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Can NOM Removal Accelerate Passivation of Copper Piping?

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Agenda

1. Background
2. Copper Corrosion Theory
3. Pilot Study Design
4. Lessons Learned
5. Next Steps

Background

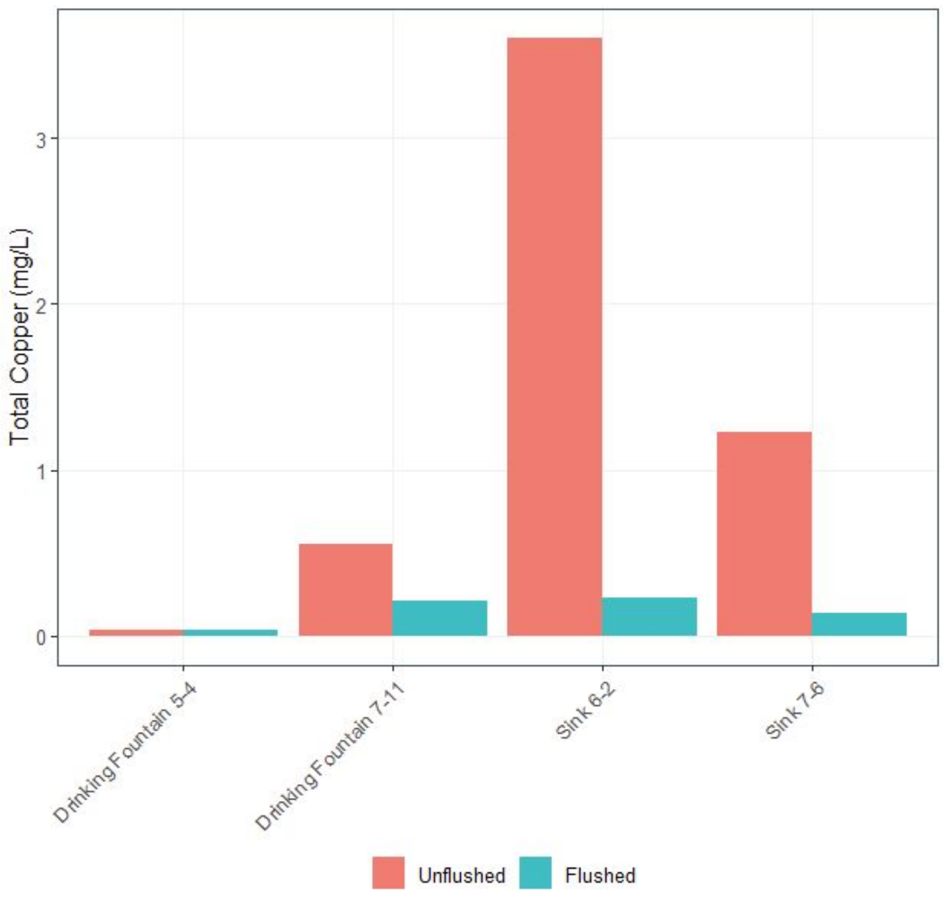
Brown AND Caldwell

Initial Observations

- Starting in 2022, high copper (Cu) levels were observed at a recently-constructed elementary school (Facility A)
  - Additional sampling found persistent elevated heterotrophic plate counts (HPC), suggesting microbially influenced corrosion (MIC)
- Subsequent sampling at other school district facilities found elevated Cu levels at several schools
  - Elevated HPCs were not detected at other locations

