# Lead and Copper Corrosion 101: Principles & Guidance

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# Rationale

- The viewer will learn about the fundamental basics of lead and copper solubility, and factors that impact levels in drinking water.
- The information presented during this webinar will help the viewer in making better decisions regarding lead and copper control in drinking water distribution systems.

# Learning Objectives

The viewers will obtain:

- An understanding of basic relationships between lead and copper concentrations and important water quality parameters in drinking water.
- An understanding of  the importance of corrosion by-products and scale properties on lead and copper release.
- A basis for developing lead and copper corrosion control strategies.
- Information to be better prepared to make decisions regarding lead and copper issues.

# Acknowledgments

- Micheal Schock, USEPA
- Christy Muhlen, USEPA

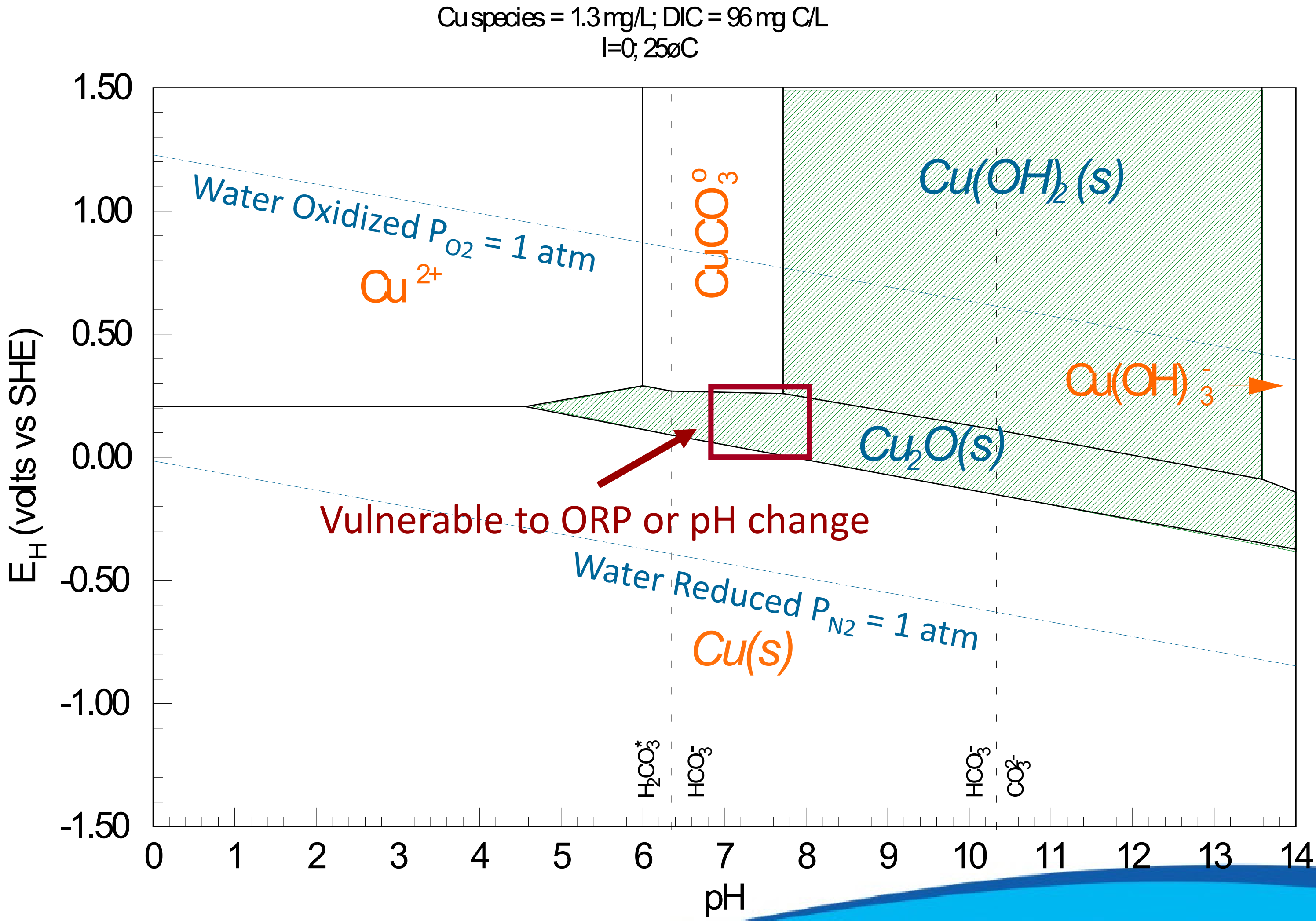
## Disclaimer

*This presentation has been reviewed in accordance with U.S. Environmental Protection Agency (EPA) policy and approved for external presentation. The views expressed are those of the author[s] and do not necessarily represent the views or policies of EPA.*

# Agenda

- Major Factors that Impact Copper (Cu) Release
  - Oxidation-reduction potential (ORP)/persistence of oxidants
  - pH/Alkalinity/Dissolved inorganic concentration (DIC) = solubility
  - Aging (several variables)
  - [*Ortho*]phosphate
  - Stagnation time
- Chlorine demand and copper corrosion
- Pitting corrosion

