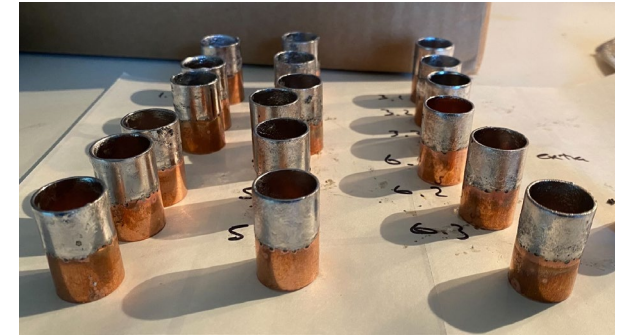
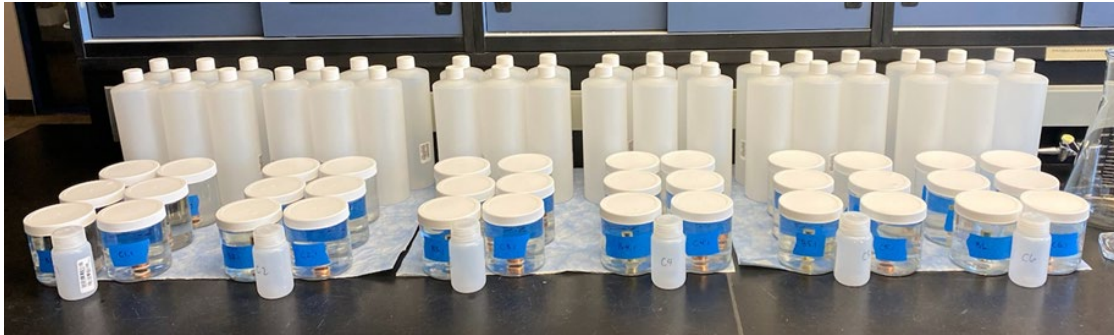


April 2022

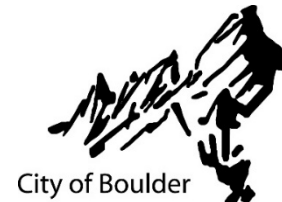
# Optimizing Corrosion Control Treatment for Low-Alkalinity Source Waters



PNWS-AWWA  
**Water 2022**  
Tacoma, WA • April 27-29



Damon K. Roth, PE, BCEE  
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Niall Stewart, PE

# Agenda

1. Introduction
2. Immersion Coupon Study Planning
3. Phase I Results
4. Phase II Results



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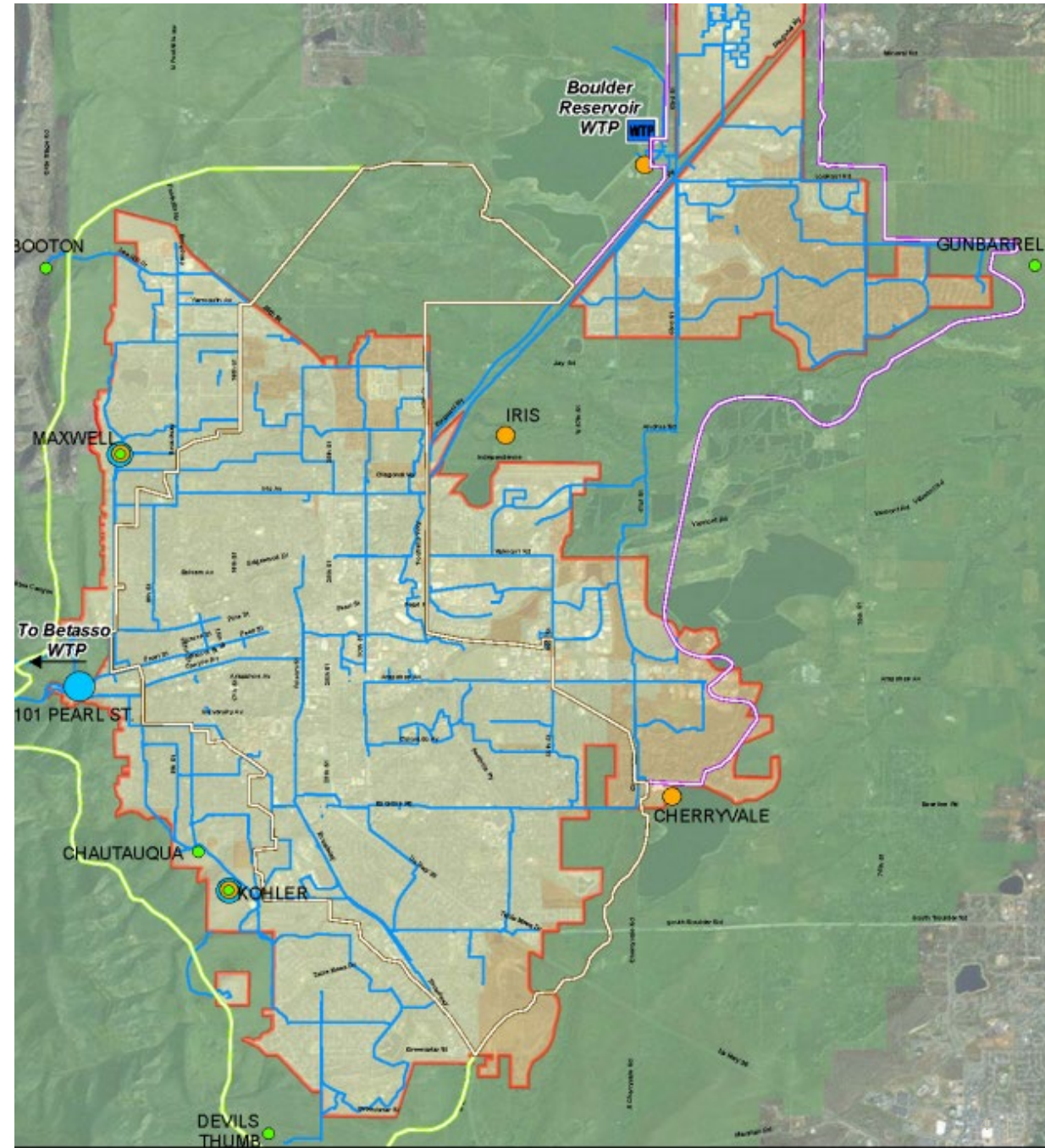
# Introduction

- Project Background
- Current CCT Performance
- Study Drivers

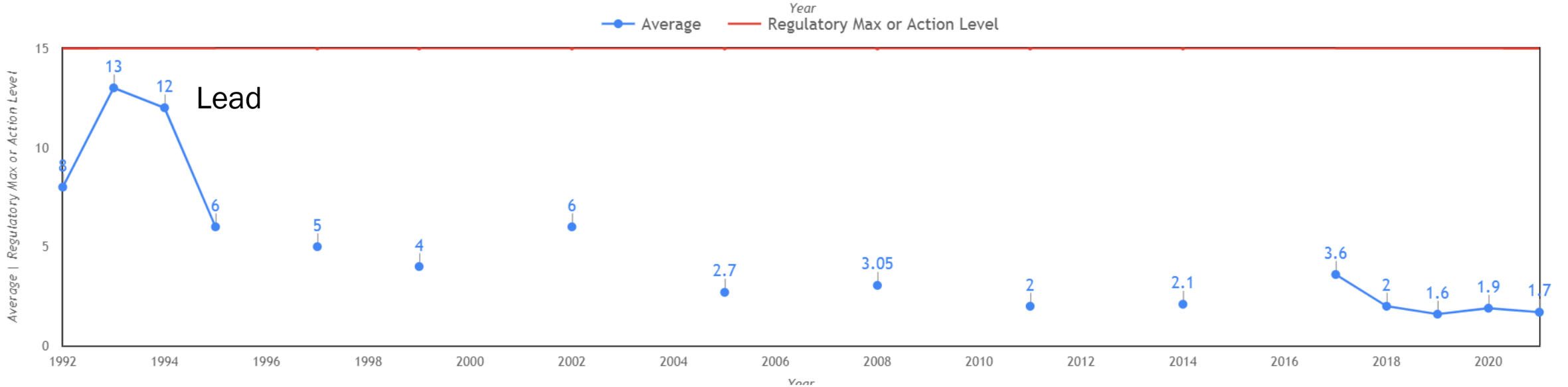
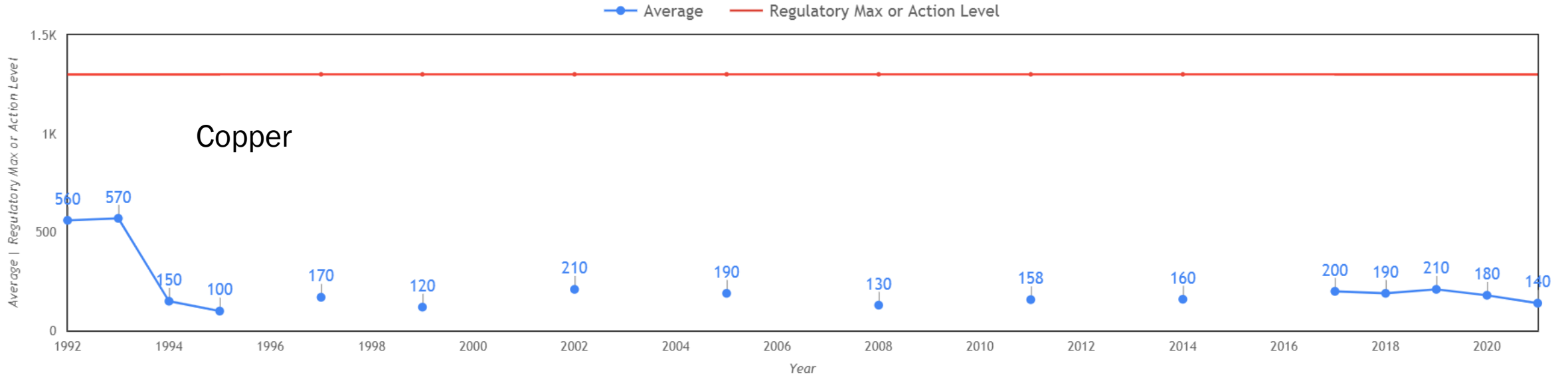


# Project Background

- Boulder operates two water treatment facilities:
  - Betasso WTP
  - Boulder Reservoir (63<sup>rd</sup> St.) WTP
- Corrosion control treatment was evaluated as part of planned upgrades at Betasso WTP

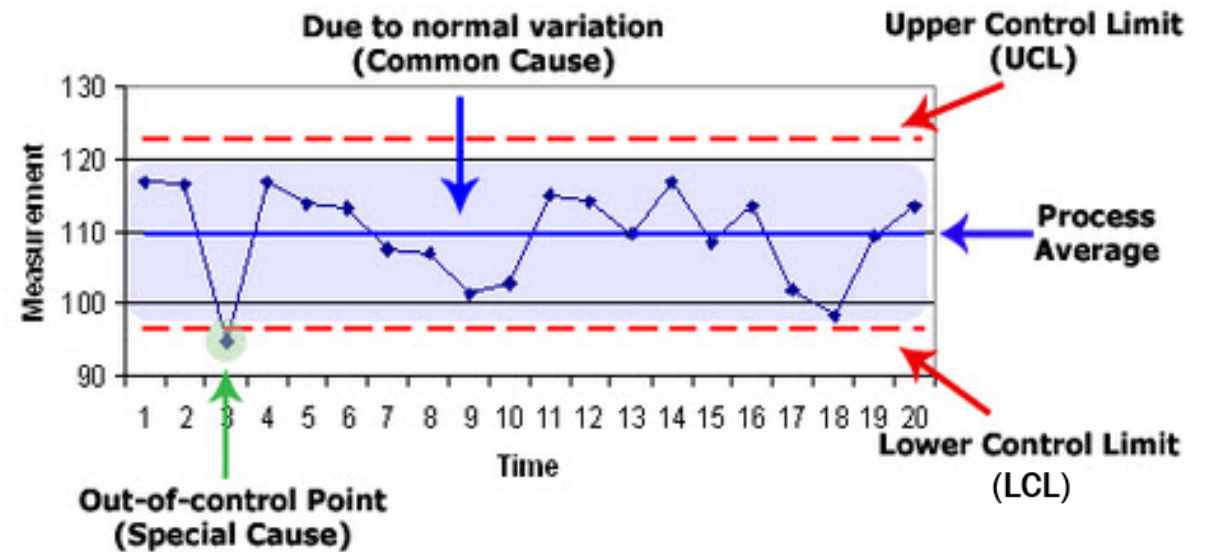


# LCR Compliance Sampling is Excellent



# Statistical Process Control Analysis

- Every process displays variation
  - *Controlled variation* is stable and consistent over time
  - *Uncontrolled variation* is characterized by a pattern of variation that changes over time
- Shewhart Control Charts allow for differentiation between controlled and uncontrolled variation
  - Analysis is based on subgroups (“bins”) of data
  - Control limits are set three sigma units on either side of central line

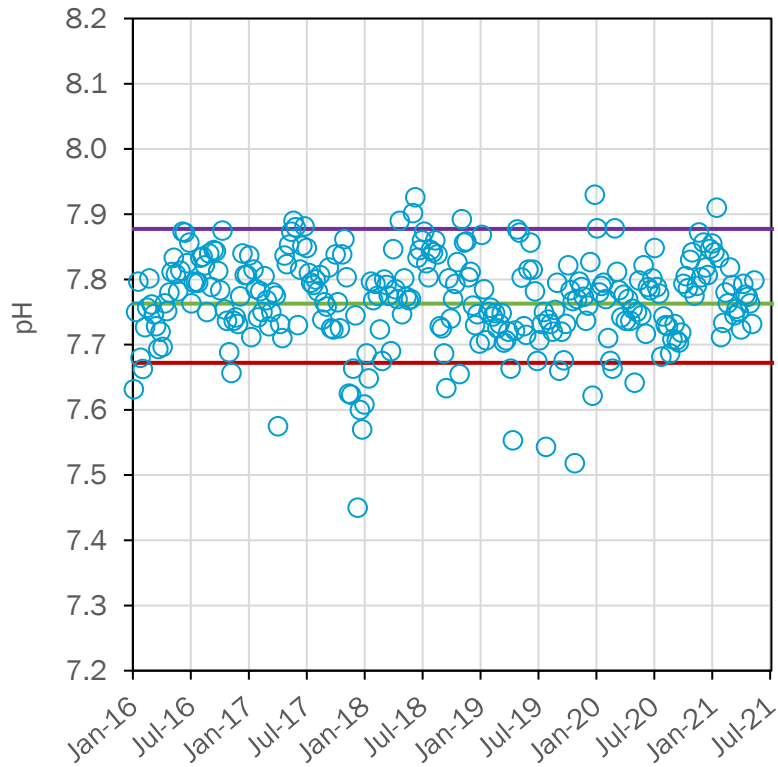


<https://www.clearpointstrategy.com/control-charts-everything-you-need-to-know/>

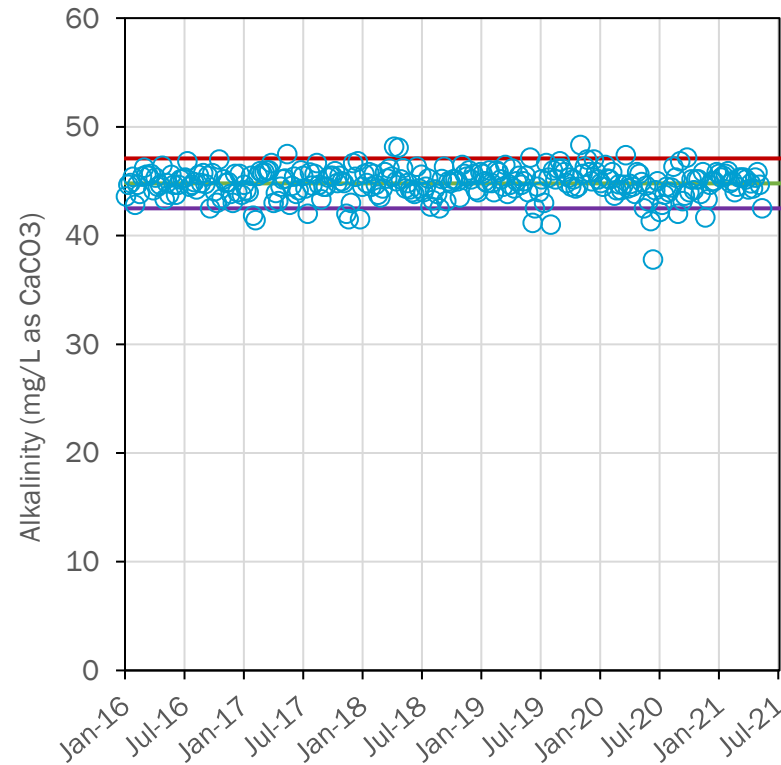
# Betasso WTP Point-of-Entry (POE)

Parameter	pH	Alk	Cl2
UCLx	7.67	47.10	1.20
Mean of Weekly Median	7.76	44.80	1.13
LCLx	7.88	42.51	1.07
Median of Weekly Median	7.78	44.9	1.1

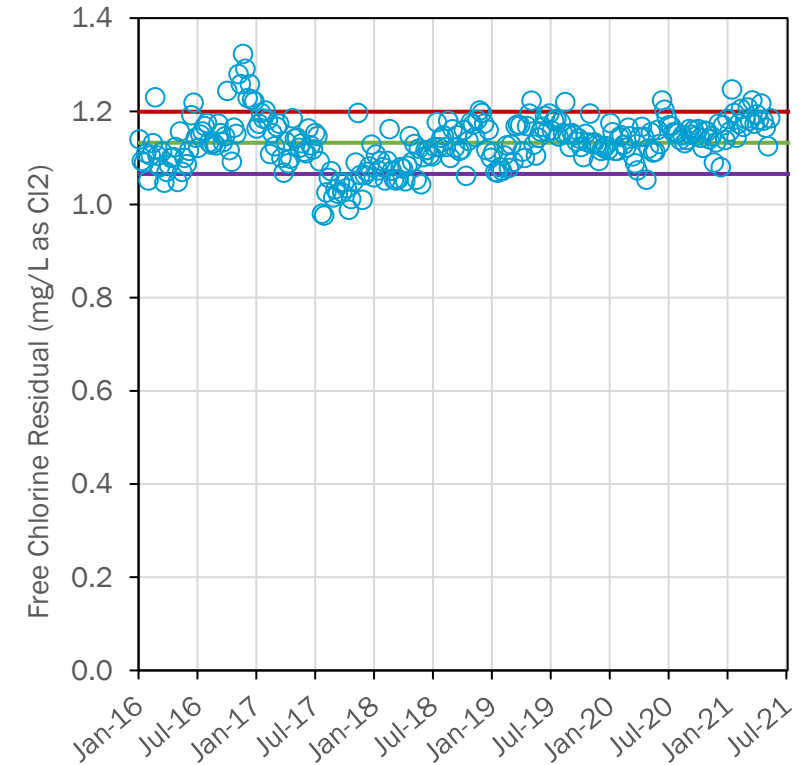
pH



Alkalinity



Free Chlorine Residual



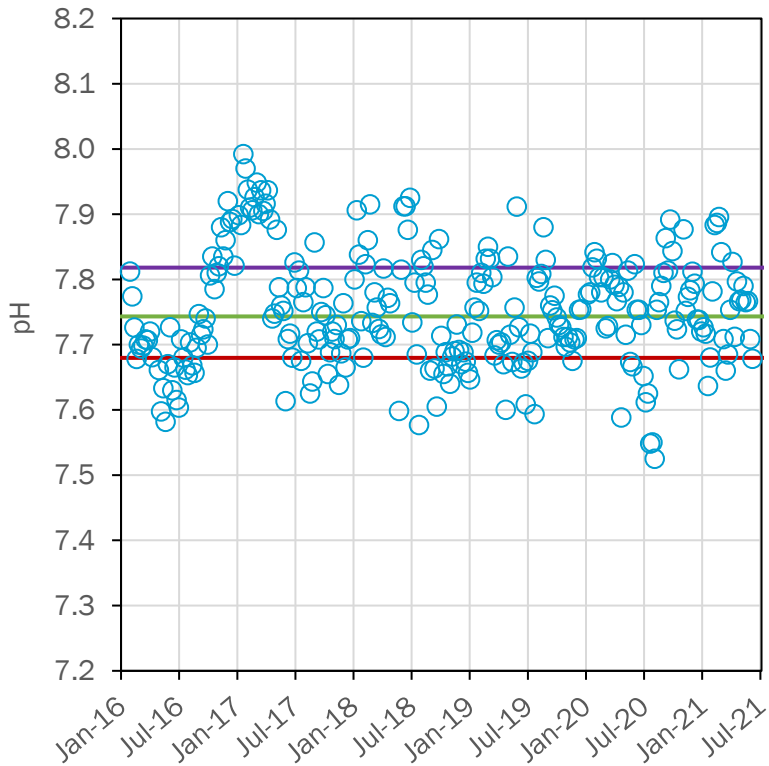
○ Weekly Median    — UCLx    — LCLx    — Mean of Weekly Median



