



Occurrence of Trace Metals and Radionuclides in Drinking Water Distribution Systems

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Acknowledgements

■ AwwaRF 3118 Project Team

- Melinda Friedman -Confluence Engineering Group
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- Gregory Korshin -University of Washington

■ References and Resources

- Michael Schock -USEPA
- Darren Lytle -USEPA



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Distribution System Regulatory Trends

■ Distribution system effects on water quality

- Coliform and HPC Bacteria
 - Disinfection Byproducts
 - Lead and Copper Release
 - Inorganics & Radionuclides
 - Coliform Bacteria Revisited
- } Revisions to the Total Coliform Rule
New Distribution System Rule

■ Water quality deterioration from WTP to tap

- Numerous reaction and transport mechanisms
- Non-conservative behavior: $in \neq out$
- DS isn't just a conduit – it's a reactor

Overview of the Issue

- **Certain inorganics are known to accumulate**
 - Pipe corrosion scales: Fe, Cu, Pb
 - Chemical precipitates: Fe, Mn, Al, Ca, PO₄
- **Some precipitates may be intentional & desirable**
 - e.g., Passivation of plumbing surfaces
- **...Most are *perceived* as nuisance but innocuous**
 - e.g., Fe and Mn discoloration episodes

What's in this "soup"?
How long should we run it
until its safe to drink?



Corrosion Scales & Sediments in the Distribution System can be Measured in Tons (dry weight) per Mile



Swabbing 1500 ft. of 8-inch dia. Cast Iron Pipe





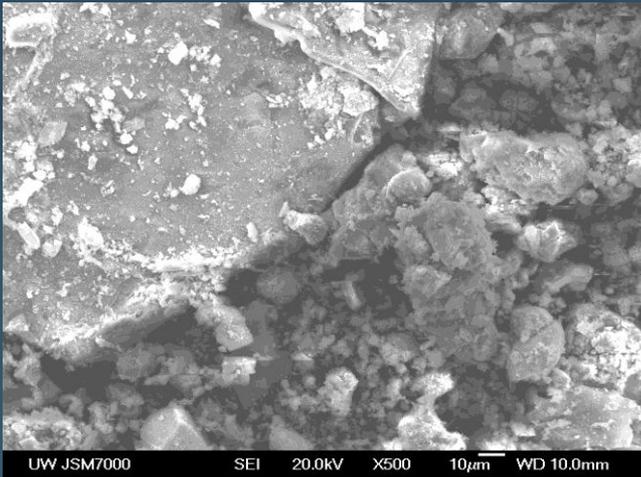
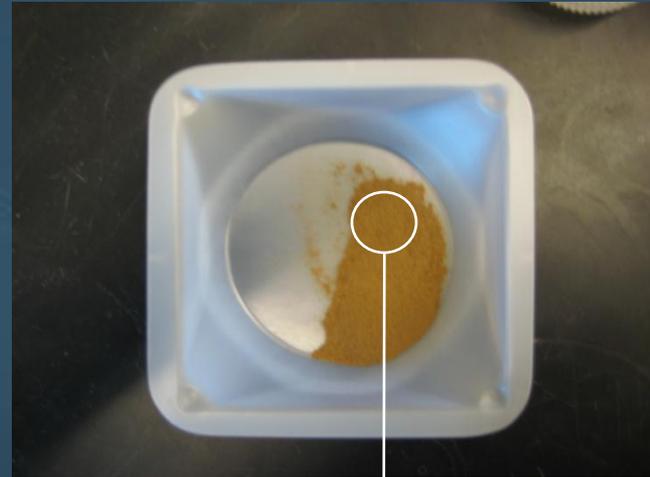




Overview of the Issue (Cont)

- **Historically, regulated trace inorganics and radionuclides were assumed to:**
 - Originate only from source water
 - Behave conservatively (in = out)
- **Recent work has shown these compounds can accumulate on DS surfaces**
 - Common scales and precipitates serve as “sinks”
 - Even if finished water concentrations are very low

Take a Closer Look ...