# ORP-pH Effects on Copper in Water

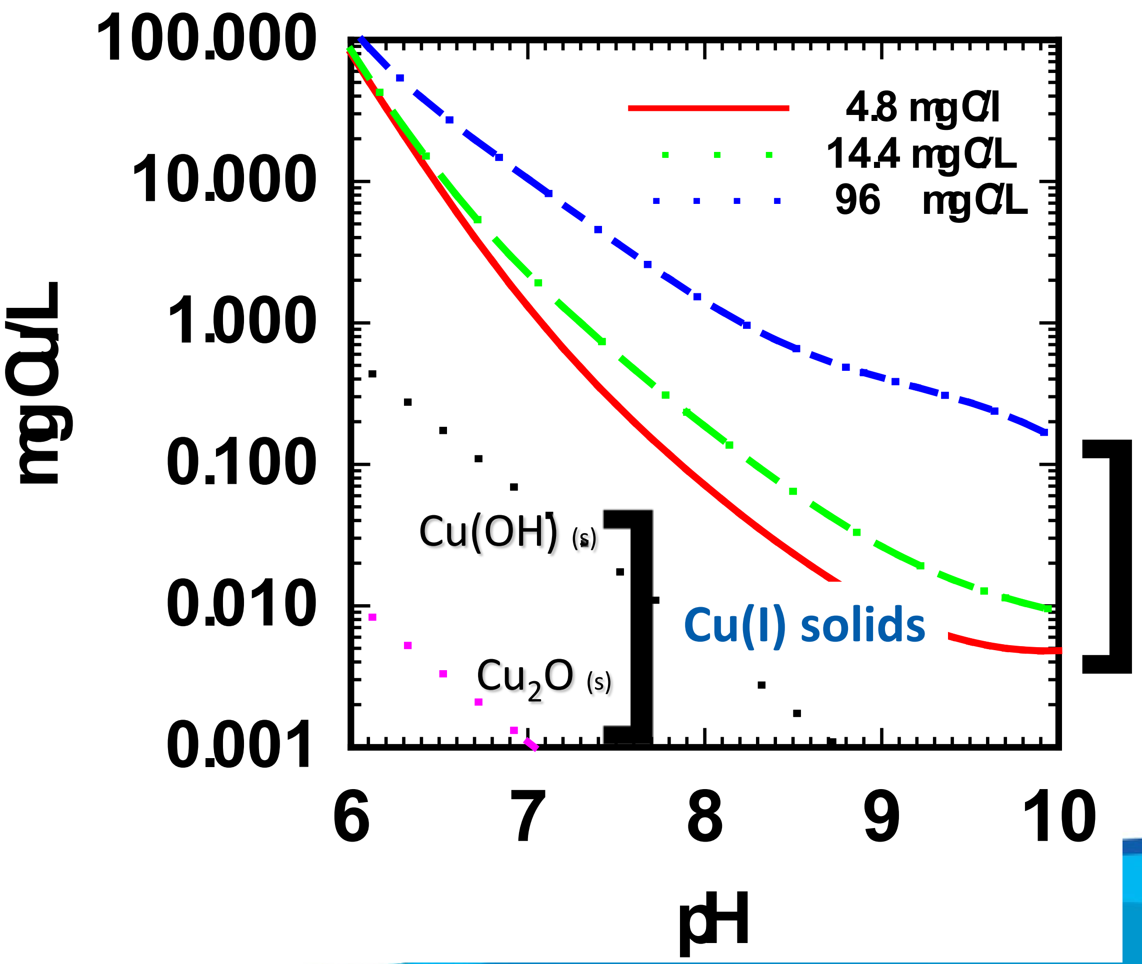



**Copper Oxidation State**

**$Cu^{1+}$ or Cu(I)**

**$Cu^{2+}$ or Cu(II)**

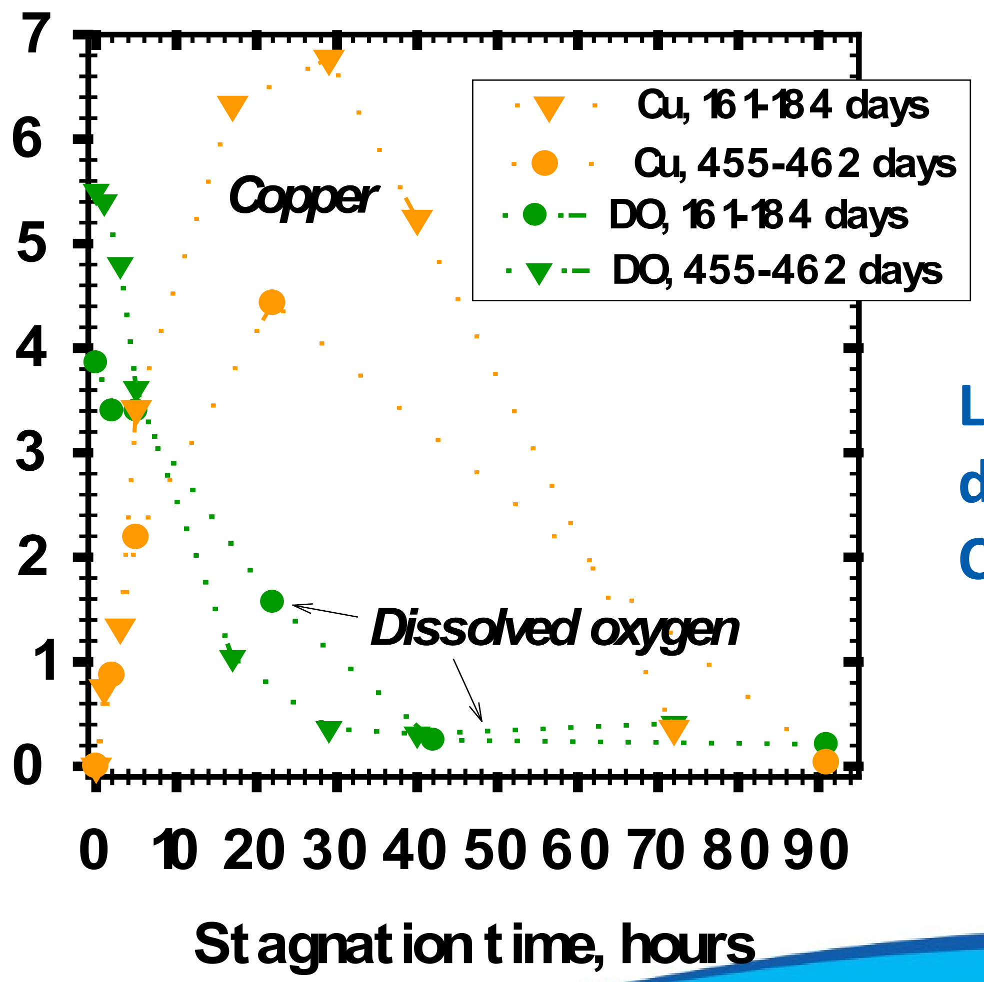
# Copper(II) Solubility at Different DIC Levels Compared to Copper(I) Solubility




Cu(II) solids are several orders of magnitude more soluble than Cu(I) solids

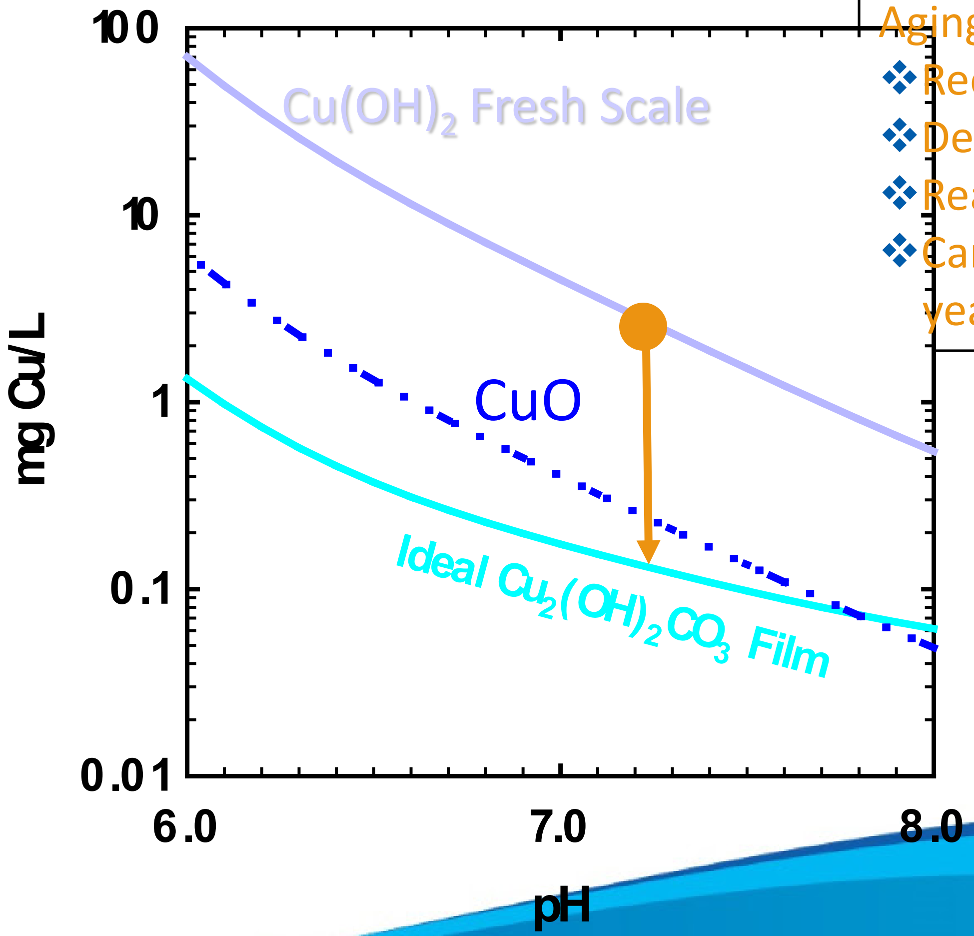
Cu(II) solids

# Age Impacts Oxidant-Limited Cu Stagnation




**Loss of oxygen (drop in ORP) during stagnation impacts Cu(II) and Cu(I) stability.**

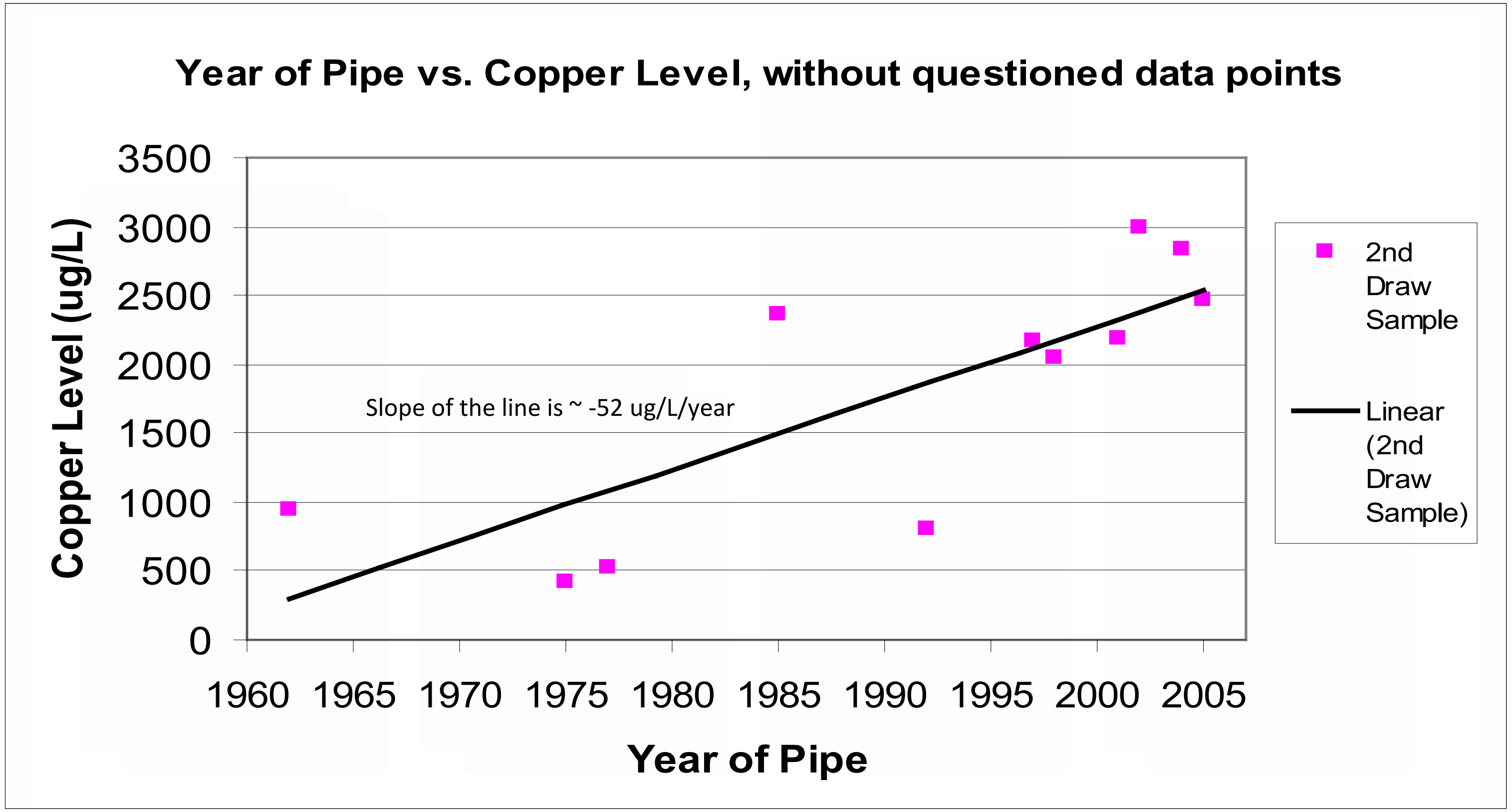
# Evolution of Scale Model for High DIC, Low pH Waters
# Copper "Aging"




Aging Process (in theory):

