**
  - UDF ~$1,000 per mile
  - Swabbing/Ice Pigging ~ $6,000 per mile

…but UDF cannot mitigate certain risks

- **More aggressive cleaning needed for effective removal of Mn, biofilm, and co-occurring metals**
- **Use an integrated main cleaning strategy instead of an "either/or"**
  - Supports objective of meeting level-of-service goal with the lowest life-cycle cost
  - Frequency depends on local conditions and rate of loading

Example Schedule for Low-Level Loading



Conclusions

- Plastic and cement pipe are not "clean" or risk-free
  - Current or historical Fe/Mn loading can lead to metal-rich deposits
- Main cleaning is critical to reduce legacy metals inventory and customer exposure risk
- Utilities will likely need to use a variety of cleaning techniques based on site-specific conditions
  - Main cleaning is expensive and labor intensive – prioritize locations and frequency based on risk factors and system-specific monitoring
- WaterRF 4509 report to be published this summer!

Questions?

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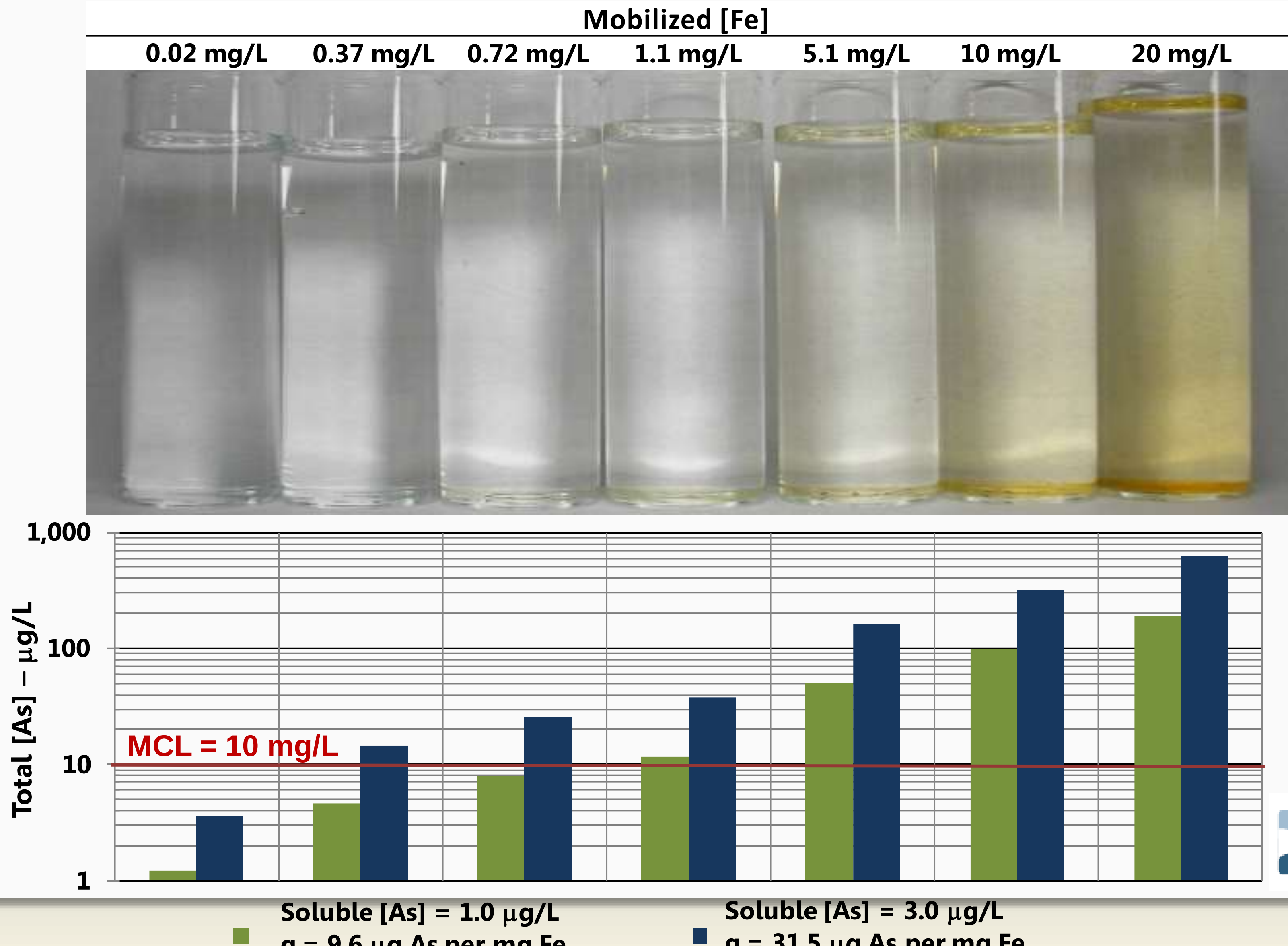
Reference Slides

