Water Distribution – Blending Different Water Chemistries in the System

Problems, Risks and Mitigation

Steve Reiber
HDR Engineering

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Distribution System

Strategic Challenges

- A changing water source (water quality) landscape and its impact on existing distribution systems
- Legal Responsibilities/Litigation Avoidance
- The necessity for new monitoring and assessment tools
- Economic Challenges

Blending Factors

Seasonal source usage or source switching
Blending of dissimilar sources (esp. GW-SW)
Bringing a new source online
Treatment and water quality changes

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Emerging Information

EPA United States Environmental Protection Agency

ARSENIC AND YOUR DISTRIBUTION SYSTEM

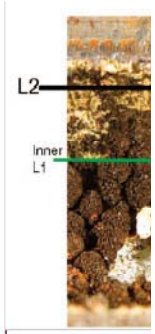
Environme
http://pubs.acs.org/sub

Science News –January 23

Pipe scales release water

Mobilization of mineral can contaminate treate

Mineral deposits inside drinking-wate arsenic, cadmium, and mercury, and t according to new research published i regulations miss such disturbances, be water enters the distribution system p



Pipe scales concentrate

U.S. EPA corrosion chemist Michael systems and found unexpectedly high concentrations as high as 426 parts pe ppm, vanadium as much as 20,000 pp would cause drinking water at the tap almost none of the utilities were in vi copper, the only inorganic contaminants currently monitored at the tap, exceeded regulator

"Our work shows that when corrosion impacts water quality, it isn't just about the metal th the pipe. Other metals can be mobilized as well," says Schock.

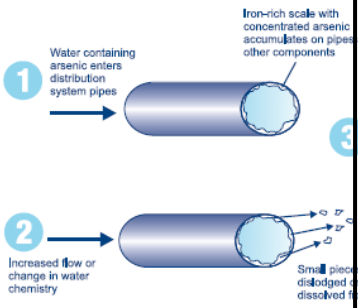
The research is important, says engineer Vernon Snoeyink at the University of Illinois, bec should open people's eyes to what may be lurking in the water distribution system. Schock could be the tip of the iceberg," he adds.

This fact sheet helps water system owners and operators in the distribution system, or with distribution system Although arsenic is measured at the entry point to the distri aware that arsenic levels could increase in the distribution s to remember that any process changes, including chlorinati at customers' taps.

Arsenic Can Build Up on and Release in Pipes and Storage Tanks

Public water systems with arsenic in their raw water may find that scales on pipes and other components in their distribution systems contain relatively high arsenic concentrations. These arsenic-rich scales can become dislodged and suspended in the water, and may be ultimately delivered to consumers.

How Arsenic Can Increase in Your Distrib

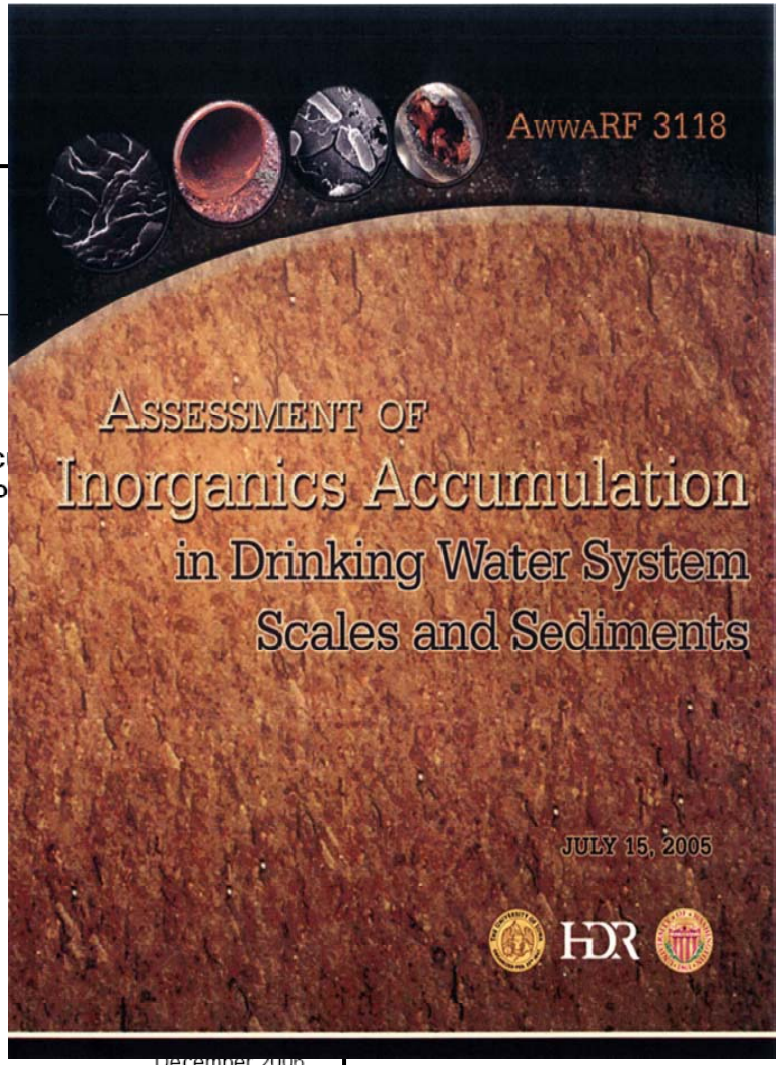


EPA United States Environmental Protection Agency

Office of Water (4601M)
Office of Ground Water and Drinking Water
Total Coliform Rule Issue Paper

Inorganic Contaminant Acc in Potable Water Distributio

December 2006



Common Blending Issues

- Re-equilibration (Scale stability)
- Corrosion Control
- Microbial Quality (Regrowth)
- Taste and Odor
- Public Health Issues

Operational Risks:

- Customer Dissatisfaction
- Taste and Odor
- Discolored Water

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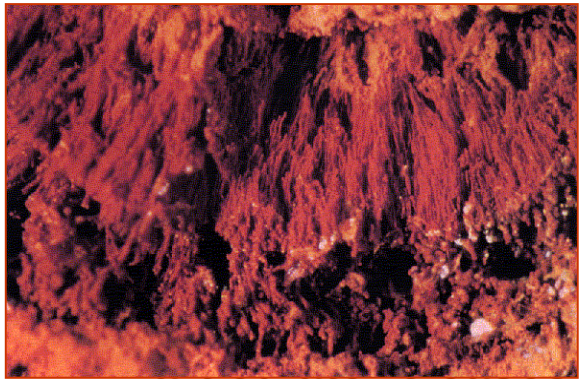
Blending Induced Re-equilibration can Weaken the Stability of Existing Scales

This makes it susceptible to hydraulic scour, flow reversals, and water hammer.