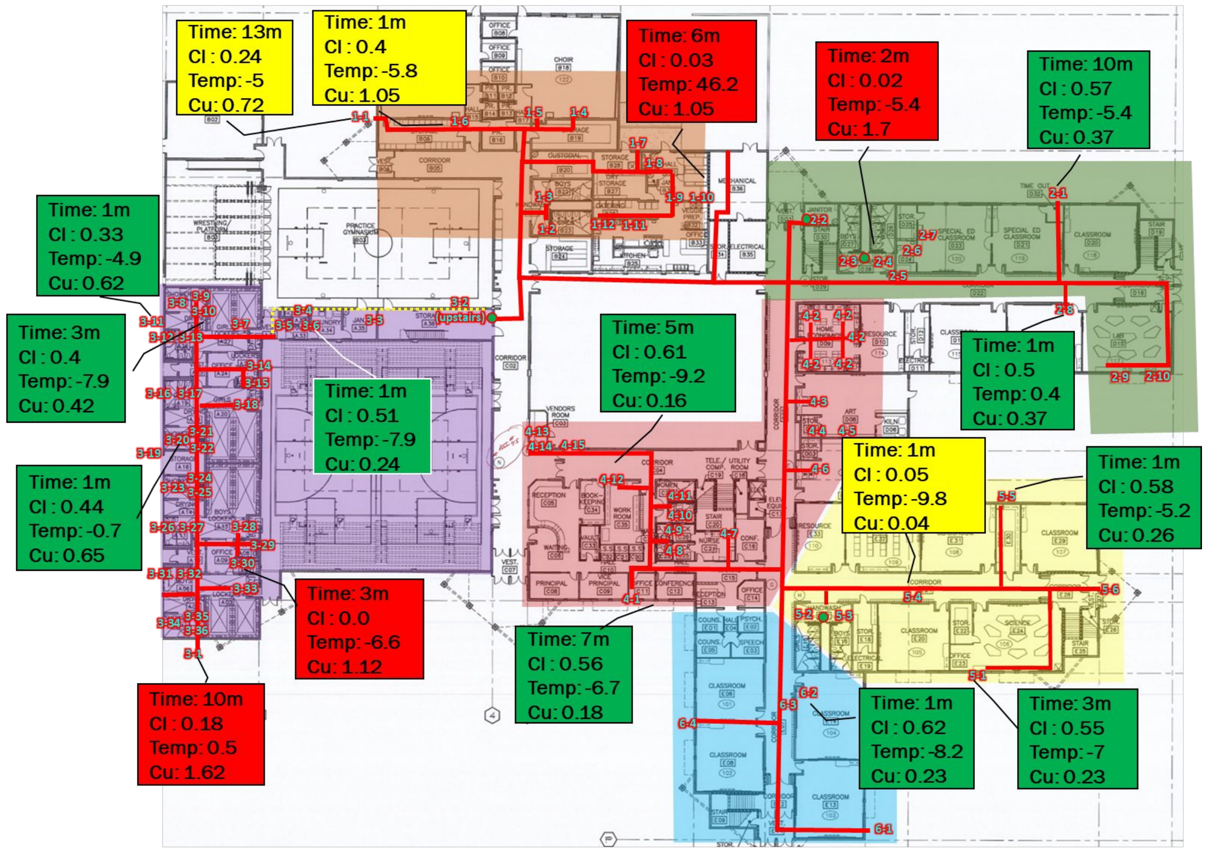
Initial Observations, cont.

- Boise School District immediately isolated impacted fixtures and provided alternate sources of water
  - Elevated temperature
  - Low chlorine residual
- Flushing found to be an effective short-term control for copper release

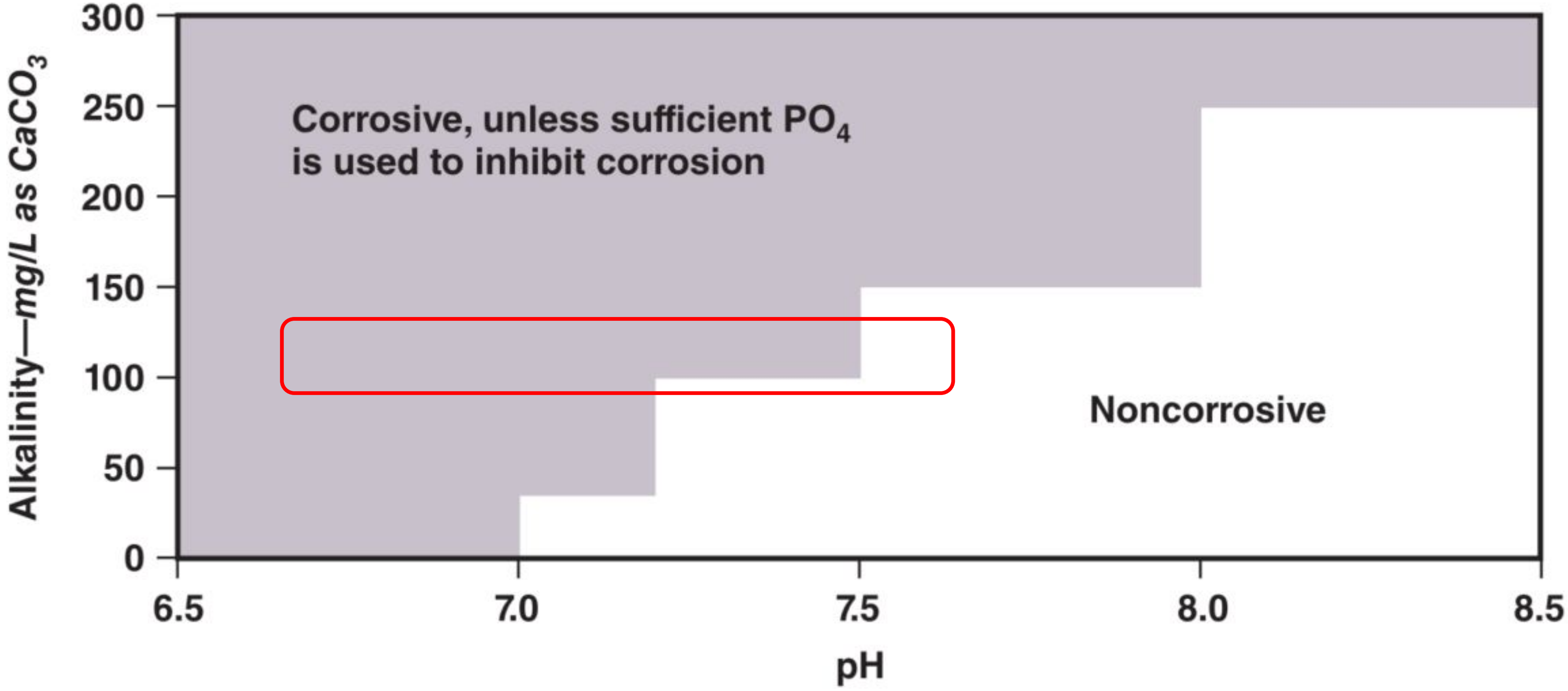


Challenges with Flushing

- Effective flushing requires sequencing and is time intensive
- Reductions in copper solubility were achieved through flushing, but reductions were not durable