SEM: 500x Zoom



SEM: 100x Zoom

... And You Will Find

| Compound | Pipe Deposits |
|-----------|----------------|
| Iron | 29% by weight |
| Manganese | 2.4% by weight |
| Calcium | 1.2% by weight |

Corrosion scale on UCI piping
Mn in finished water 0.004 mg/L
Hard water: 112 mg/L as CaCO₃

| Compound | Finished Water | MCL | Pipe Deposits |
|----------|----------------|---------------------------|-------------------------|
| Arsenic | 0.0005 mg/L | 0.010 mg/L | 125 µg/g ^(a) |
| Barium | 0.071 mg/L | 2 mg/L | 456 µg/g |
| Chromium | 0.0006 mg/L | 0.1 mg/L | 91 µg/g |
| Lead | 0.00006 mg/L | 0.015 mg/L ^(b) | 19 µg/g |
| Nickel | 0.0004 mg/L | 0.1 mg/L ^(c) | 338 µg/g |
| Uranium | 0.0012 mg/L | 0.03 mg/L | 18 µg/g |
| Vanadium | Non-Detect | None ^(d) | 42 µg/g |
| Zinc | 0.0016 mg/L | 5 mg/L | 645 µg/g |

(a) µg/g = ppm

(b) Action Level

(c) Remanded in 1995

(d) On Contaminant Candidate List #3

Reasons for Industry Concern

■ Accumulated contaminants can be released

- Can result in elevated concentrations at the tap
 - MCL exceedances have been documented
- Potential public health implications if consumed

■ Limitations of current regulatory framework

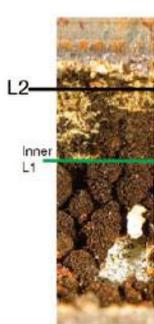
- Monitoring is at system entry-points: assumes in = out
- MCLs intended to protect against chronic health effects
 - Long-term exposure (lifetime)
 - Low contaminant concentration
- Fails to consider intermittent exposure to elevated levels
 - Potential for acute and sub-chronic health effects
 - Need to consider magnitude, frequency, duration

Emerging Information

Environment
<http://pubs.acs.org/subsci>
Science News –January 23,
Pipe scales release
water

Mobilization of mineral can contaminate treated

Mineral deposits inside drinking-water arsenic, cadmium, and mercury, and according to new research published in regulations miss such disturbances, bec water enters the distribution system pip



Pipe scales concentrate r

U.S. EPA corrosion chemist Michael S systems and found unexpectedly high concentrations as high as 426 parts per ppm, vanadium as much as 20,000 ppm would cause drinking water at the tap to almost none of the utilities were in viol copper, the only inorganic contaminant

"Our work shows that when corrosion i the pipe. Other metals can be mobilized

The research is important, says enginee should open people's eyes to what may could be the tip of the iceberg," he add

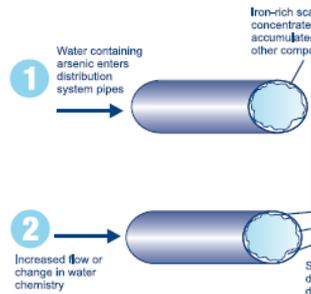
EPA United States Environmental Protection Agency
ARSENIC AND YOUR DISTRIB

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

Arsenic Can Build Up on and Release Pipes and Storage Tanks

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

How Arsenic Can Increase in Your D



EPA United States Environmental Protection Agency
**Inorganic Contaminar
 in Potable Water Distr**

