Evaluating Impacts of Legacy Mining on a Watershed Scale

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AMERICAN SOCIETY OF RECLAMATION SCIENCES
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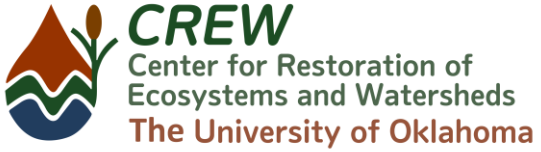

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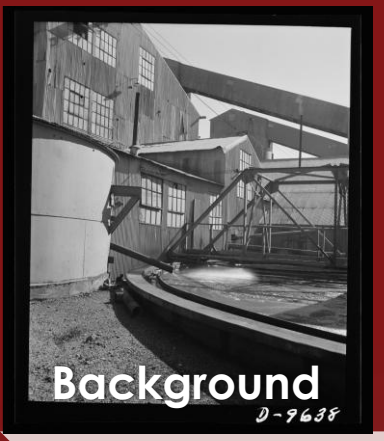
Outline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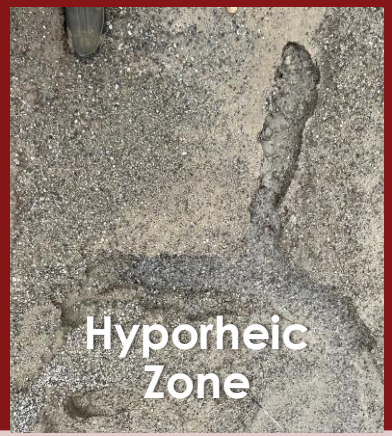
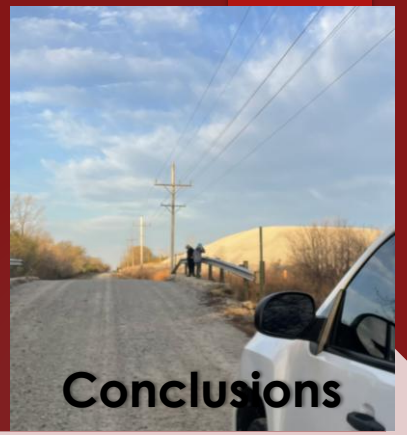
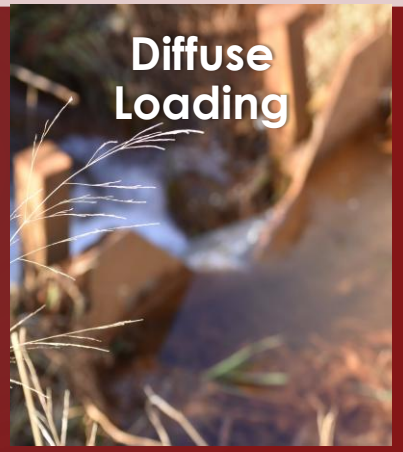
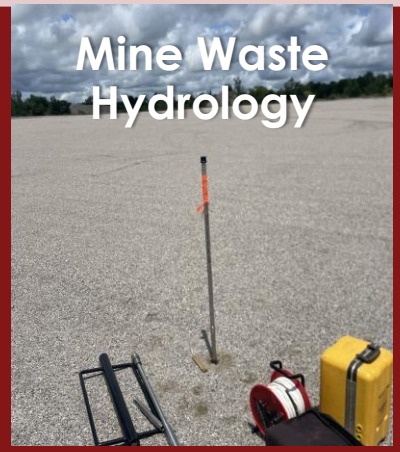

Hyporheic Zone


Conclusions


Diffuse Loading

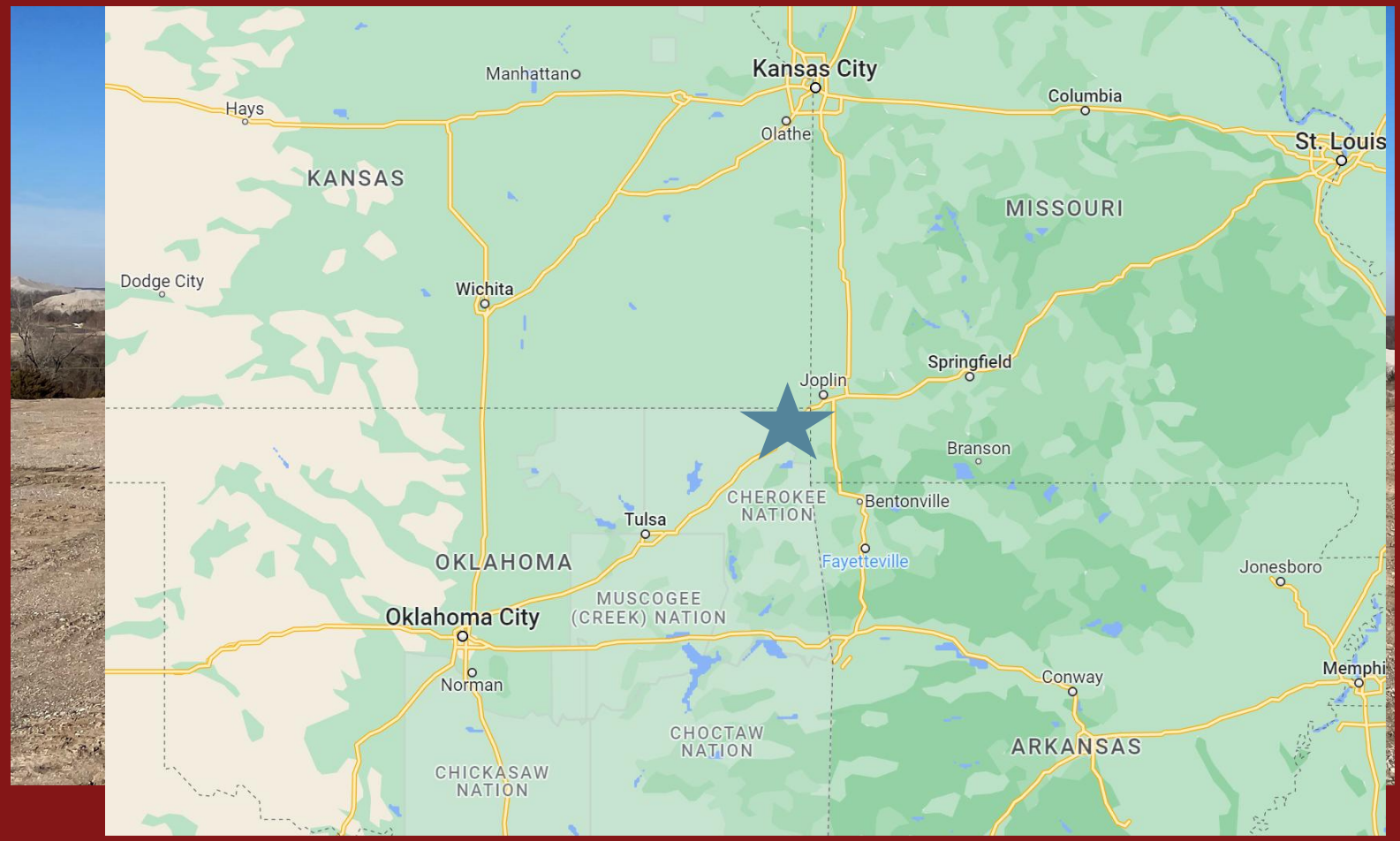

Mine Waste Hydrology

Background

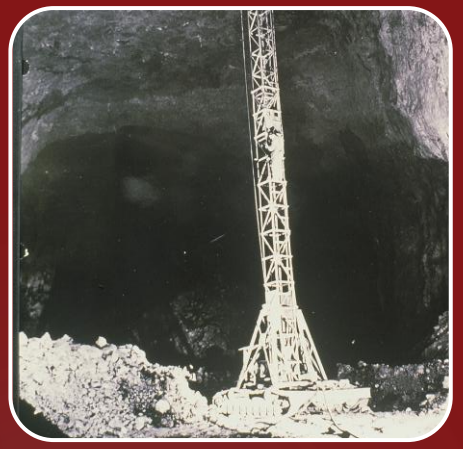
Photo courtesy of Nick Shepherd

Legacy Mining and Industrial Sites

- Large, complex sites
- Contaminated media
  - Source material
  - Water
  - Soil and sediment
- Efficient remediation needed



Tri-State Lead-Zinc Mining District



Mining

- 19th and 20th centuries
- Missouri, Kansas, Oklahoma

Closure

- Late 1960s
- Mine drainage in late 1970s

EPA

- National Priorities List
- Tar Creek Superfund Site

Other Work – Water

- EPA – Surface water and groundwater
  - Diversion of Lytle Creek
- CREW
  - Watershed monitoring
  - Passive treatment
  - Mine pool inflows and outflows

Aerial imagery courtesy of Brandon Holzbauer-Schweitzer

Other Work – Mine Waste

- EPA – mining, mill, and smelter waste
  - Removal of mine waste
  - Commercial reuse
- EPA – surface water and sediment
  - Remedial investigation ongoing
  - Interim measures
    - Partial mine waste removal
    - Sediment traps

Research Questions

- Where can remedial efforts have the greatest effect?
- What sets those areas apart?
- How can we address diffuse pollution sources sustainably?