Challenging Influent Water Matrix



Challenge

- Copper piping in impacted facilities continues to release copper above acceptable levels
  - Mitigation through flushing is a temporary solution
- Boise Sc[...] y to change i[...]
  - Adding alkalinity and/or adjusting pH would establish facility as a non-transient, non-community water system and require licensed operators

Can passivation of copper piping be accelerated?

Copper Corrosion Theory

Copper Solubility

- Edwards et al (1996) found copper release from fresh copper piping was consistent with solubility predictions based on cupric hydroxide, $Cu(OH)_{2(s)}$
- Over time, cupric hydroxide will convert to malachite or tenorite:

$$2Cu(OH)_2 + CO_2 \rightarrow Cu_2(CO_3)(OH)_2 + H_2O$$

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

Scale Analysis

- University of Colorado Boulder performed scale analyses on cold and hot water piping harvested from Facility A.
- **SEM-EDS** analysis characterized spatial distribution of elements
- **XRD** analysis characterized crystalline minerals present

Cold Water Pipe, Harvested January 3,

Hot Water Pipe, Harvested January 3,

SEM-EDS Analysis

Top of Pipe

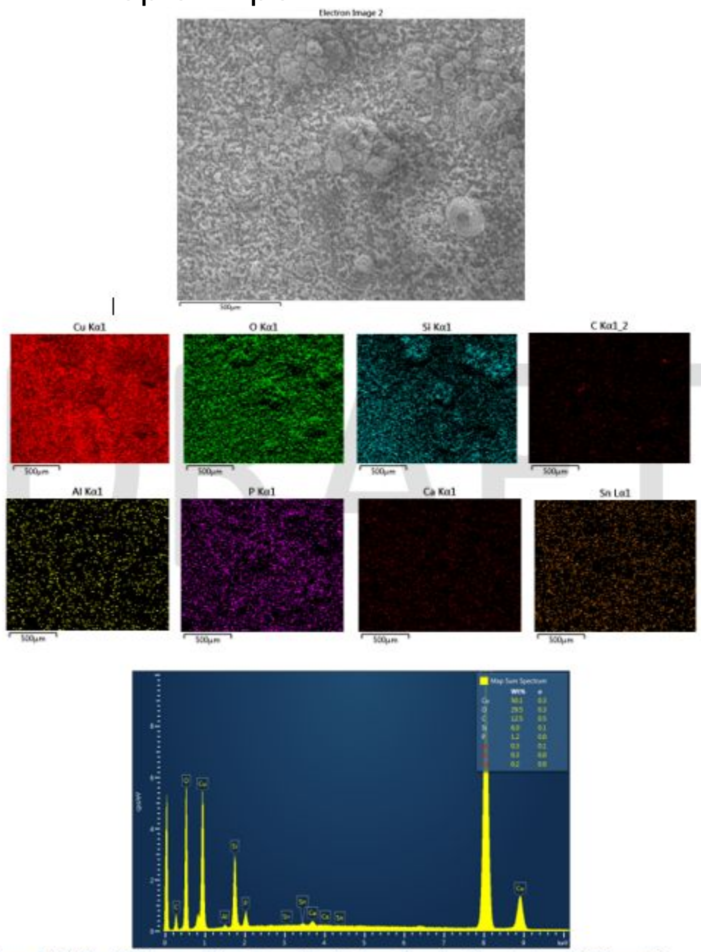


Figure 8. (a) The SEM image of the bottom of the inside surface of cold-water pipe. (b) Elemental mapping of different elements. (c)Map sum spectrum showing the elemental weight percentages.