- **Red water episodes**
- **Higher coliform / HPC counts**
- **Increased corrosion**

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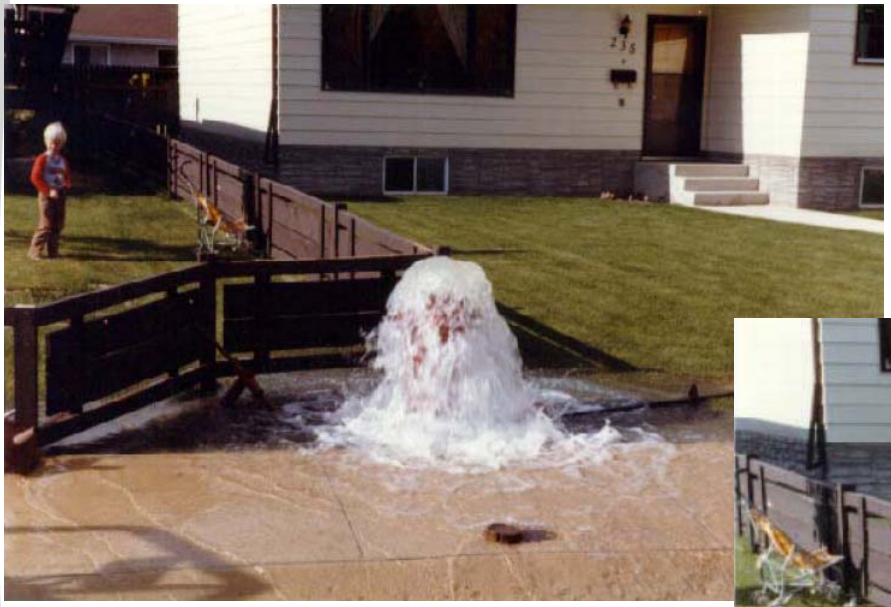
Corrosion scales and sediments in the distribution system can be measured in Tons (dry weight) per Mile



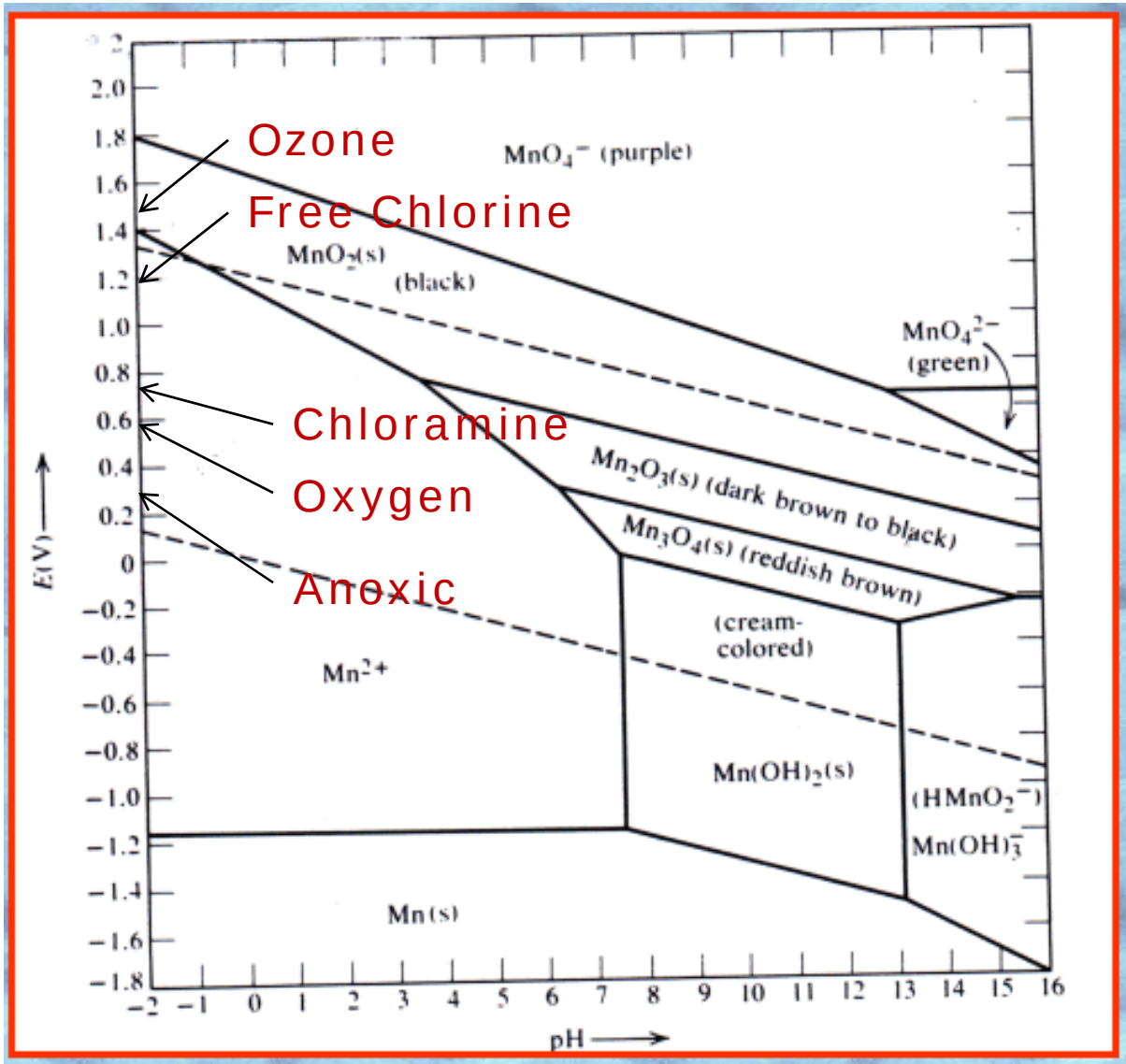
Credit: R.V. Anderson Assoc.