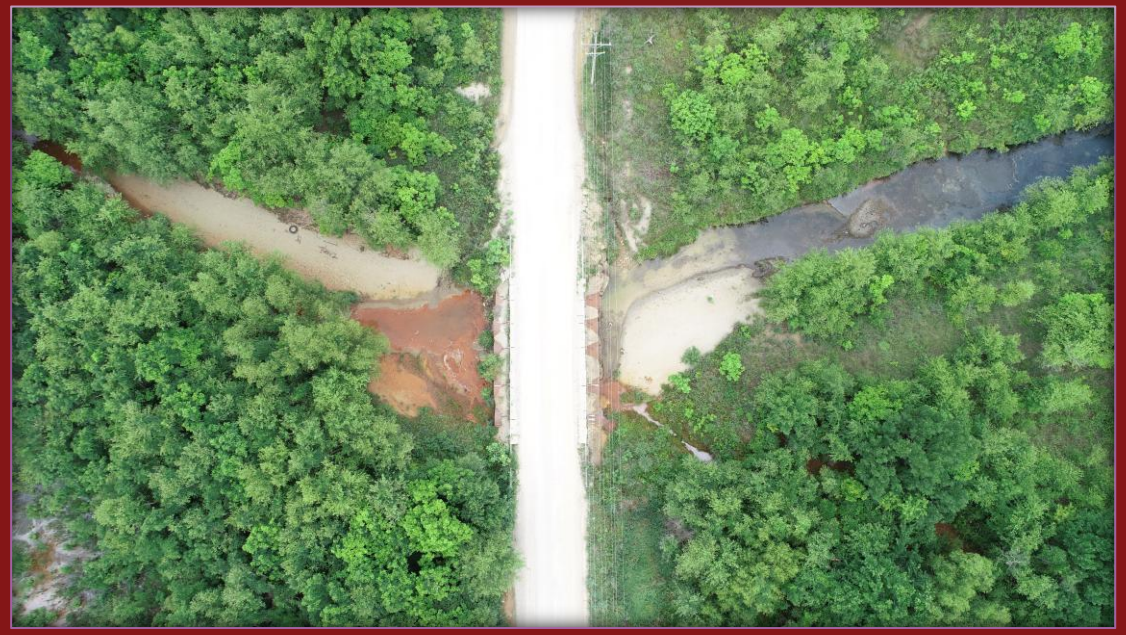


Photo courtesy of Brandon Holzbauer-Schweitzer

Hypotheses and Objectives

- Mine drainage seeps, when flowing, contribute most of the daily metals load to the stream as they add large volumes of water with elevated metal concentrations
- Hyporheic exchange contributes greater metal concentrations in seasons when the water table is higher than it does during drier periods due to increased infiltration and reductive dissolution
- Metals loading to the stream from mine waste processed by size sorting will exceed loading from unprocessed waste rock and tailings, due to concentration of finer materials and greater exposure to oxygen, respectively

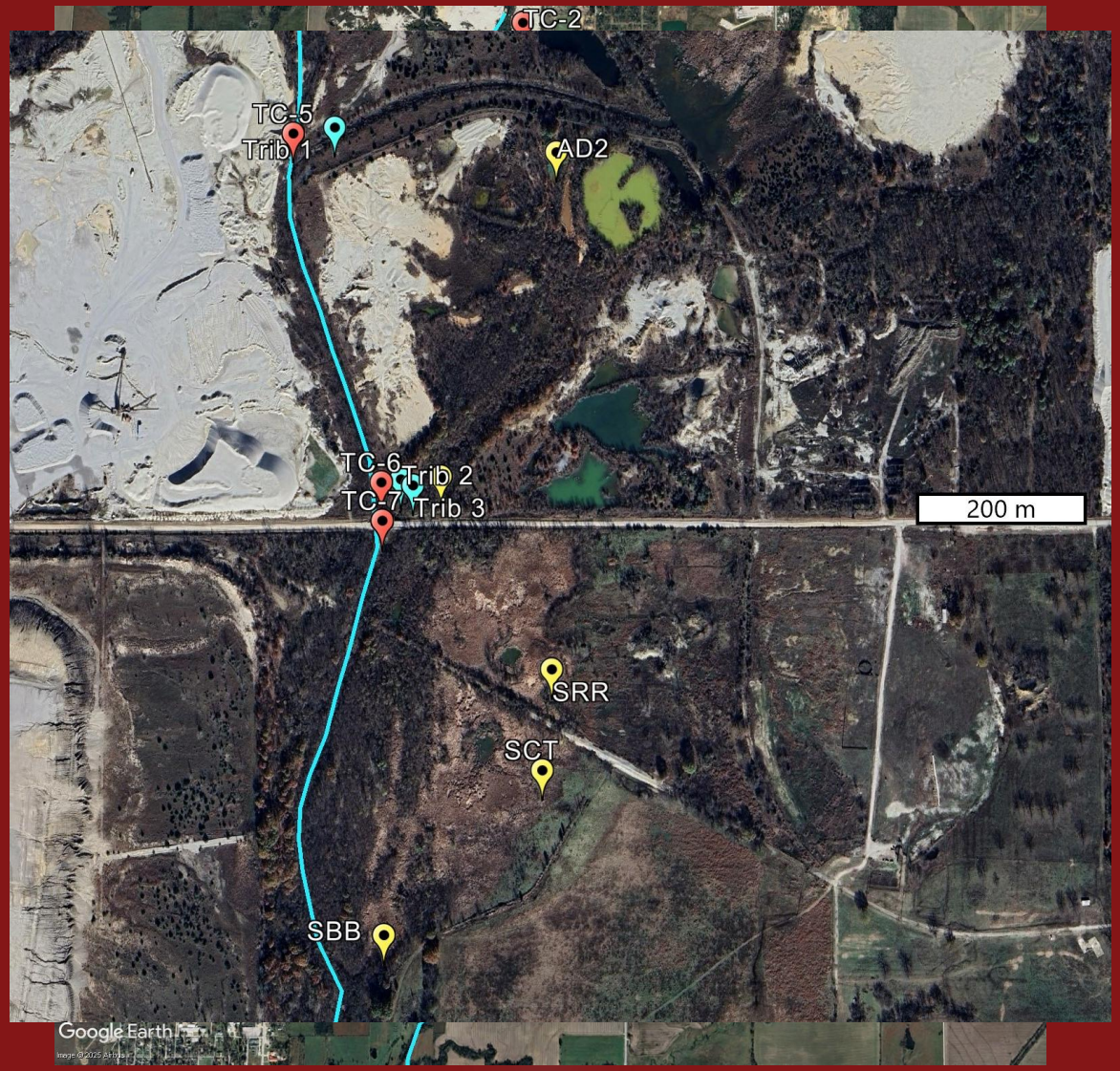
- Quantify loading of metals from different potential source areas within a mining-impacted watershed
- Quantify hyporheic and diffuse groundwater flow and their contributions of metals to a mining-impacted stream
- Document water quality and quantity of the perched aquifers located in waste rock piles

Diffuse Loading

Photo courtesy of Maria Nairn

Introduction and Methods

- Synoptic sampling
- March 2023 – August 2025
- Tar Creek
  - TC-2 – background
  - TC-3 – partial remediation
  - TC-4 – volunteer wetland
  - TC-5 – TC-6 – mine waste
  - TC-7 – TC-8 – mine waste and mine drainage
- Tributaries
  - Tributary 1 – mine waste-affected stormwater
  - Tributaries 2 & 3 – mine-drainage dominated
- Seeps