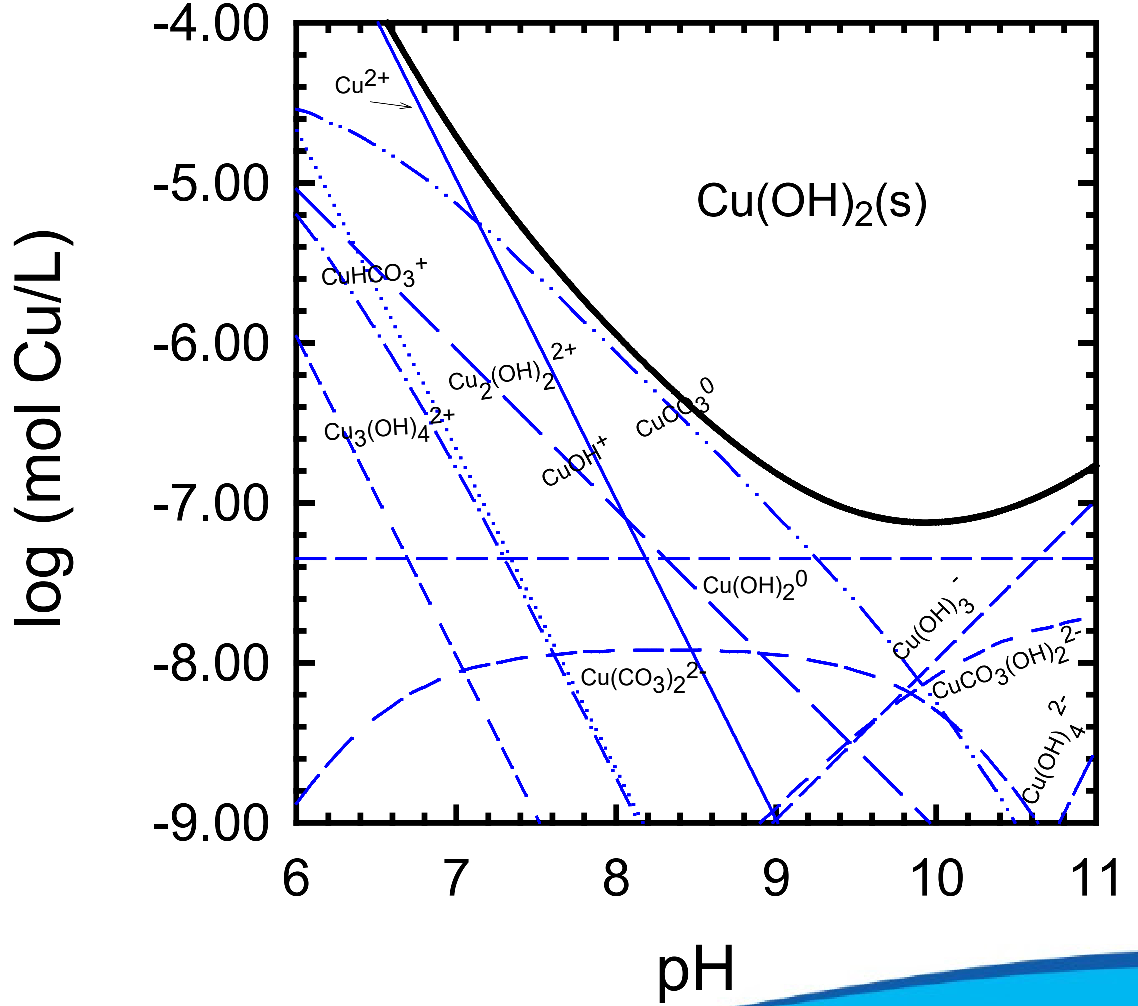
- Recrystallizing
- Decreasing surface area
- Reacting with $CO_3$ or $HCO_3^-$
- Can take 20, 30 or more years with high DIC

# Impact of Plumbing Age on 2nd Draw Copper Concentrations



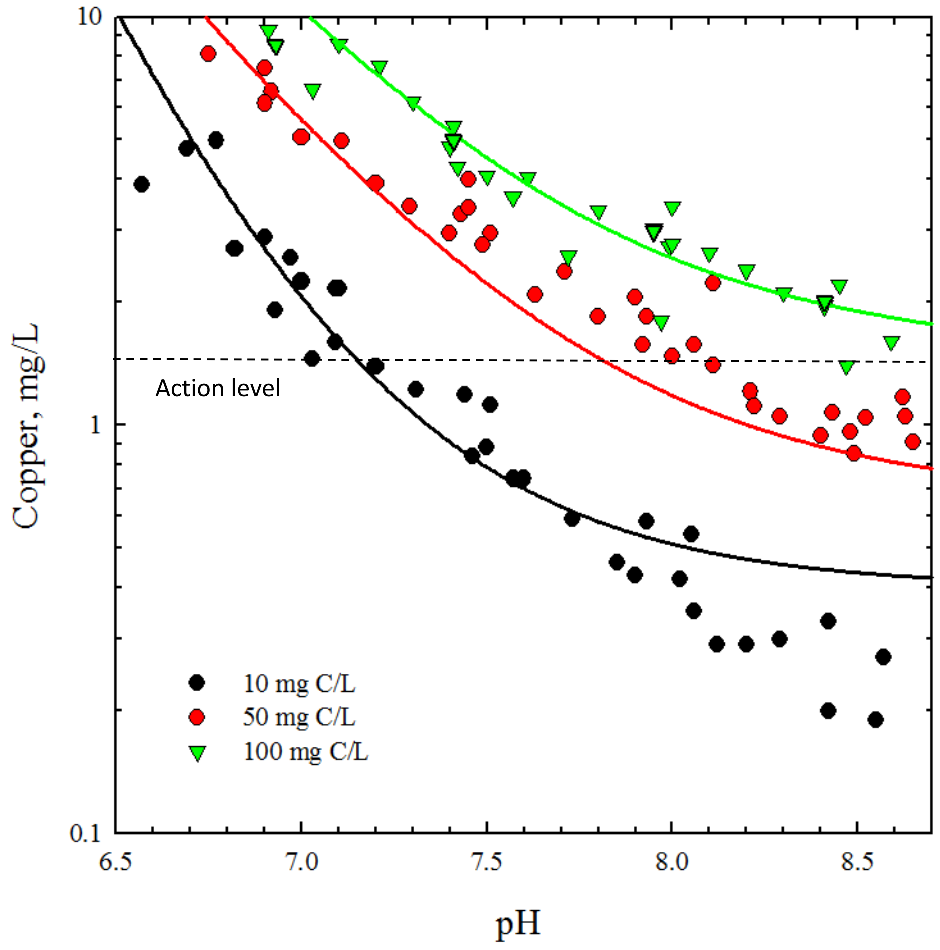

Data from M.S. Thesis of N. Turek, “Investigation of Copper Contamination and Corrosion Scale Mineralogy in Aging Drinking Water Distribution Systems”, AFIT, 2006.

# Aqueous Chemistry of Cu(II) Very Complicated



# Batch Testing- *Solubility Results*

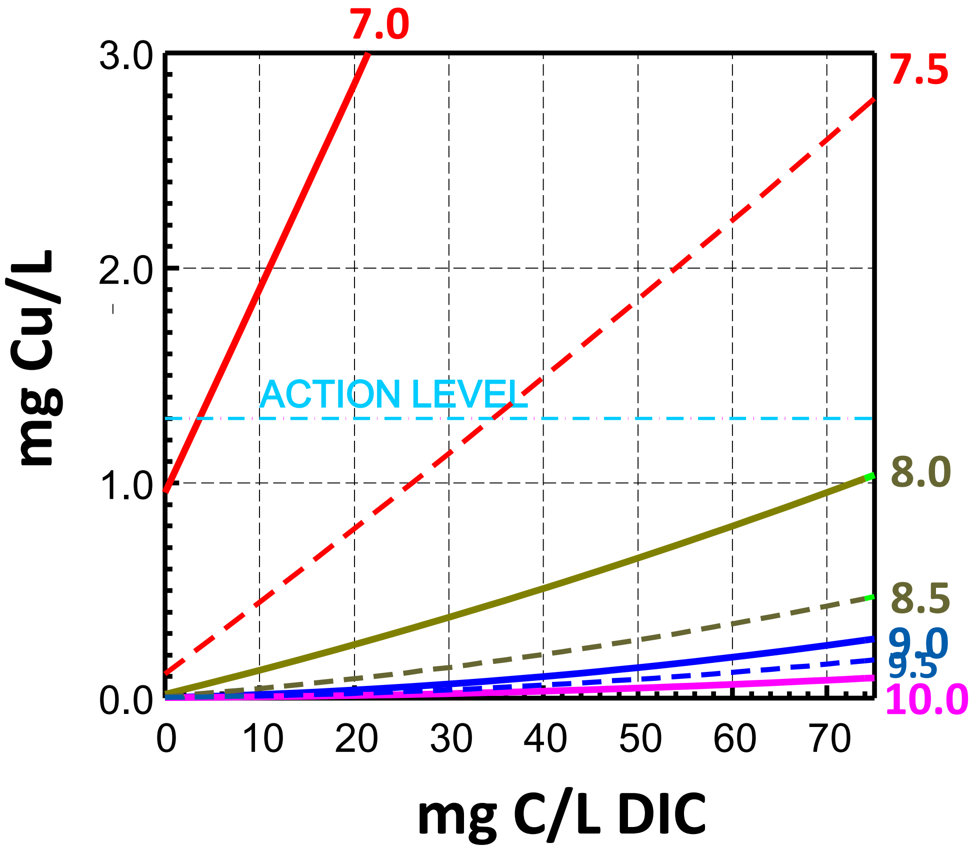
## Effect of DIC and pH on Copper Solubility (23$^{o}$C)*