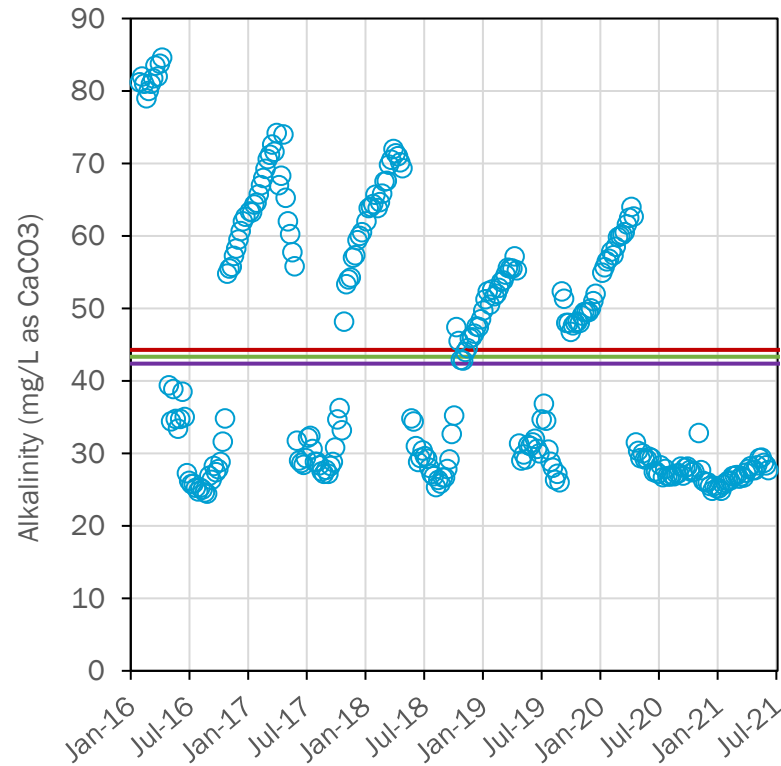
# 63<sup>rd</sup> WTP Point-of-Entry (POE) Full Data Set

Parameter	pH	Alk	Cl2
UCLx	7.68	44.29	1.17
Mean of Weekly Median	7.74	43.33	1.09
LCLx	7.82	42.38	1.02
Median of Weekly Median	7.74	34.8	1.1

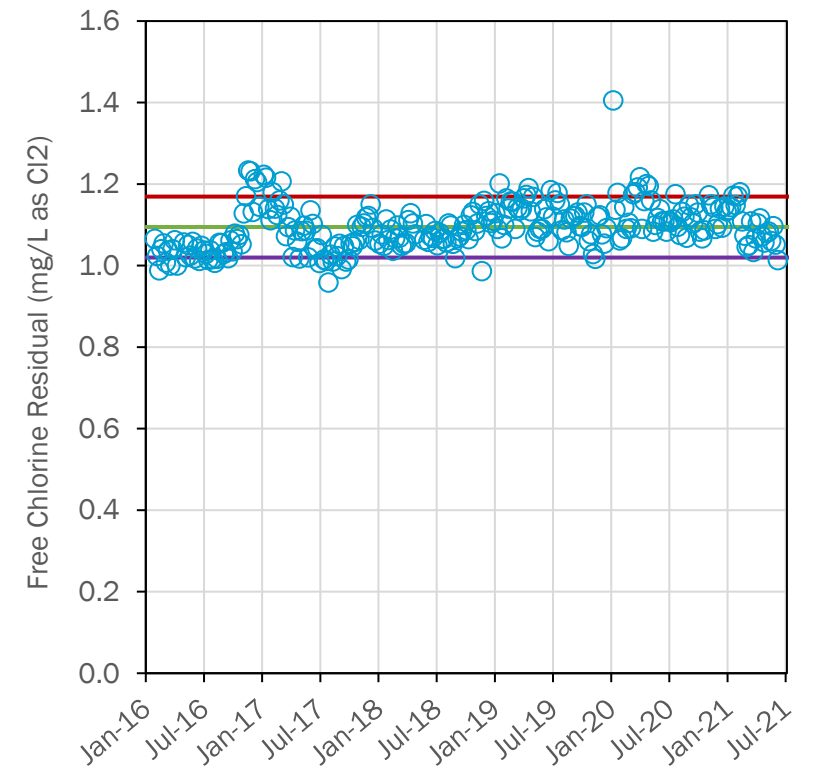
pH



Alkalinity



Free Chlorine Residual



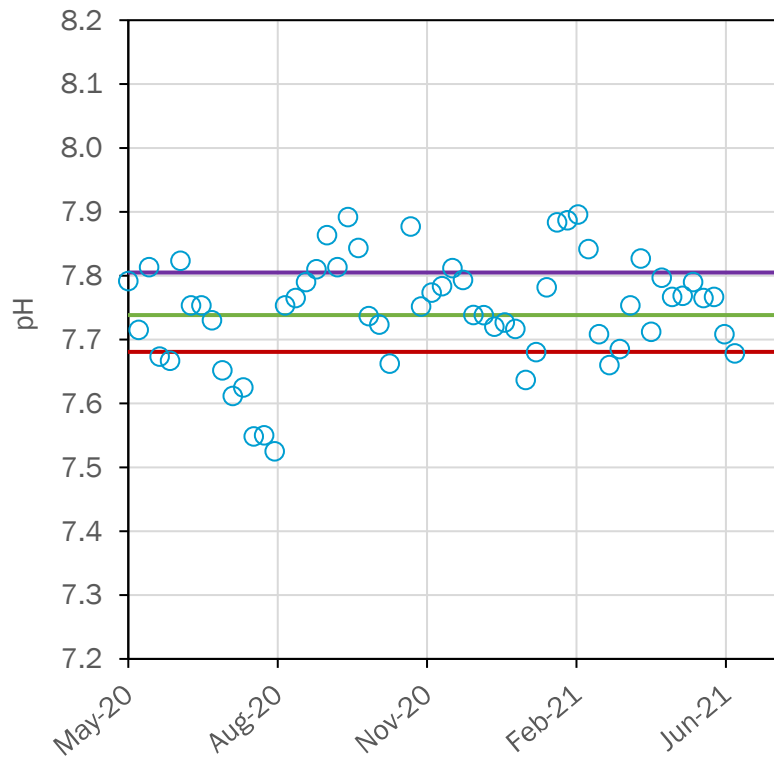
○ Weekly Median    — UCLx    — LCLx    — Mean of Weekly Median



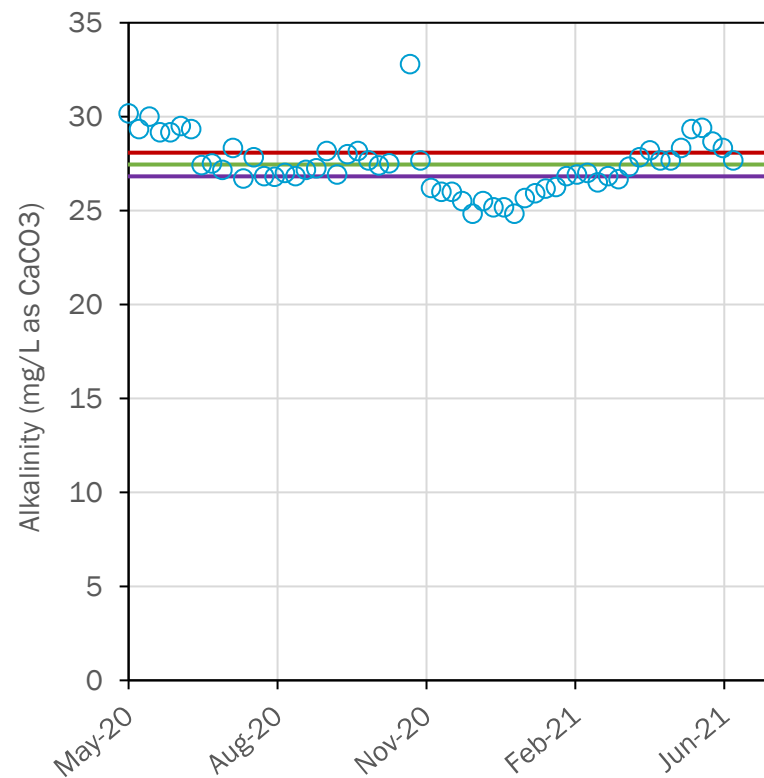
# 63<sup>rd</sup> WTP Point-of-Entry (POE) Post April 2020

Parameter	pH	Alk	Cl2
UCLx	7.68	28.08	1.19
Mean of Weekly Median	7.74	27.45	1.11
LCLx	7.80	26.82	1.03
Median of Weekly Median	7.75	27.4	1.1

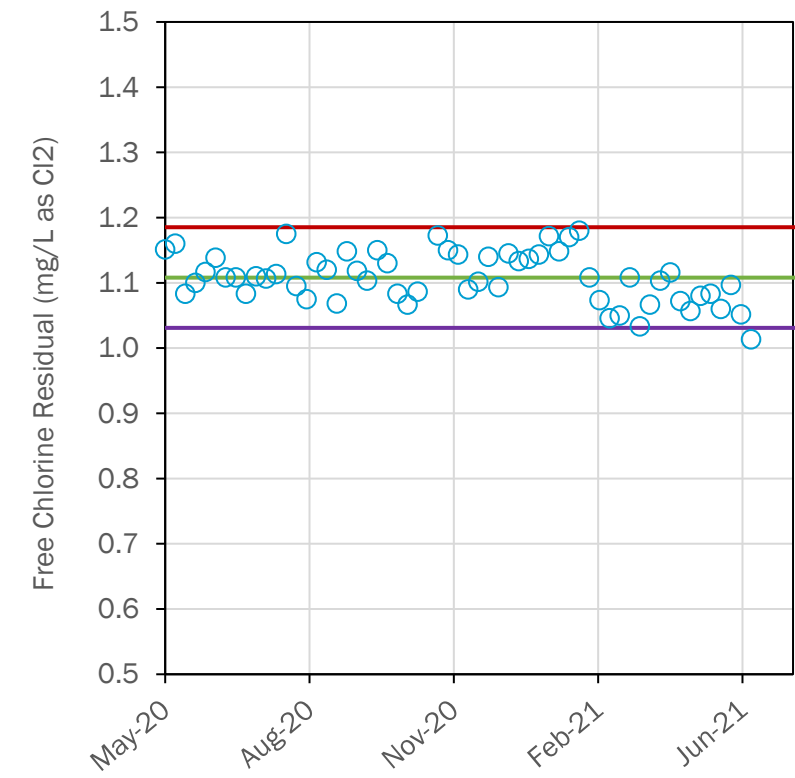
pH



Alkalinity



Free Chlorine Residual



○ Weekly Median    — UCLx    — LCLx    — Mean of Weekly Median

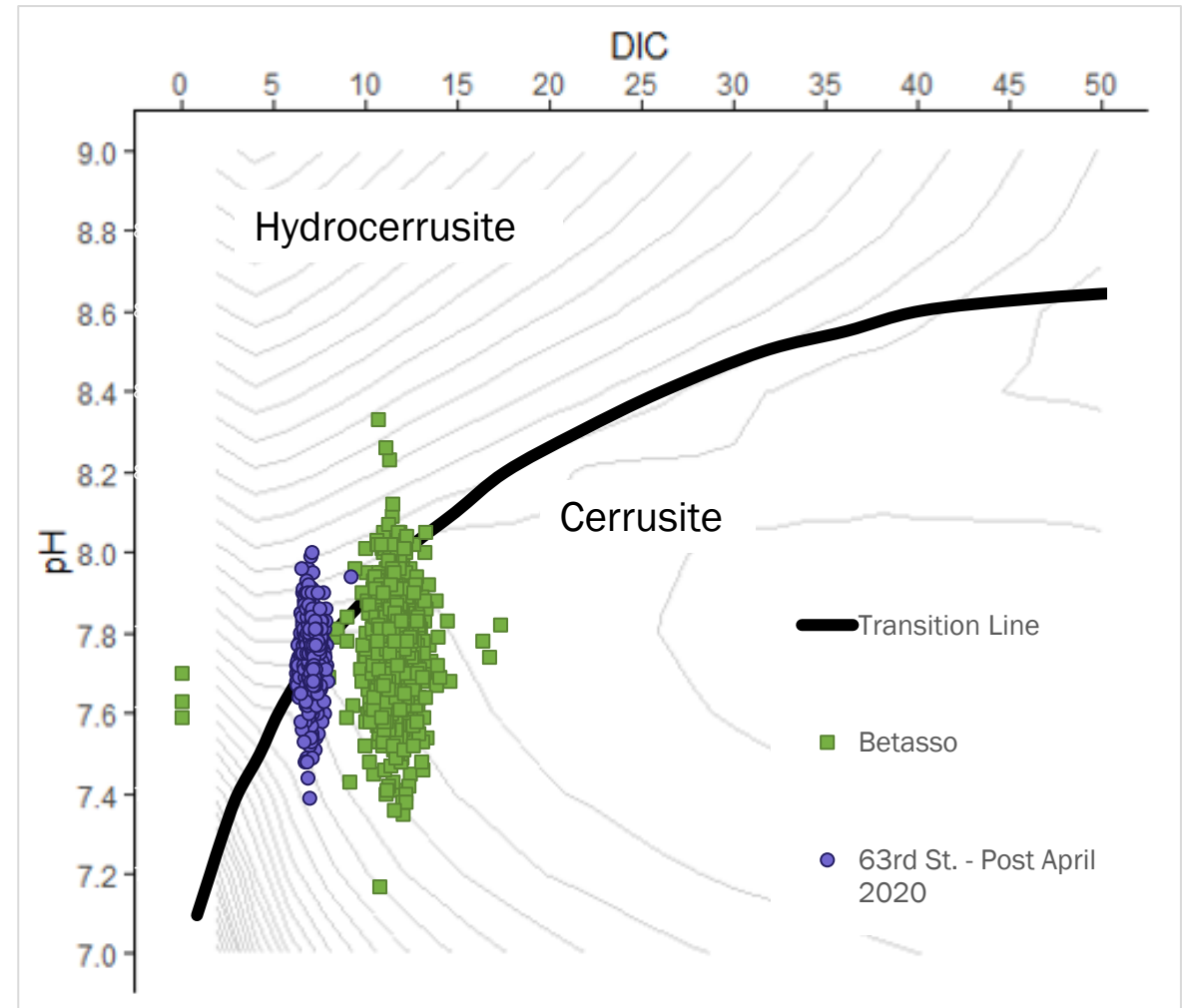
# Current CCT Favors Different Lead Scales

- **Hydrocerrusite**

- $\text{Pb(II)}_3(\text{CO}_3)_2(\text{OH})_2$  (s) anhydrous lead carbonate
- More stable
- Dissolves at higher DIC

- **Cerrusite**

- $\text{Pb(II)CO}_3$  (s) lead carbonate
- Less stable
- More prone to sloughing, formation of particulate lead
- Dissolves easily when WQ not favorable to production



# Study Drivers

- Planned improvements at Betasso WTP
  - Improvements to disinfection capacity
  - Replacement of aging chemical feed equipment
    - Lime
    - CO<sub>2</sub>
- Implementation of LCRR may change tap sampling locations
  - Historical LCR compliance data may not predict future LCR compliance sampling results
- Determine the best lead and copper control strategy for the City

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# Corrosion Study Review

- Overview
- Test Conditions
- Jars and Coupons



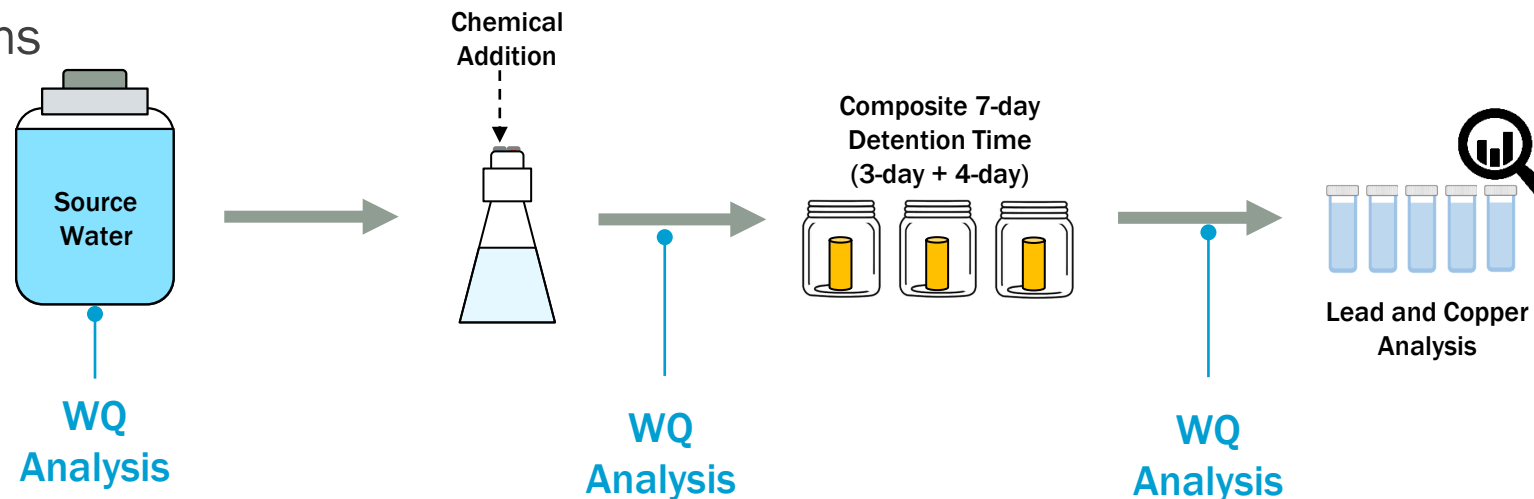
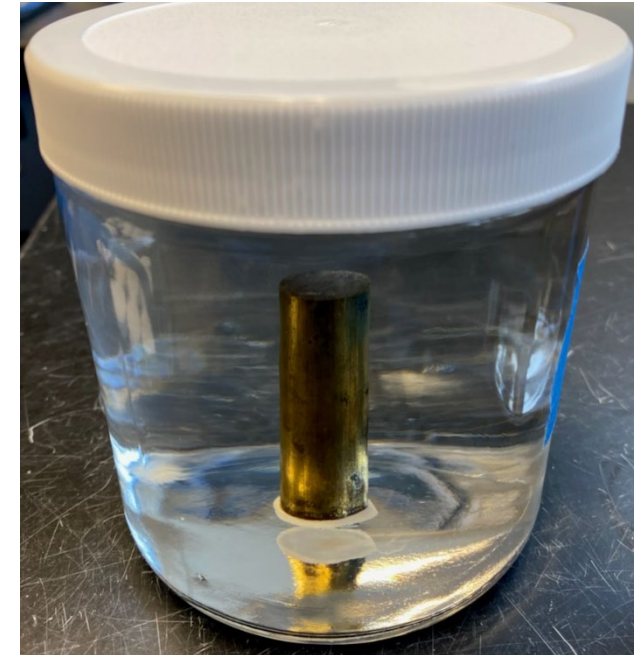
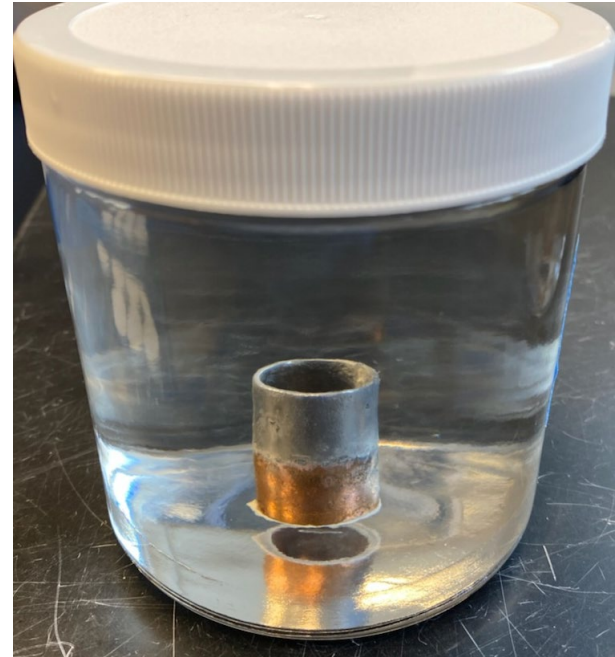
# Corrosion Study Review - Overview