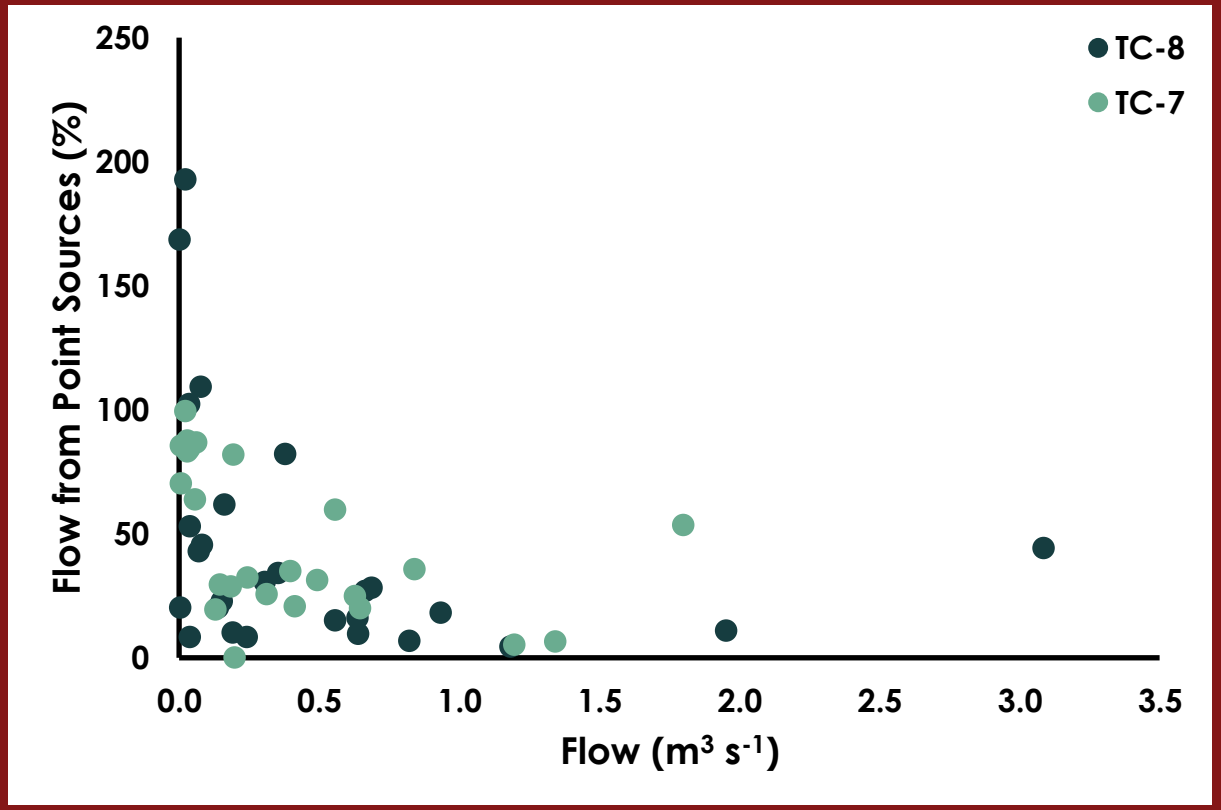


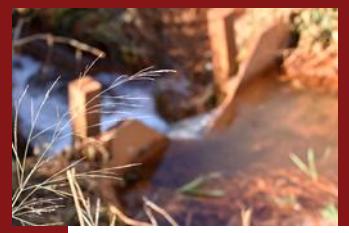
Introduction and Methods, continued

- Water quantity
  - ADV FlowTracker
  - USGS stream gage
- Water quality
  - Physiochemical parameters
  - Total and dissolved metals
  - Anions
- Measured and expected load calculations
  - Load = Concentration * Flow
  - Expected load = Upstream load + Tributary load

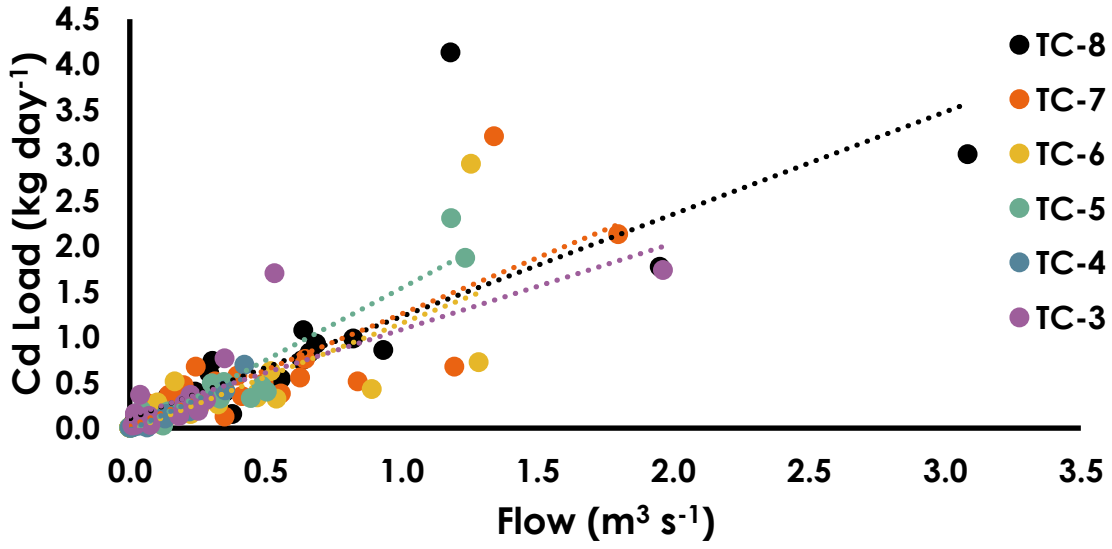
Water Quantity

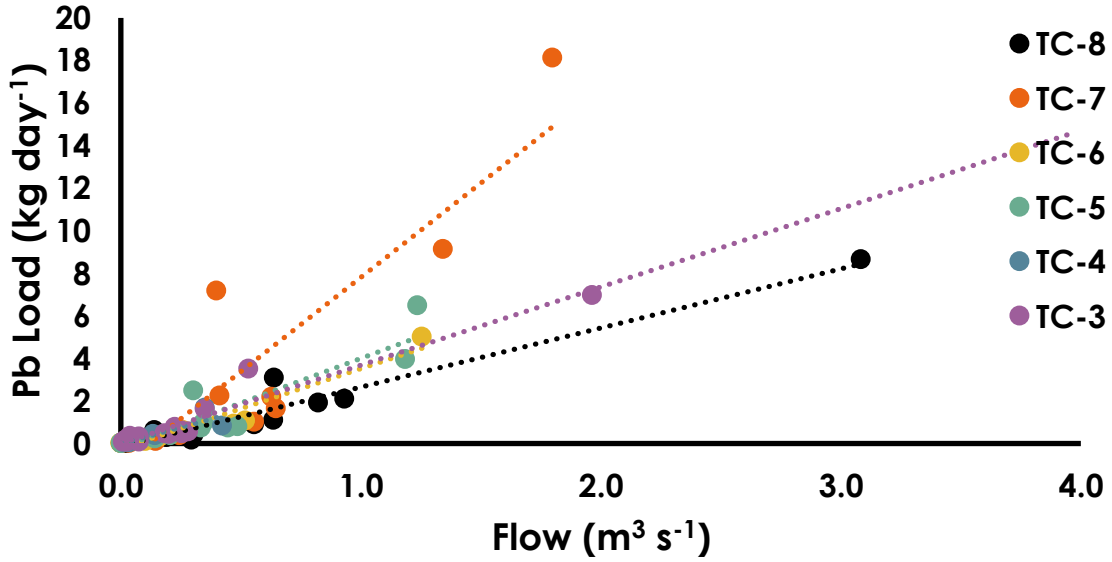
- Sampling events: flows at TC-8 between 0.001 and 3.1 m^3/s
  - 20 years of daily means from USGS – about 75th percentile
- Greater percent of flows from point sources in low flow events
  - Dry periods → low mine pool and little runoff





Loading


Cd Load (kg day-1)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Flow (m3 s-1)
TC-8
TC-7
TC-6
TC-5
TC-4
TC-3


Pb Load (kg day-1)
20
18
16
14
12
10
8
6
4
2
0
0.0
1.0
2.0
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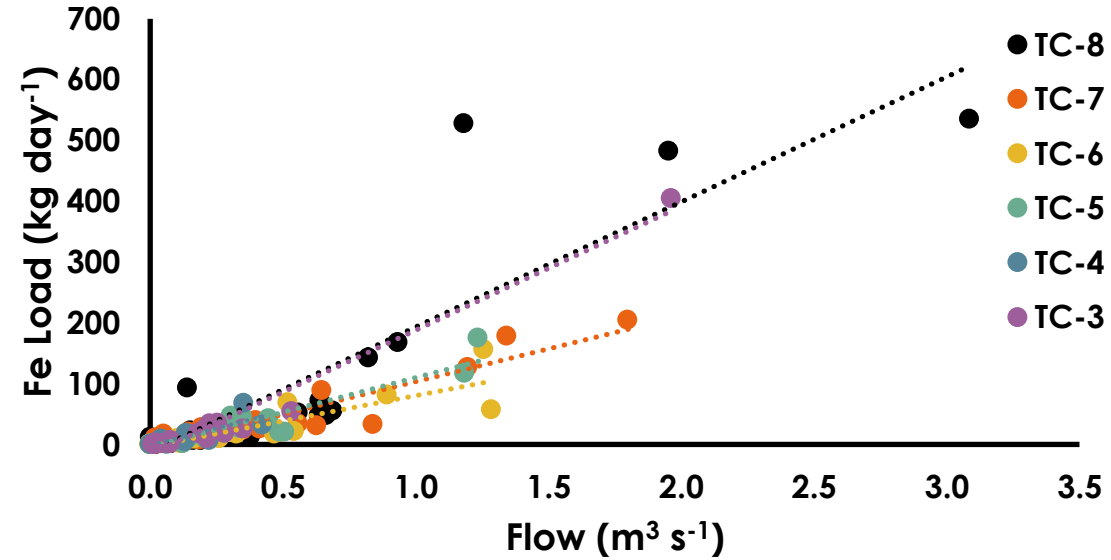
4.0
Flow (m3 s-1)
TC-8
TC-7
TC-6
TC-5
TC-4
TC-3