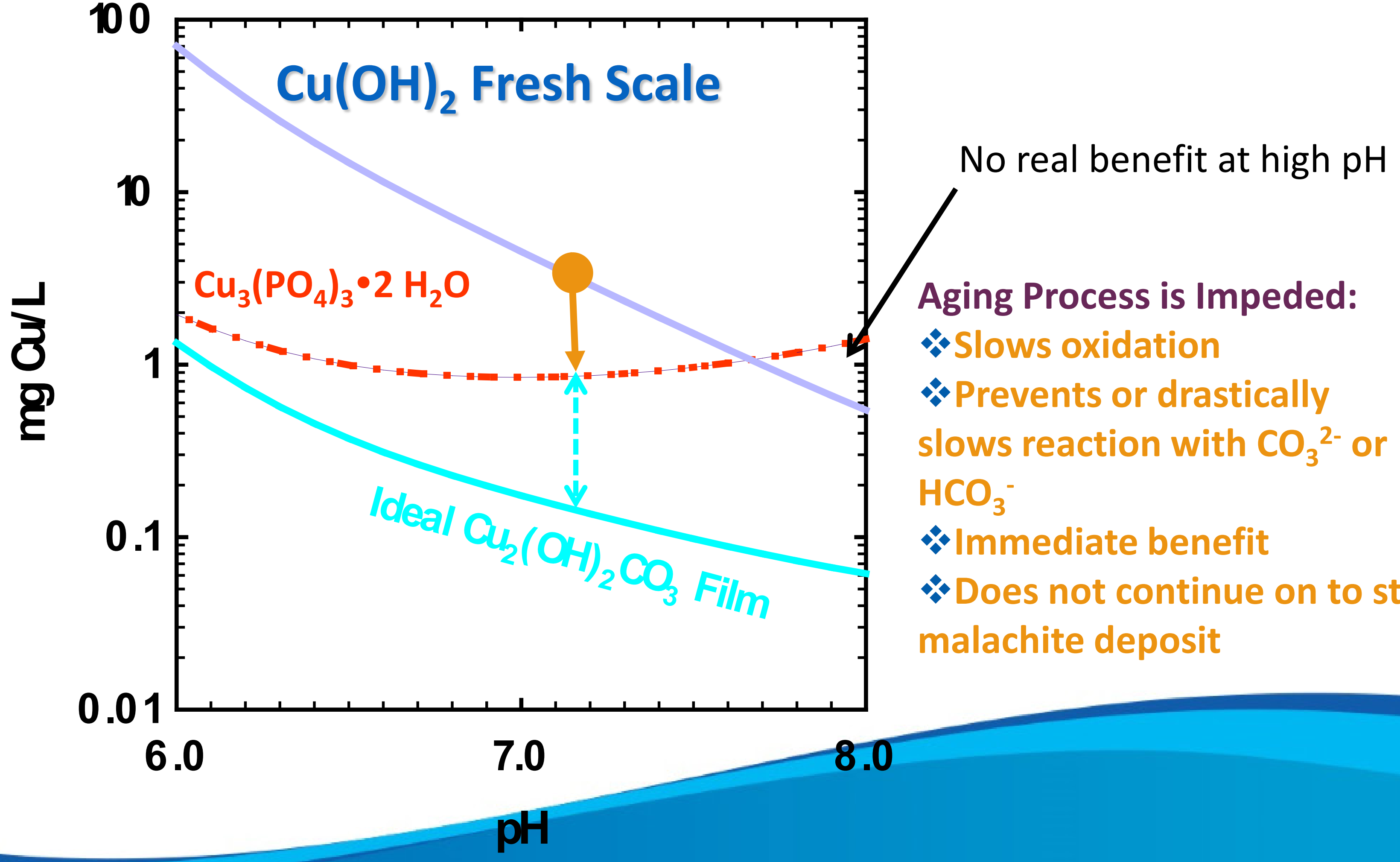

* Model predictions based on $Cu(OH)_2$

# Cu(II) Solubility & pH Adjustment

- If **pH > 7.5**, no problems if **DIC < 35**
- If **DIC < 5**, no problems if **pH > 7**
- If DIC > 35-40, scaling & buffering prevents sufficient pH adjustment to solve problems
- Lime softening, blending of anion exchange or RO treated water can achieve lowered DIC and acceptable Cu without phosphate



# Orthophosphate Inhibits Aging




**Aging Process is Impeded:**

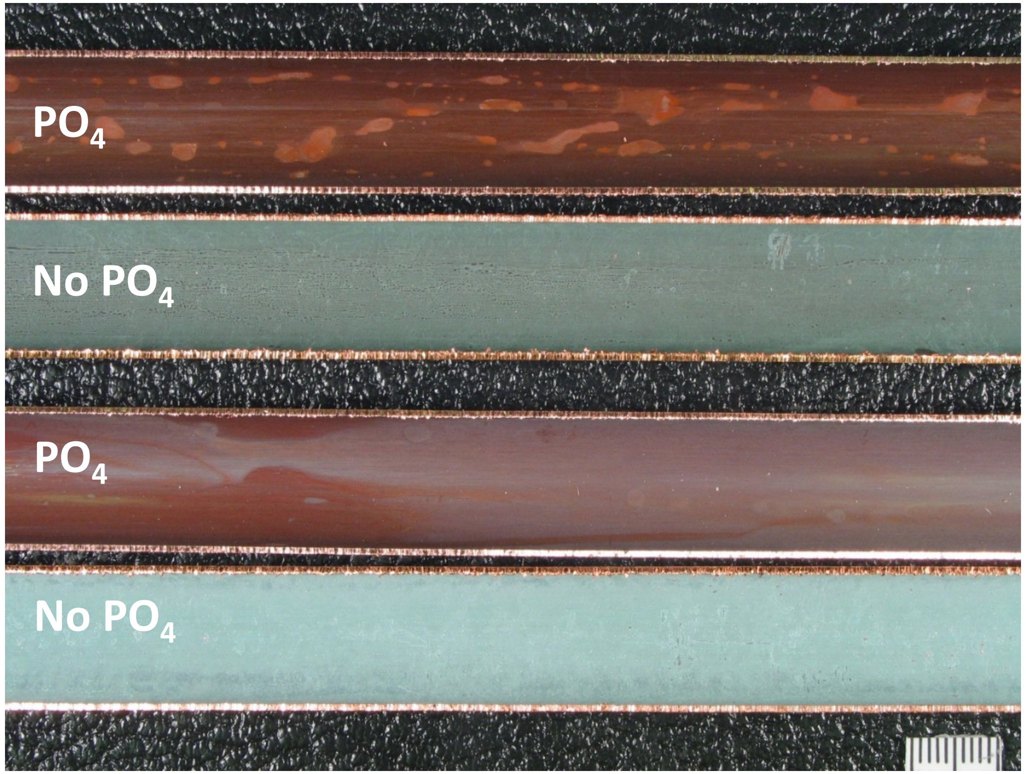
- Slows oxidation
- Prevents or drastically slows reaction with $CO_3^{2-}$ or $HCO_3^-$
- Immediate benefit
- Does not continue on to stable malachite deposit

# Orthophosphate Inhibits Aging

**DIC = 50 mg C/L, $PO_4$= 3.0 mg/L (upper pipes)**

pH 8.0

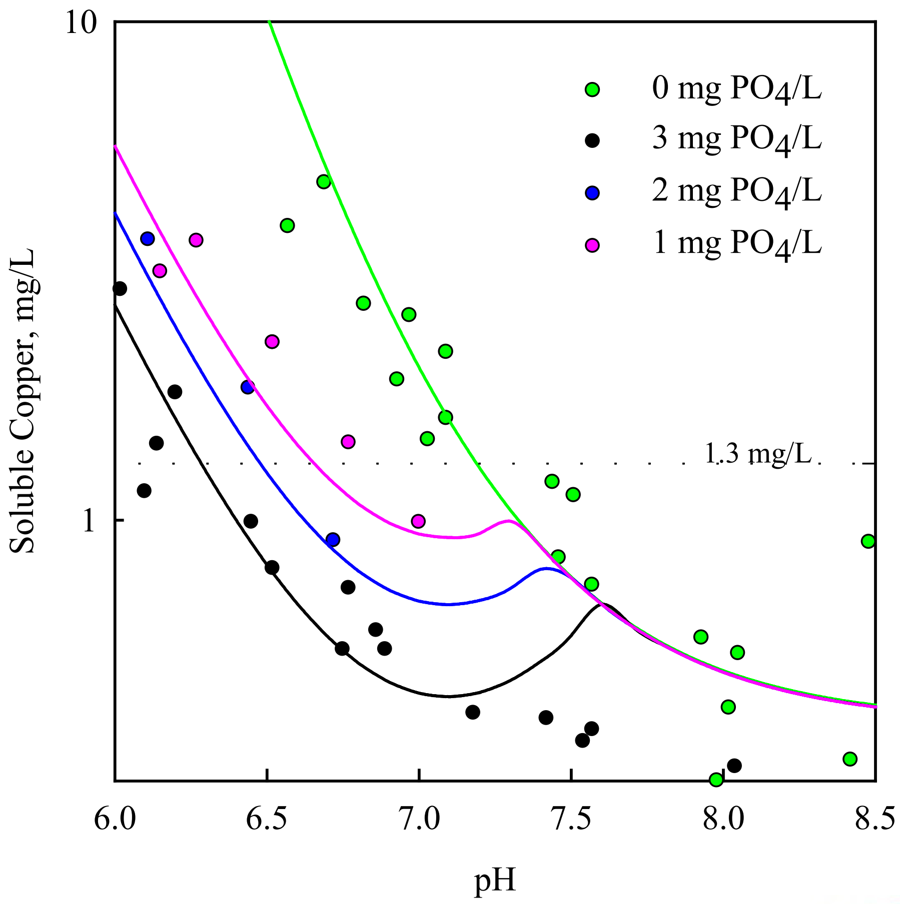
pH 7.0




- Tradeoff between short-term health goal and long-term Cu passivation that takes years to decades.
- Aging won't proceed "normally" when orthophosphate is added.
- Enough ortho-P must be added to *immediately* offset elevation of copper by the carbonate level for new plumbing