Critical Blending Chemistry

Chemical stability is the goal – variability the enemy

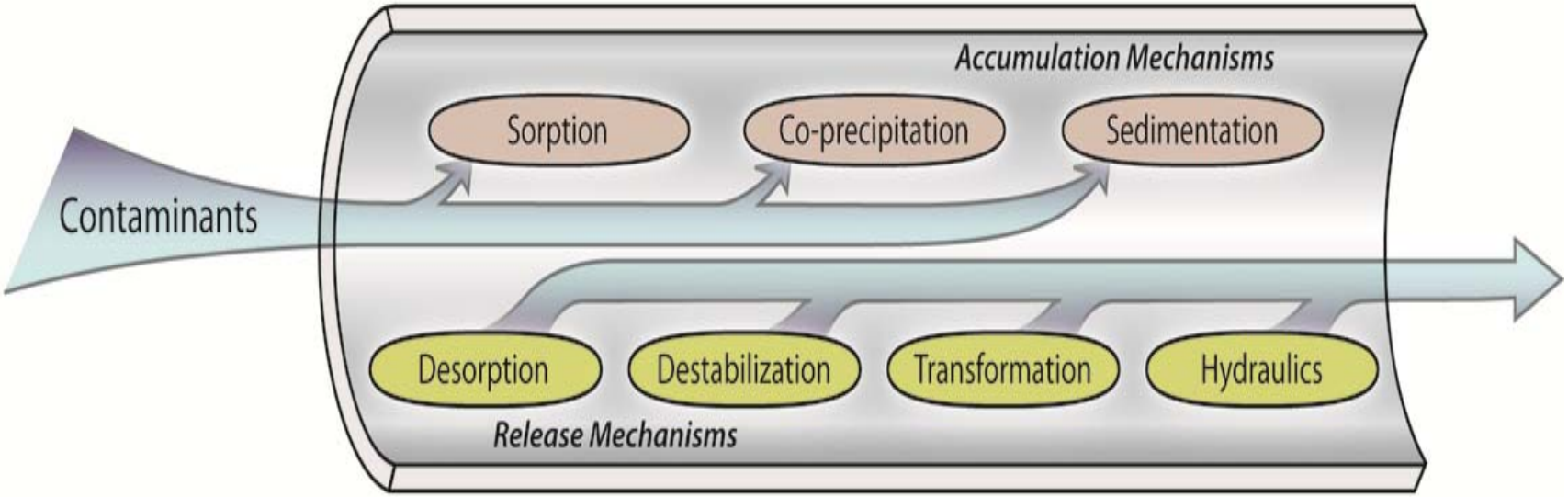
- **Redox Condition**
- pH/Buffering
- TDS/Chloride
- NOM Content

Mn Redox Diagram



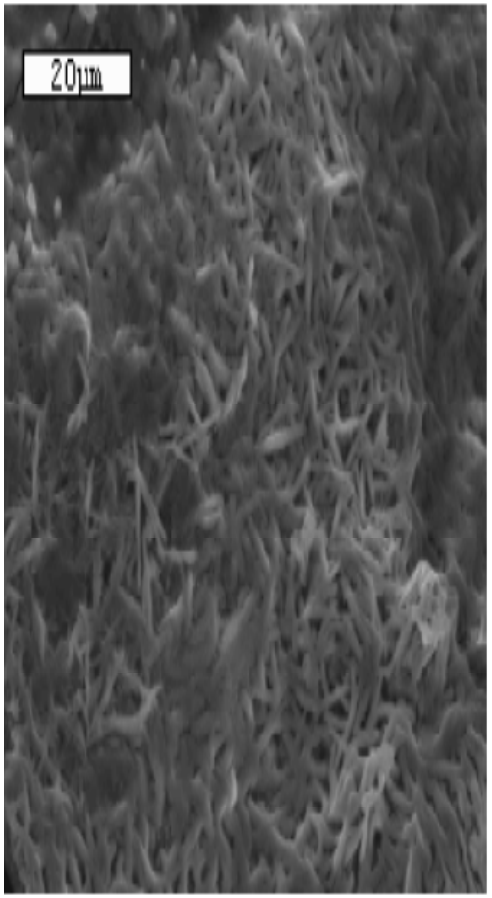
“Dist. Systems Aren’t Just Conduits – They're Chemical Reactors”

Numerous reaction and transport mechanisms
Non-conservative behavior: in ≠ out

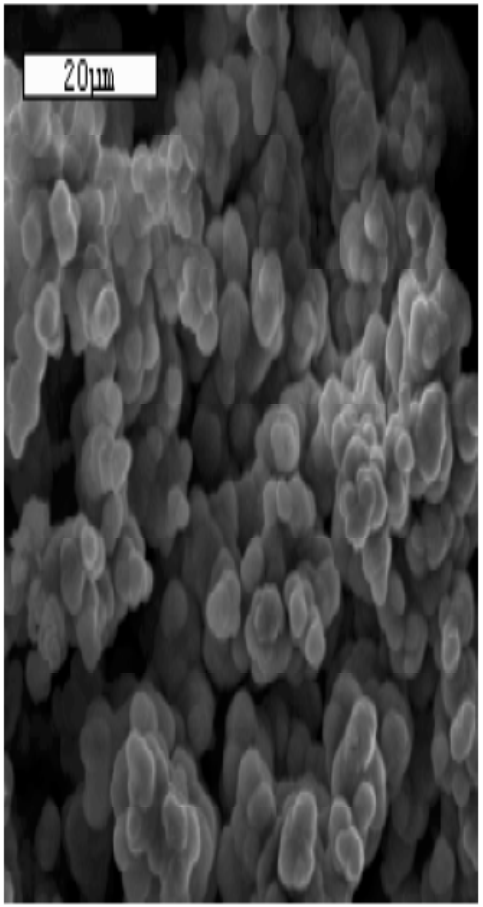


All of these processes can occur simultaneously on the same pipe surface!