Fe Load (kg day-1)
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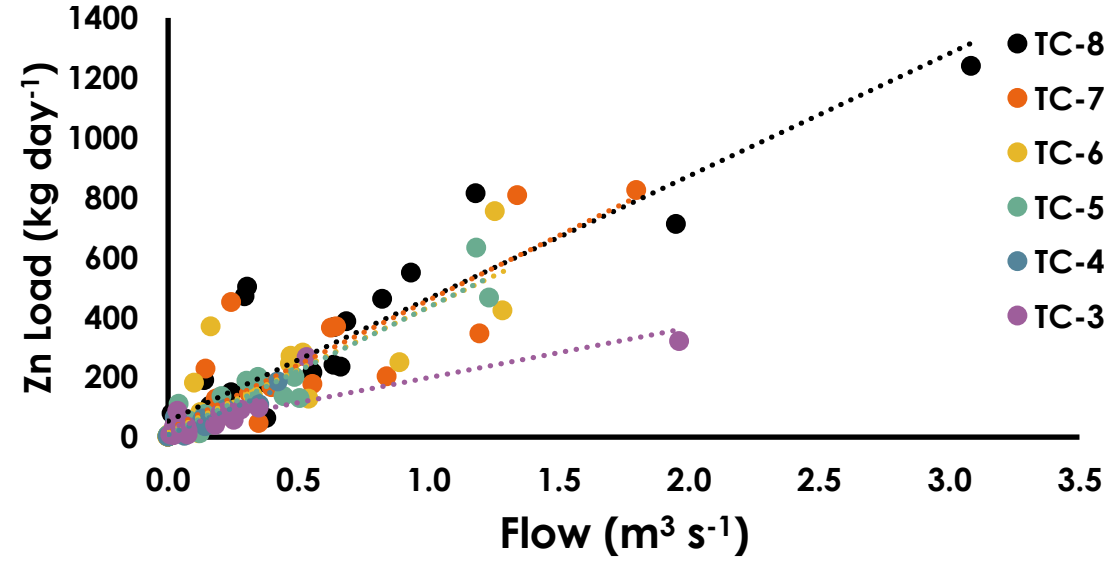
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Flow (m3 s-1)
TC-8
TC-7
TC-6
TC-5
TC-4
TC-3


Zn Load (kg day-1)
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1200
1000
800
600
400
200
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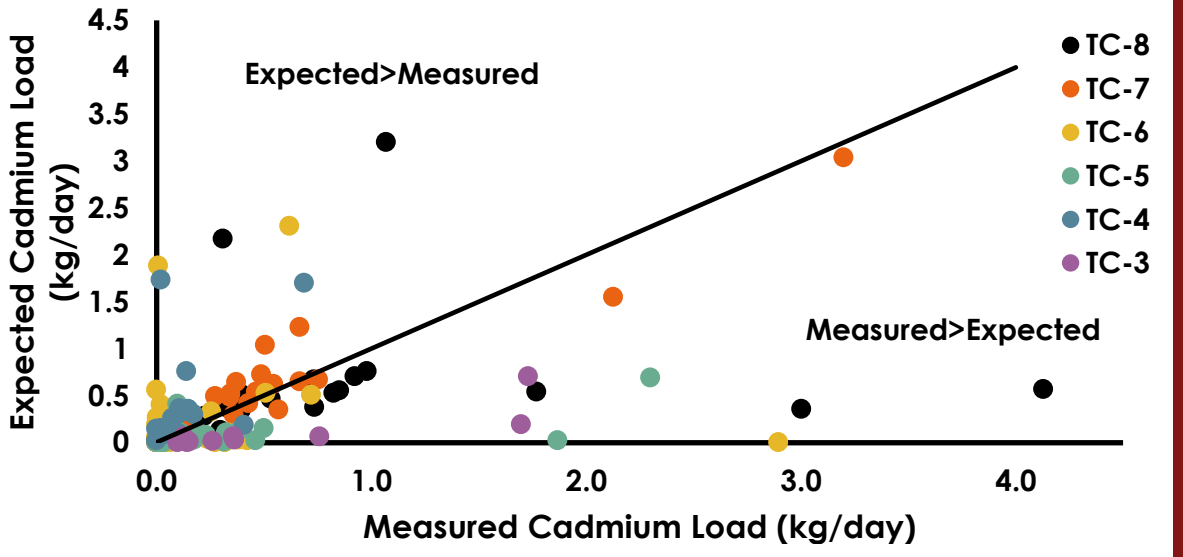
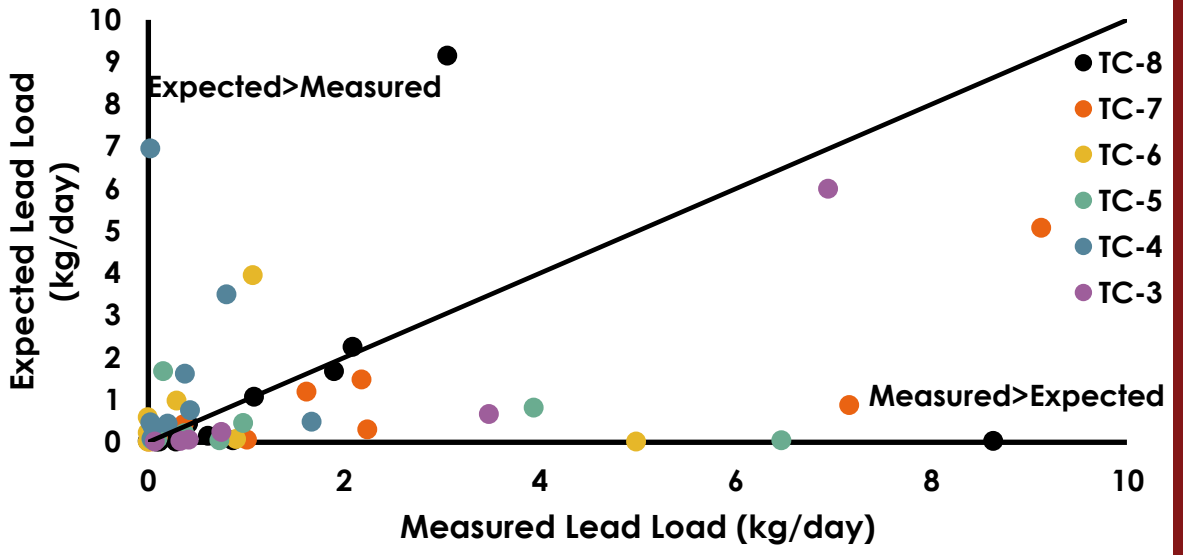
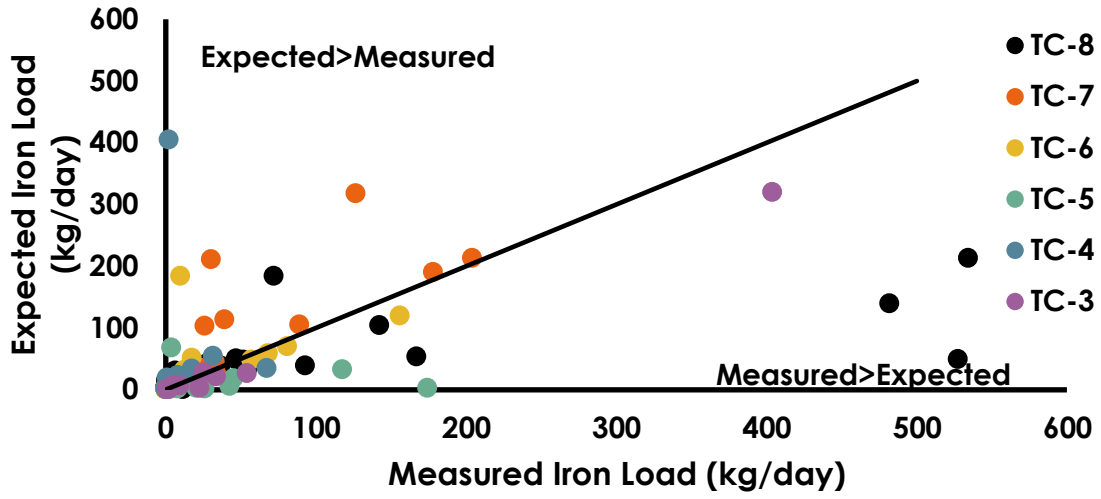
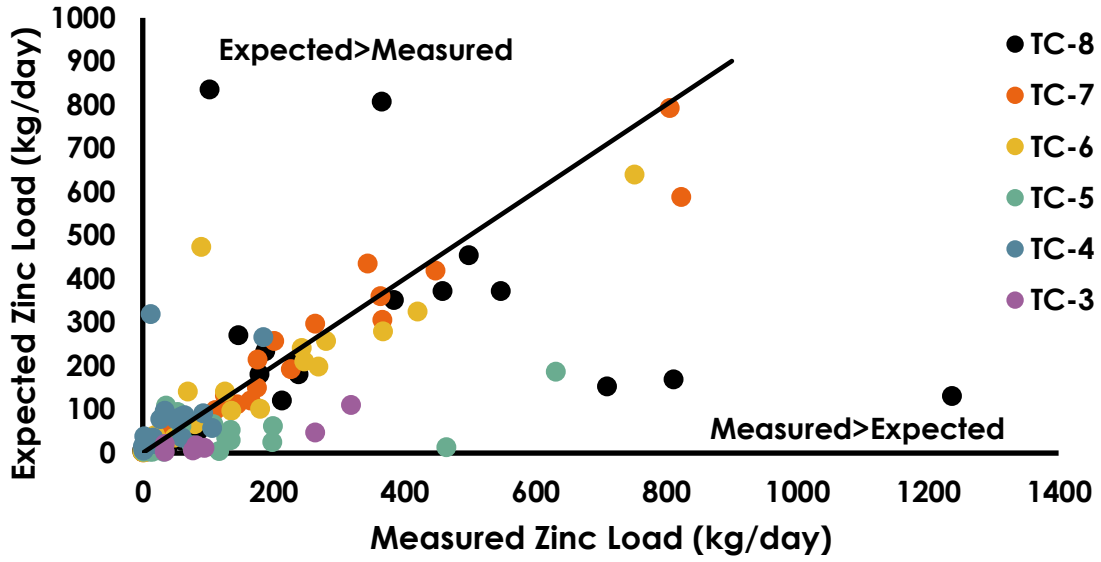
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Flow (m3 s-1)
TC-8
TC-7
TC-6
TC-5
TC-4
TC-3