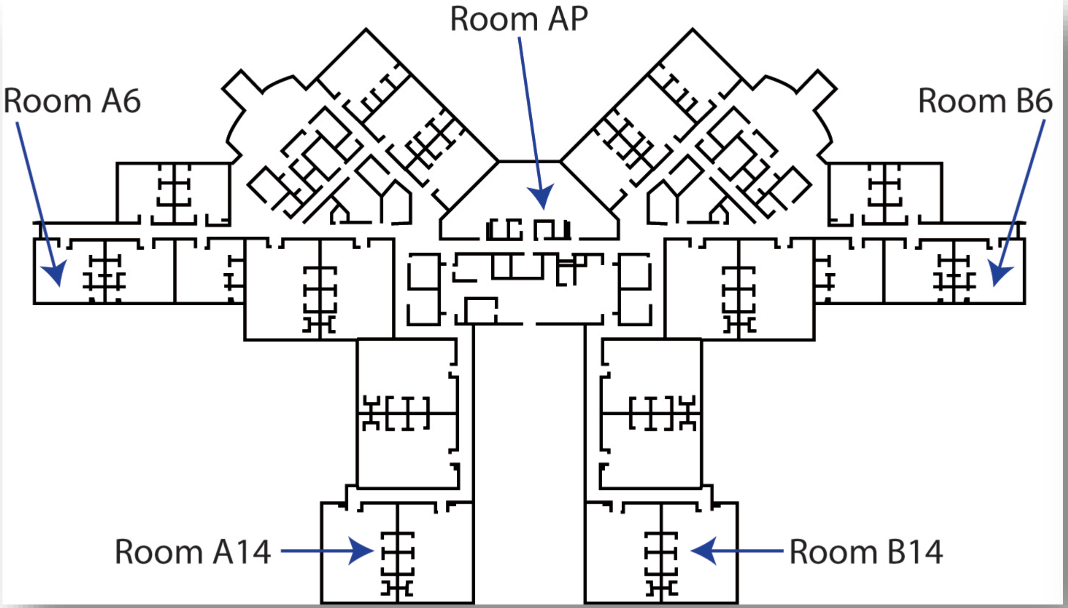
# Batch Testing- *Solubility Results*

## Effect of Orthophosphate and pH on Copper Solubility (23°C, 10 mg C/L)

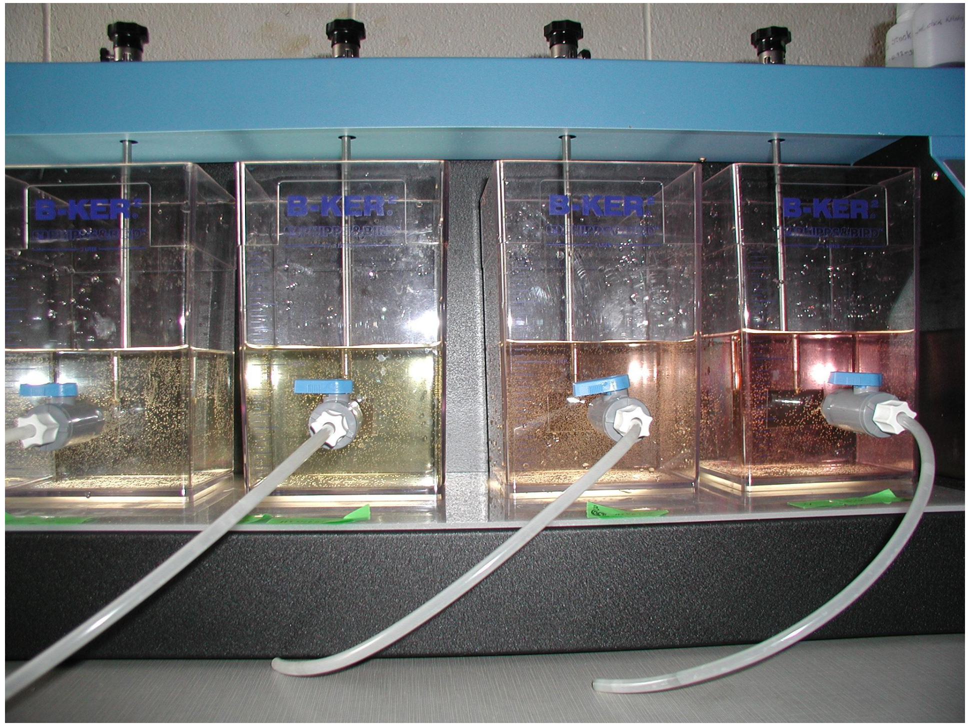



*Model predictions based on $Cu_3(PO_4)_2$?$2H_2O$ and $Cu(OH)_2$

# Full-scale Demonstration of Orthophosphate Addition to Control Copper in a Building



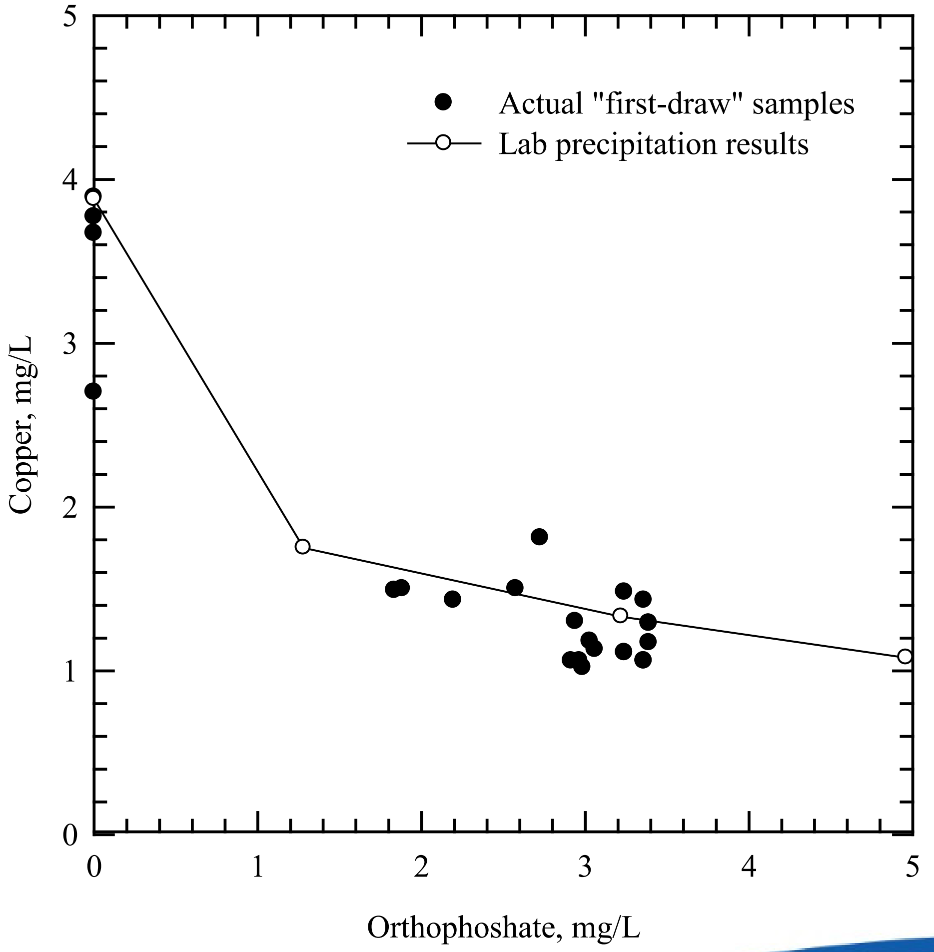

# Jar Testing as a Tool to Estimate Orthophosphate Dose to Reduce Copper

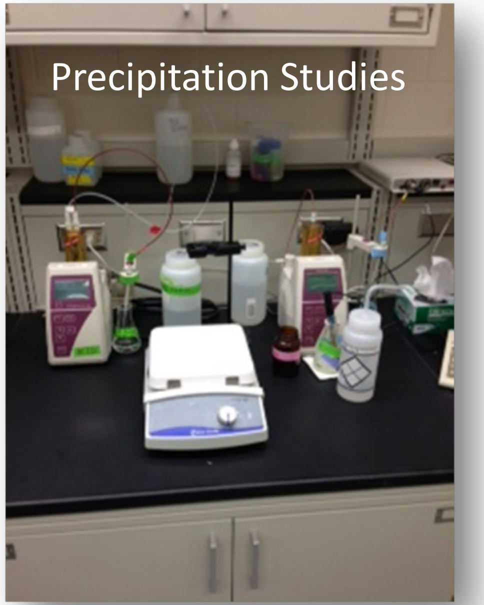



- Intent is to predict solubility of lead and copper in the field with DS water
- Evaluate lead and copper reduction strategies

# Value of Jar Testing to Predicting Copper Solubility in the Field

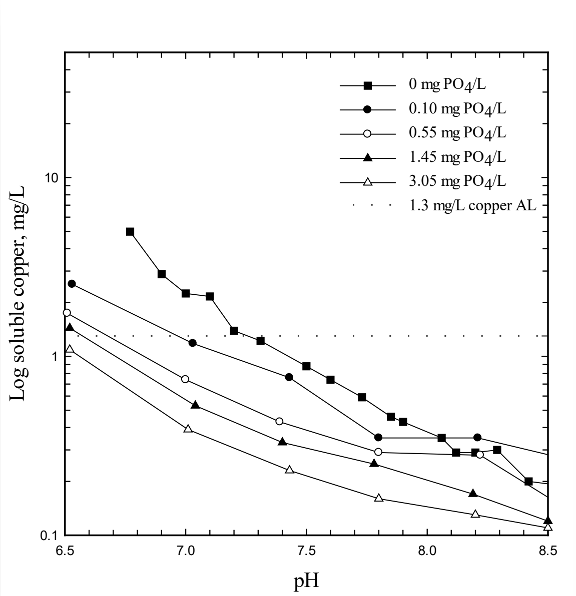
## Case Study (pH= 7.4, 73 mg C/L DIC)