## Phase Testing Approach

- Phase I – Six (6) test conditions
  - Weeks 1-12
- Phase II - Six (6) test conditions
  - Weeks 13-20

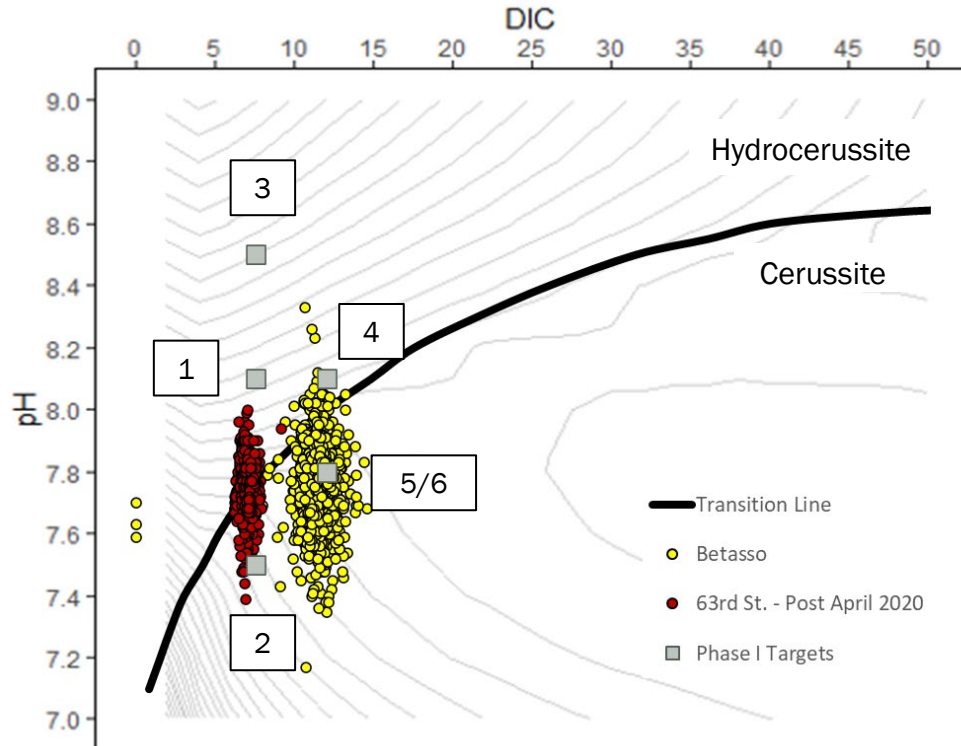
## Immersion Coupon Testing

- Copper with lead solder (CLS)
- Brass coupons



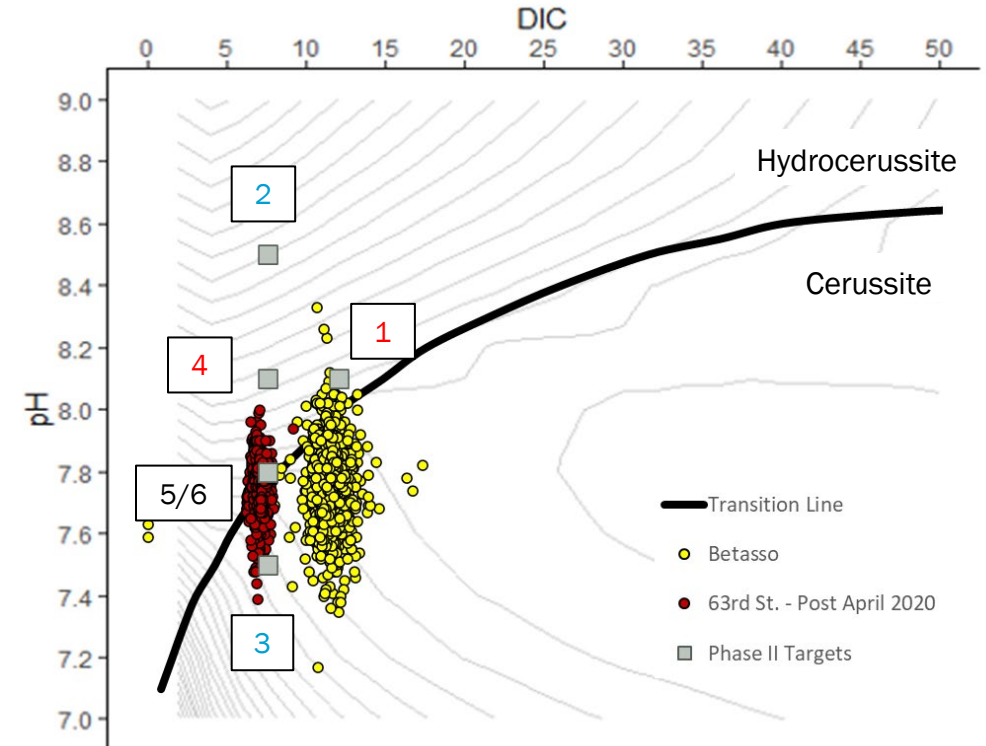
# Corrosion Study Review – Test Conditions

## Phase I



Phase I Test Conditions					
Condition	Source	pH	DIC	Cl <sub>2</sub>	PO <sub>4</sub>
1	63 <sup>rd</sup>	8.1	7.5	1.1	--
2	63 <sup>rd</sup>	7.5	7.5	1.1	--
3	63 <sup>rd</sup>	8.5	7.5	1.1	--
4	Betasso	8.1	12	1.1	--
5	Betasso	7.8	Amb.	1.1	1
6	Betasso	7.8	Amb.	1.1	3

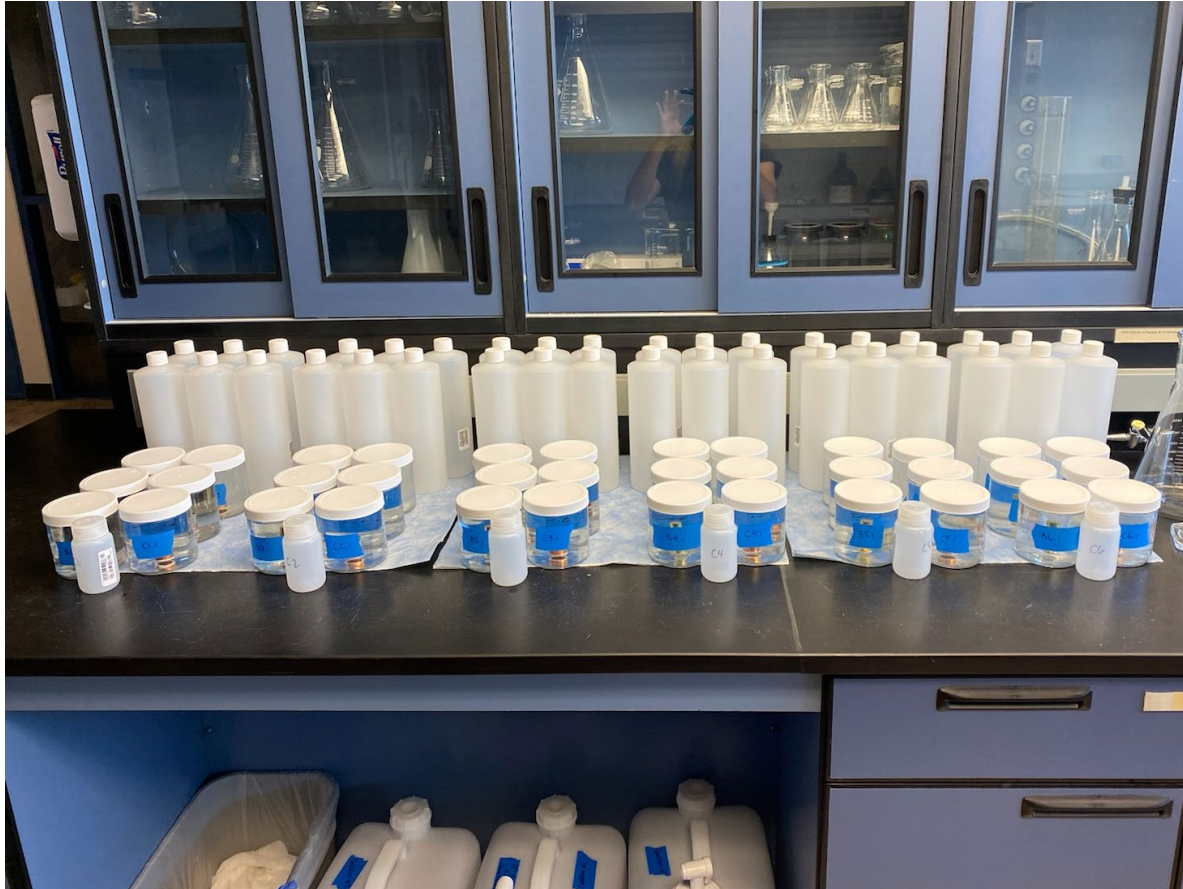
## Phase II



Phase II Test Conditions					
Condition	Source	pH	DIC	Cl <sub>2</sub>	PO <sub>4</sub>
1	Betasso	8.1	12	1.1	--
2	63 <sup>rd</sup>	7.5	7.5	1.1	--
3	63 <sup>rd</sup>	8.5	7.5	1.1	--
4	63 <sup>rd</sup>	8.1	7.5	1.1	--
5	63 <sup>rd</sup>	7.8	7.5	1.1	1
6	63 <sup>rd</sup>	7.8	7.5	1.1	3



# Corrosion Study Review – Jars and Coupons



## Testing Highlights

20 weeks

1,440 change-outs of immersion water

720 samples collected

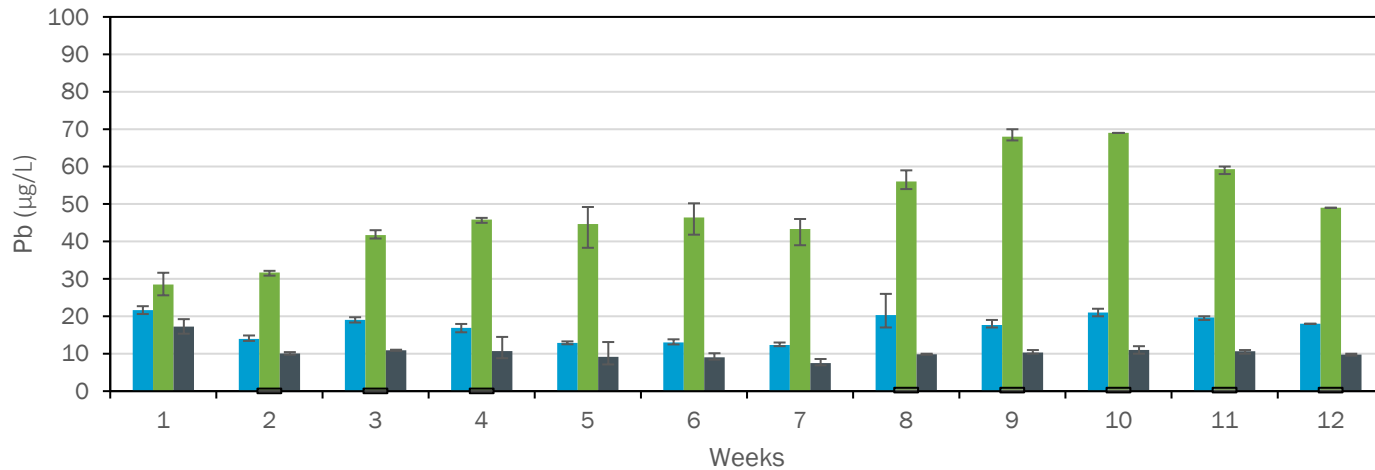
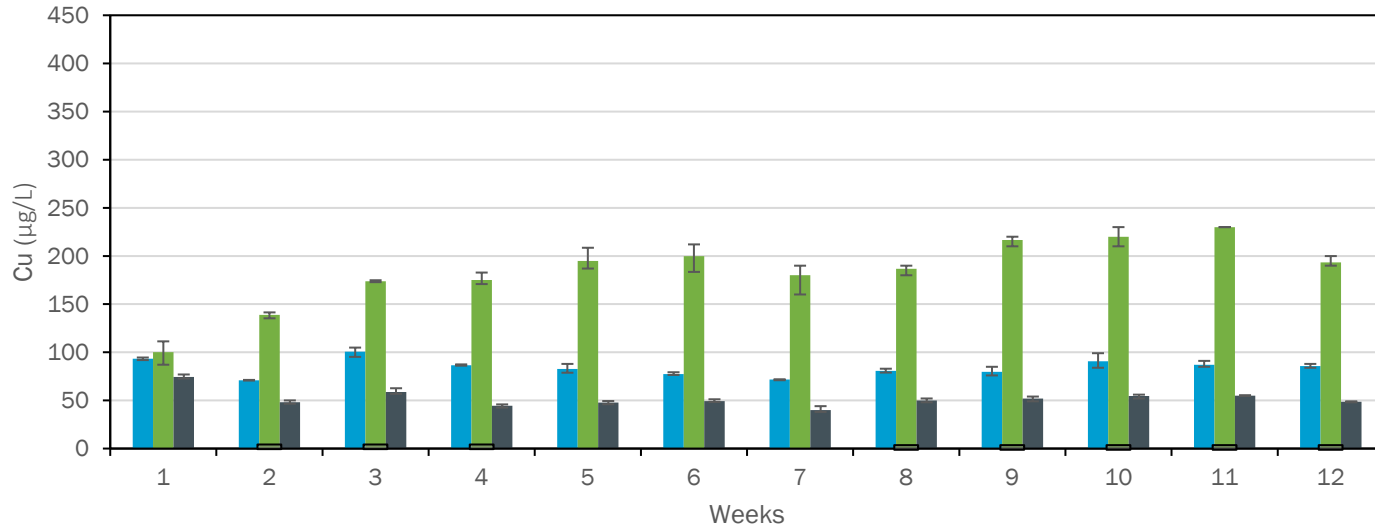
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# Phase I Results

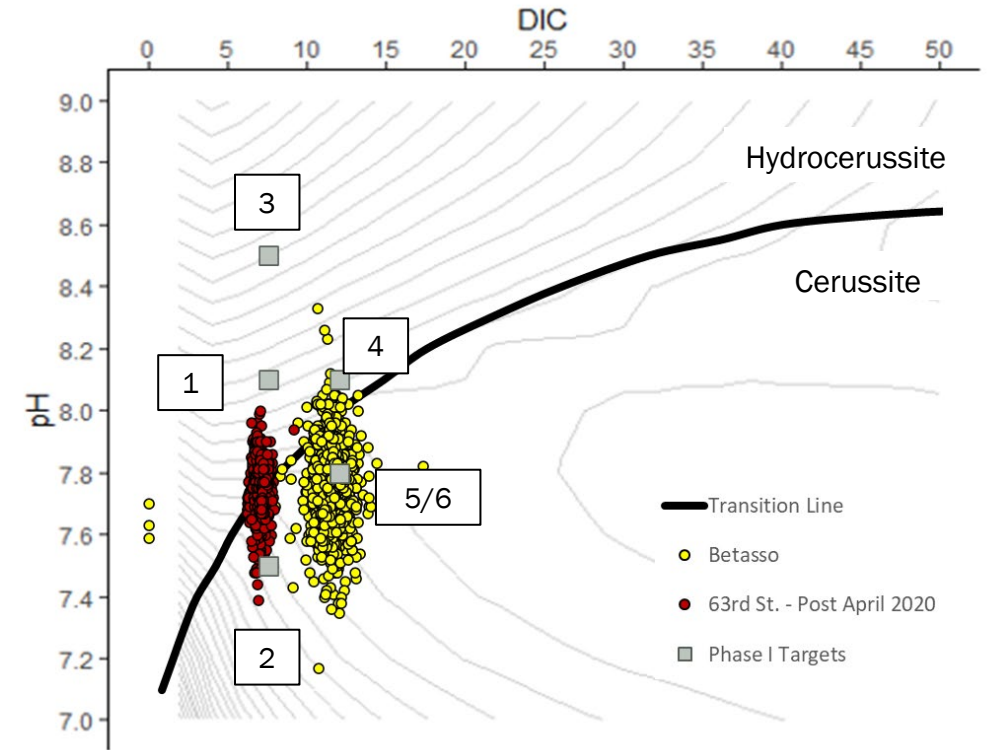
- Brass Coupons
- CLS Coupons
- Key Findings



# Phase I Results – Brass Coupons



■ Condition #1   
 ■ Condition #2   
 ■ Condition #3   
 ■ 63rd Source Water

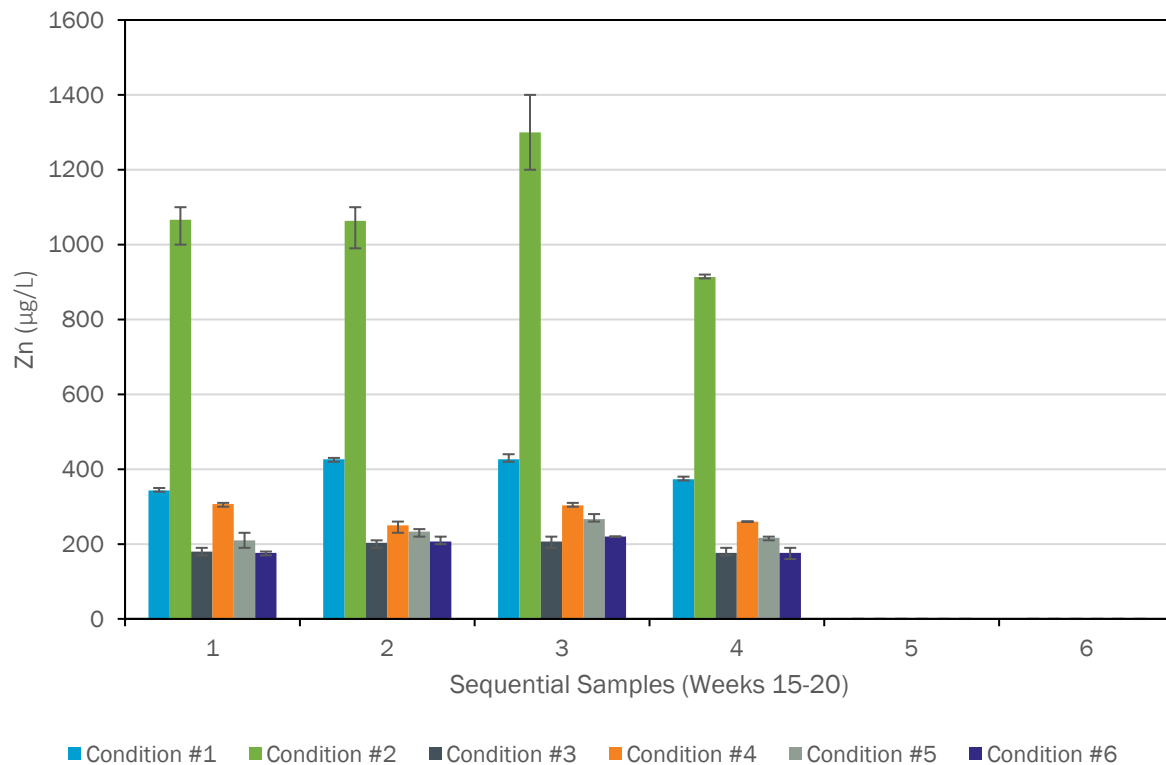


Source Water Concentrations

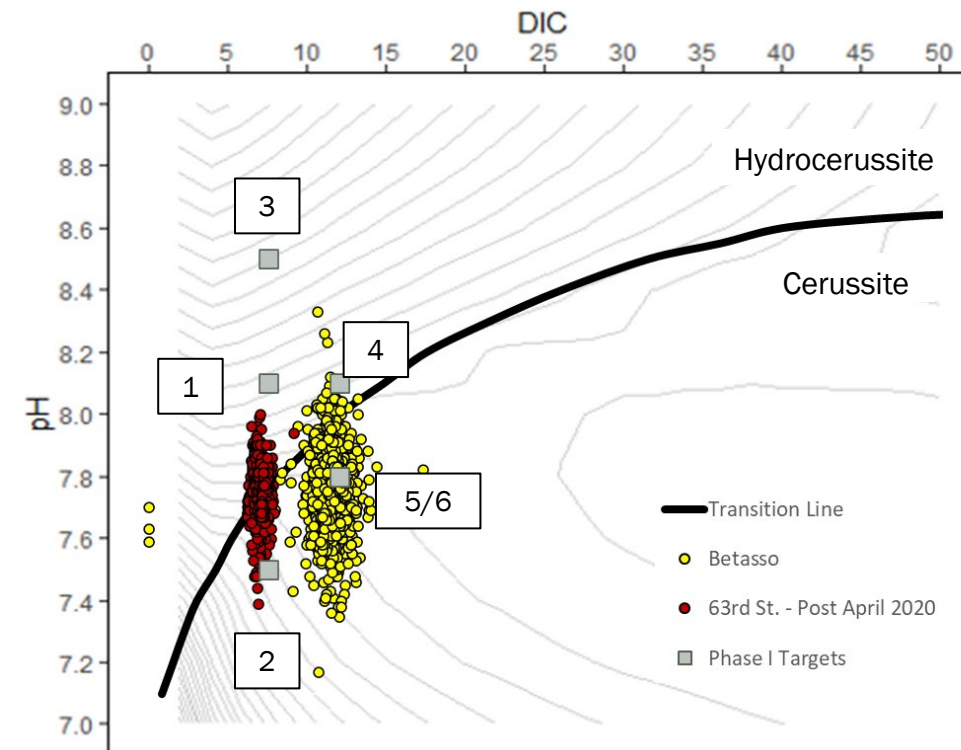
Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.67	0.06	96.0	6.16
8-9	< 2.0	< 0.5	82.0	5.90
10-14	< 2.0	< 0.5	--	--

Error bars represent min and max triplicate results

# Phase I Results - Zn results from Brass Coupons



Zn Data from phase II testing. Conditions reflect (pH, DIC) values of phase I.