Loading, continued









Loading: Mine Drainage vs. Runoff

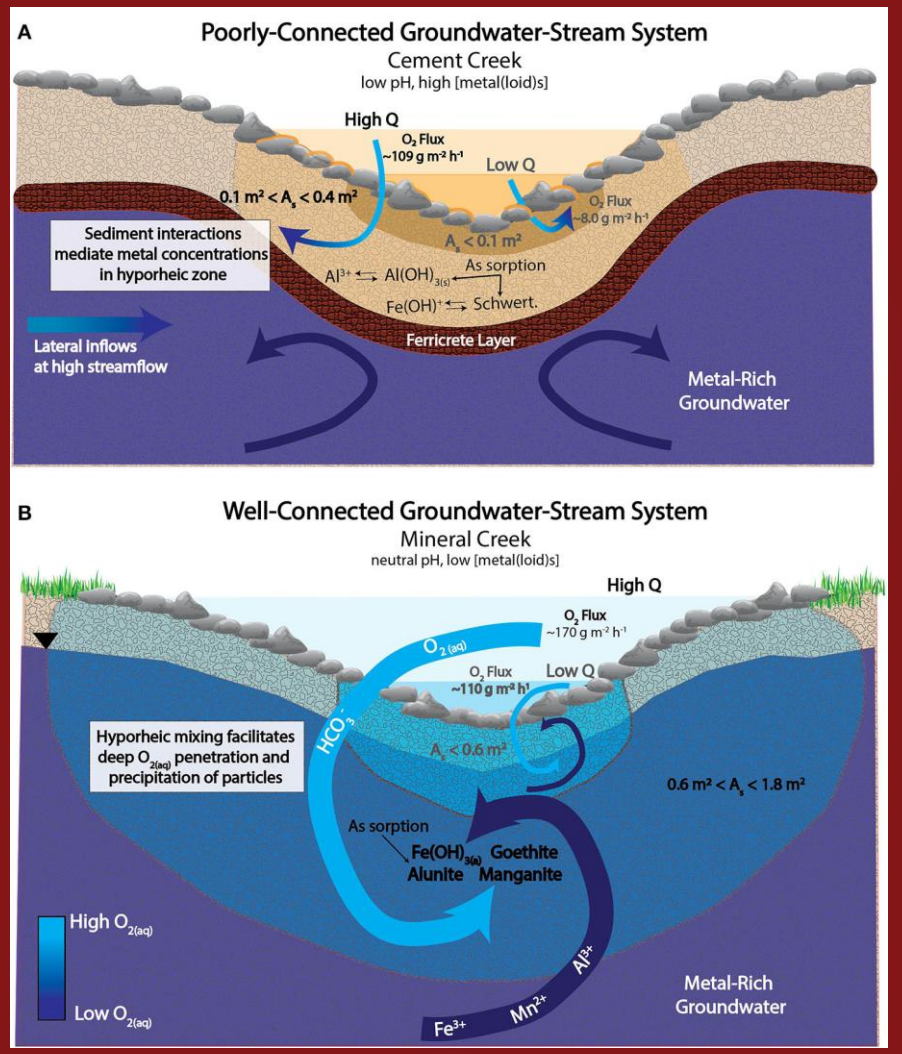
- Mine drainage more likely to be the source of iron and cadmium
- Runoff from mine waste more likely to be the source of lead (at TC-7) and zinc
- Remediation of mine drainage and mine waste are both necessary to improve water quality

Site - % of load from seeps	Cadmium	Iron	Lead	Zinc
TC-7 - > 50% seeps (n=28)	18	20	2	12
TC-8 - > 50% seeps (n=29)	16	23	16	12

Hyporheic Zone

Hyporheic Zone Introduction

- Mixing of surface water and groundwater below and adjacent to stream bed
- Varying exchange based on geomorphology and hydrology
- Redox gradient – biologically active and significant to water chemistry



From Hoagland et al. 2020

Methods

- Cross sections and depth profiles from 5 sites
  - Anions, total metals, filtered metals measured
  - Stream bed predominantly mine waste
  - Recently removed mine waste at TC-3
  - Volunteer wetland at TC-4
  - Mine drainage influence at TC-7
- Added deeper samples in last 3 months
- Measured hydraulic head in porewater