Exposure Risk due to Hydraulic Release

Simulated Fe-As Particle Mobilization



Source: Hill et al, 2010

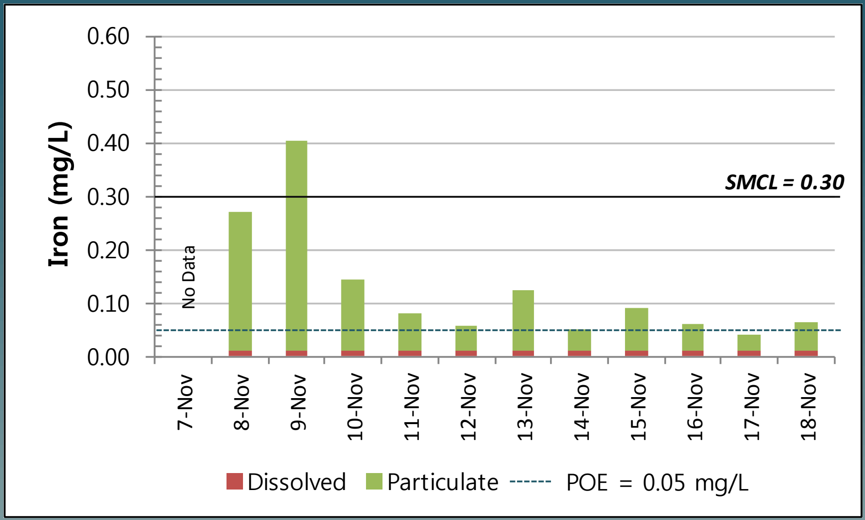
How Does Ice Pigging Work?

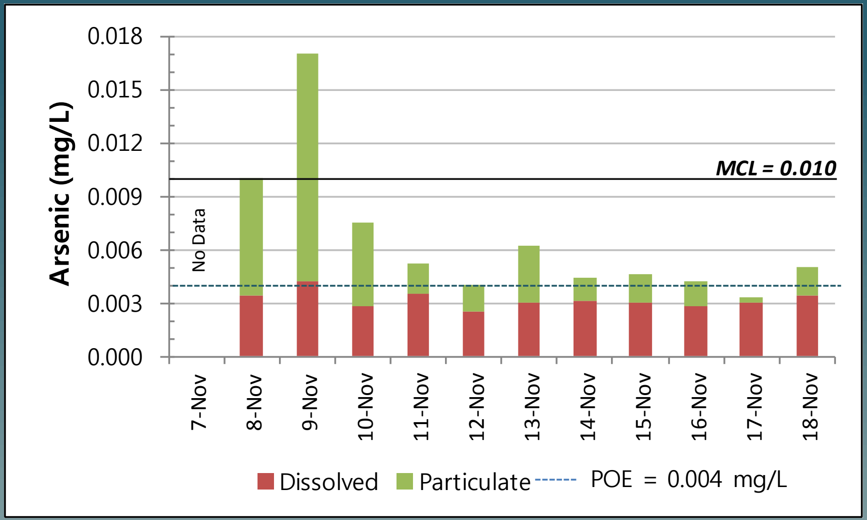
- **An ice pig is a semi-solid material (slurry)**
  - Pumped like a liquid
  - Behaves like a solid once the pig is formed in the pipe

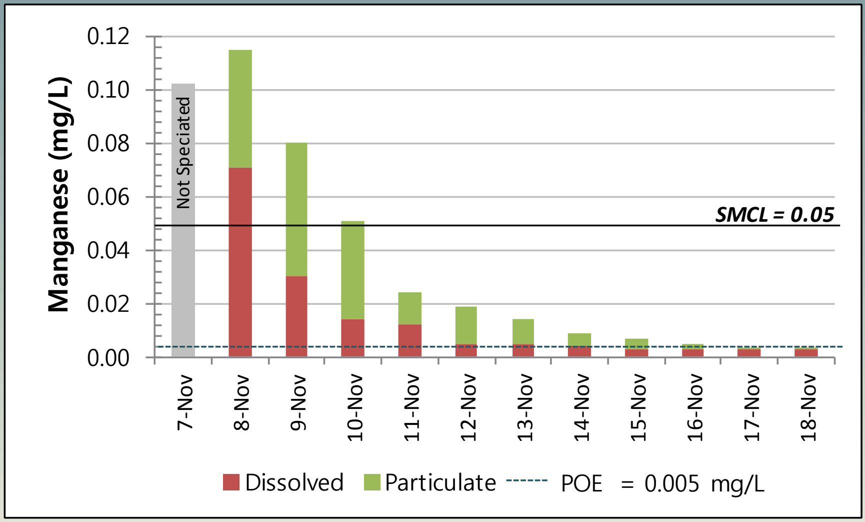
- **Proprietary process**
  - Slurry is generated on-site using utility water and specialized eqpmt.
  - NSF-approved NaCl is used as freezing point depressant