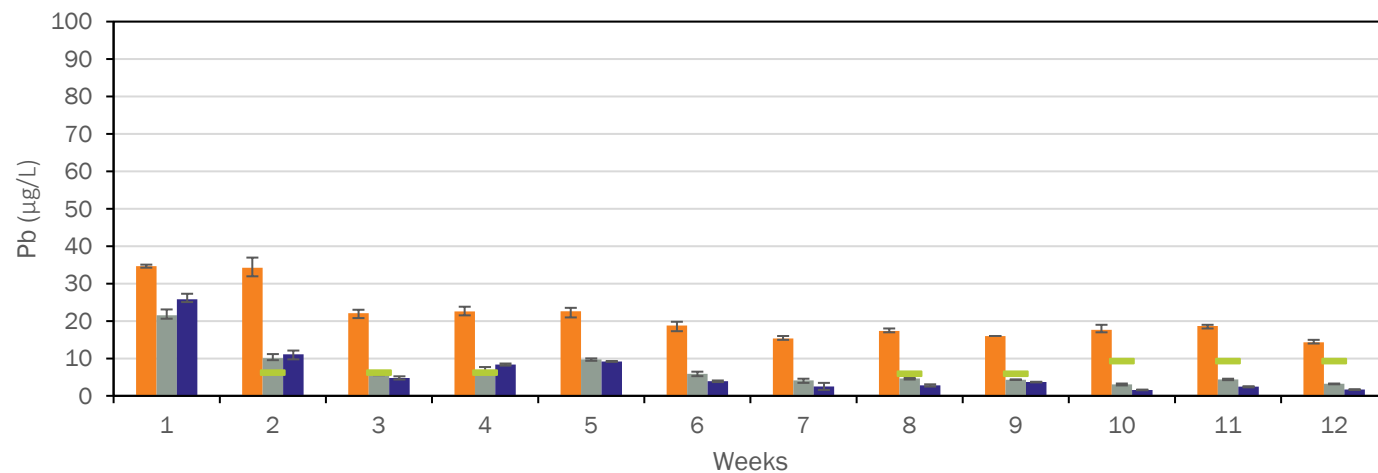
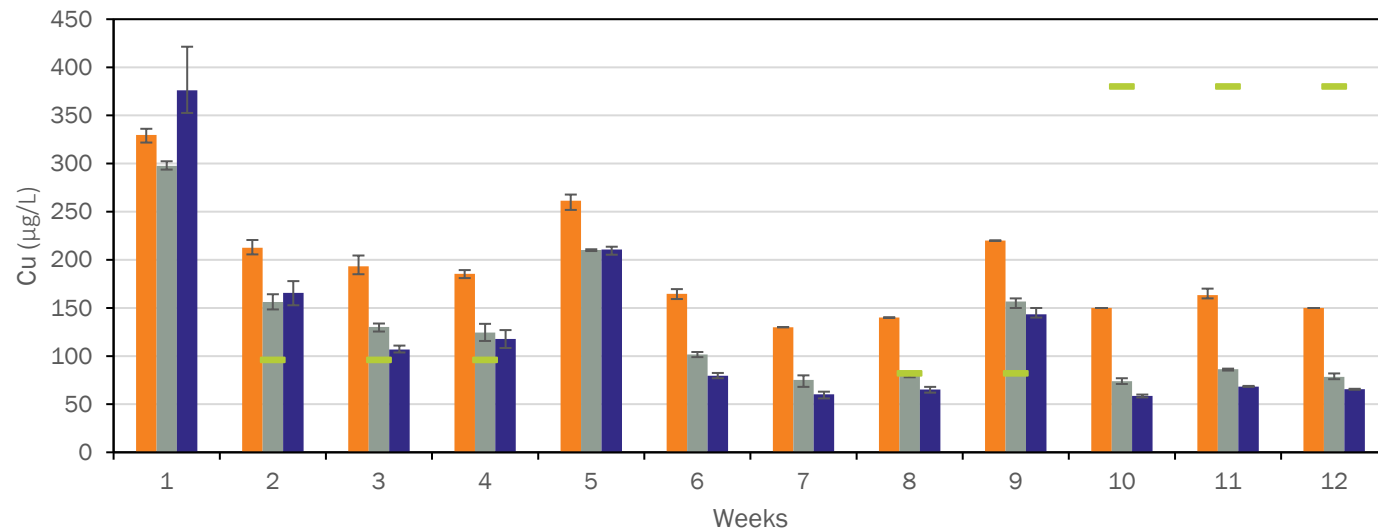


Source Water Concentrations

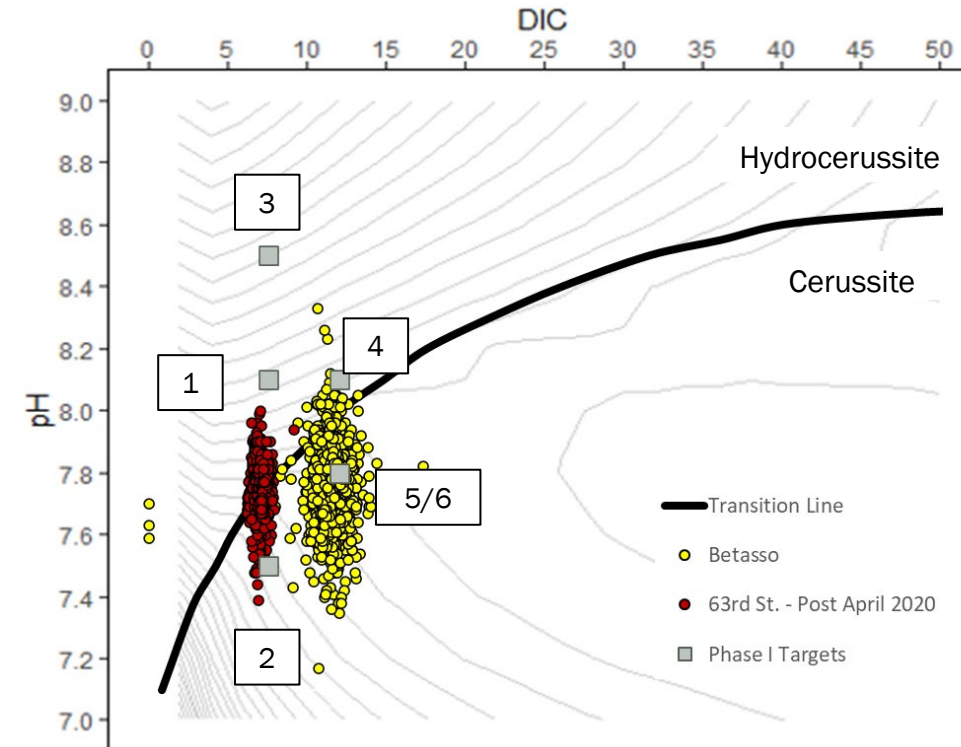
Weeks	63 <sup>rd</sup> Zn (ug/L)	Betasso Zn (ug/L)
15-20	ND	ND

Error bars represent min and max triplicate results

# Phase I Results – Brass Coupons



Condition #4 Condition #5 Condition #6 Betasso Source Water

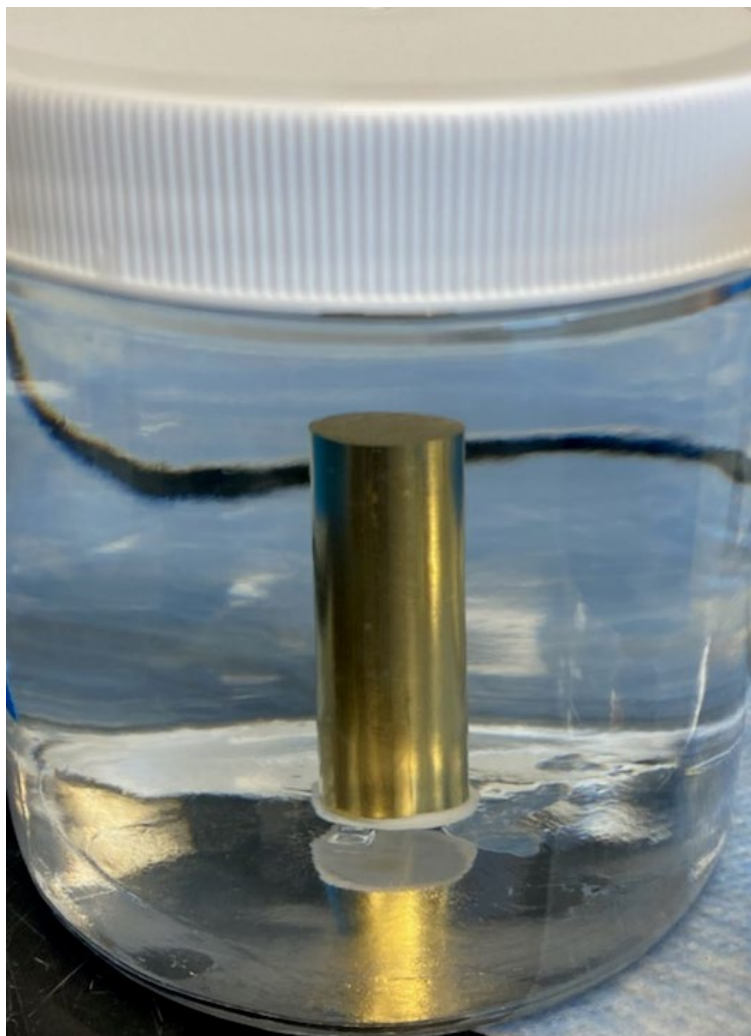


Source Water Concentrations

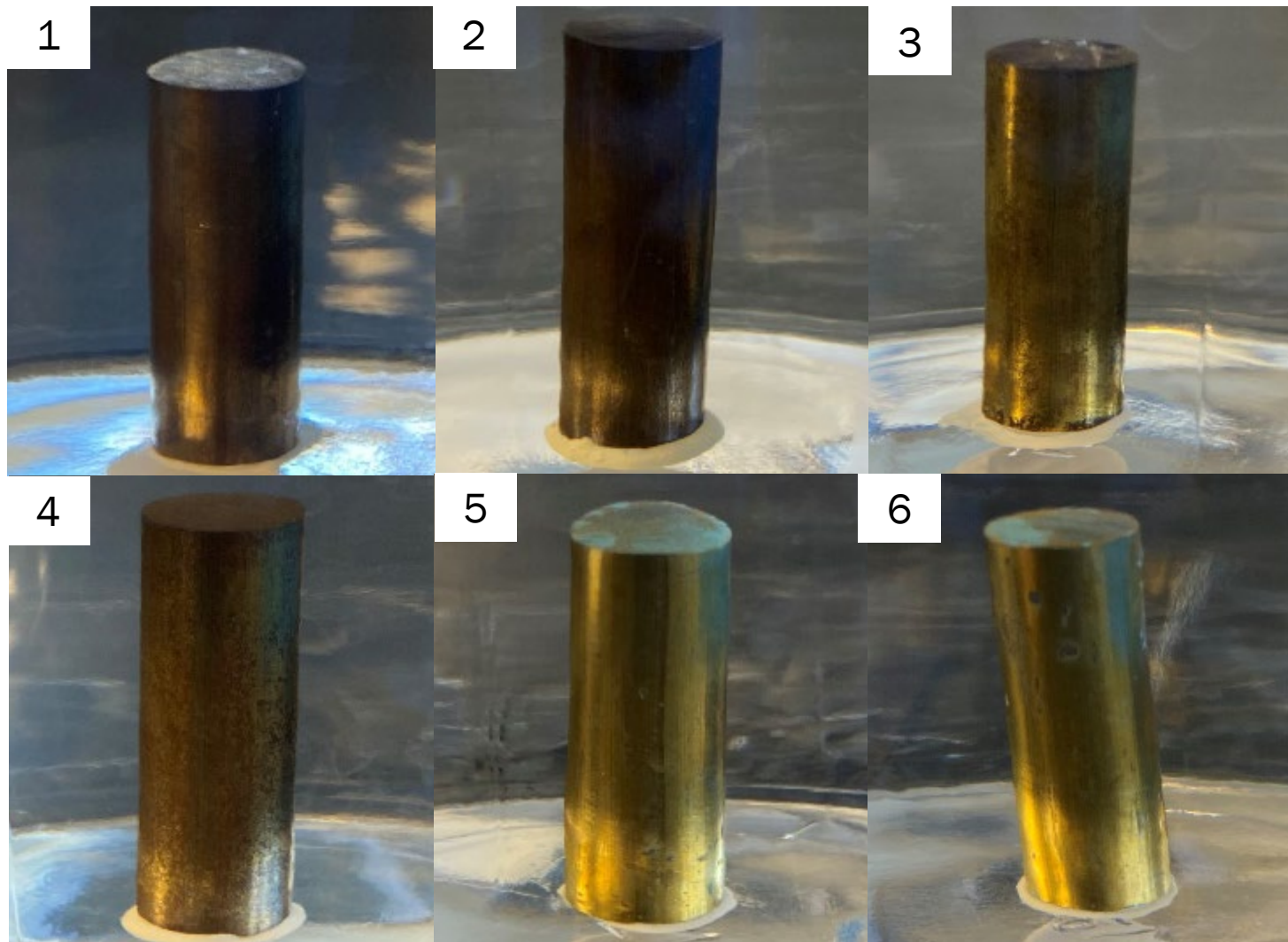
Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.67	0.06	96.0	6.16
8-9	< 2.0	< 0.5	82.0	5.90
10-14	< 2.0	< 0.5	--	--

Error bars represent min and max triplicate results

# Phase I Results – Brass Coupons Image

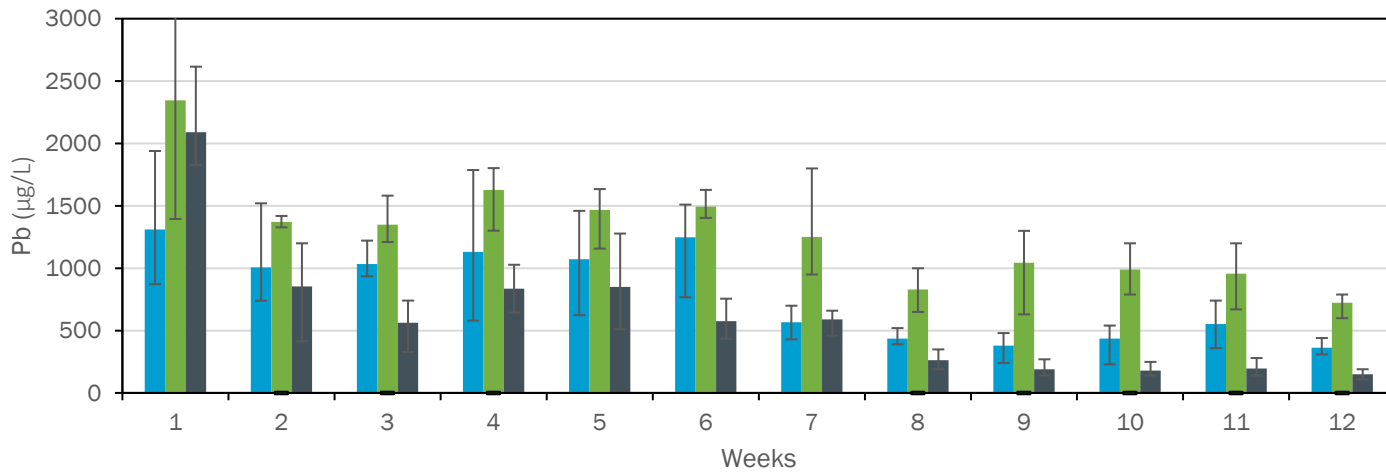
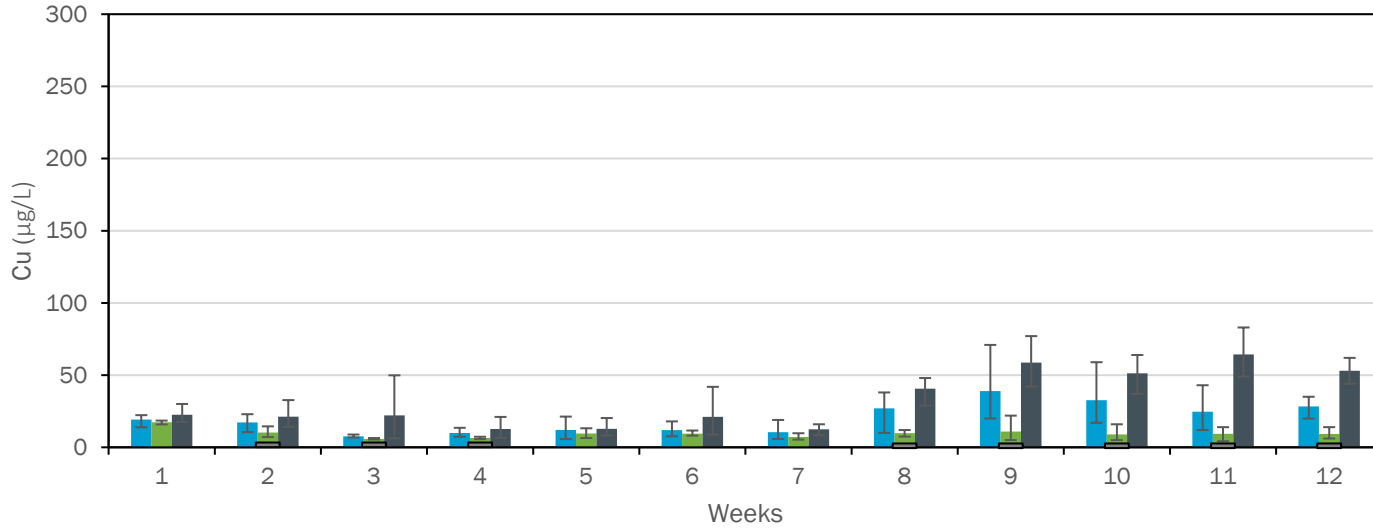