Bottom of Pipe

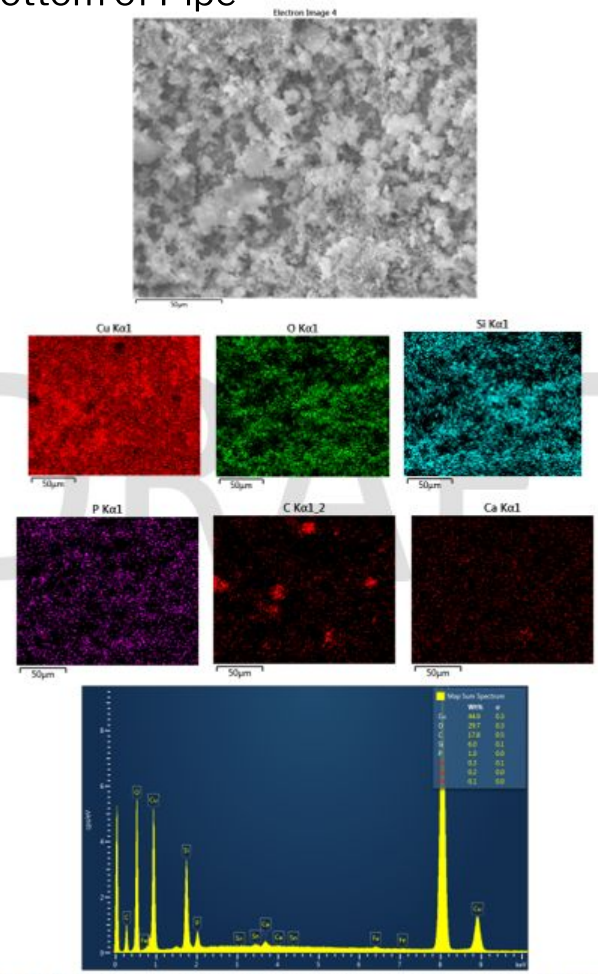
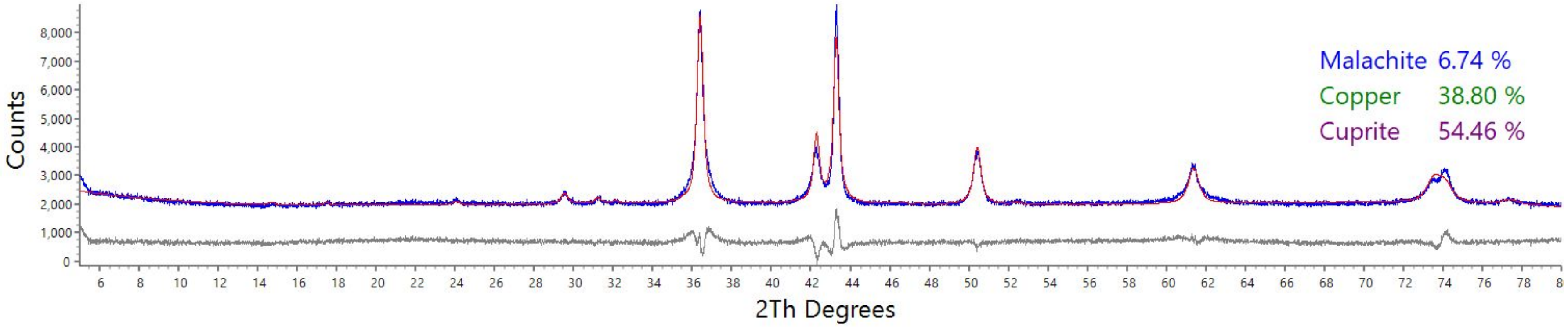


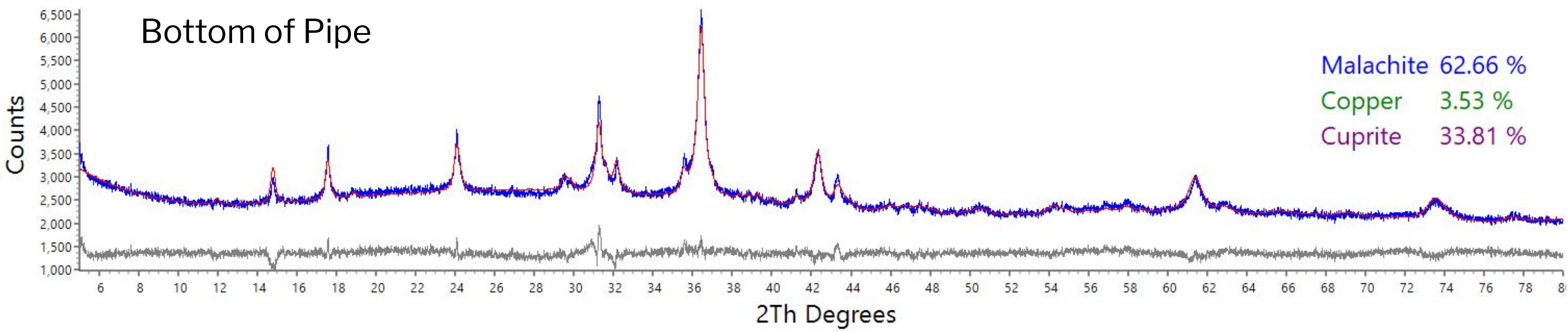
Figure 9. (a) The SEM image of the bottom of the inside surface of cold-water pipe. (b) Elemental mapping of different elements. (c)Map sum spectrum showing the elemental weight percentages.