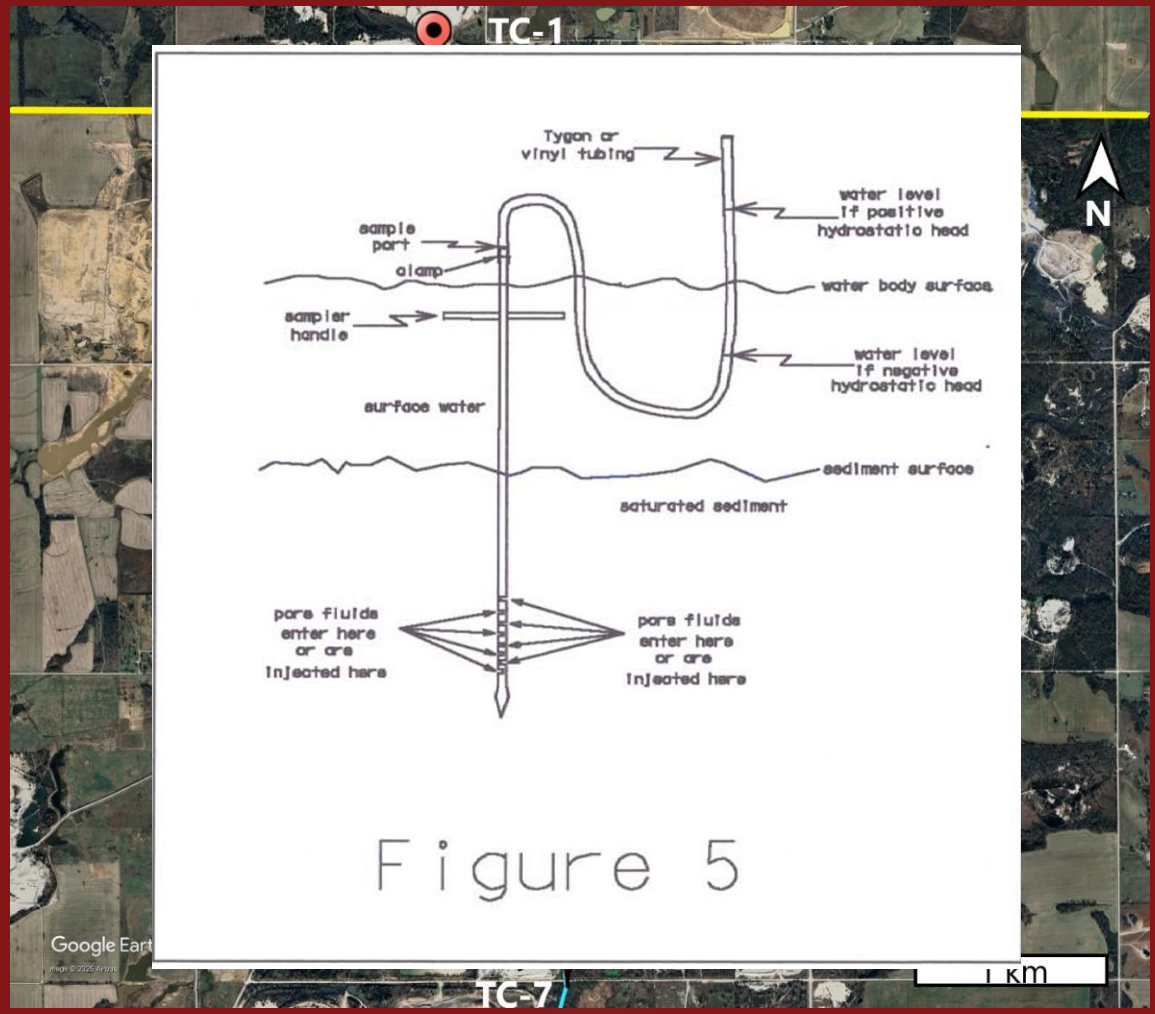
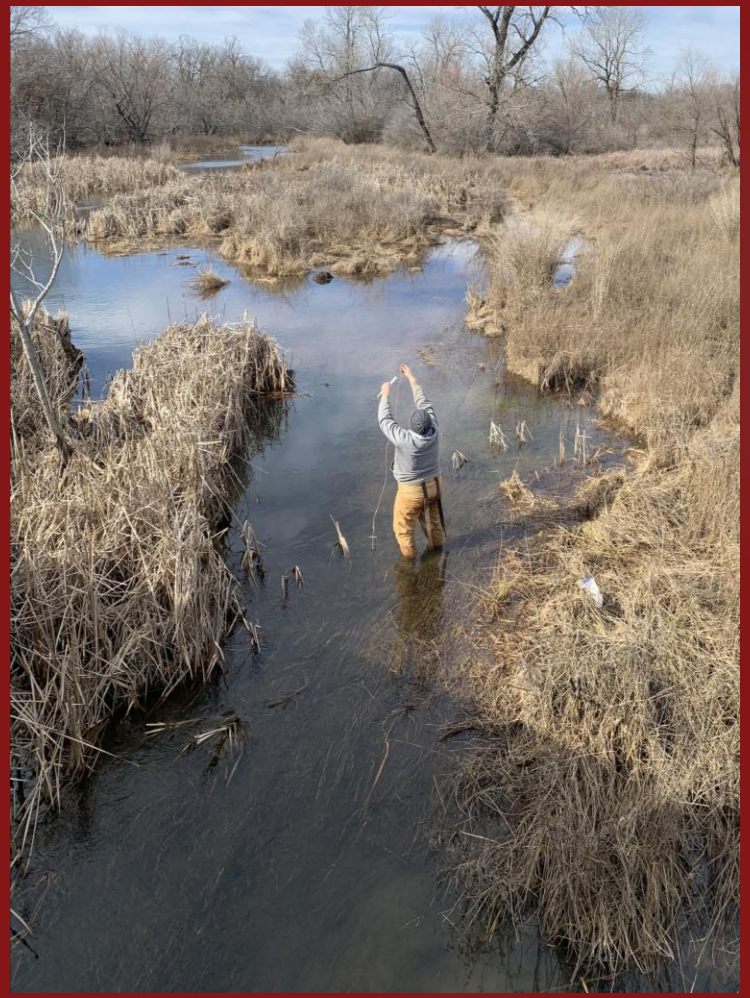


Diagram from mheproducts.com

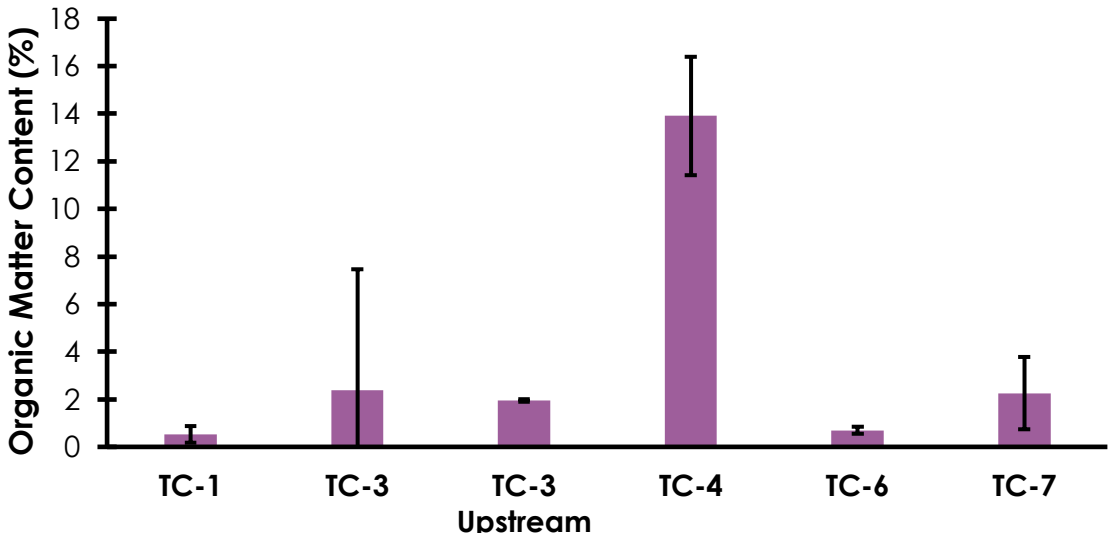
Hyporheic Zone Water

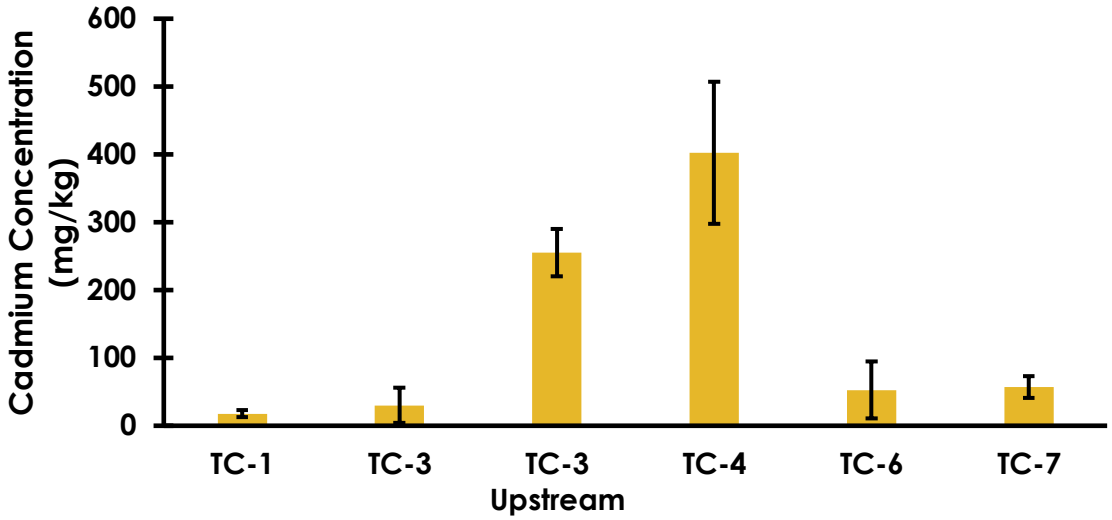
- Hydraulic head in subsurface usually equal to surface water level
  - Not a source or sink of metals
- Surface water and porewater showed different concentrations of metals
  - Concentration from evaporation
  - Dilution from rainfall
  - Sorption to sediment – TC-4