*Virgin brass coupon*

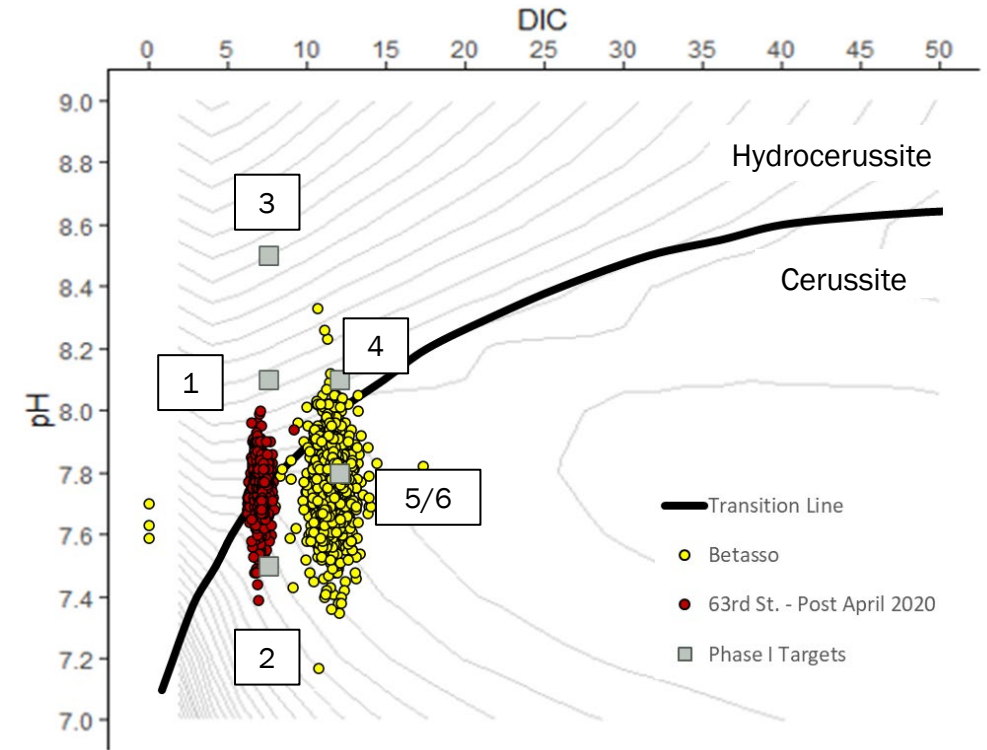




# Phase I Results – CLS Coupons



■ Condition #1 ■ Condition #2 ■ Condition #3 — 63rd Source Water

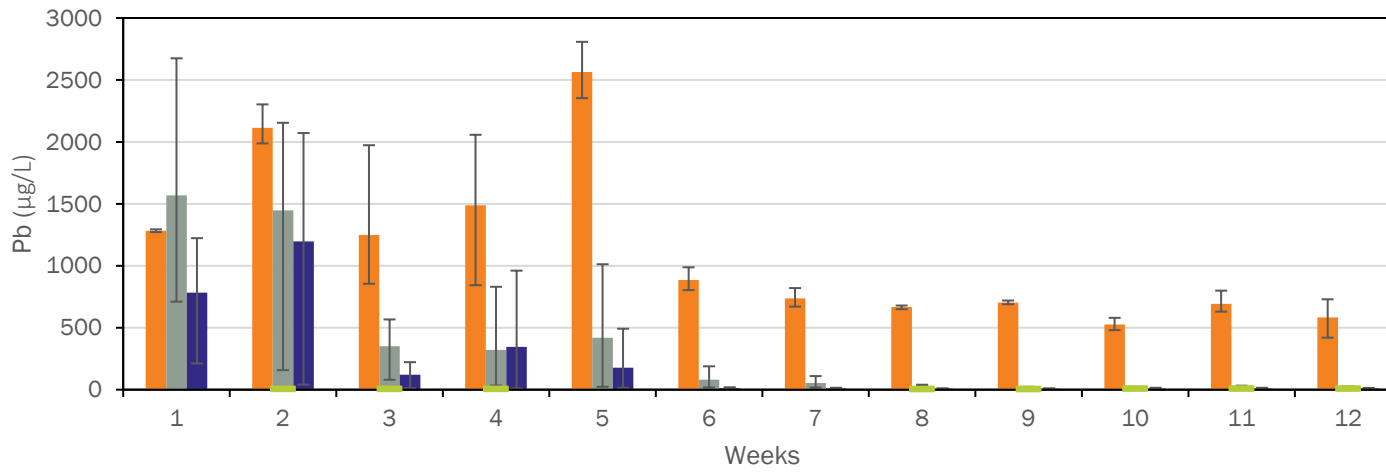
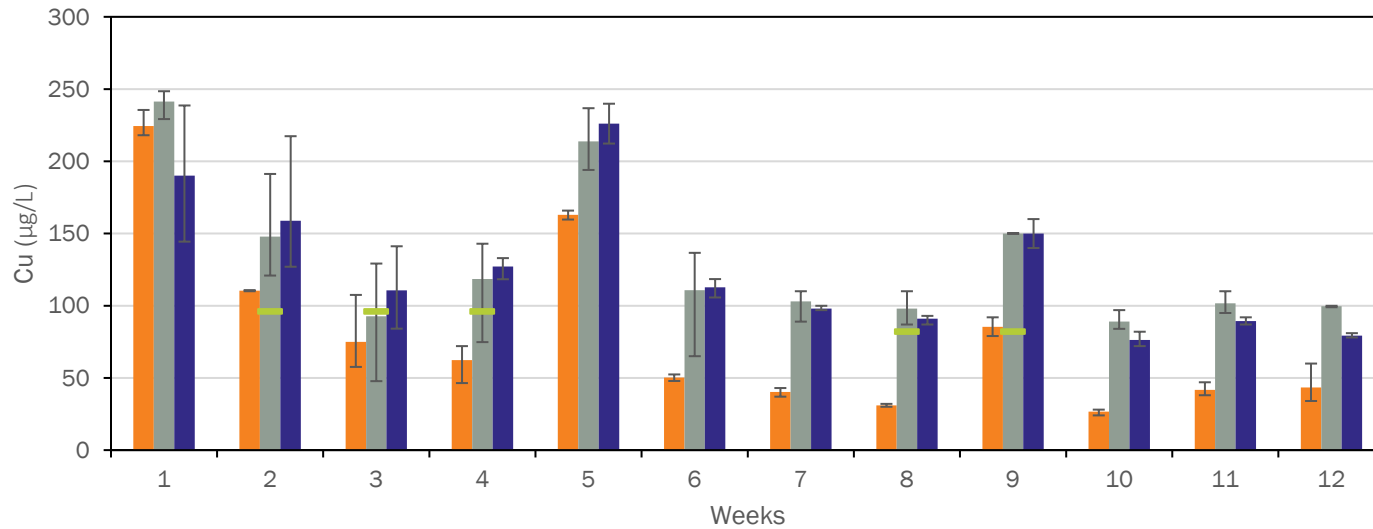


Source Water Concentrations

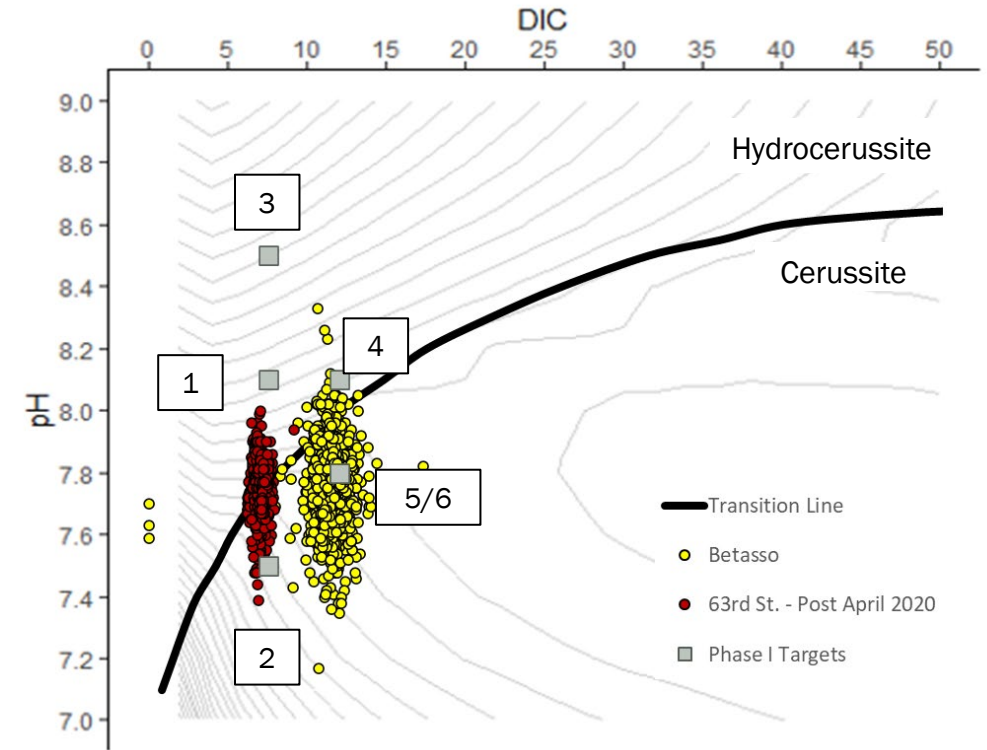
Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.67	0.06	96.0	6.16
8-9	< 2.0	< 0.5	82.0	5.90
10-14	< 2.0	< 0.5	--	--

Error bars represent min and max triplicate results

# Phase I Results – CLS Coupons



Condition #4   Condition #5   Condition #6   Betasso Source Water



Source Water Concentrations

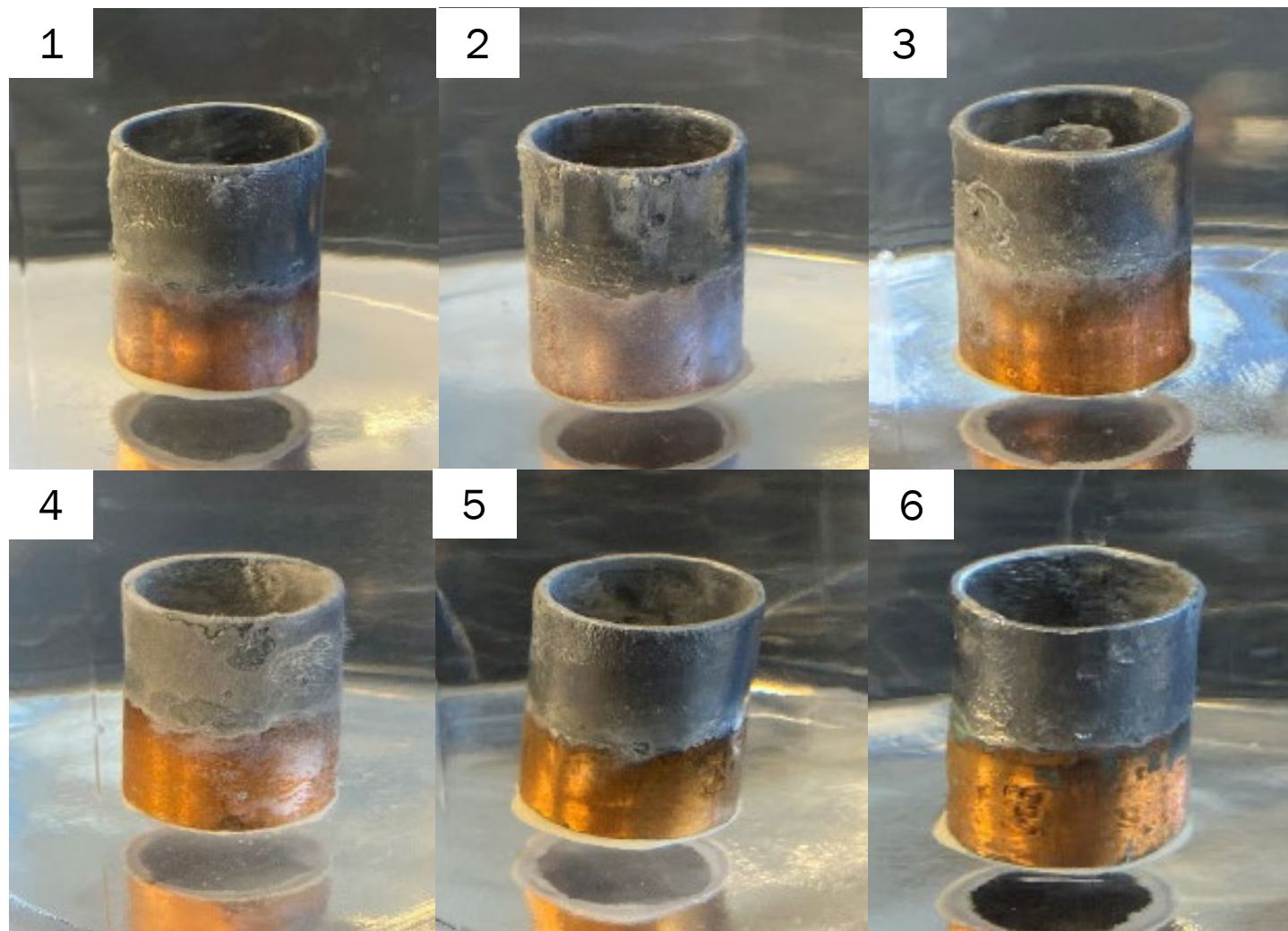
Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.67	0.06	96.0	6.16
8-9	< 2.0	< 0.5	82.0	5.90
10-14	< 2.0	< 0.5	--	--

Error bars represent min and max triplicate results

# Phase I Results – CLS Image



*Virgin copper with lead solder coupon*



# Phase I Results – Key Findings

1. Low pH/low DIC (Condition 2) indicated increased corrosivity towards brass associated with dezincification.
2. Orthophosphate (Conditions 5 and 6) controls the release of Pb well from brass and CLS, but increases Cu release from CLS compared to existing CCT at Betasso (Condition 4).
3. High pH/low DIC (Condition 3) compares favorably to current CCT at Betasso (Condition 4).
  - a) On brass coupons, Condition 3 performed at least as well as Condition 4.
  - b) On CLS coupons, Condition 3 controlled Pb release better than Condition 4, although Cu release was slightly higher.





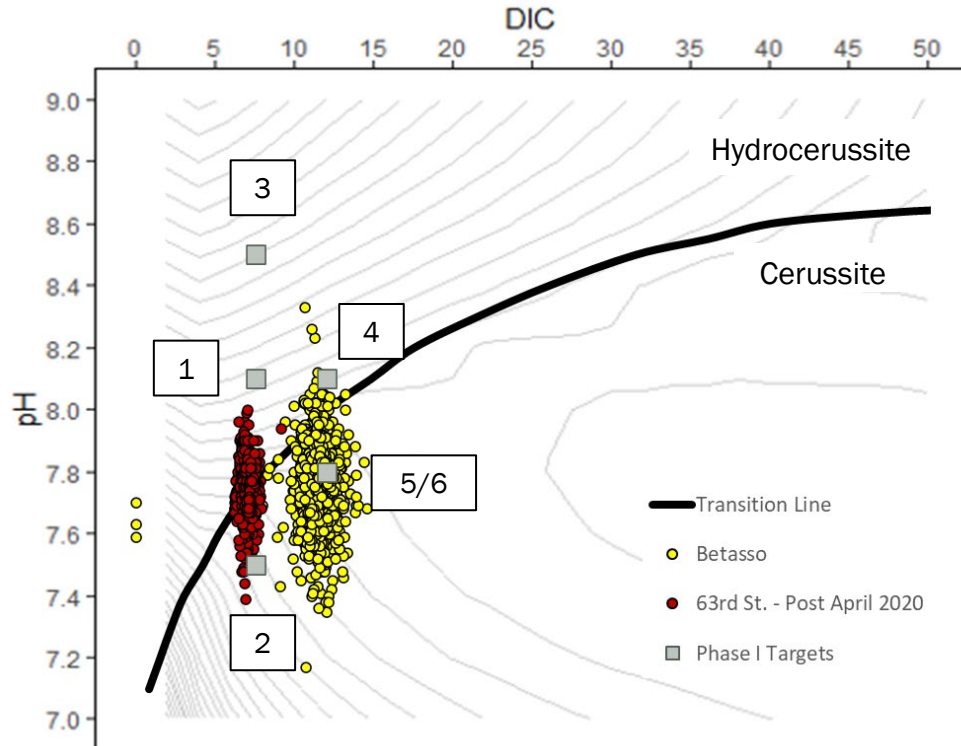
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# Phase II Results

- Brass Coupons
- CLS Coupons
- Key Findings

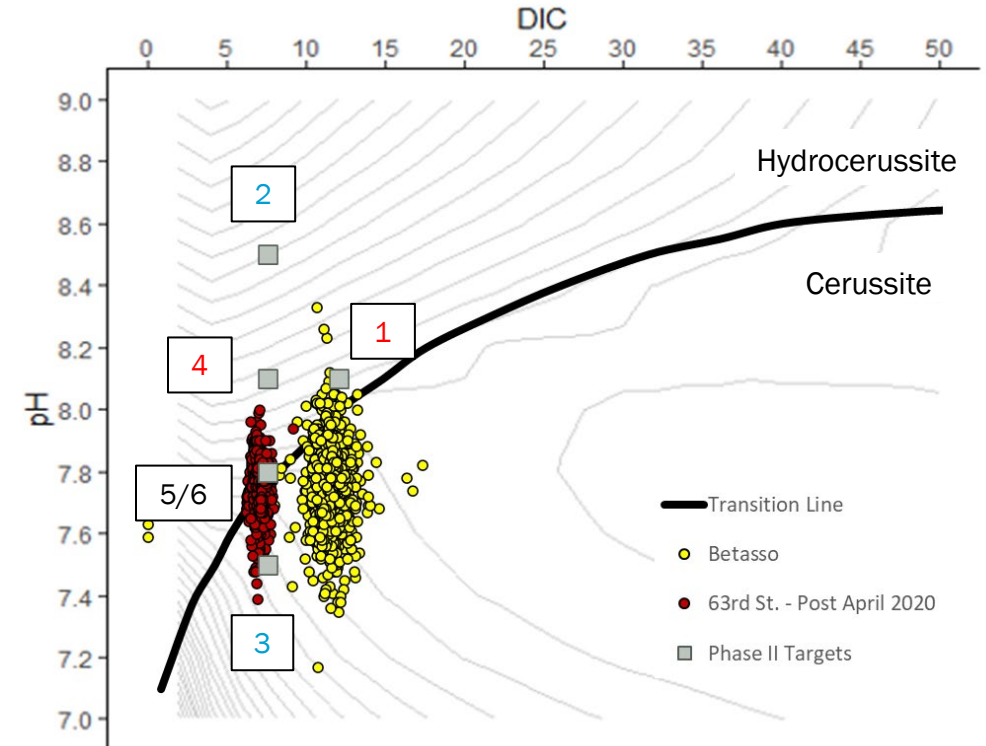
# Corrosion Study Review – Test Conditions