XRD Analysis

Top of Pipe

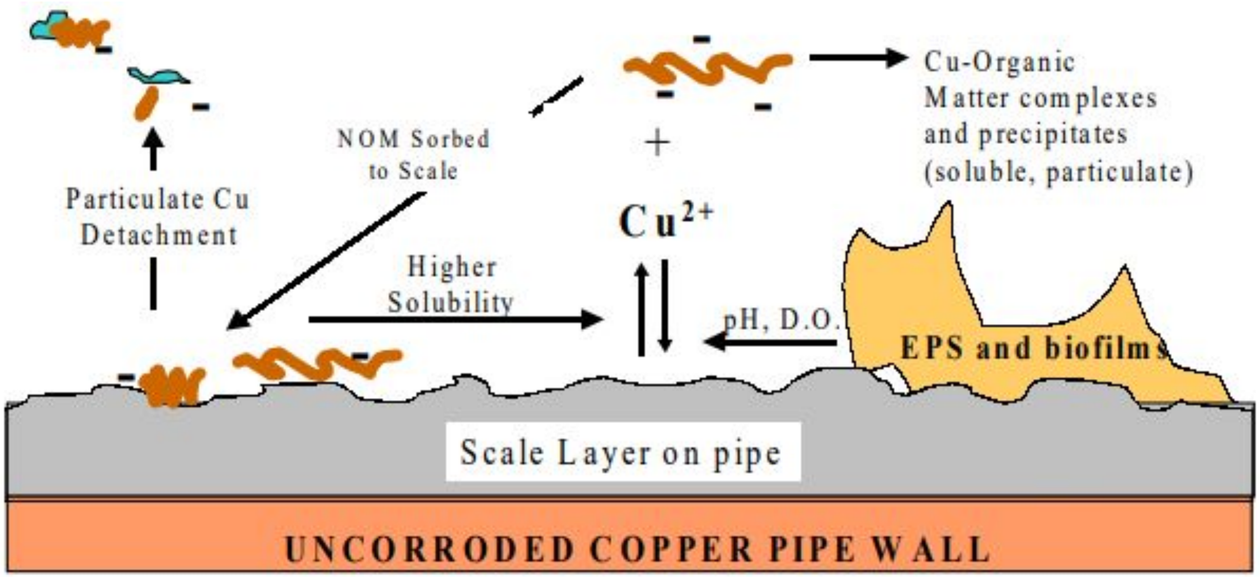


Bottom of Pipe

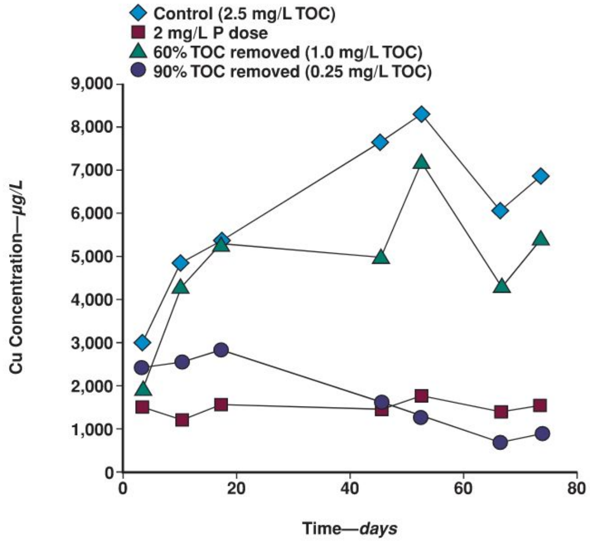


What is Disrupting Scale Formation?

- Edwards and Sprague (2001) found that NOM influences copper solubility by:
  - Interfering with the natural aging process of $Cu(OH)_2$
  - Complexing with copper corrosion by-products
  - Mobilizing/dispersing colloids



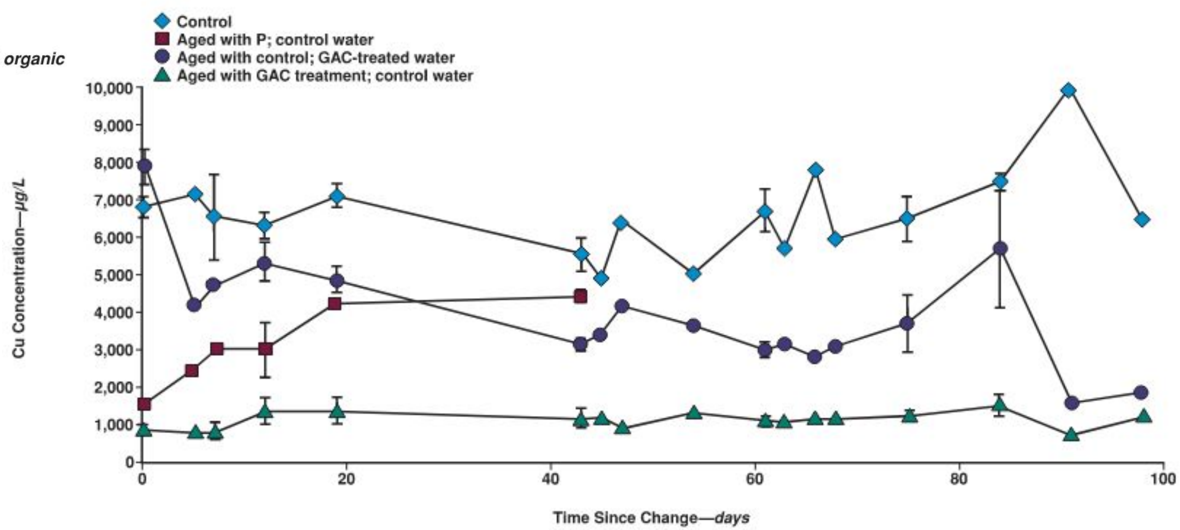
Can Passivation Be Accelerated?