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

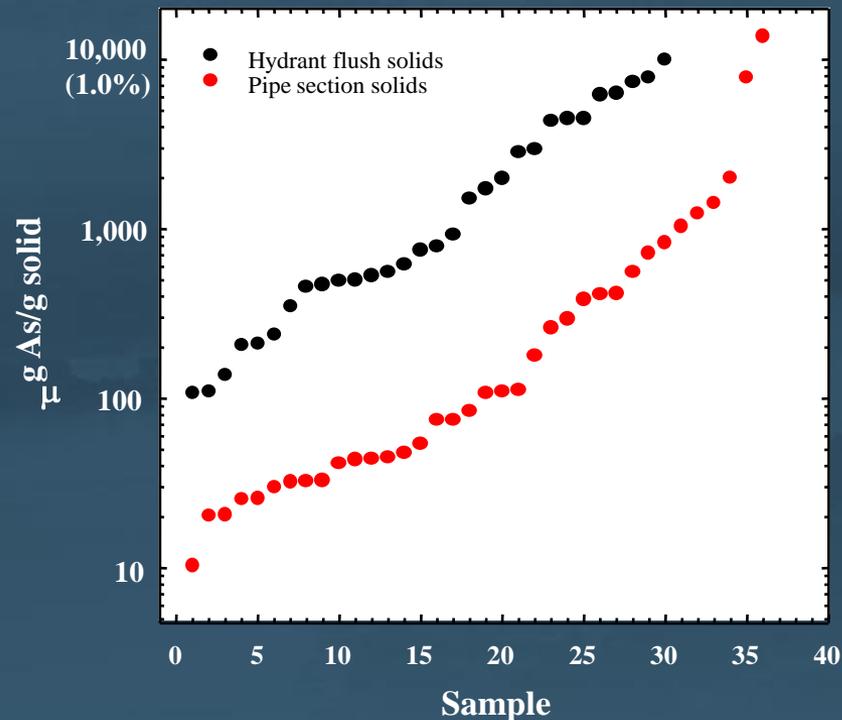
AWWARF 3118

**ASSESSMENT OF
 Inorganics Accumulation
 in Drinking Water System
 Scales and Sediments**

JULY 15, 2005

Evidence of Arsenic Accumulation

- Recent research is conclusive enough to motivate the EPA Fact Sheet on arsenic accumulation risks



Arsenic Content of Flushed Solids and Pipe Scale
(Source: Darren Lytle, 2004)

Accumulation “Sinks”

■ Pipe corrosion scales

- Distribution mains
- Service plumbing

■ Sedimented deposits

- Fe and Mn carryover
- Scales of Ca, Al, PO₄
- Clays, silts, and sand

■ Biofilm

The various “sinks” exist in a heterogeneous matrix reflective of the various factors that influence their formation and stability



Smooth Manganese Scale
(Courtesy: Michael Schock)



Mixture of Sedimented Material

Pipe Corrosion Scales

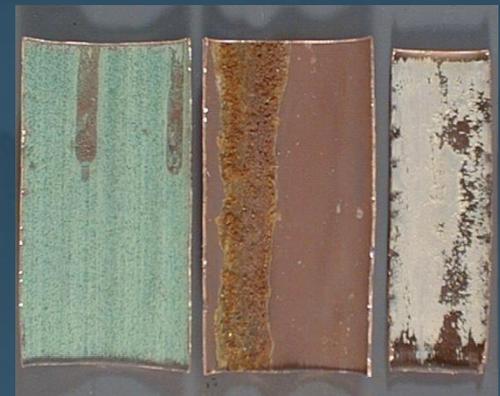
- Ubiquitous in distribution systems
- Substantial volume & surface area
 - >10-fold magnification of surface area
- Very strong adsorptive properties
 - Fe coagulant/media used for treatment



Iron Oxide Scale Accumulation



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



Copper Service Line Scale
(Courtesy: Steve Reiber)

Accumulation “Sinks”

- Even “non-corrosive” piping is vulnerable
 - PVC & HDPE
 - Cement-lined
- Common sinks include:
 - Mobilized corrosion by-products
 - Manganese film