Iron Tubercle Surfaces – Adsorption Sites (Schock, 2005)



Hard outer scale layer



Soft inner layer

Composition of a Typical Iron-Based Scale

	(% dry weight)
Iron oxides	>55
Other metal oxides	<5
Carbonates	>20
Silicates	<1
Sulfur Compounds	1 - 2
Sand / inorganic sediment	<15
Total organic/biomass	5 - 10

Sulfur Appears to be the Glue that Holds Many Corrosion Scales Together (SRBs)

Iron drinking water main

Scale structure

SEM micrographs and Elemental mapping

- Sulfur was a relatively large component of iron corrosion scales
- Amount of sulfur related to redox conditions
- Sulfur and iron mineralogy was controlled by SRB activity
- SRBs still active in tubercles of well chlorinated tap water

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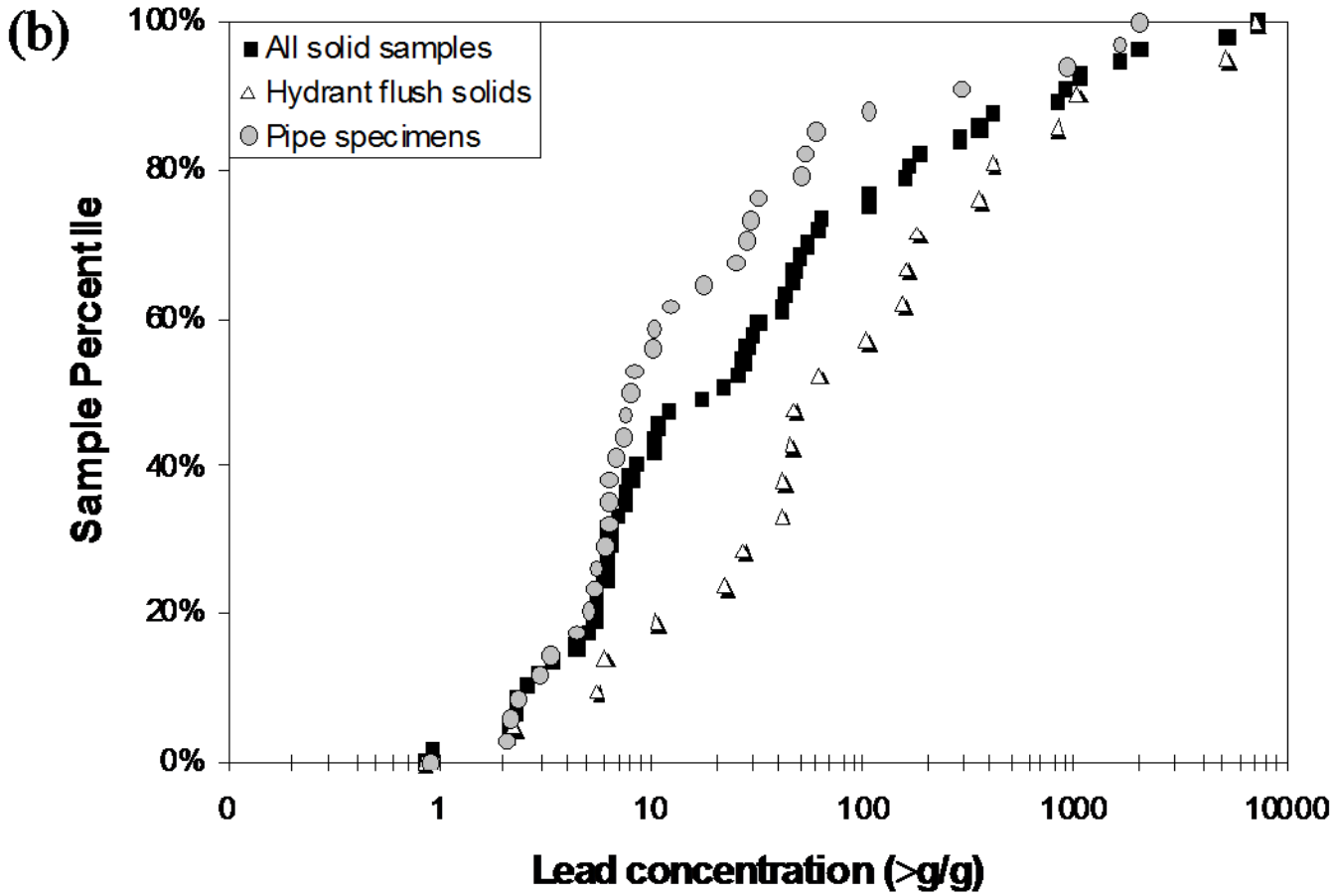
Trace Metals Appear in All Distribution Solids – in Surprising Concentrations!



Hydrant flush and main samples from 25 utilities

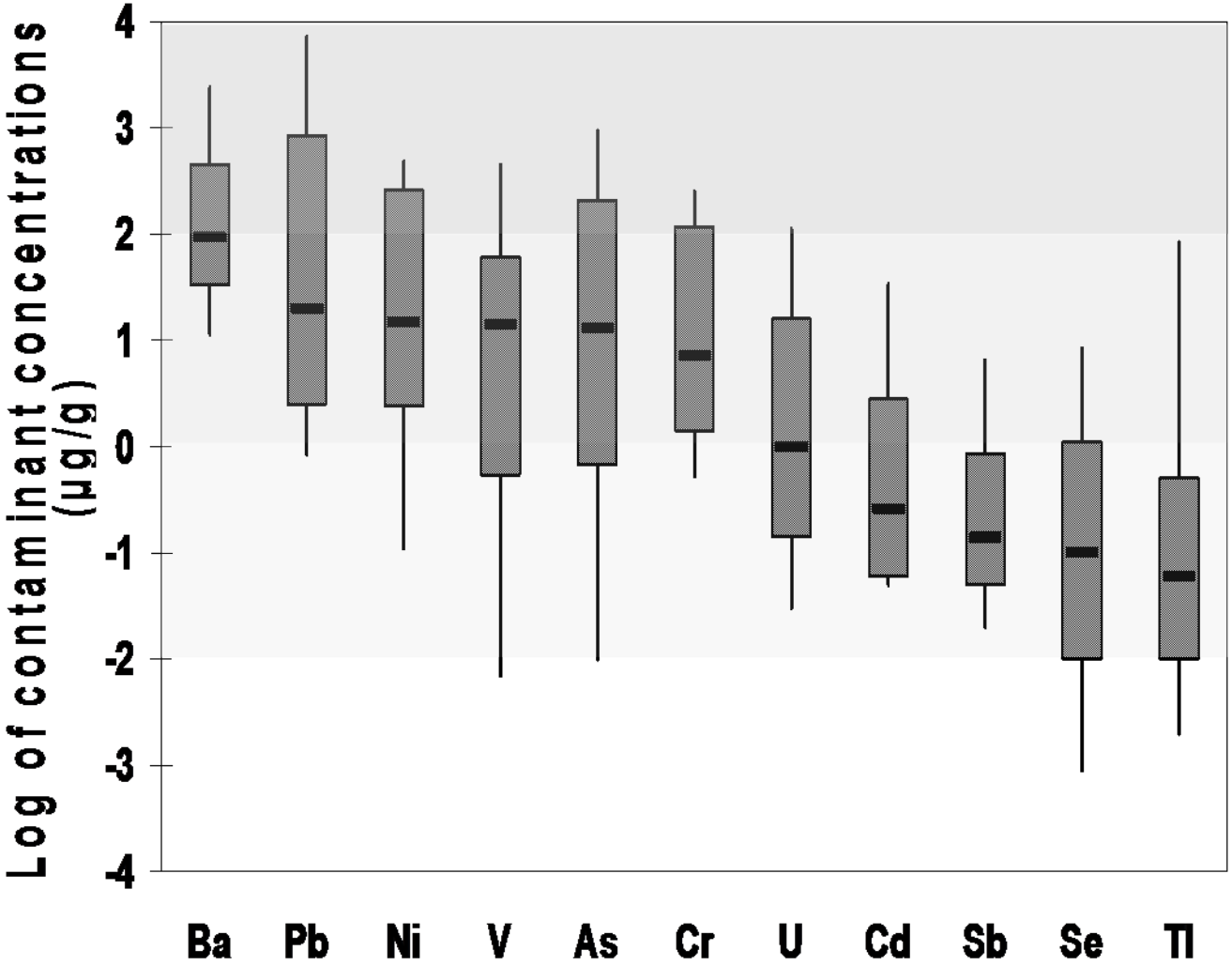
Public Health Issues: Not Inconsequential