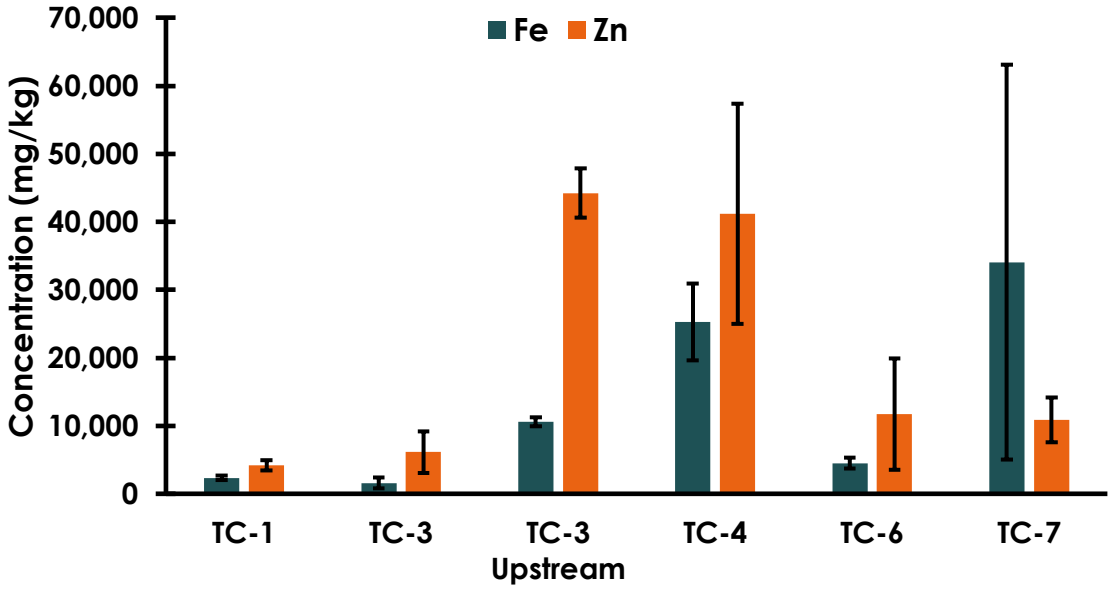


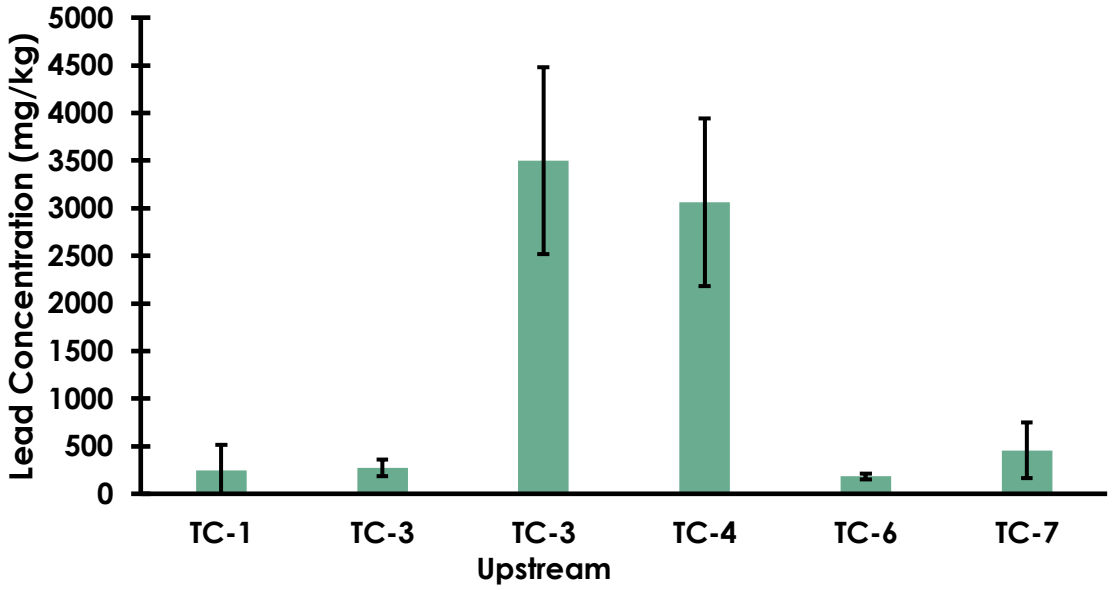
Picture courtesy of Sam Taylor

Hyporheic Zone Sediment









Hyporheic Zone Conclusions

- Hypothesis rejected
  - Hyporheic zone not a source or sink of metals
- Coarse grained mine waste in sediments at most sites
  - Water moves quickly
  - Few sites for sorption
- Some seasonal variation from evaporation and precipitation
- Thermal imagery may help locate areas influenced by diffuse groundwater
- Removal of mine waste from creek may disrupt steady-state conditions

Picture courtesy of Vikky Stallings

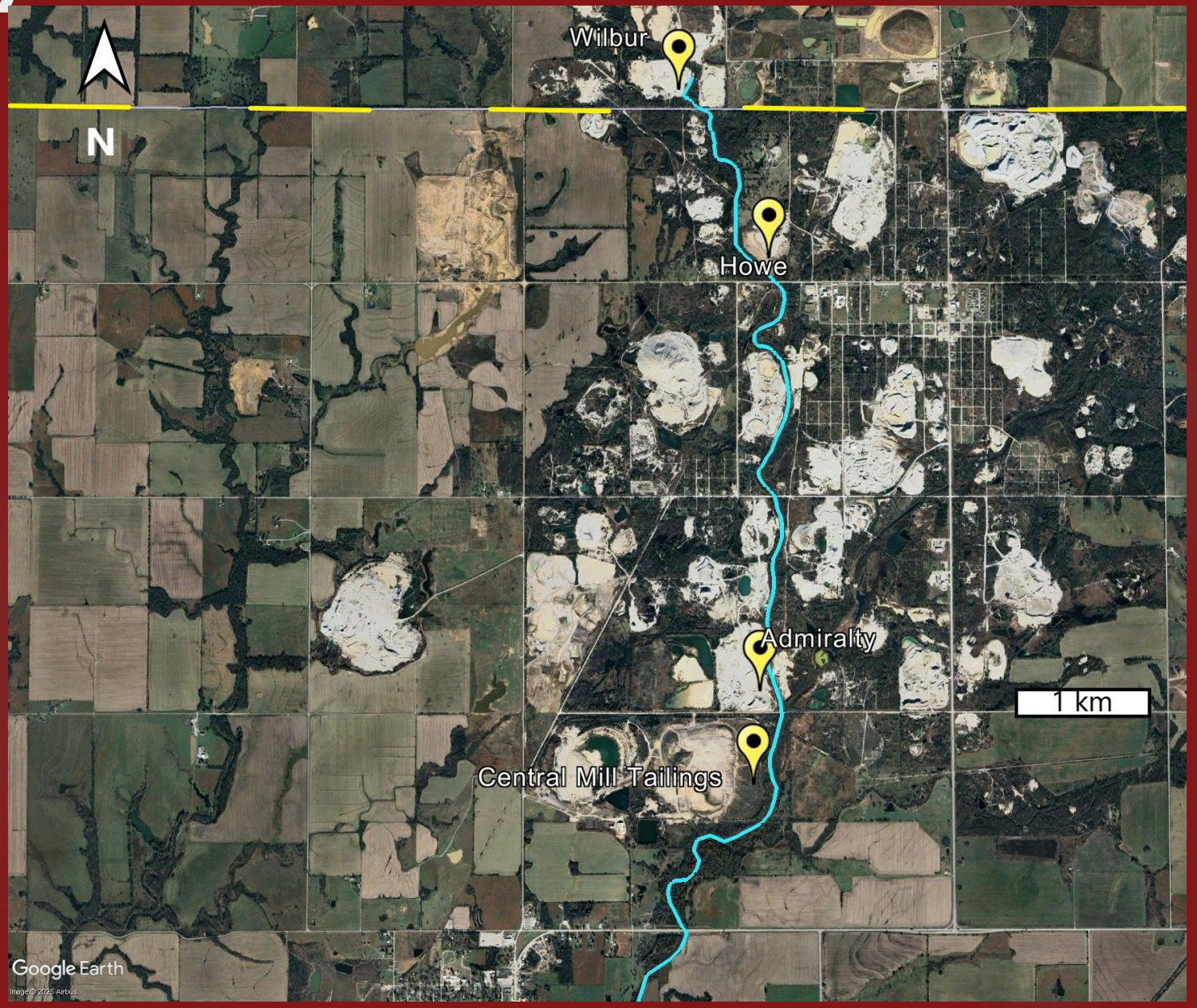
Mine Waste Hydrology

Introduction

- Rainwater infiltrates mine waste, forms perched aquifers
- Decreases peak flow in creek
- Increases interaction between mine waste and water
  - Influence on stream water quality
- Weathering of mine waste controlled by
  - Mineralogy
  - Geochemistry
  - Hydrogeology
  - Meteorology