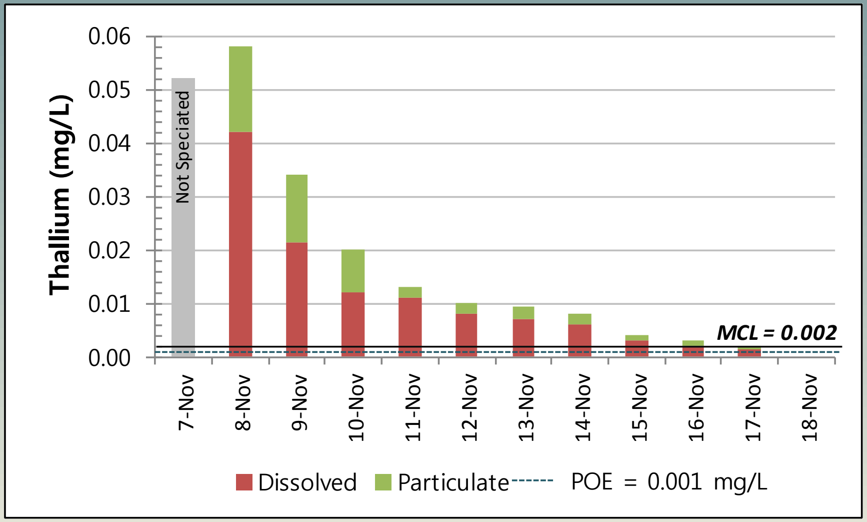
Source: Confluence Engineering Group, LLC