- Distribution system solids represent a substantial reservoir of trace metals in immediate proximity to the consumer

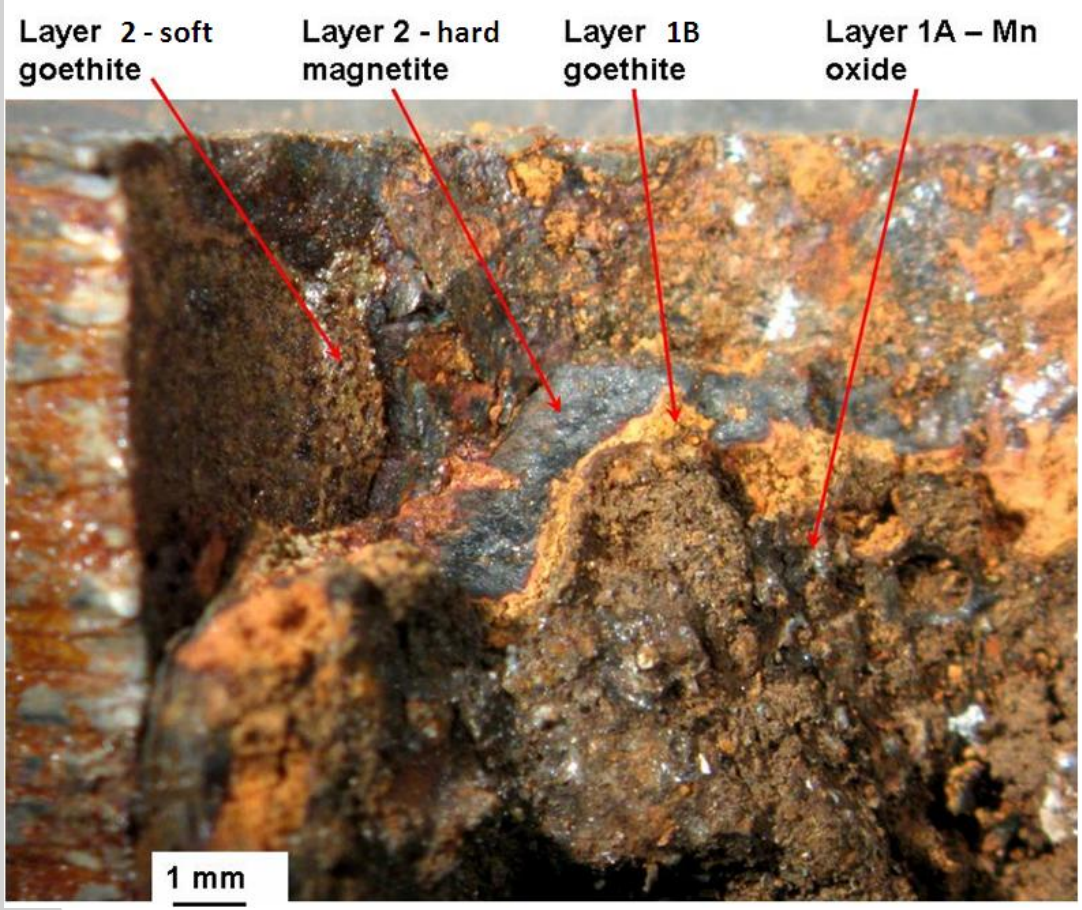
Case Studies:

• Arsenic Release in Nebraska

•"Lead Crisis" in District of Columbia



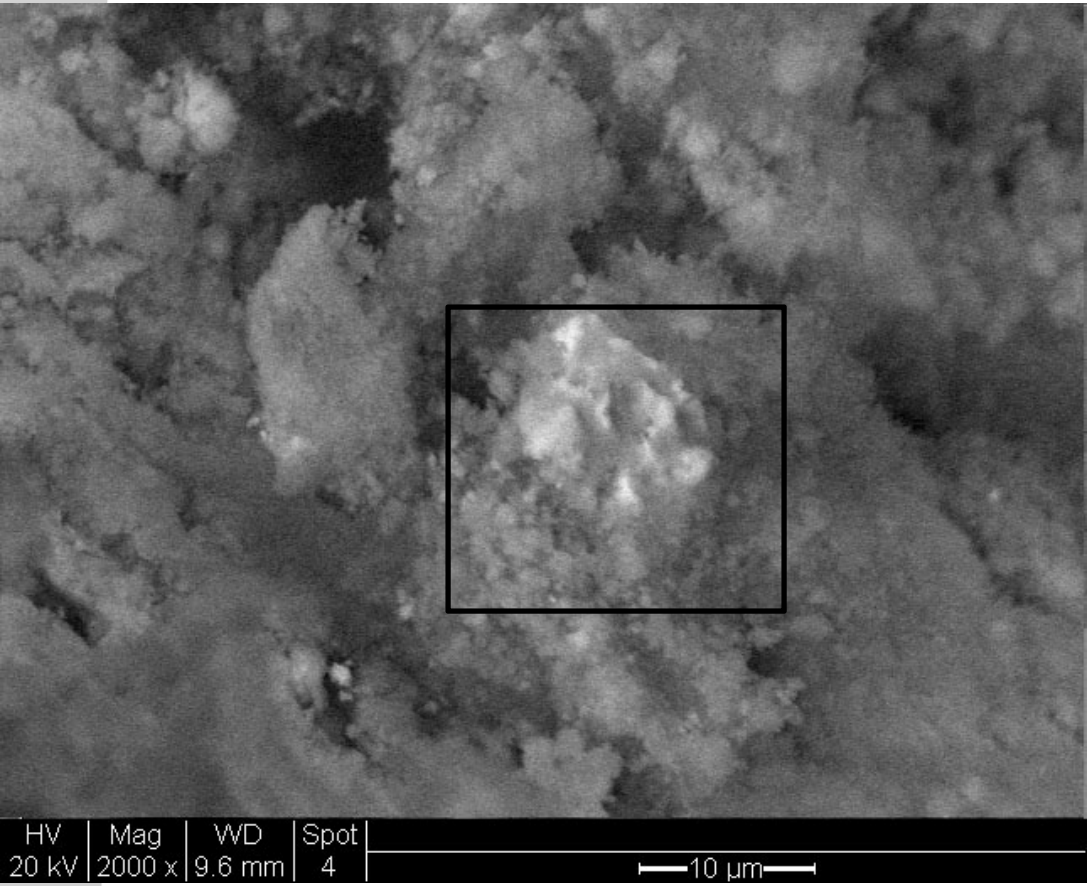
Iron Scale Composition Analysis



University of Cincinnati Department Of Geology

- Iron Scales Separated into defined layers
- Scrapings from layers and scrapings from Tubercles analyzed with EDAX
- Substantial variation in lead content observed from site to site
- Range of lead content from hundredths of a percent in some homes to as high as 8% in another
- High lead content observed even in deepest layers of iron scale

Iron Scale Analysis



University of Cincinnati Department Of Geology

- Numerous discrete deposits of lead minerals identified on iron scale surfaces:
  - ✓Pyromorphite
  - ✓Apatite
  - ✓Lead Oxides
  - ✓Cerussite & Hydrocerussite

- Appear to be embedded in scale matrix

Blending Driven Chemical Change in the Distribution System?

- Internal reactions within the water itself (blend induced)
- Reaction between the water & pipe wall (re-equilibration)
- Primary factors
  - Water quality leaving treatment plant / well
  - Pipe material & condition
  - Hydraulic detention time
  - Water temperature
  - O&M practices
  - Pressure & flow control
  - Disinfectant residual

Like a Good Beer, Water is a Perishable Product

- **Shelf life - detention time (water age)**
- **Preservative - chlorine/chloramine**
- **Packaging - pipes & reservoirs**

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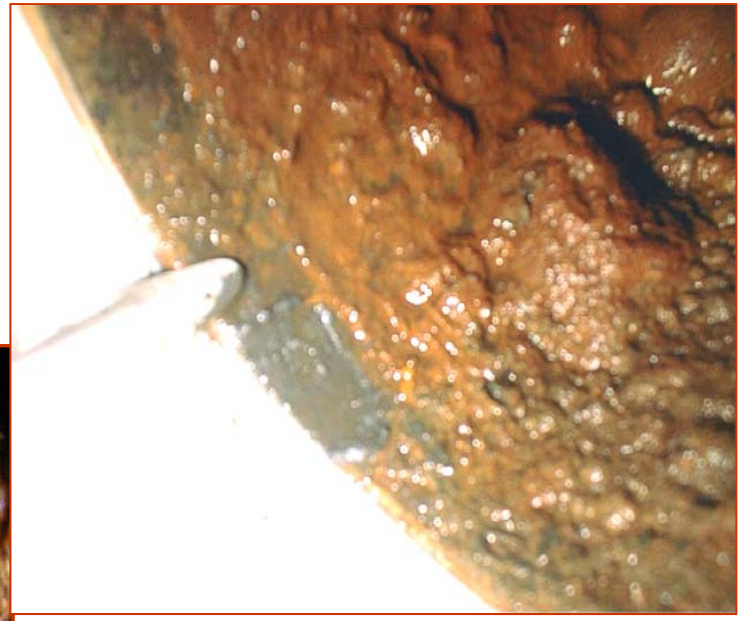
Soft Iron Sinks are the Major Problem

22% of all distribution piping is unlined cast-iron - decades of scale accumulation

Iron scales occupy 10X the volume of the corroded base metal.



Friable scales release both particulate and dissolved iron

Older galvanized iron service lines

Large amount of iron surface area in contact with water

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Other Distribution System Sinks: Cu, Mn

Ubiquitous in distribution systems

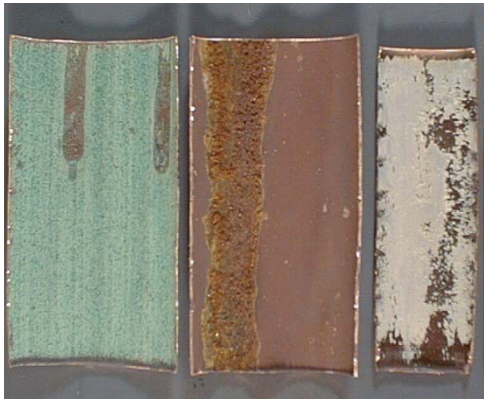
Substantial volume & surface area

>10-fold magnification of surface area

Strong adsorptive properties

Fe, Mn Oxide Scale Accumulation

Pb(II) Scale Rich in Fe, Mn, and Al
(Source: Michael Schock, 2008)



Copper Service Line Scale

Distribution System Blending Control Factors

There are several attractive options

- **Phosphate Strategies**
- **Redox Control Strategies**
- **PH/Alkalinity/Buffering Management**
- **Operational Strategies**