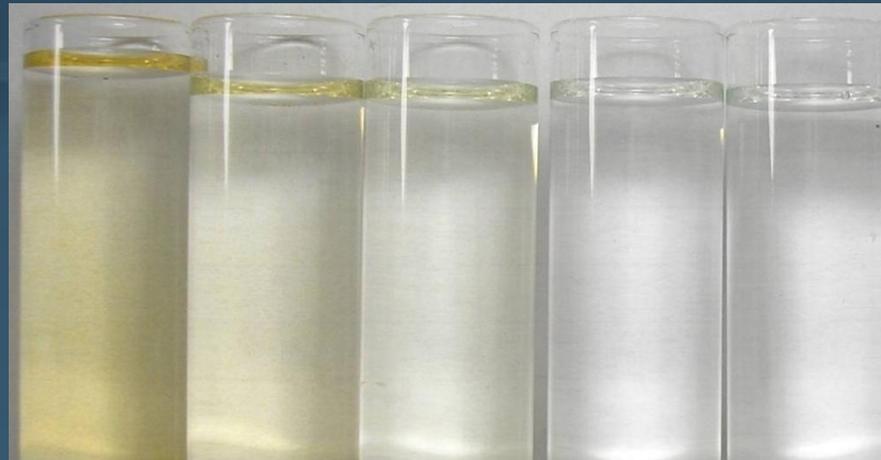
Contaminant Accumulation on PVC Pipe
(Source: Darren Lytle, 2004)

Accumulation and Release Mechanisms

1) Physical Processes: deposition & re-suspension

- ❑ Solids-associated contaminants and chemical precipitates
- ❑ Reversible under hydraulic disturbances
 - Peak flows, fire flows, flow reversals, main breaks, conv. flushing
- ❑ Some consumer protection may be provided by aesthetic degradation

Turbidity 4.4 ntu
Iron 20 mg/L
Arsenic 193 $\mu\text{g/L}$



Turbidity 0.39 ntu
Iron 0.72 mg/L
Arsenic 6.8 $\mu\text{g/L}$

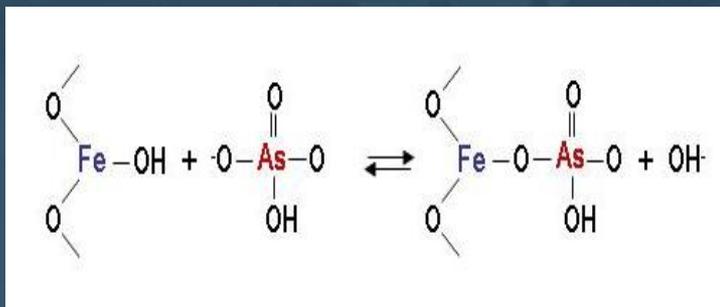
Tap Water Discoloration Due to Solids Mobilization

Accumulation and Release Mechanisms

2) Chemical Processes: adsorption and desorption

- Soluble contaminants that are retained on or within “sink”
- Chemical equilibrium – potentially reversible with change in water chemistry/quality
 - Contaminant desorption
 - Scale solubilization
 - Scale destabilization

Contaminants are released in a soluble form – no discoloration



Adsorption of Arsenate onto Goethite Scale



Impact of Scale Destabilization on Water Quality
(Source: Reiber, 1997)