## Phase I



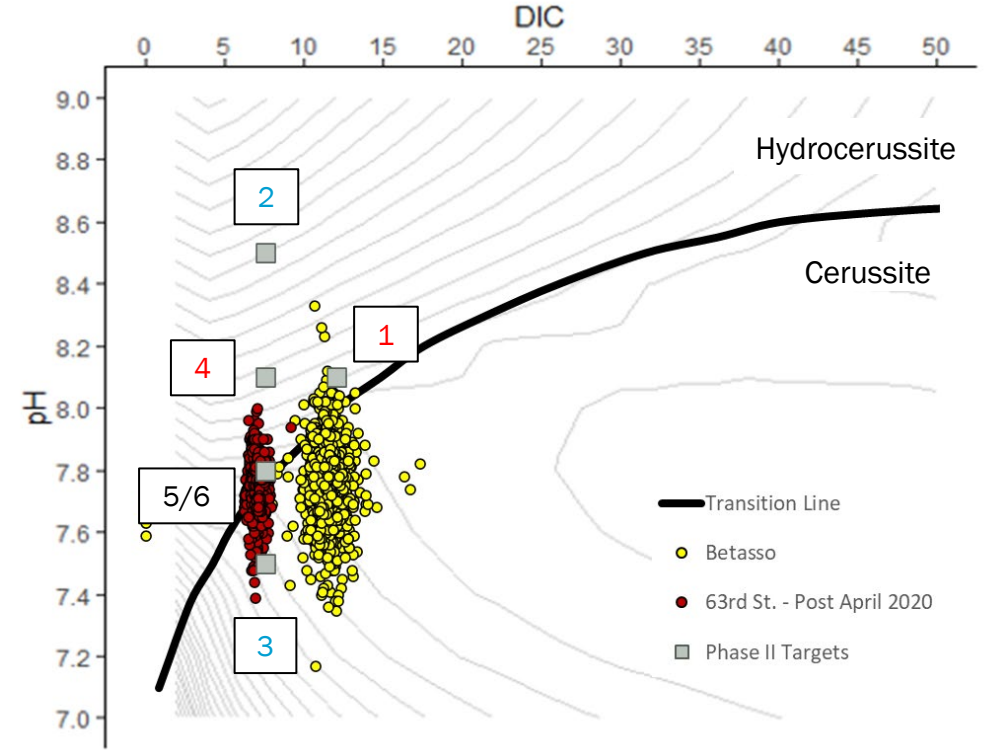
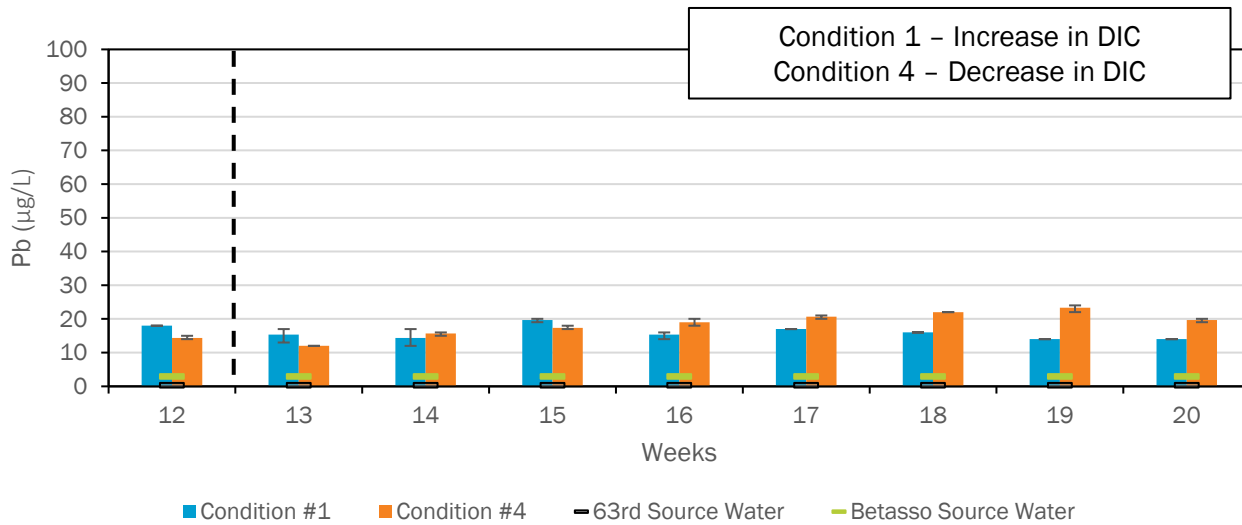
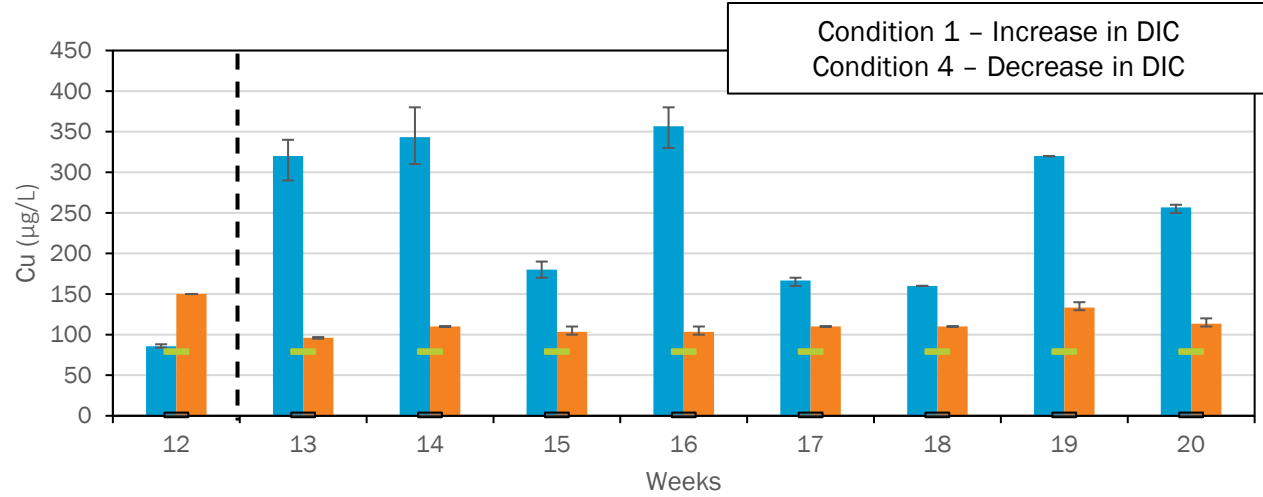
Phase I Test Conditions					
Condition	Source	pH	DIC	Cl <sub>2</sub>	PO <sub>4</sub>
1	63 <sup>rd</sup>	8.1	7.5	1.1	--
2	63 <sup>rd</sup>	7.5	7.5	1.1	--
3	63 <sup>rd</sup>	8.5	7.5	1.1	--
4	Betasso	8.1	12	1.1	--
5	Betasso	7.8	Amb.	1.1	1
6	Betasso	7.8	Amb.	1.1	3

## Phase II



Phase II Test Conditions					
Condition	Source	pH	DIC	Cl <sub>2</sub>	PO <sub>4</sub>
1	Betasso	8.1	12	1.1	--
2	63 <sup>rd</sup>	7.5	7.5	1.1	--
3	63 <sup>rd</sup>	8.5	7.5	1.1	--
4	63 <sup>rd</sup>	8.1	7.5	1.1	--
5	63 <sup>rd</sup>	7.8	7.5	1.1	1
6	63 <sup>rd</sup>	7.8	7.5	1.1	3

# Phase II Results – Brass Coupons



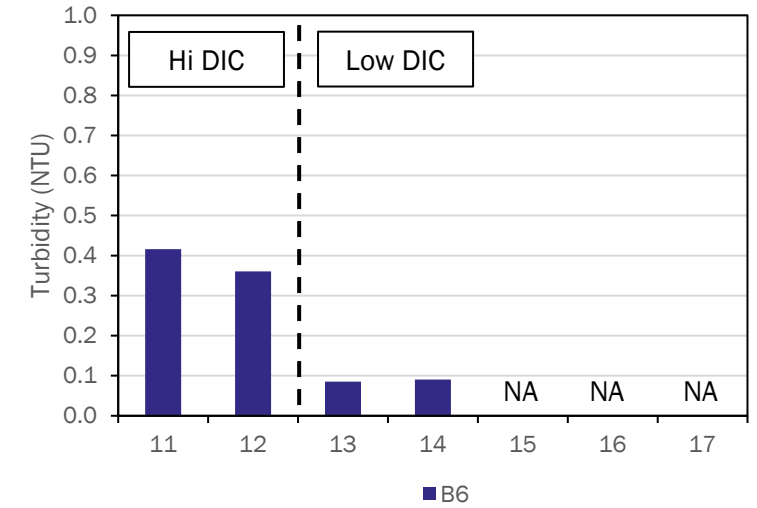
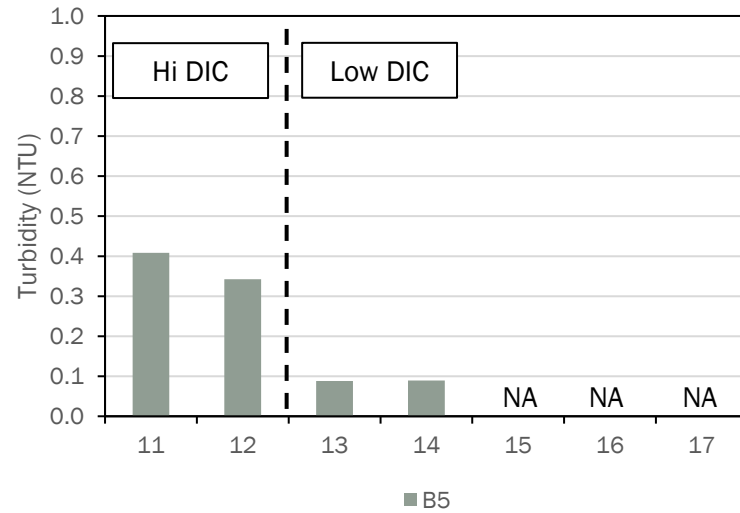
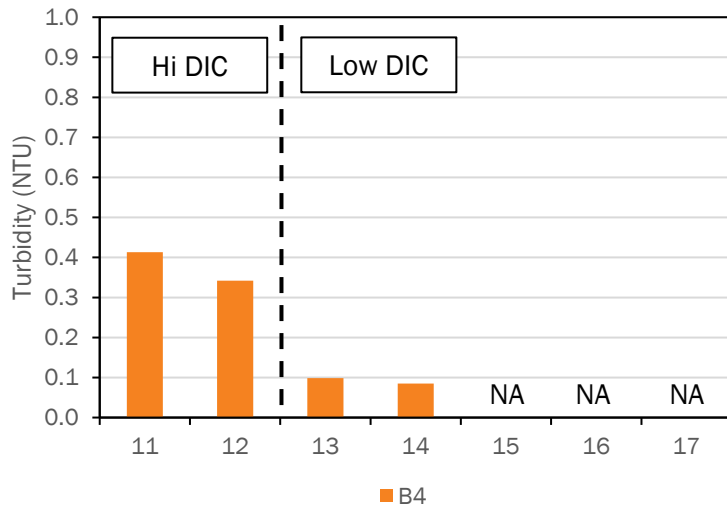
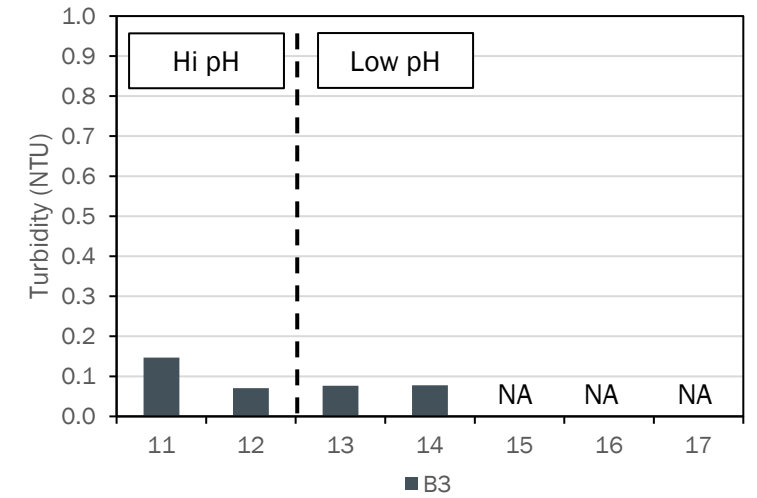
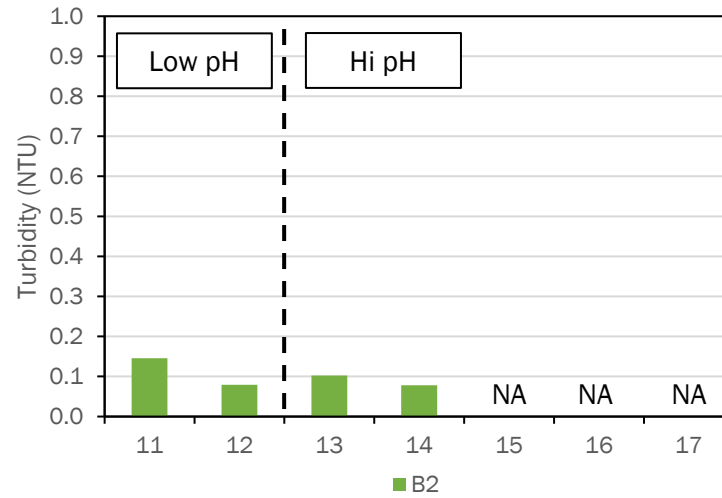
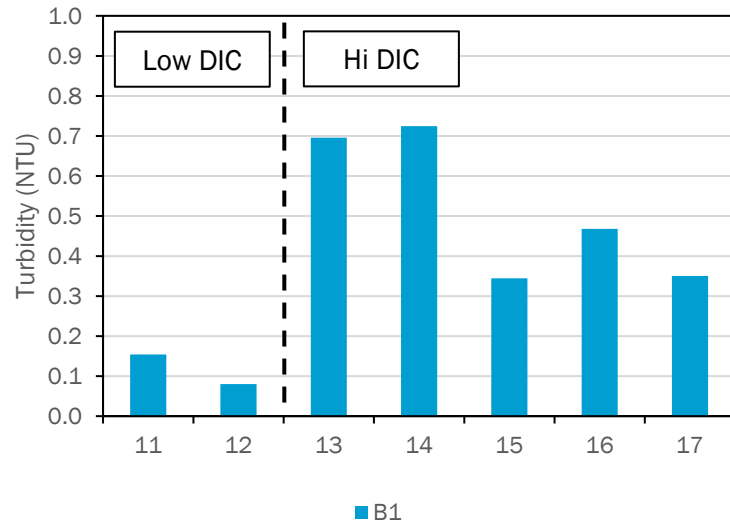
Source Water Concentrations

Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

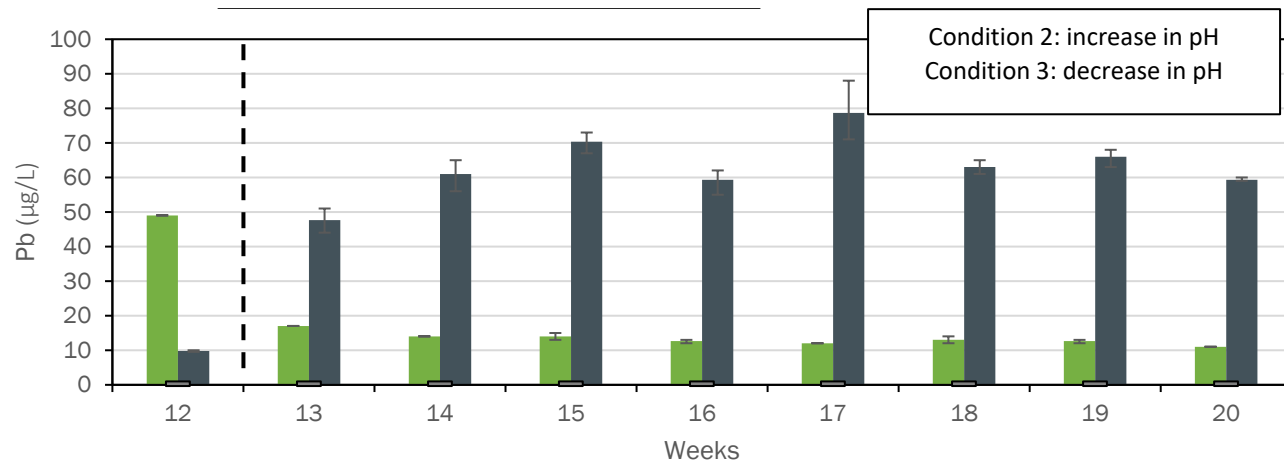
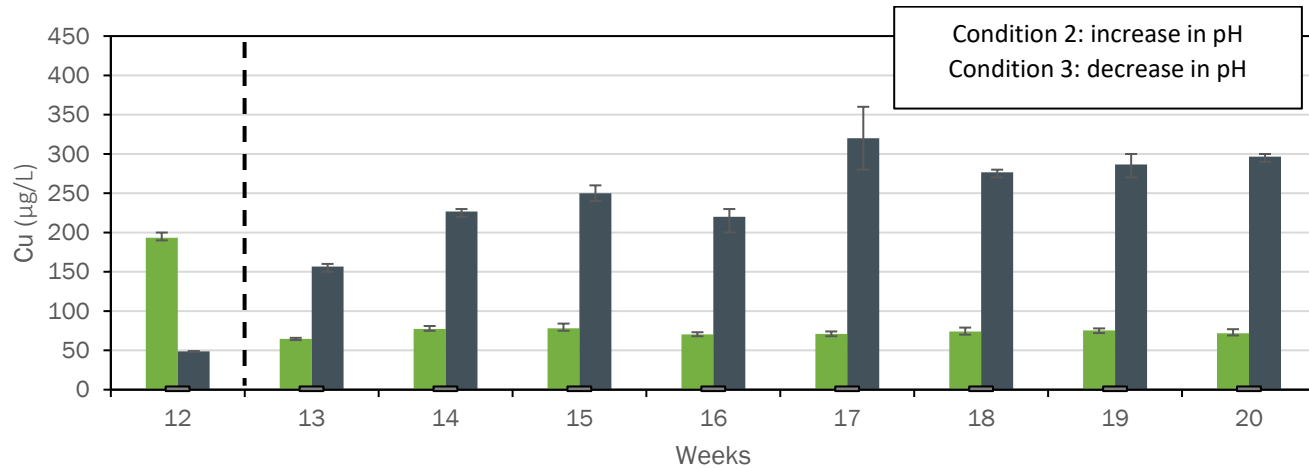
Error bars represent min and max triplicate results

# Phase II Results– Turbidity

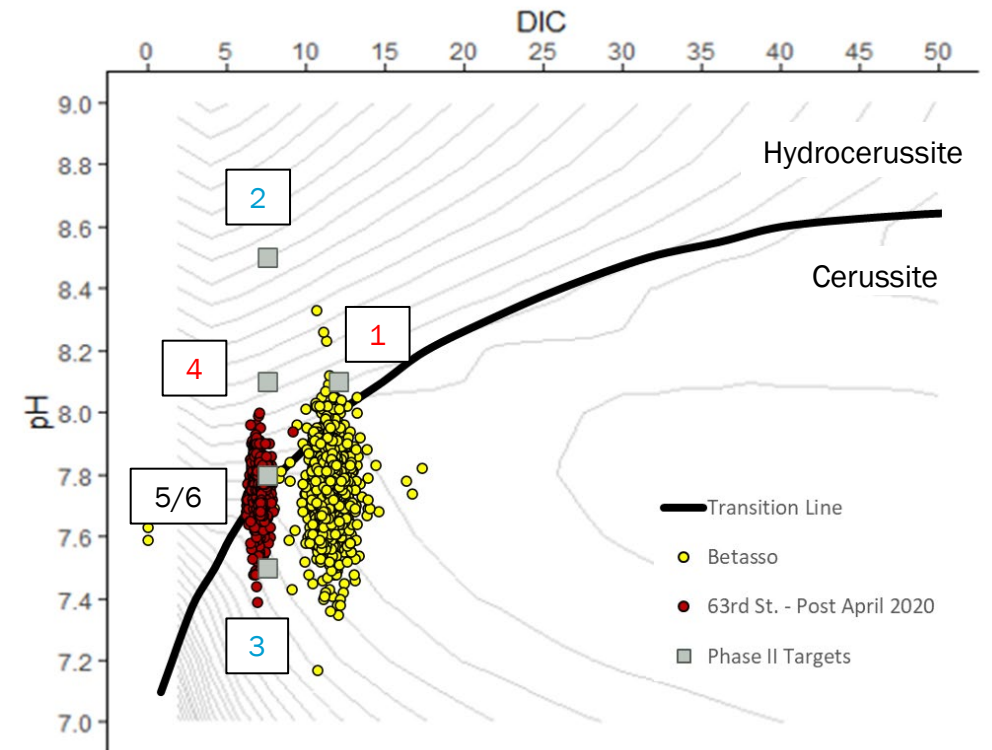
Phase I	1 (low DIC)	2 (low pH)	3 (high pH)	4 (Hi DIC)	5 (High DIC)	6 (Hi DIC)
Phase II	4 (Hi DIC)	3 (high pH)	2 (low pH)	1 (low DIC)	5 (Low DIC)	6 (Low DIC)