4-inch cast-iron main

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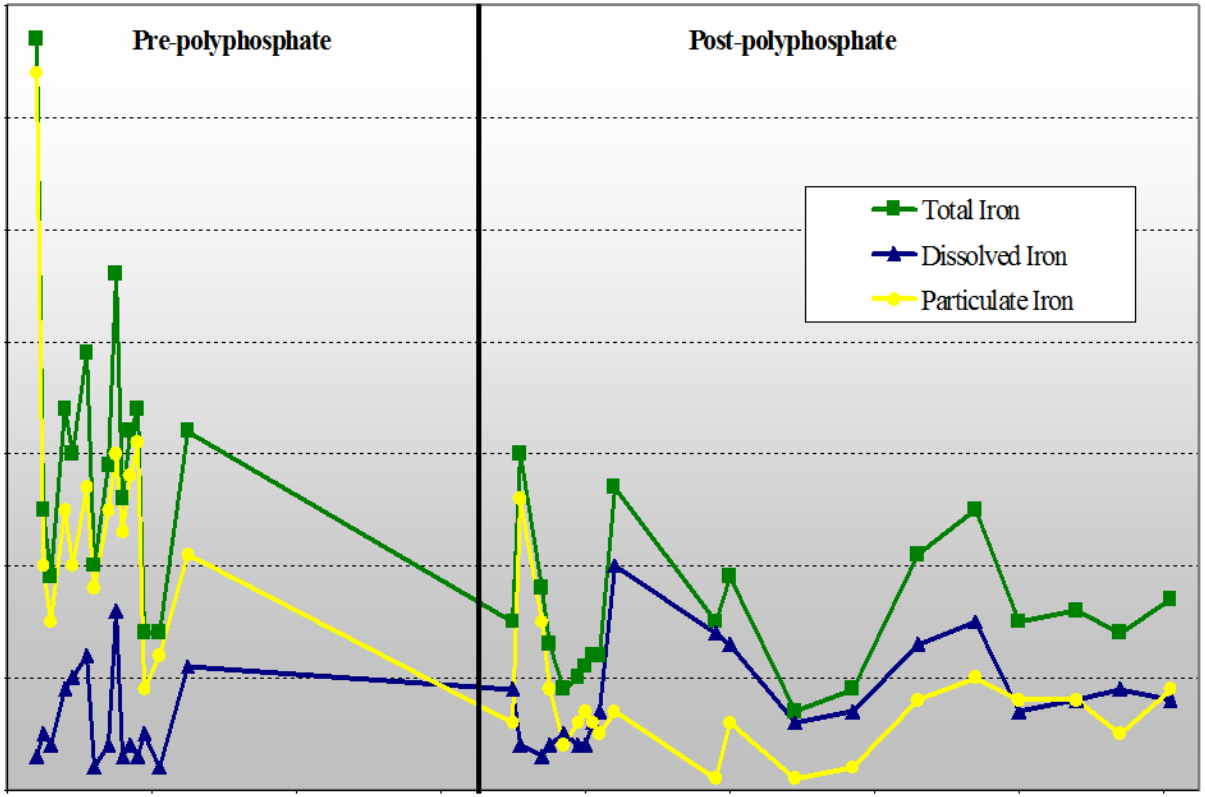
Phosphates are a useful tool for modifying the structure of existing corrosion scales

Almost always enhance scale stability – reduce blending impacts

- Orthophosphates
  - Harden iron scales
- Polyphosphates
  - Mobilize friable iron
  - Stabilize corrosion scale core