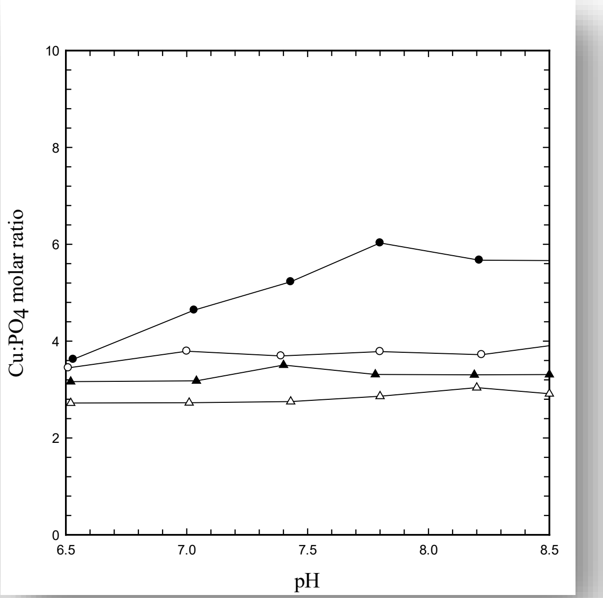



# Impact of pH and Orthophosphate on Cu(II) Solubility

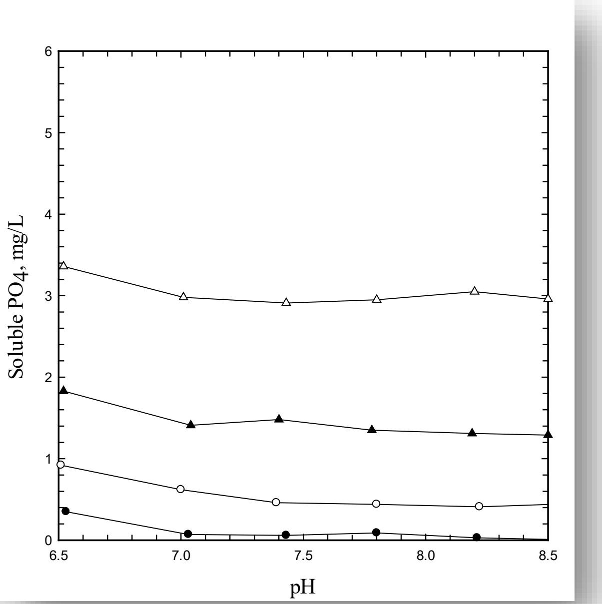
## DIC = 10 mg C/L




Soluble Copper




Cu:$PO_4$ in Solid



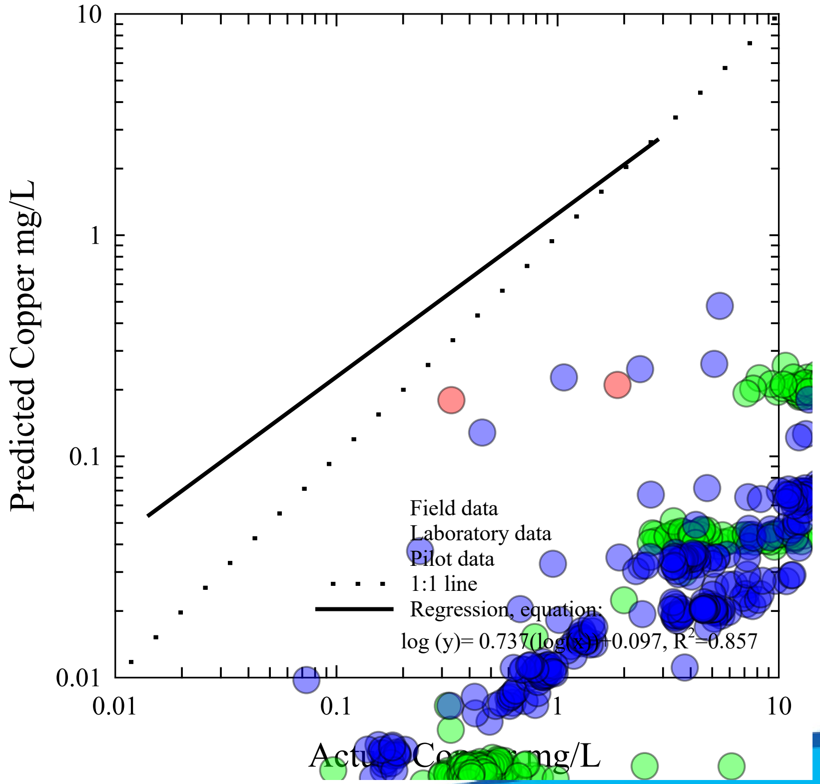

Soluble Phosphate

# Model and Experimental Fit

$$Cu = (56.68)\exp[(-0.77)(pH)]\exp[(-0.20)(PO_4)](DIC^{0.59})$$

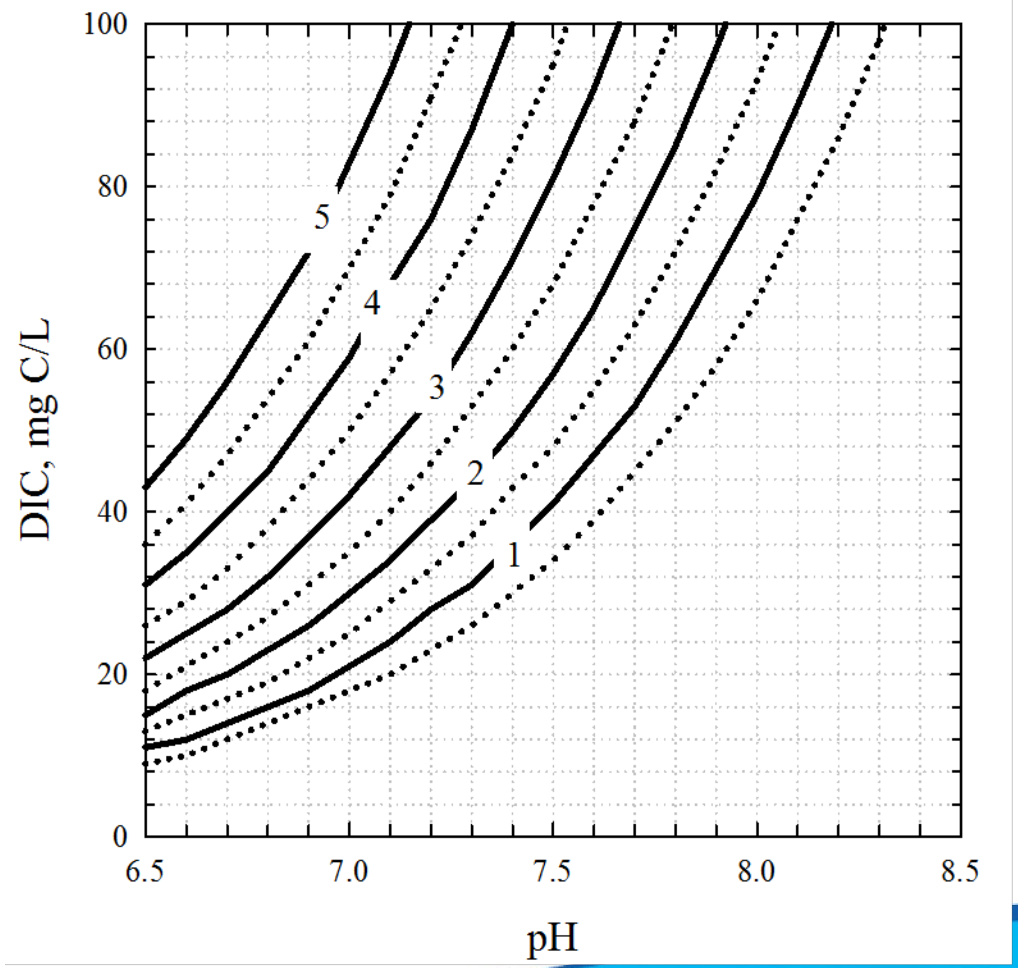
Actual copper values of field, laboratory, and pilot data versus the copper values predicted by the empirical model based on pH, dissolved inorganic carbon (DIC), and orthophosphate dose.

- Bench- and pilot-scale laboratory data and full scale field data collected from a multitude of studies reported over 20 years.
- 851 observations
- $R^2$= 0.857