Cu—copper, P—phosphorus, PO4—orthophosphate, TOC—total organic carbon

48-h stagnation times

Arnold et al (2012) found that temporary GAC treatment removing 90% of TOC present resulted in long-term reduction of copper solubility



Cu—copper, GAC—granular activated carbon, P—phosphorus

Cu concentration at time = 0 represents copper release immediately before change in experimental protocol; error bars represent 95% confidence interval above and below the mean

Pipe Study Design

Brown AND Caldwell

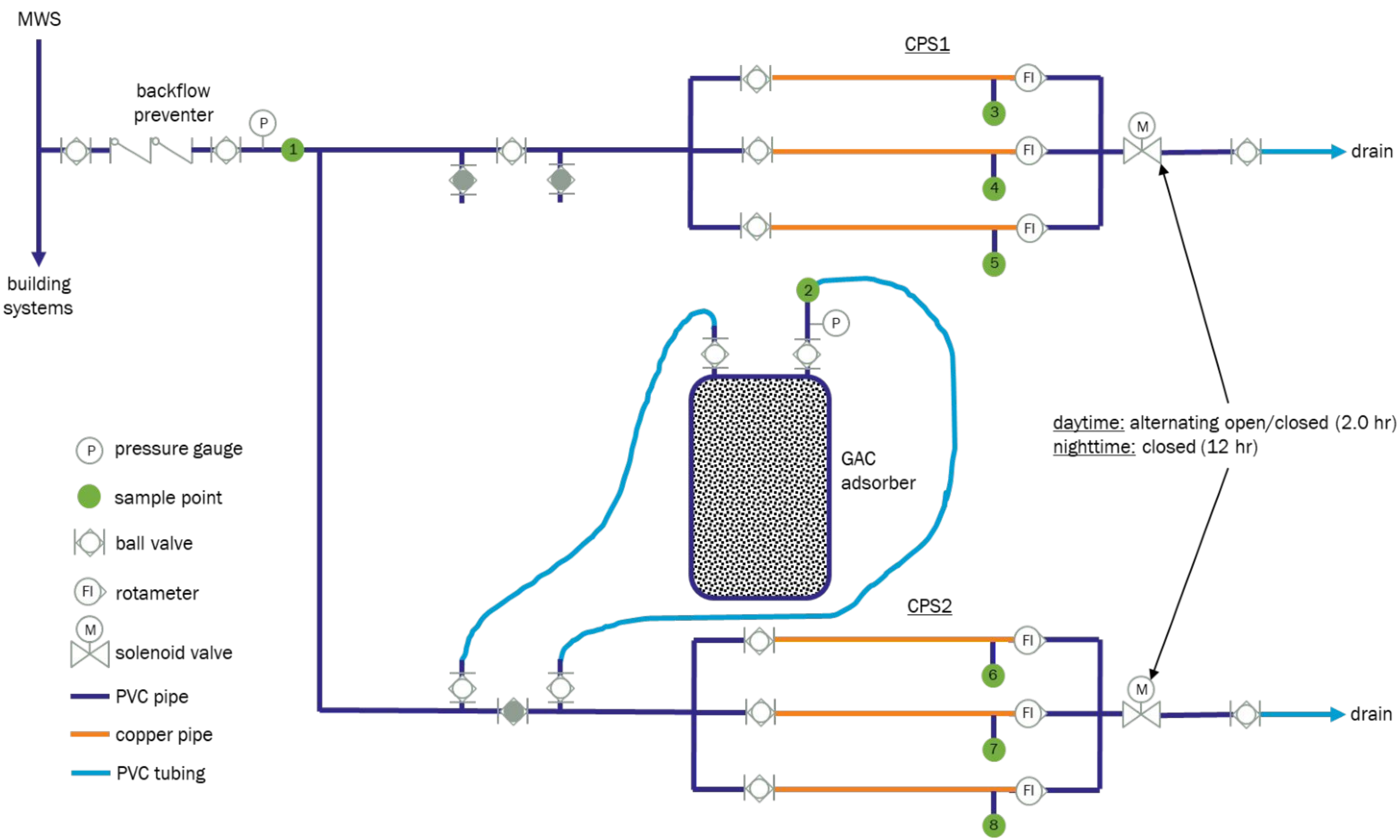
Pilot Study Objectives

- Evaluate whether natural organic matter (NOM) removal using granular activated carbon (GAC) can reduce copper corrosion by accelerating passivation
- Evaluate durability of copper passivation without continued GAC treatment