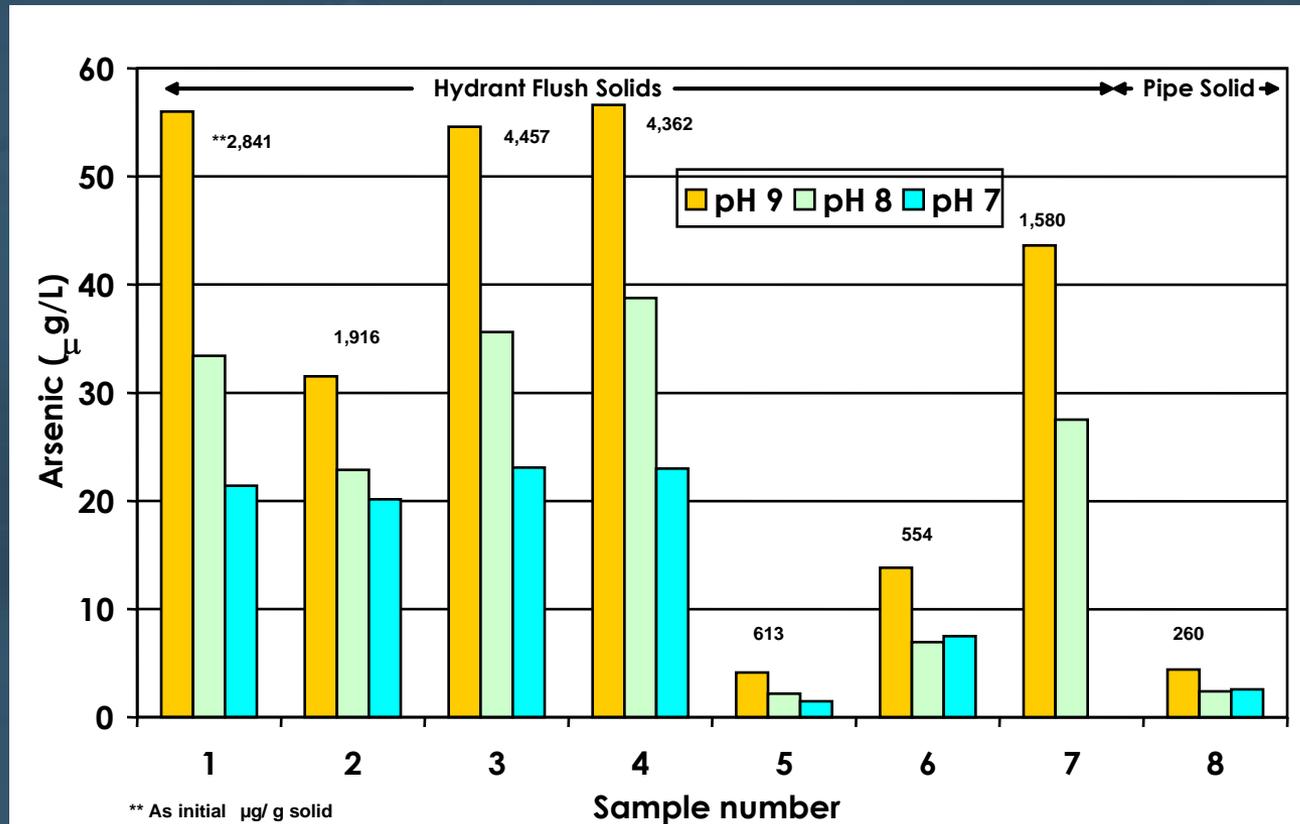
Risk Factors for Chemical Release

- Seasonal source usage or source switching
- Blending of dissimilar sources (esp. GW-SW)
- Bringing a new source online
- Treatment and water quality changes
 - Disinfection: implementation, conversion, ORP change
 - Corrosion control: adjustment of pH, alkalinity/DIC, PO_4