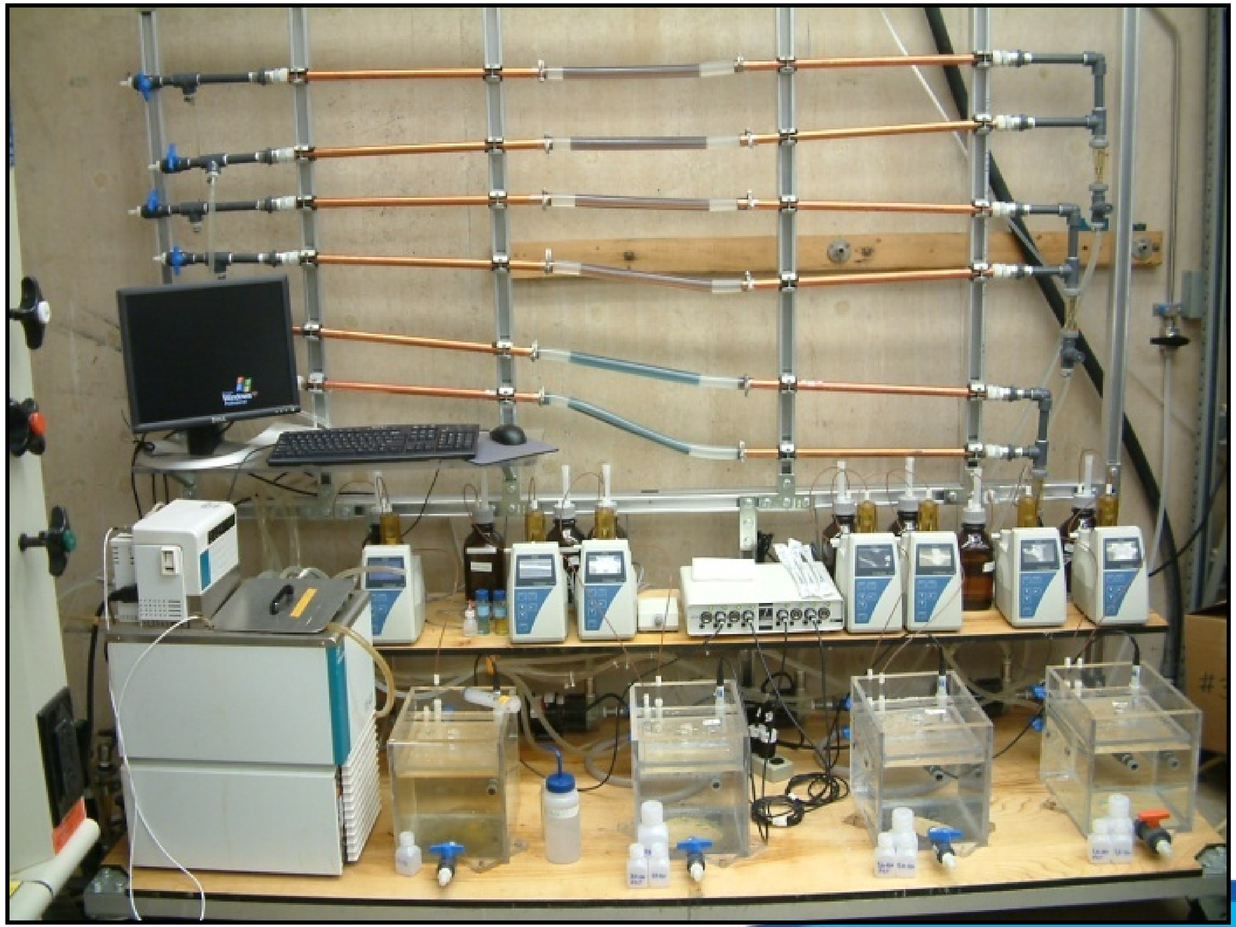



| | Range |
|---|---|
| pH | 6.42-9.23 |
| DIC | 4.1-73 |
| PO4 | 0.0-4.5 |
| Cu | 0.01-2.82 |

# Model Predicted Orthophosphate Dose Necessary to Reach Copper Action Level (1.3 mg/L)

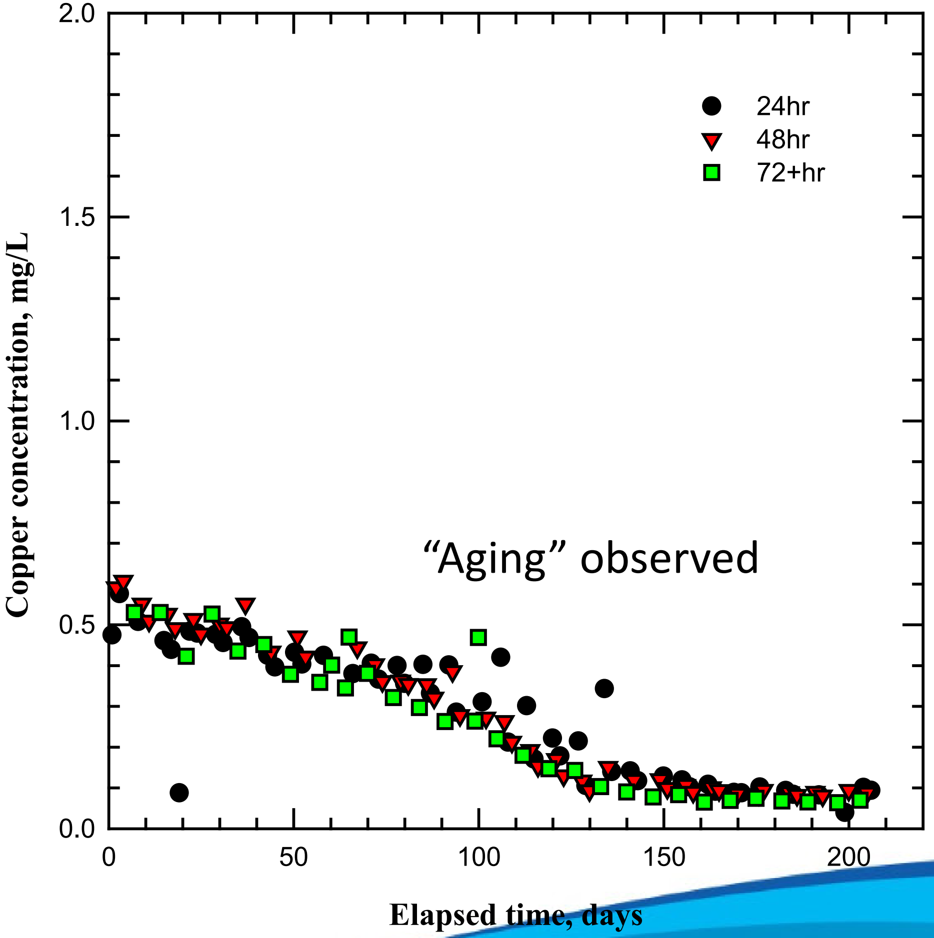


# Copper Recirculation Test Loop



# Copper Concentration over Time: Impact of Recirculation Time

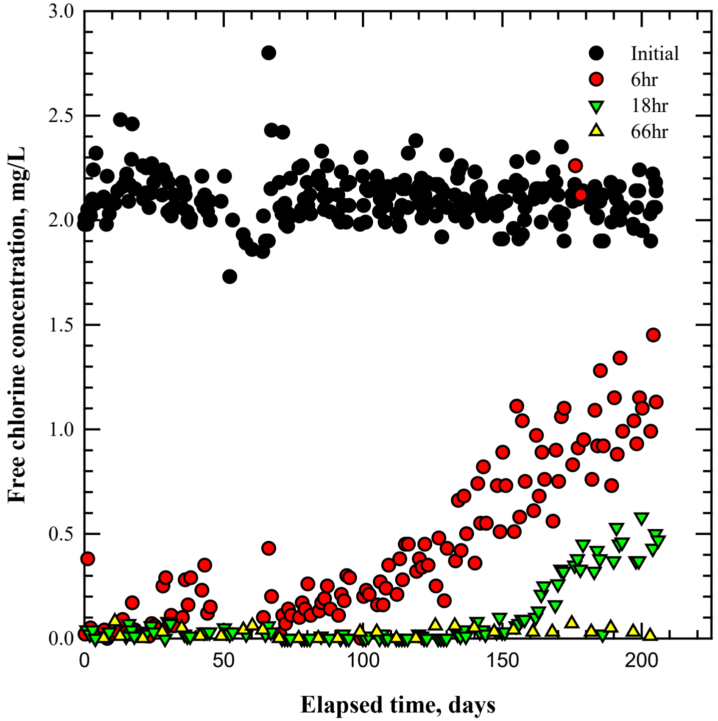
(pH 8.20, 10 mg C/L, 100 mg $Cl^-$/L, 100 mg $SO_4$/L, 2 mg $Cl_2$/L)



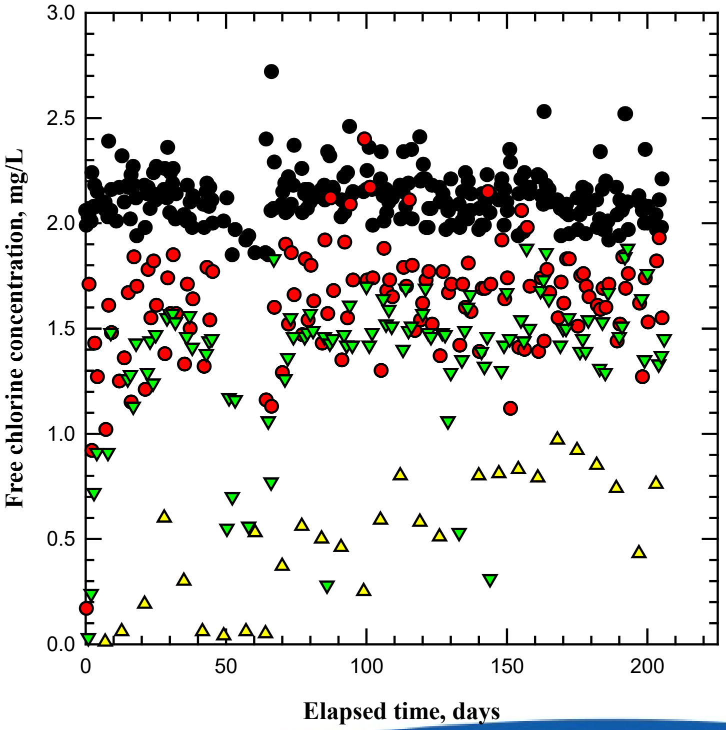
# Chlorine Demand Associated with Corroding Copper