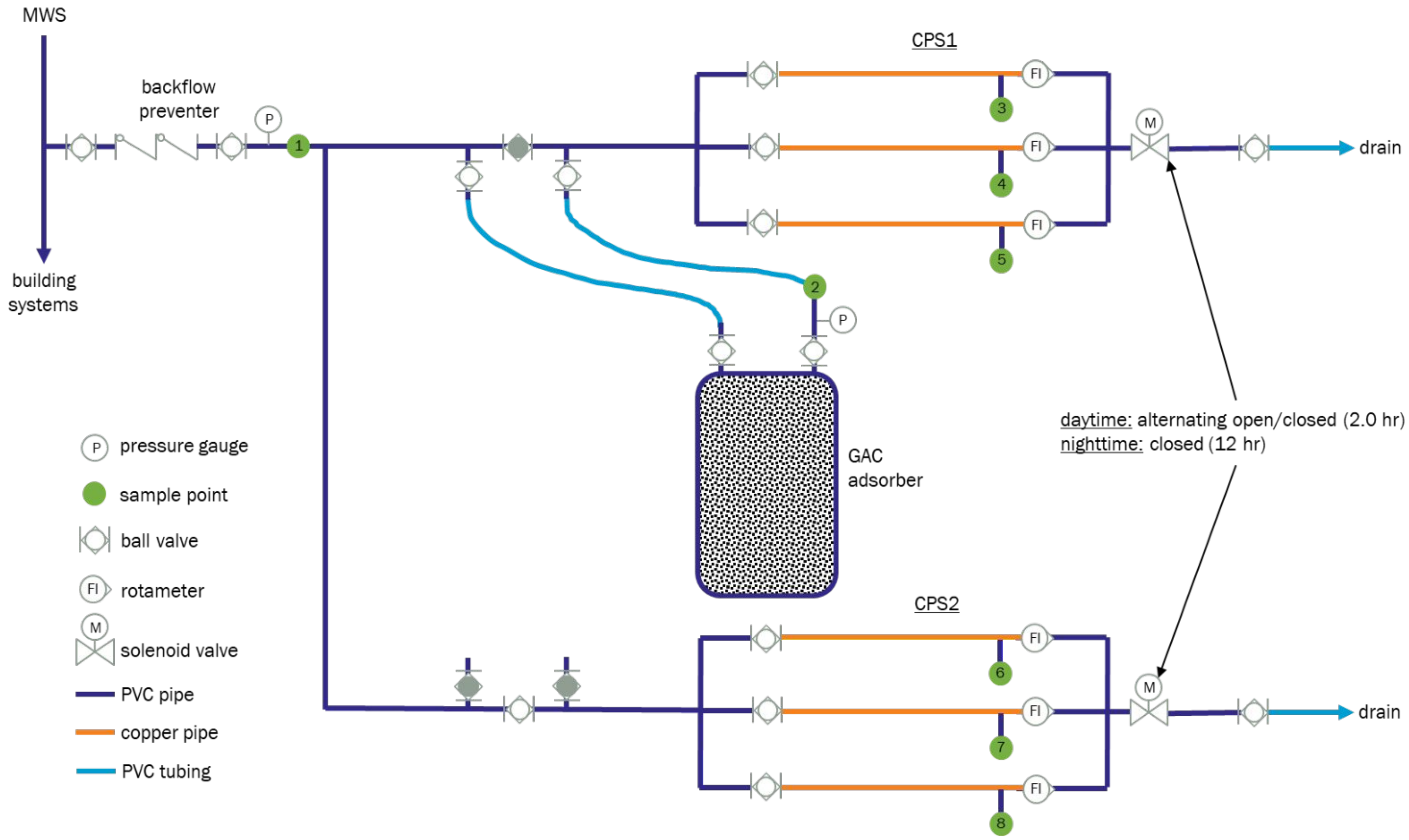
Pilot Study Test Plan

Phase	Copper Pipe Set 1	Copper Pipe Set 2
1	Water: municipal water Pipe: new type K copper Simulation: new construction with no municipal water supply pretreatment	Water: GAC-treated municipal water Pipe: new type K copper Simulation: new construction with municipal water supply pretreatment as if GAC been installed immediately following building construction completion
2	Water: GAC treated municipal water Pipe: aged type K copper Simulation: old construction with municipal water supply pretreatment, if GAC were newly installed in the future	Water: municipal water Pipe: aged type K copper Simulation: old construction with no municipal water supply pretreatment, if GAC was installed but removed in the future

Pilot Rig Design – Phase 1



Pilot Rig Design – Phase 2

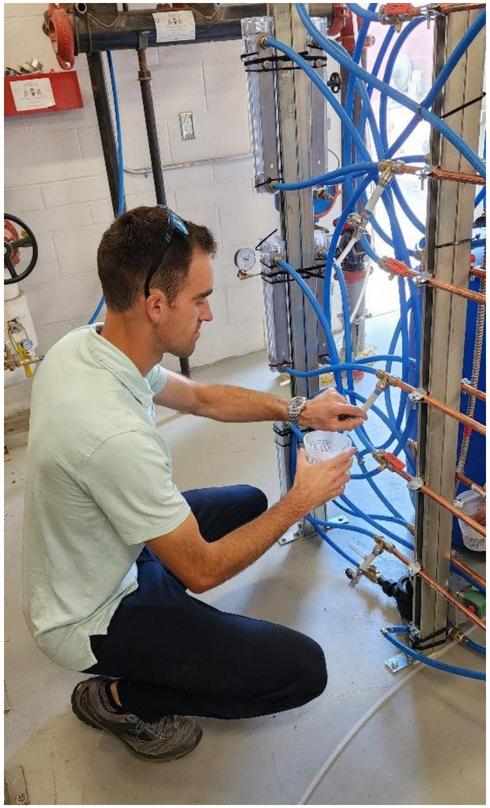


Constructed Pilot Rig

Pilot Rig Design Parameters

Parameter	Value	Units	Notes/Equipment
Pipe			type K copper
Nominal diameter	0.50	in	
Length	10	ft	
Hydraulics			
Velocity	0.37	ft/s	limited by GAC barrel pressure
Residence time			
Flowing	27	s	solenoid valves controlled by microPLC
Stagnating			
Daytime	2.0	hr	
Nighttime	12	hr	
GAC			Calgon Disposorb (F400)
Empty bed contact time	51	min	
Hydraulic loading rate	0.28	gpm/ft^2	