# Phase II Results - Brass Coupons



■ Condition #2   ■ Condition #3   ■ 63rd Source Water

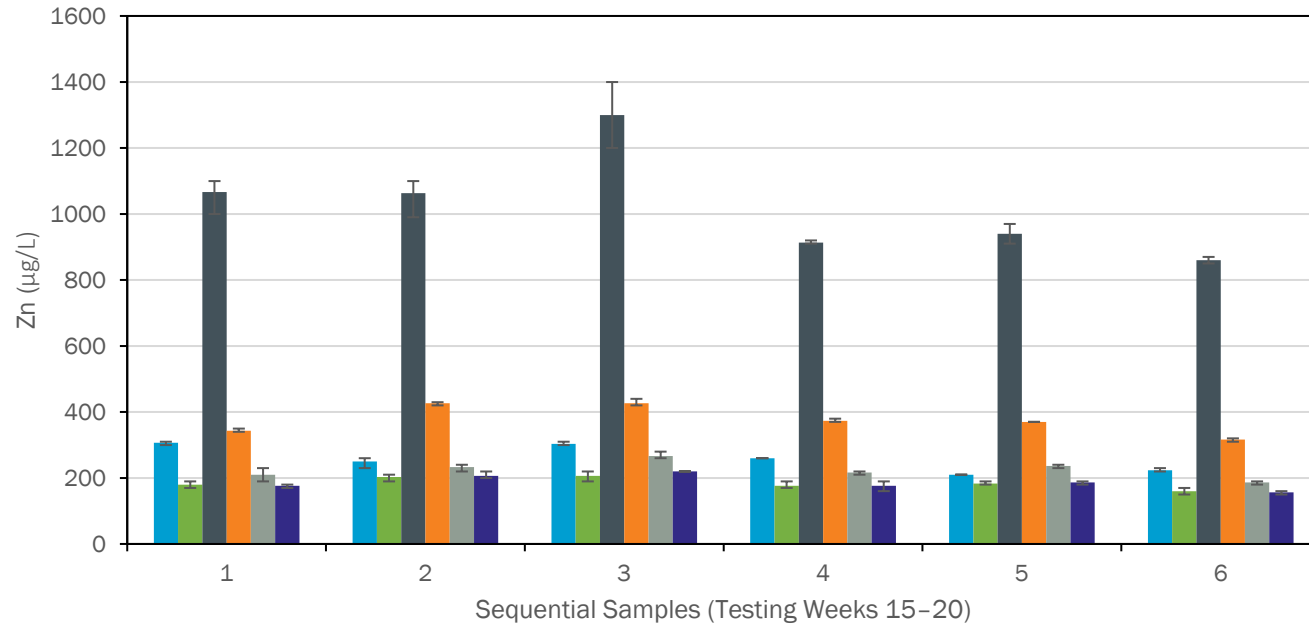


Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

Error bars represent min and max triplicate results

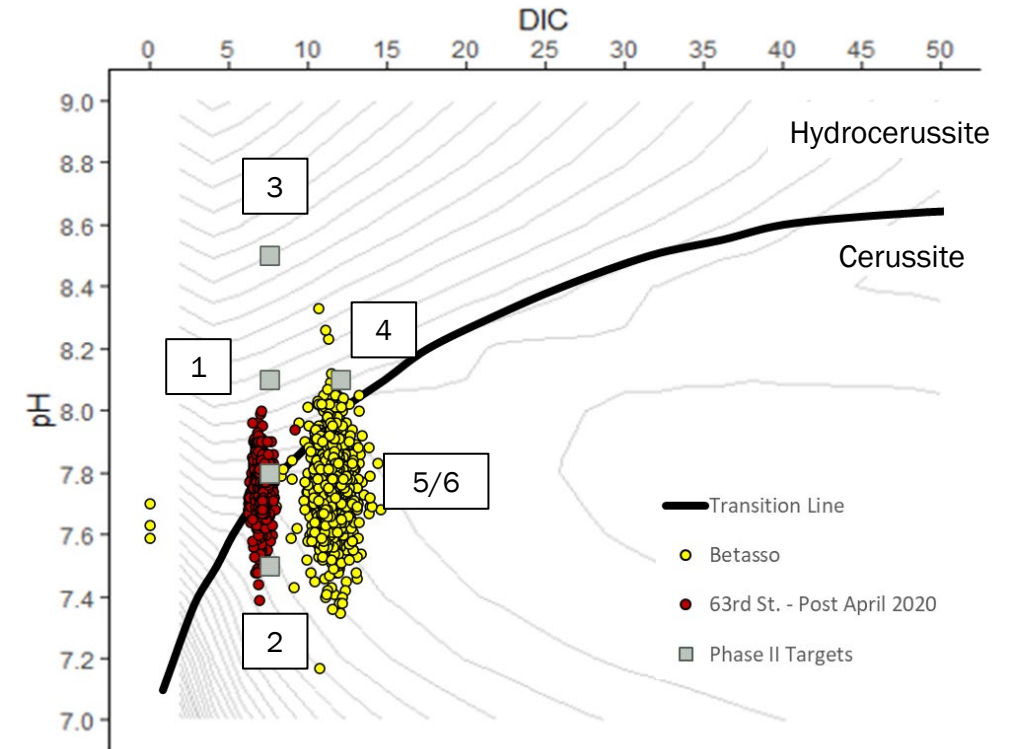


# Evidence of Dezincification



Condition #1   Condition #2   Condition #3   Condition #4   Condition #5   Condition #6

Zn Data from phase II testing. Conditions reflect (pH, DIC) values of phase II.

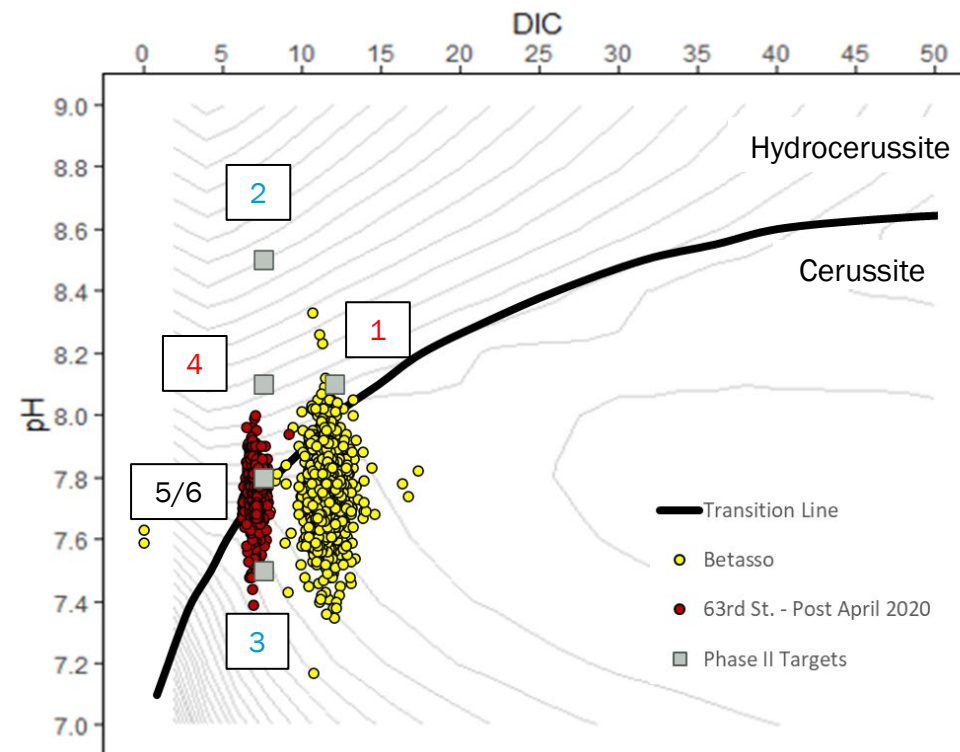
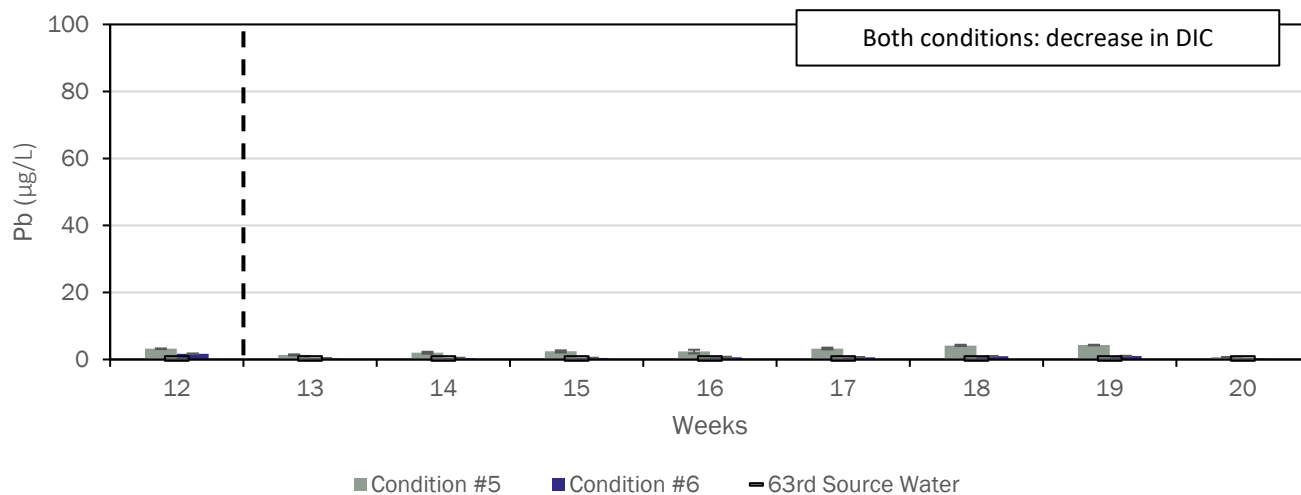
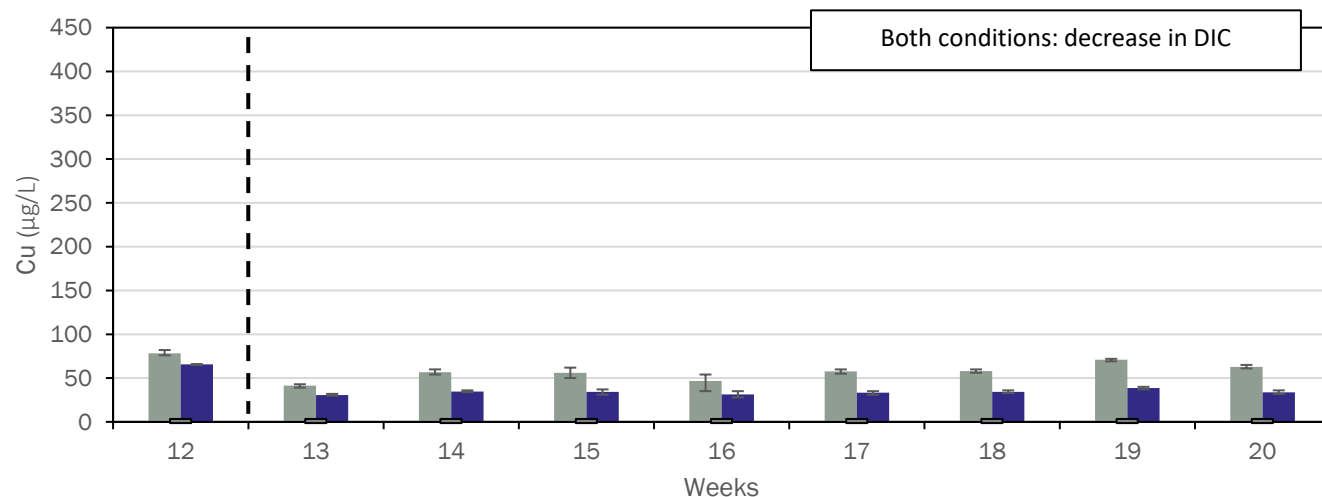


Source Water Concentrations

Weeks	63 <sup>rd</sup> Zn (ug/L)	Betasso Zn (ug/L)
15-20	ND	ND

Error bars represent min and max triplicate results

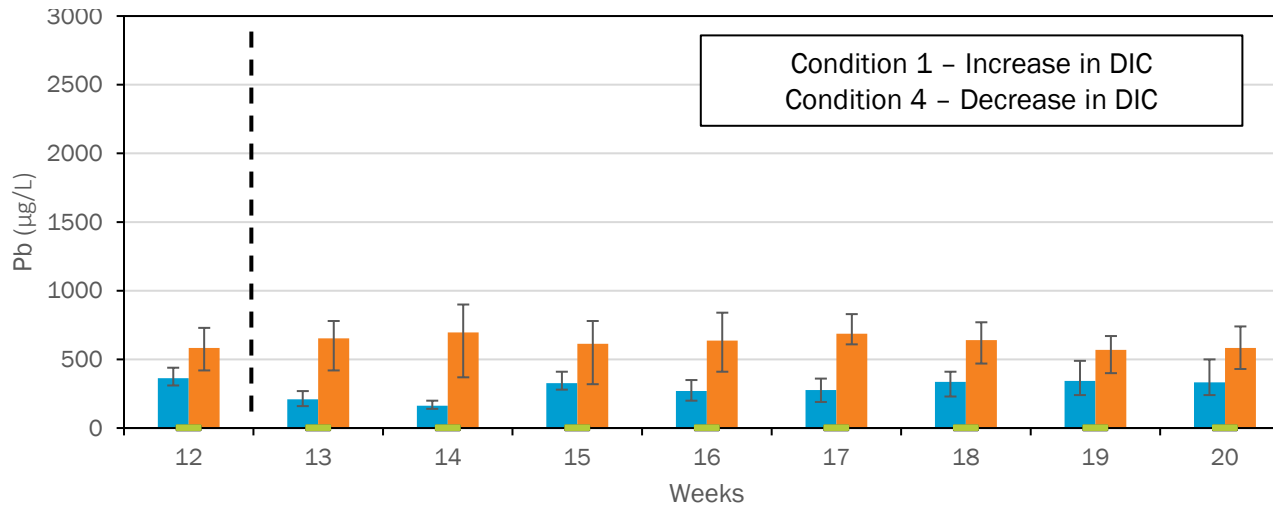
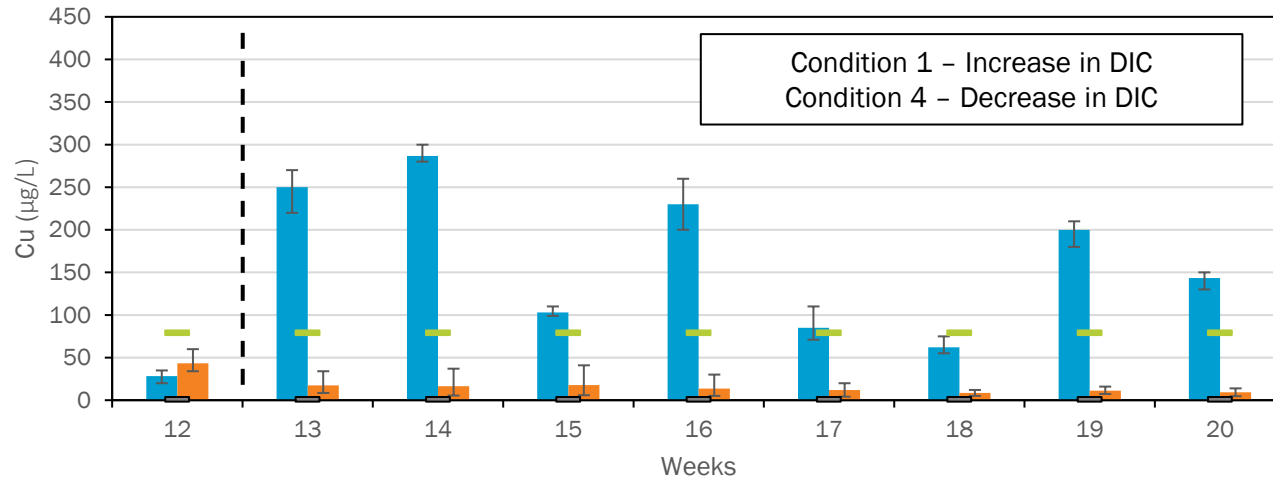
# Phase II Results - Brass Coupons



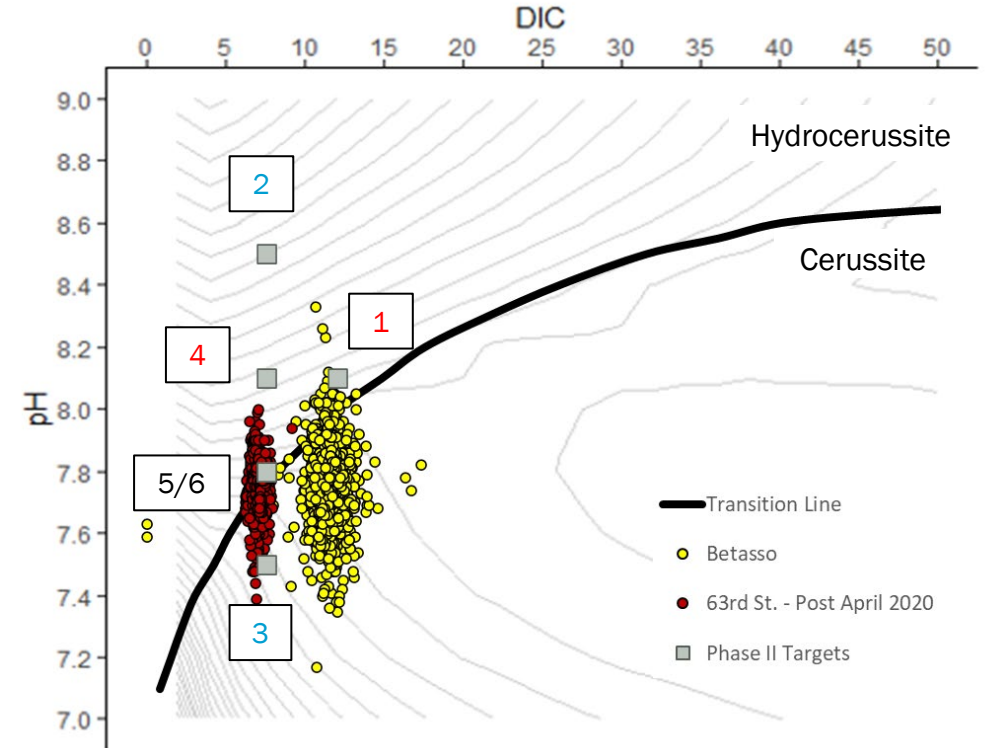
Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