**pH 7, 10 mg C/L, 100 mg $Cl^-$/L, 100 mg $SO_4^{2-}$/L, 2 mg $Cl_2$/L**

## Without $PO_4$

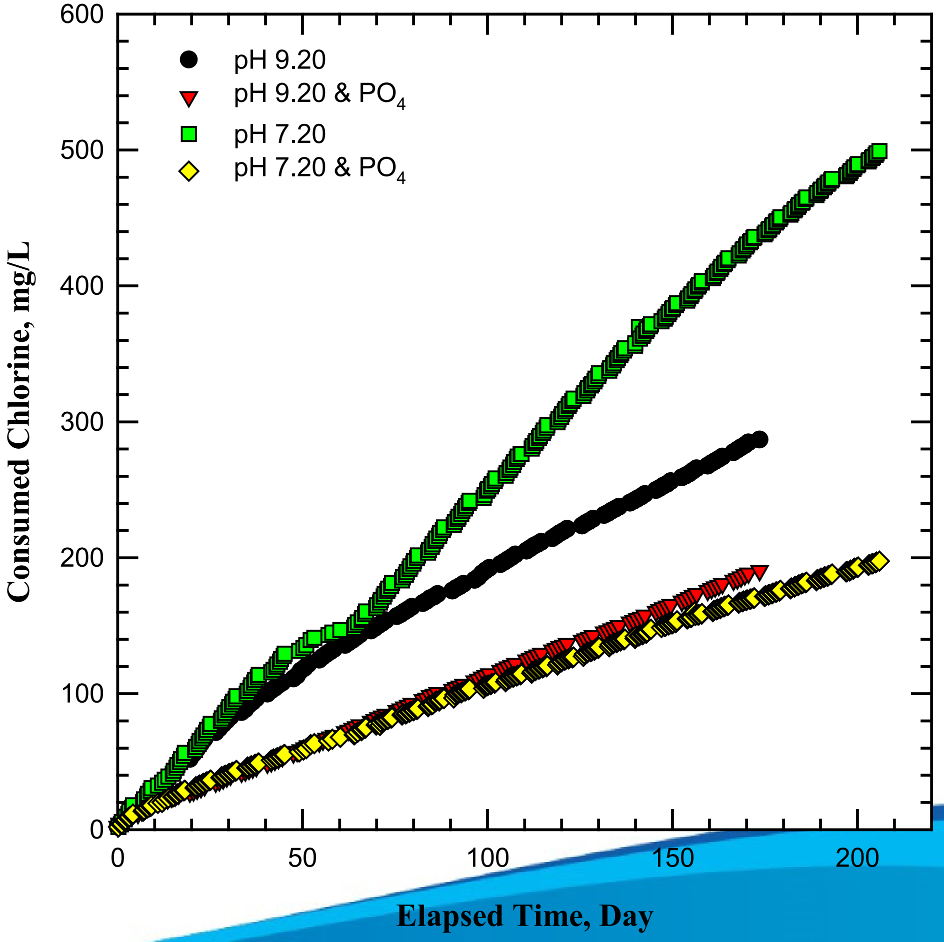



## With 3 mg $PO_4$/L

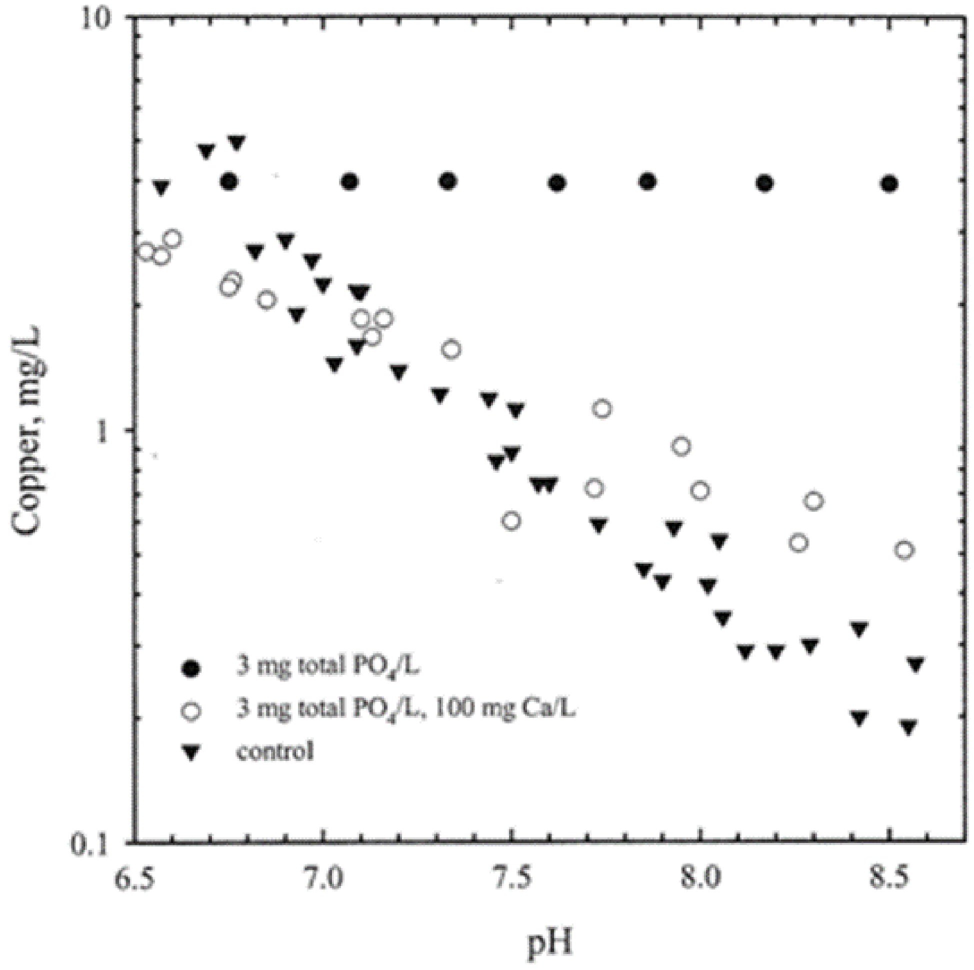


# Total Chlorine Consumption over Time: Impact of Orthophosphate

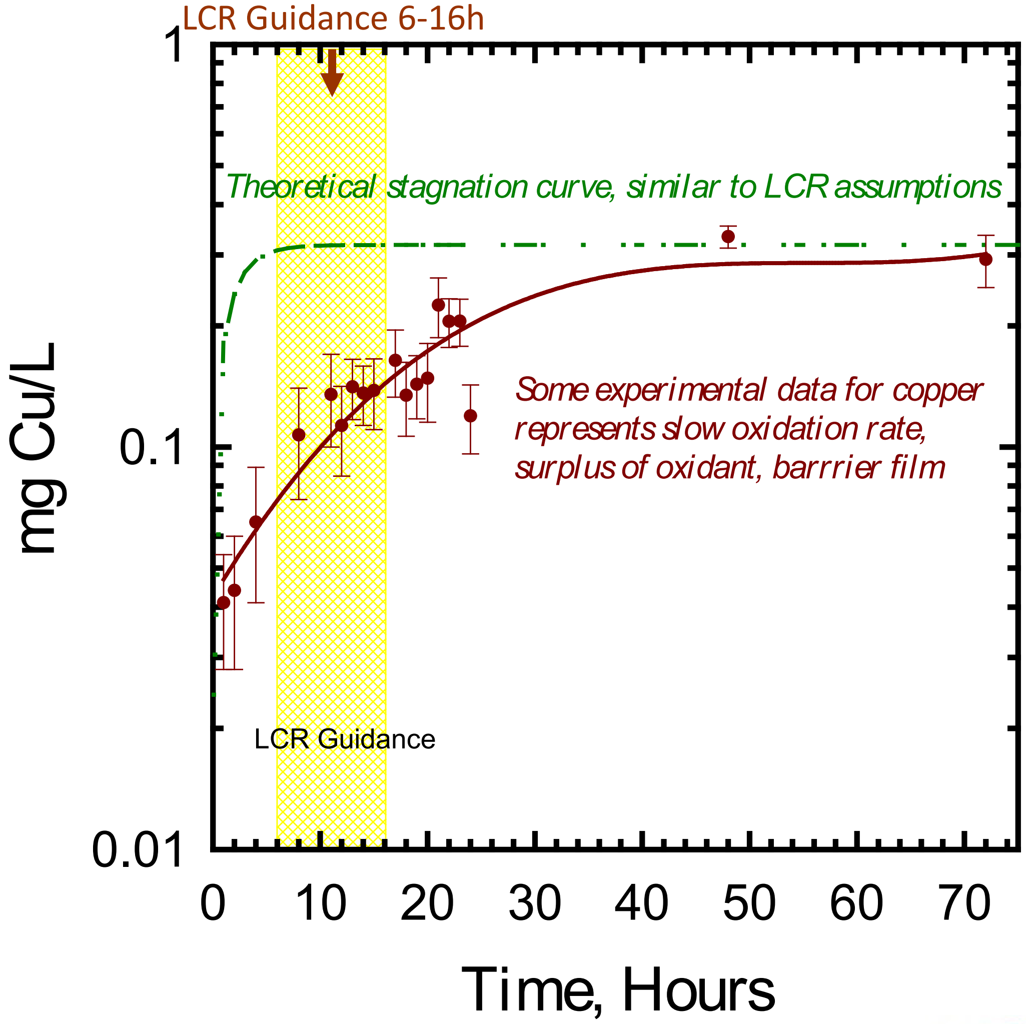
## (10 mg C/L, 100 mg $Cl^-$/L, 100 mg $SO_4$/L, 2 mg $Cl_2$/L)



# Polyphosphates ≠ Orthophosphate
## Effect of Hexametaphosphate on Copper (10 mg C/L)



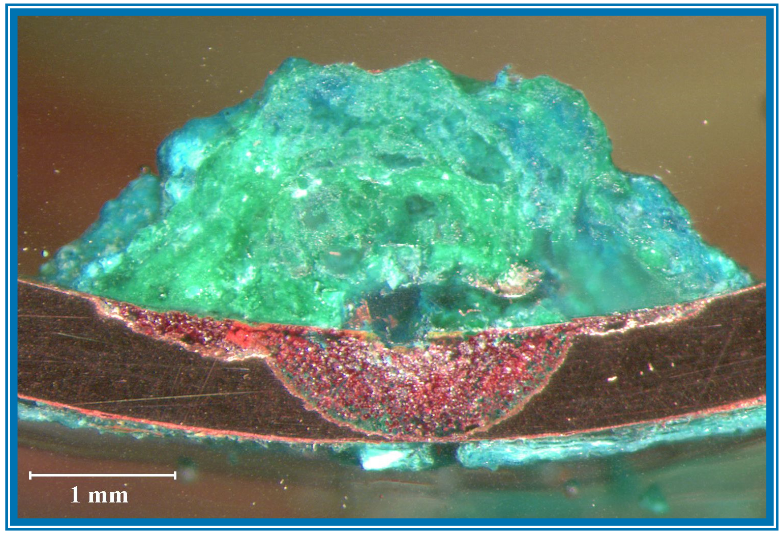
# Copper Stagnation Profiles with Time



# Copper Pitting Corrosion and Water Quality

Based on practical experience and research, low alkalinity high pH water has been associated with copper pitting corrosion:

- Low DIC (< 10-15 mg C/L)
- High pH (> 8.5-9)
- Chloride (>10 mg/L)
- Sulfate (?)




Other factors include age of plumbing, history of treatment, corrosion control, and others.