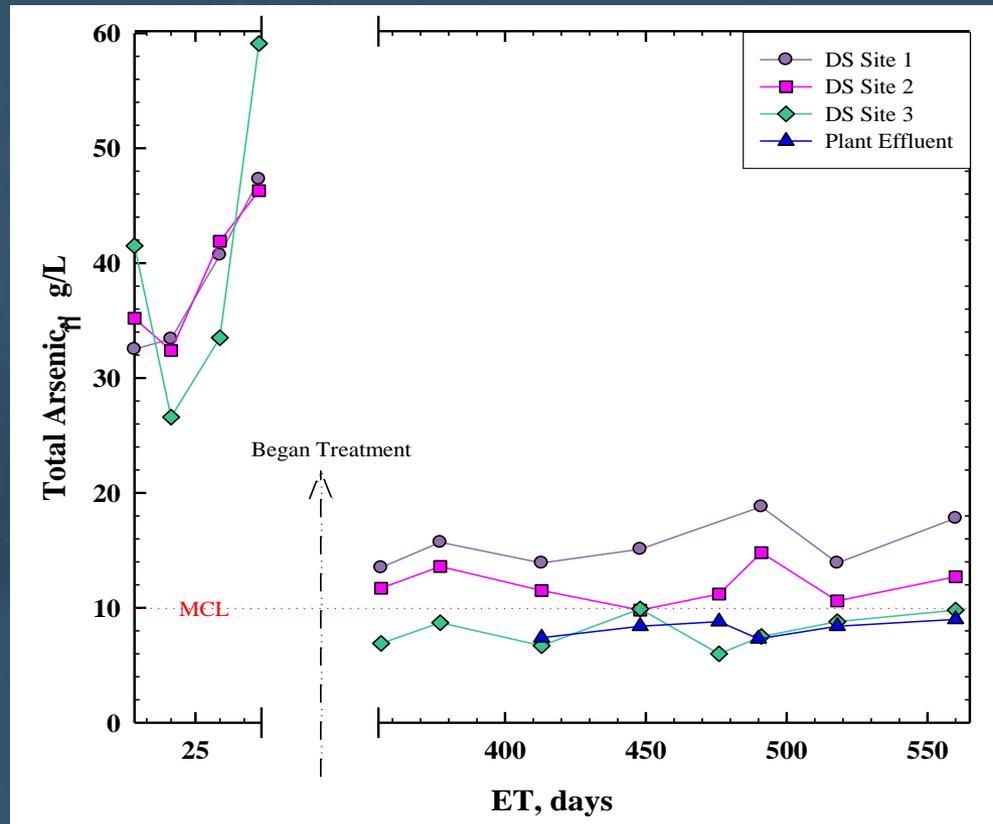
Scales and Adsorbed Contaminants Exist in a Dynamic Equilibrium with Bulk Water Quality

Effect of pH on Arsenic Release



pH-Reversibility of Arsenic Adsorption onto Distribution System Solids
(Source: Copeland, 2006)

Real-World Example of Arsenic Release



Arsenic Desorption Trend within a Distribution System
(Source: Lytle, ND)

Introduction to AwwaRF 3118 Project - Objectives

- Determine the occurrence of representative inorganic contaminants in corrosion scales and sediments
- Examine relationships between the occurrence of these contaminants in water and solids accumulated in distribution systems
- Examine associations between concentrations of inorganic contaminants and common constituents of corrosion scales and sediments
- Examine whether the inorganic contaminants are associated preferentially with the mobile part of corrosion solids
 - – Hydrant flush solids as a representative groups

Analytical Targets (analytes)

- Commonly occurring elements
 - Iron, manganese
 - Phosphorus, sulfur, carbon (organic and inorganic), (silicon)
 - Calcium, magnesium, aluminum
 - Zinc
- Inorganic contaminants
 - Antimony, arsenic, selenium
 - Cadmium, thallium, uranium
 - Nickel, chromium, vanadium
 - Barium, lead, (zinc)

Sampling and Analytical Methodologies

Number and types of samples

- All samples of solid phases (N=58)
- Hydrant flush samples (N=23)
- All pipe specimens (N=35)
 - Live samples (N=25)
 - Galvanized pipe samples (N=4)
 - All other live samples (N=21)
 - Boneyard samples (N=10)

Preliminary Conclusions – inorganic contaminants

- All hydrant flush solids and pipe specimens are highly complex morphologically and structurally
- A wide range of inorganic contaminants have been found in them
- Their concentrations change dramatically from one site to another and within each site
- Concentrations of Chromium, Lead and Zinc displayed the highest variability – likely to be the result of the presence of internal sources of these metals.