Error bars represent min and max triplicate results

# Phase II Results - CLS Coupons



■ Condition #1   ■ Condition #4   ■ 63rd Source Water   ■ Betasso Source Water



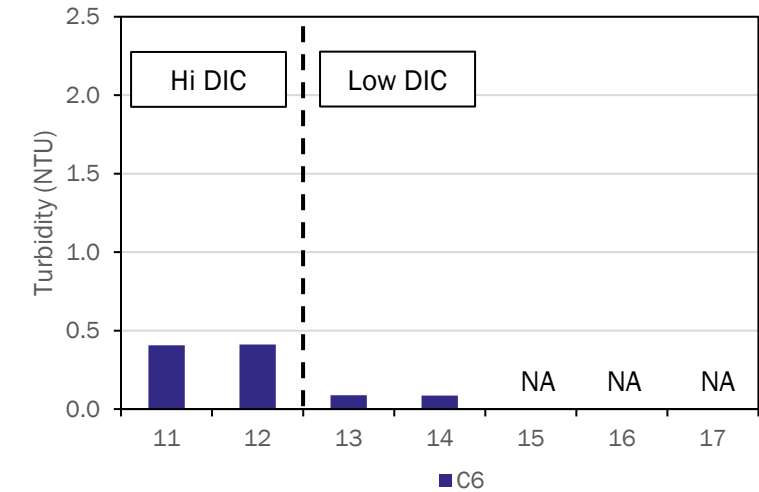
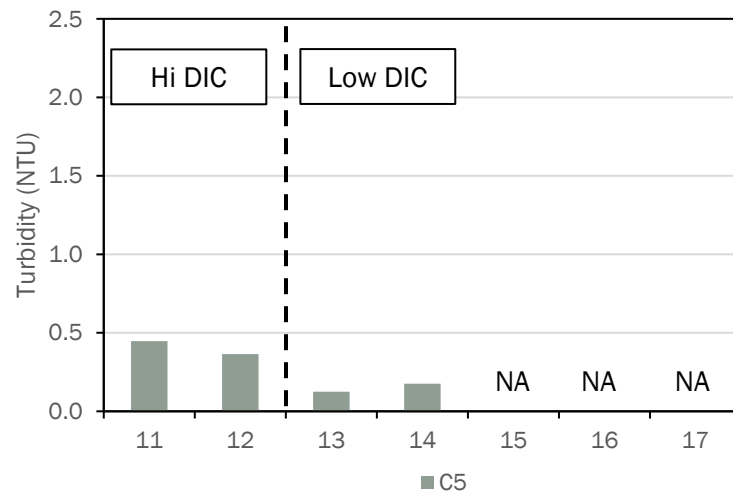
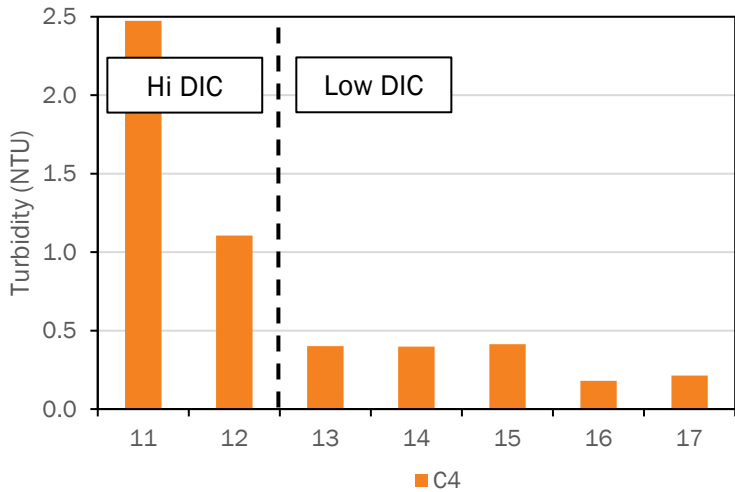
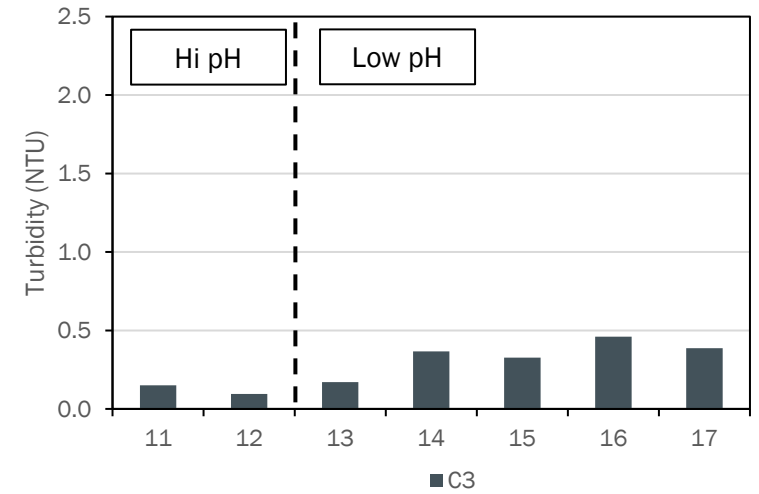
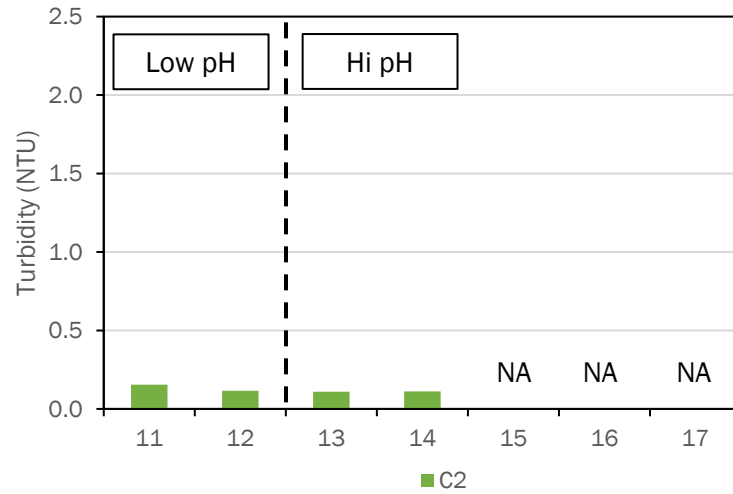
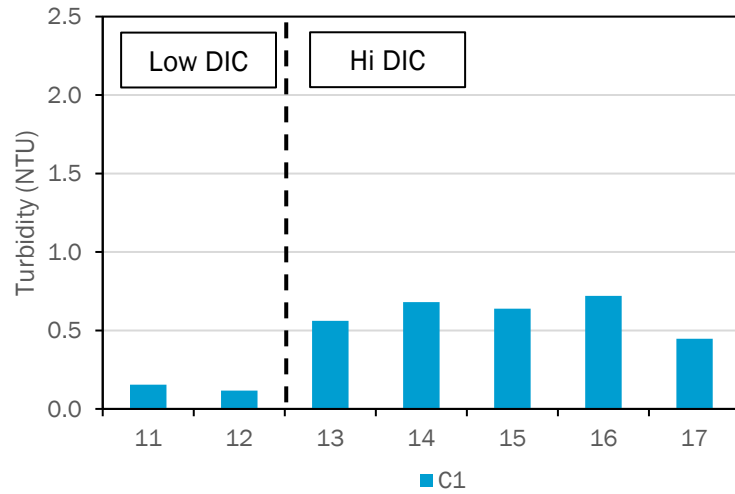
Source Water Concentrations

Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

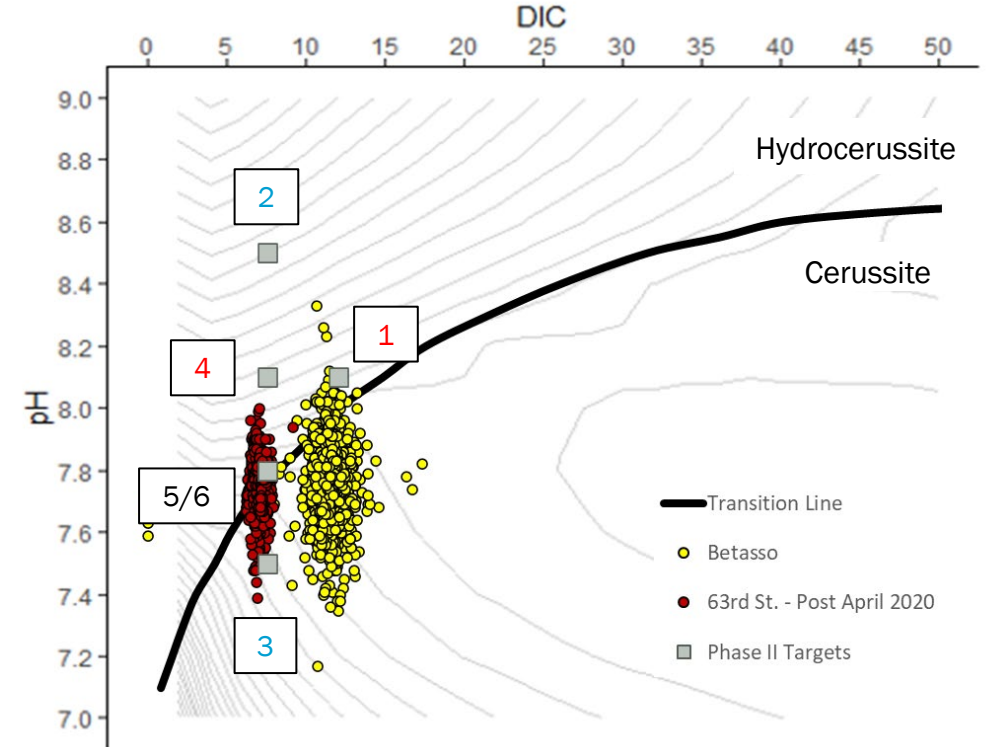
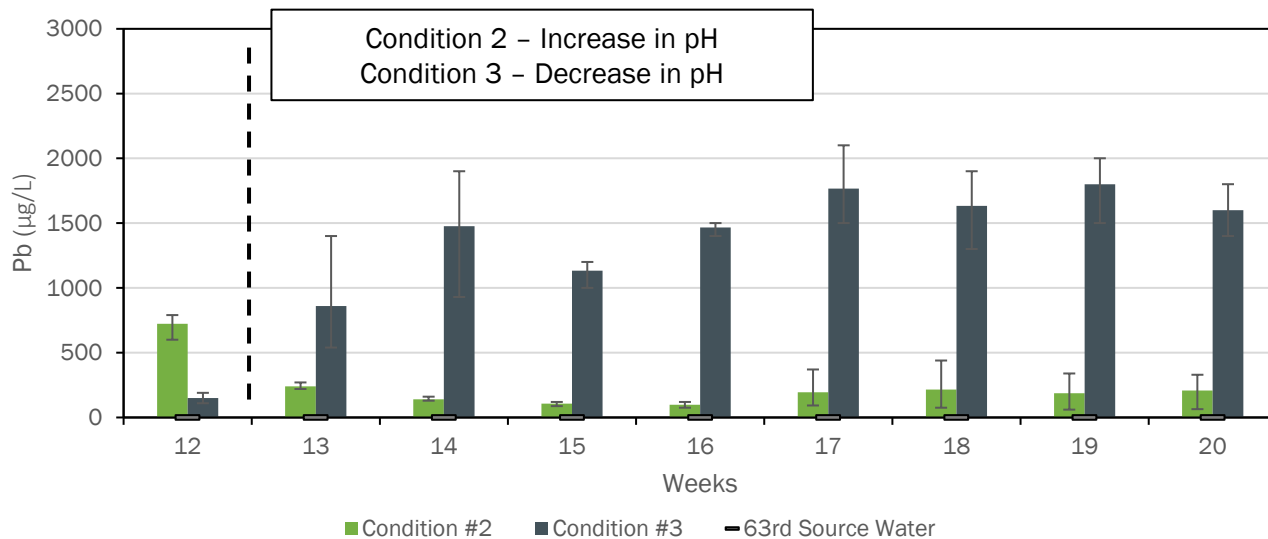
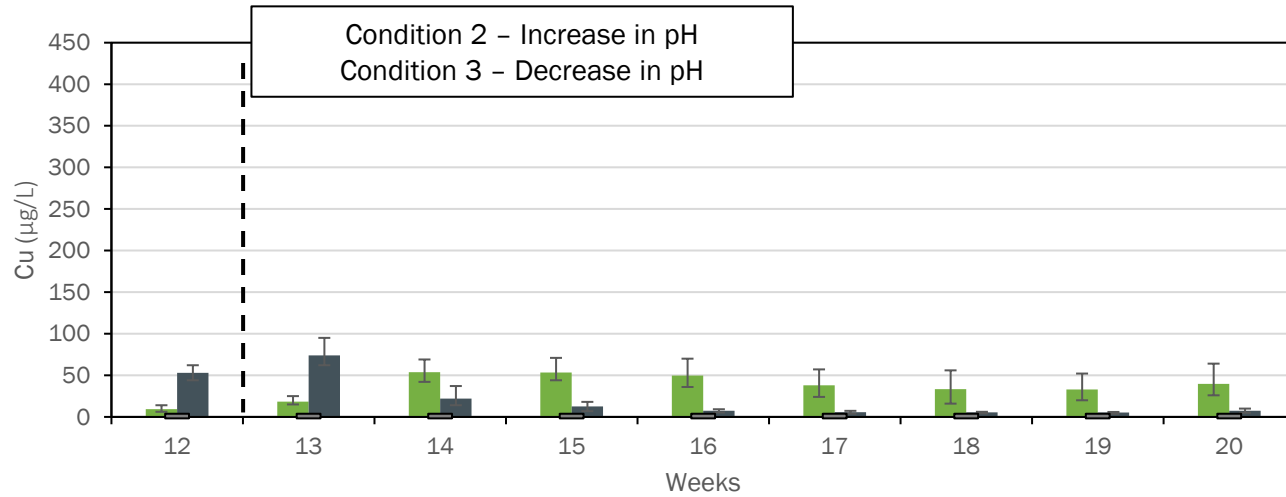
Error bars represent min and max triplicate results

# Phase II Results – Turbidity

Phase I	1 (low DIC)	2 (low pH)	3 (high pH)	4 (Hi DIC)	5 (High DIC)	6 (Hi DIC)
Phase II	4 (Hi DIC)	3 (high pH)	2 (low pH)	1 (low DIC)	5 (Low DIC)	6 (Low DIC)



# Phase II Results - CLS Coupons



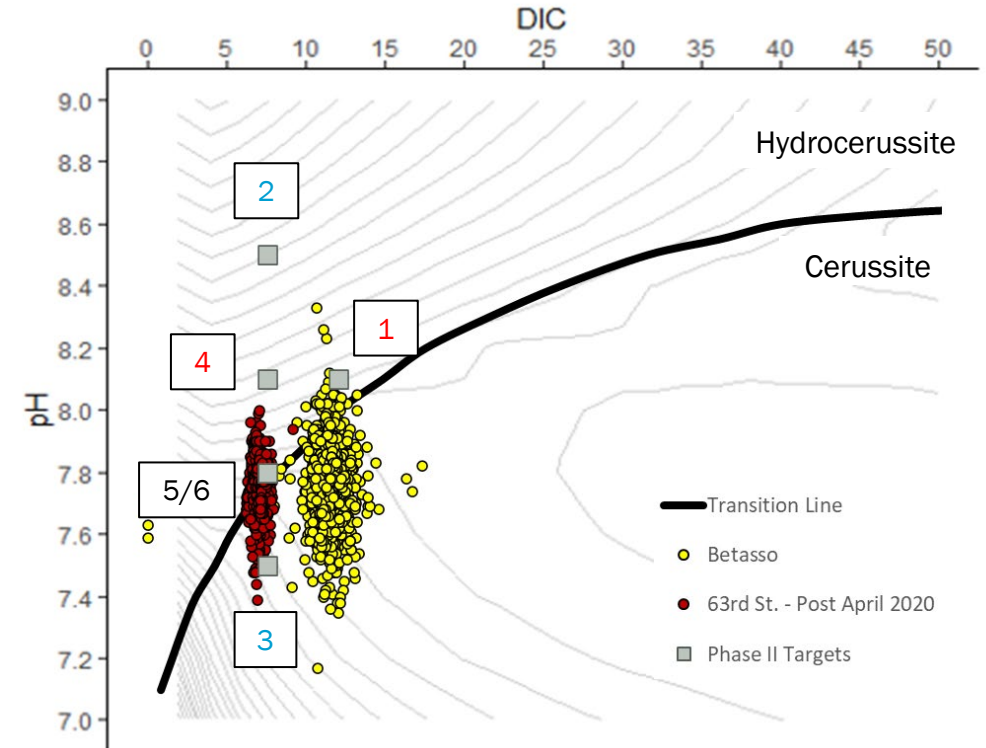
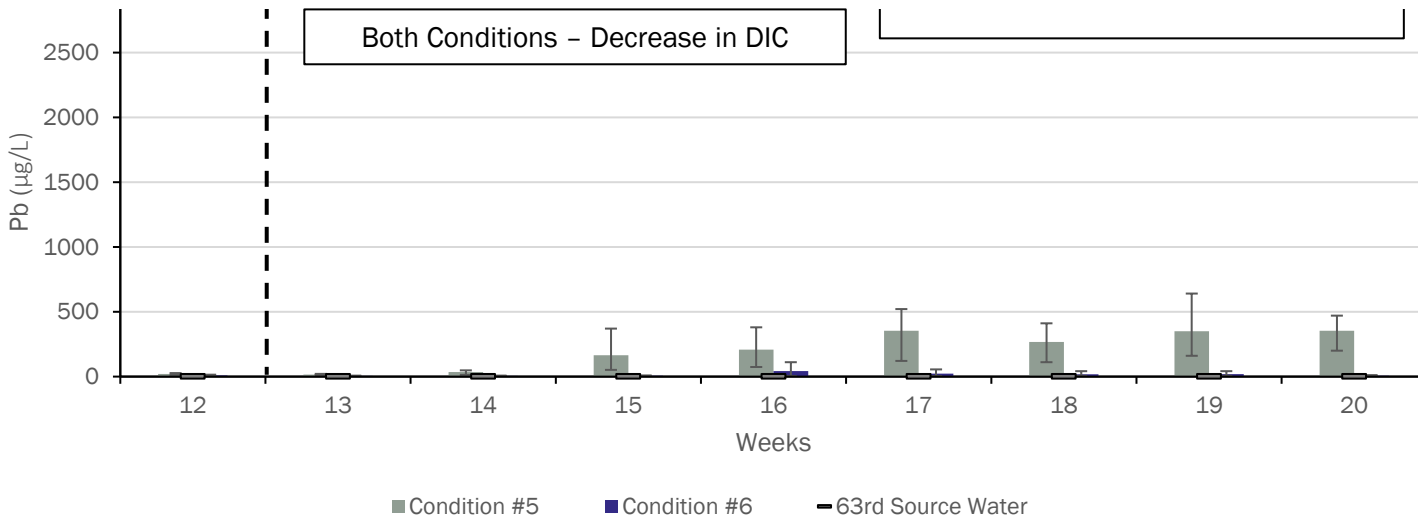
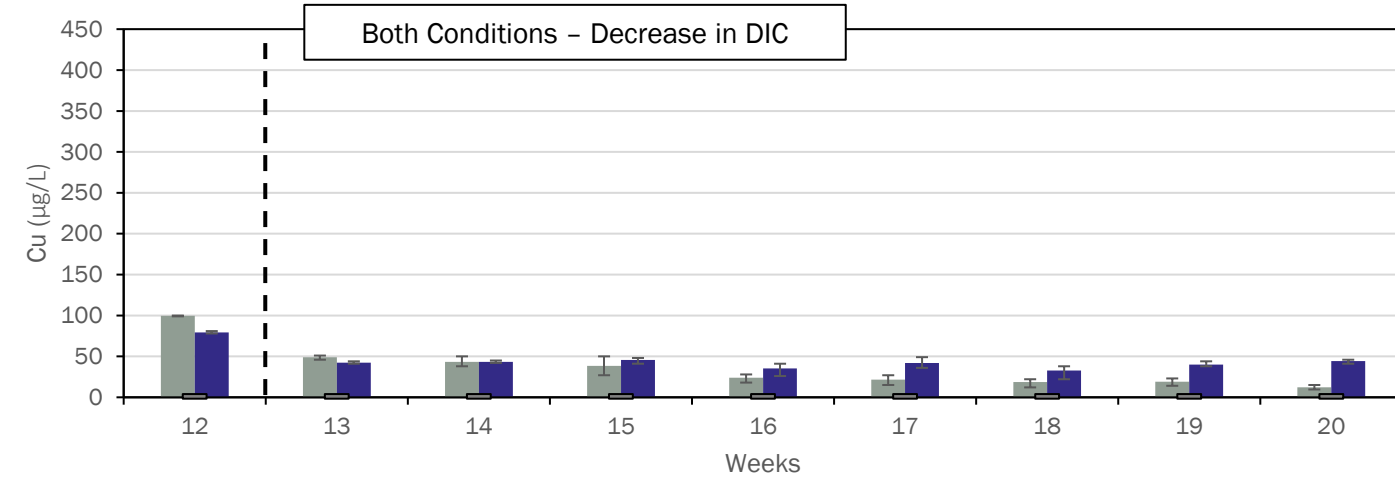
Source Water Concentrations

Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

Error bars represent min and max triplicate results



# Phase II Results - CLS Coupons



Source Water Concentrations

Weeks	63rd		Betasso	
	Cu (ug/L)	Pb (ug/L)	Cu (ug/L)	Pb (ug/L)
2-4	1.7	0.1	96	6.2
8-9	< 2.0	< 0.5	82	5.9
10-14	< 2.0	< 0.5	--	--
15-20	< 2.0	< 0.5	79	2.9

Error bars represent min and max triplicate results

# Phase II Results – Key Findings

1. Transitioning from low to high DIC can increase turbidity and Cu release from brass and CLS. Impact on Pb release is minimal.
2. Transitioning from low to high pH decreases Cu and Pb release in brass due to reduced dezincification.
3. Transitioning from low to high pH increases Cu release and decreases Pb release. Cu release changes to a lesser extent than Pb release.
4. The lower  $\text{PO}_4$  dose tested showed increased Pb solubility after 4 weeks at the lower DIC. Pb release from this  $\text{PO}_4$  condition was higher than that from the high pH/low DIC condition.



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# Lessons Learned

# Lessons Learned

- pH/alkalinity adjustment can be an effective strategy for controlling lead and copper release in low-alkalinity source waters
- Brass can be a significant source of lead if dezincification occurs
- Lead and copper levels in source waters are *usually* nominal, but not always
  - Consider sampling source waters prior to study plan development
  - Effective CCT can sequester lead and copper
- Even for high-performing systems, there may be room for improving CCT further