WQ Parameters



Parameter	Municipal Water Supply	GAC-Treated Municipal Water Supply	Each Copper Pipe Effluent
Alkalinity	1x/mo	1x/mo	1x/wk†
Chlorine, free	1x/mo	1x/mo	1x/wk
Copper	1x/mo	1x/mo	1x/wk
Dissolved	1x/mo	1x/mo	1x/wk
Total	1x/mo	1x/mo	1x/wk
Heterotrophic plate count	1x/mo	1x/mo	1x/mo†
pH	1x/mo	1x/mo	1x/wk
Total organic carbon	1x/mo	1x/mo	1x/wk†

†Sampled from one replicate only

Lessons Learned

Operational Considerations at Non-Water System Facilities

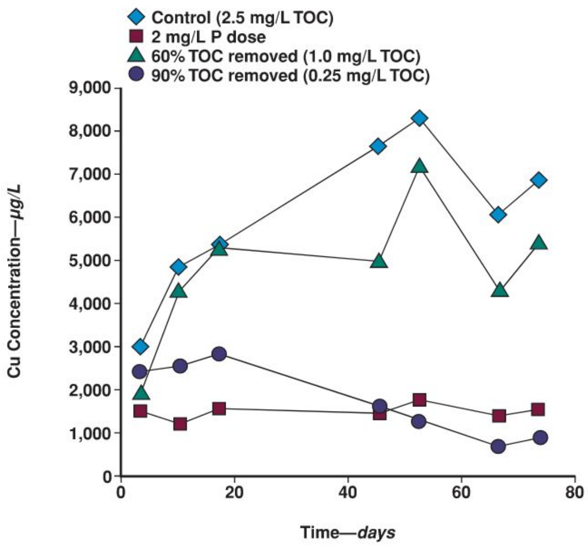
- Access
- Staff knowledge and familiarity w/ water testing
- Water quality consistency

Pilot Troubleshooting

- MicroPLC:
  - Needed to alternate flowing/stagnating
  - Program created using IDEC software
  - Loaded program to PLC using laptop computer
  - Not easily adjustable using PLC display
- Pressure:
  - Limitations on Calgon Disposorb of ~7 psi limited flow, needed pressure reducing value and backflow preventer
  - Requirements for solenoid valve actuation – started with 5 psi minimum and had to switch to 0 psi minimum

Next Steps

Can Bench-scale Results be Replicated?



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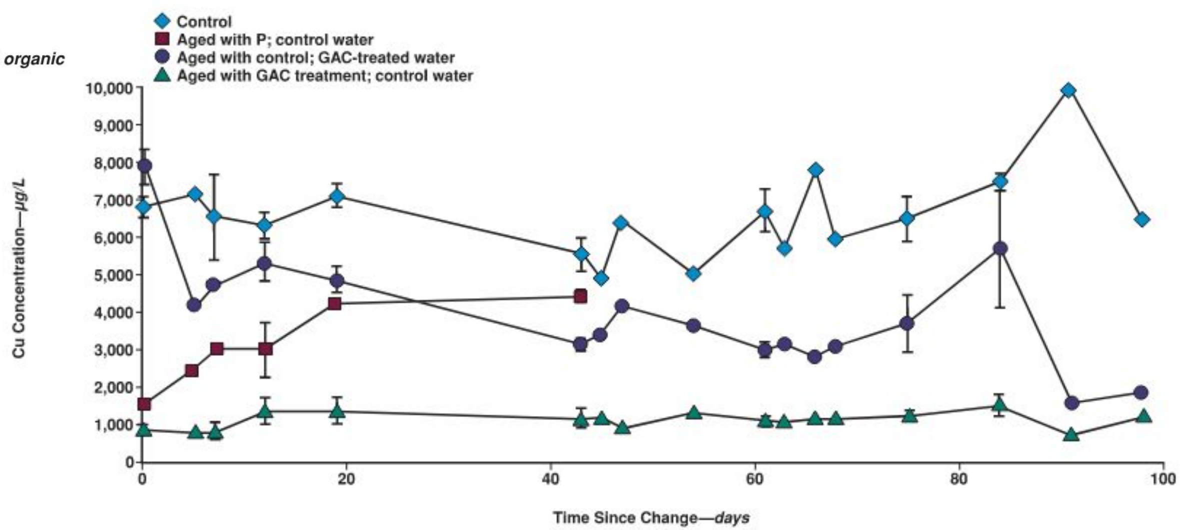

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Thank you.

Questions?