Metals Releases and Correlations

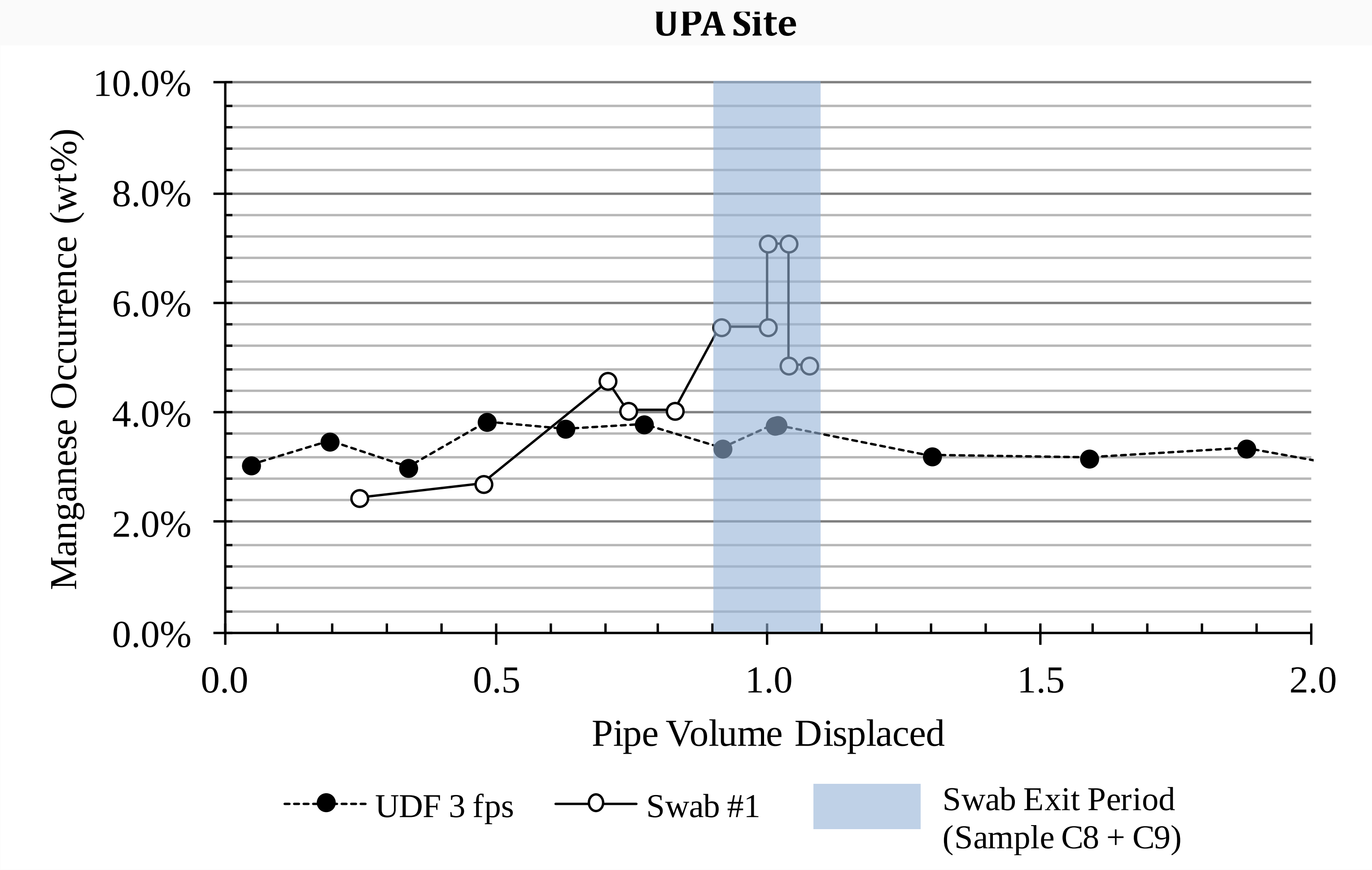








Occurrence Profiling



TIC Removal Heat Map

Site	Technique	Total Solids (TS)	Common Matrix Elements				Trace Inorganic Contaminants			
			Fe	Mn	Al	TUEs[1]	As	Pb	Tl	TTICs[2]
AST	UDF – 3 fps	4%	30%	5%	6%	2%	23%	5%	4%	8%
	UDF – 6 fps	7%	48%	7%	11%	4%	34%	9%	8%	15%
	Ice Pigging	56%	57%	110%	92%	48%	98%	86%	89%	77%
	Swab – 1 run	59%	64%	92%	87%	58%	90%	89%	88%	78%
	Swab – 2 runs	100%	100%	100%	100%	100%	100%	100%	100%	100%
UPA	UDF – 3 fps	7%	11%	5%	6%	7%	29%	8%	4%	5%
	UDF – 6 fps	12%	19%	7%	10%	11%	44%	12%	7%	7%
	Ice Pigging	95%	70%	49%	54%	99%	54%	39%	48%	55%
	Swab – 1 run	88%	84%	95%	92%	87%	93%	95%	96%	93%
	Swab – 2 runs	100%	100%	100%	100%	100%	100%	100%	100%	100%

Legend:

- $RPD \geq 100\%$ (substantially favored)
- $100\% > RPD \geq 50\%$ (moderately favored)
- $50\% > RPD \geq 10\%$ (slightly favored)
- $10\% > RPD \geq -10\%$ (negligible change)
- $-10\% > RPD \geq -25\%$ (slightly impaired)
- $-25\% > RPD \geq -50\%$ (moderately impaired)
- $-50\% > RPD$ (substantially impaired)

$$\text{Relative Percent Difference (RPD)} = \left[\frac{RCE_{Element}}{RCE_{TS}} - 1\right] \times 100\%$$

Comparison of Scale-Forming vs Non Scale Forming Pipe

- **Relatively low solids inventory (lb/mile) due to absence of scale and recent high-velocity flushing**
- **But solids are relatively concentrated (ug_i/g) with certain trace metals (As, Pb) due to co-precipitation with iron and manganese**

Why this distinction matters:

- **Deposited co-precipitates tend to be more mobile**
- **Lower mass, but could be more concentrated**
- **Release of concentrated deposits presents an increased risk of exposure to elevated TIC levels with less obvious visual indication or discoloration**

PCMC Same-Zone Comparison

Parameter	Units	Galvanized Iron (WaterRF 3118)	Cement-Lined (WaterRF 4509)
Solids Inventory	lb/mile	250	20.8
Fe Occurrence	wt%	30	8.1
As:Fe	µg/mg	2.7	8.3
Mn Occurrence	wt%	0.2	0.6
Tl Occurrence	mg/kg	80	320

Note: both pipe samples collected from Thaynes

The Attempted Approach