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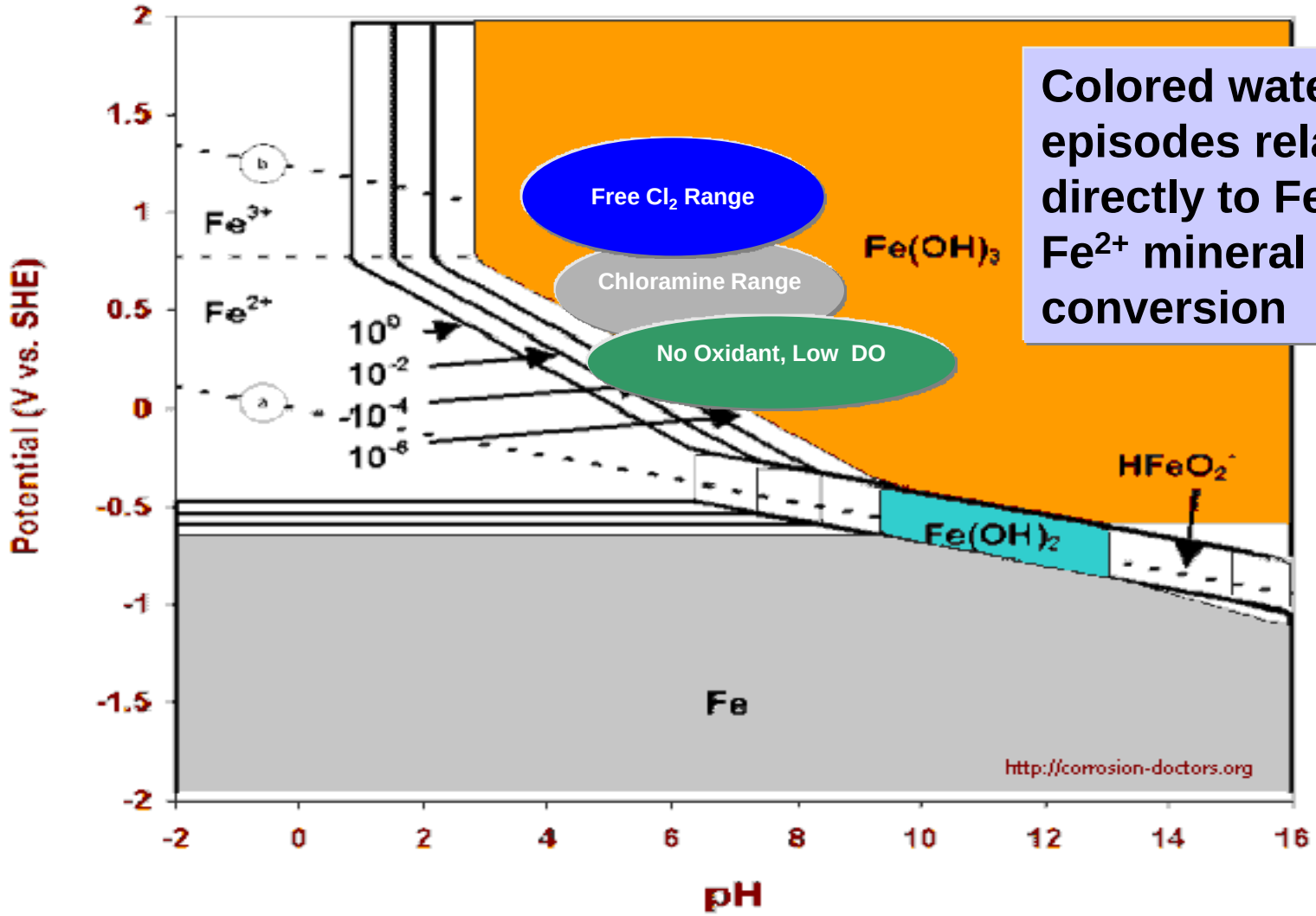
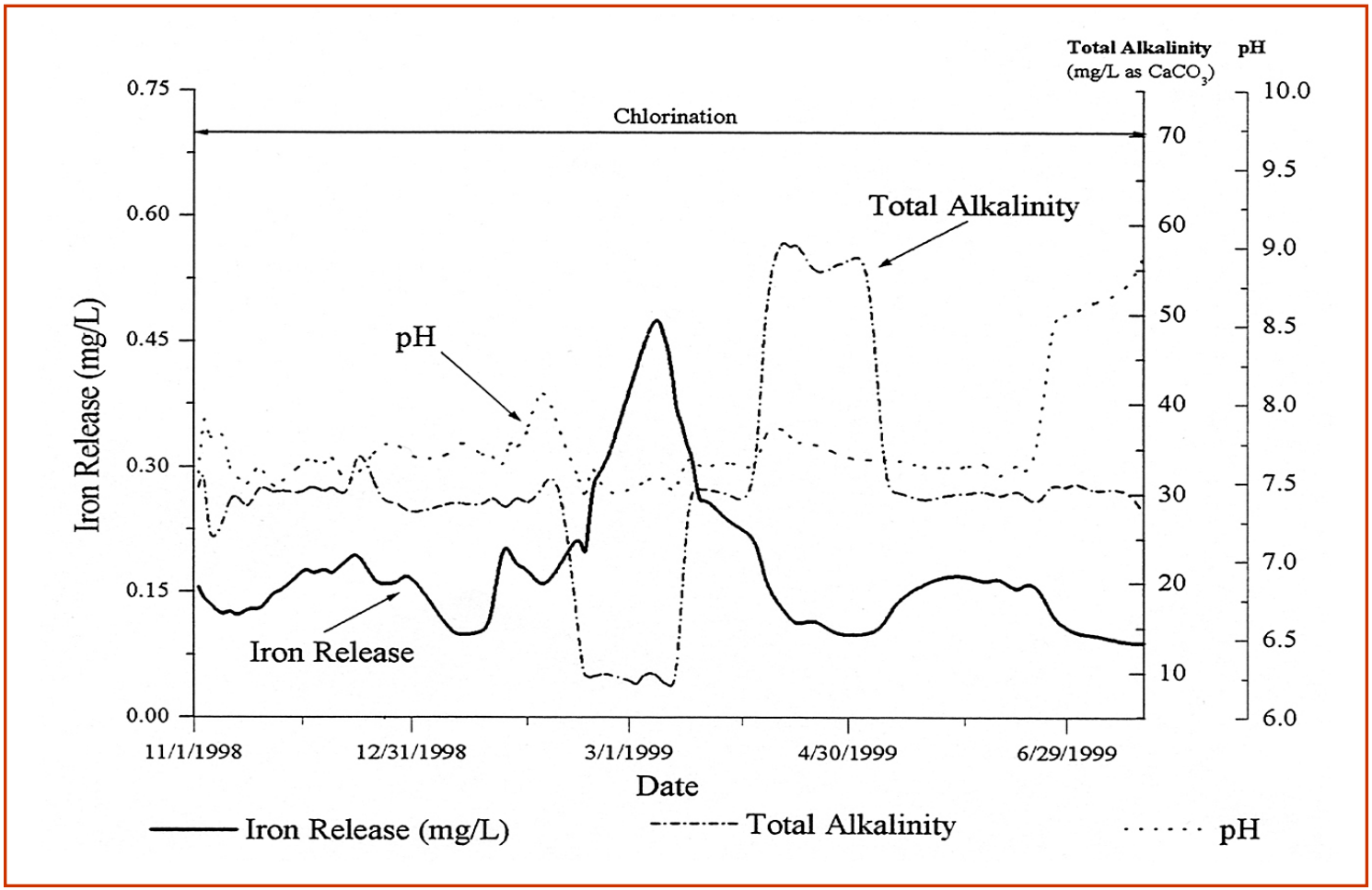
Corrosion Scale Stability is Directly Related to Redox Condition – Higher is Better



Colored water episodes relate directly to Fe^{3+} to Fe^{2+} mineral conversion

pH/Alkalinity Control - Unlined Cast Iron Pipe

The effect of Total alkalinity and pH on iron release from 90-year old unlined cast iron pipes.



- Iron release sensitive to carbonate
- Decreasing carbonate increases iron release rate
- Mechanism: Buffering? Scale structure?

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Proactive Blend Steps (1)

Courtesy: A. Hill

Monitor for trace metals in your distribution system

Identify what's there

- Focus on "high-risk" areas (see risk factors for accumulation)
- Pipe specimen removal and/or flushing to remove deposits
- Extraction and analysis to determine elemental composition

Assess its behavior

- Water sampling in the distribution system and at taps
- IOC analyses is costly – so focus on "high risk" events
  - Before and after source usage and treatment changes
  - In response to complaints of discoloration or poor taste
  - During and after flushing, main breaks, peak demands
  - Areas of high water age

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Proactive Blend Steps (2)

Install and/or optimize treatment

- Assess/address water quality during blending
- Consider Phosphate Addition
- Higher Cl_2 Residuals, DBPs permitting
- Greater Buffer Capcity
- Get the iron, manganese and other solids out
  - Fe $\leq$ 0.05 mg/L
  - Mn $\leq$ 0.01 mg/L

Implement and/or optimize flushing

- Uni-directional Flushing (UDF) only – no more conventional flushing
- UDF is not a “cure-all” – will only remove loose materials
- Pigging may be more effective

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Final Points: Chemistry of Blending and Re-Equilibration

- Iron scales (sinks) iare an inherently unstable, adsorptive, multi-layered structure with a porous core and a friable surface.
- Destabilized scales represent a substantial mass of trace (toxic) metals in close proximity to the consumer
- Redox conditions are key – a reducing environment guarantees iron release and other bad things.

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