Photo courtesy of Vikky Stallings

Study Areas


N
Wilbur
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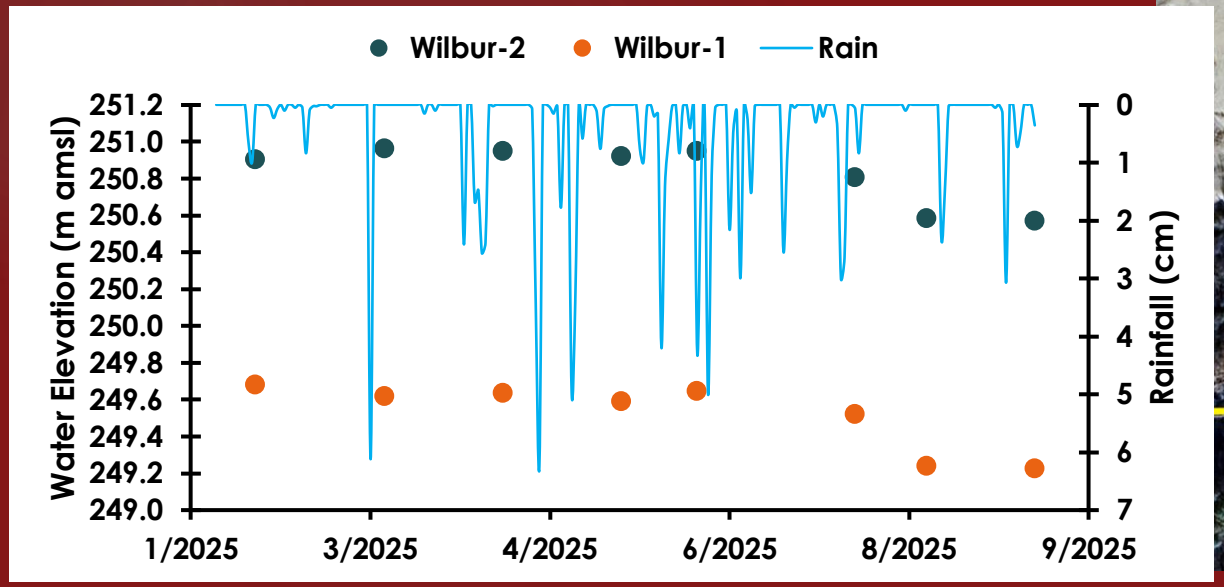
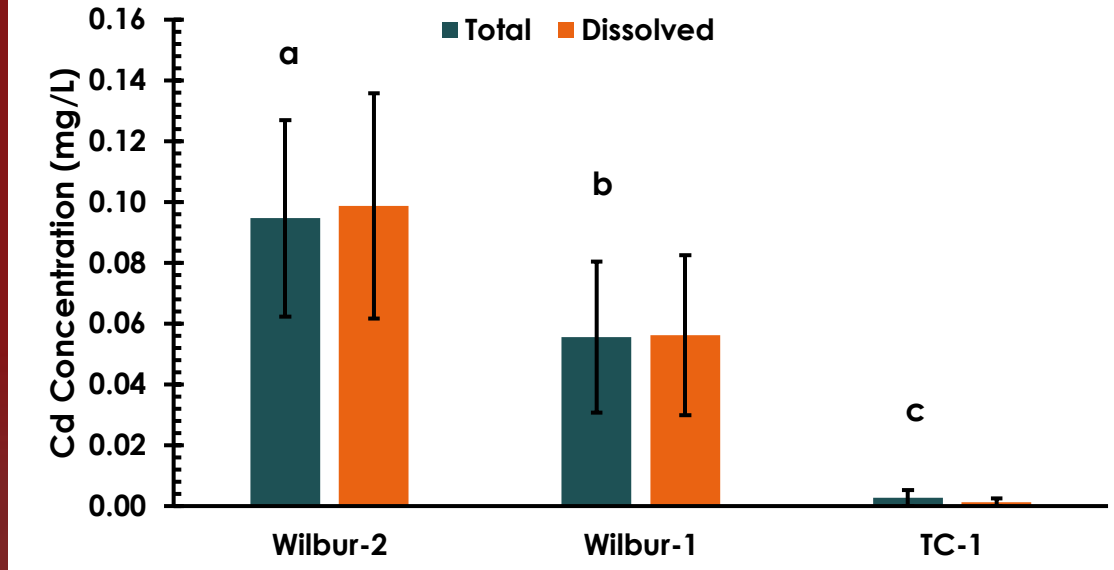
Central Mill Tailings
1 km
Google Earth

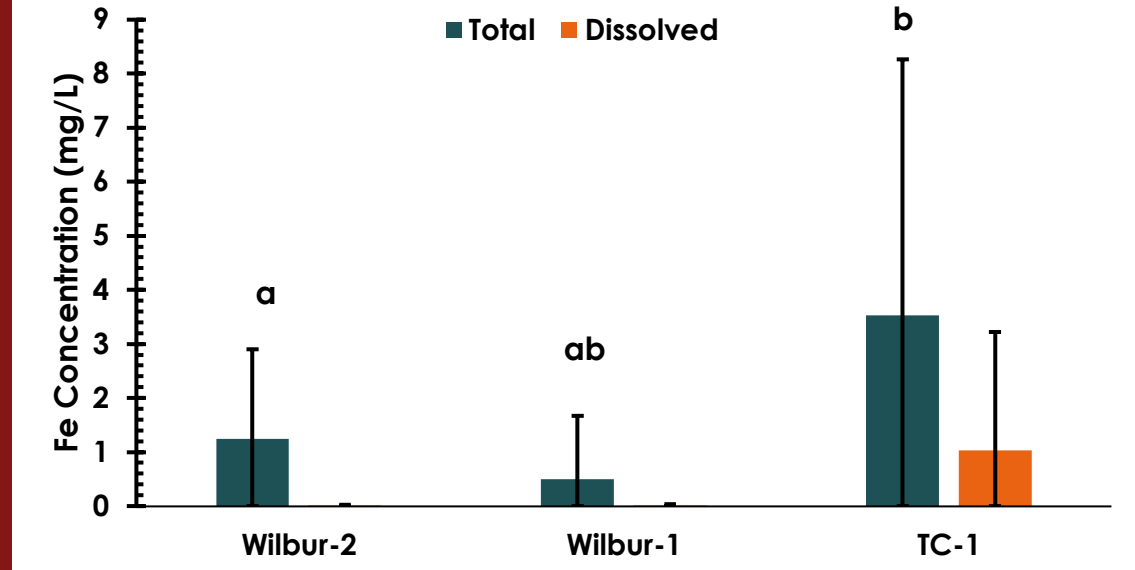
Study Areas – Wilbur

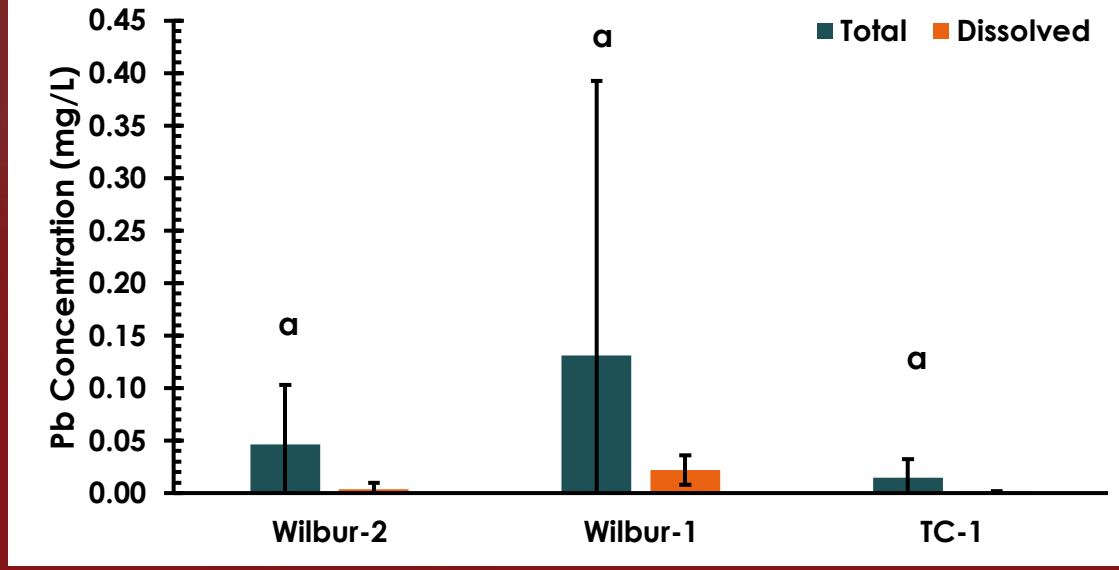
- Undisturbed mine waste
  - Two wells
  - Surface water sample TC-1

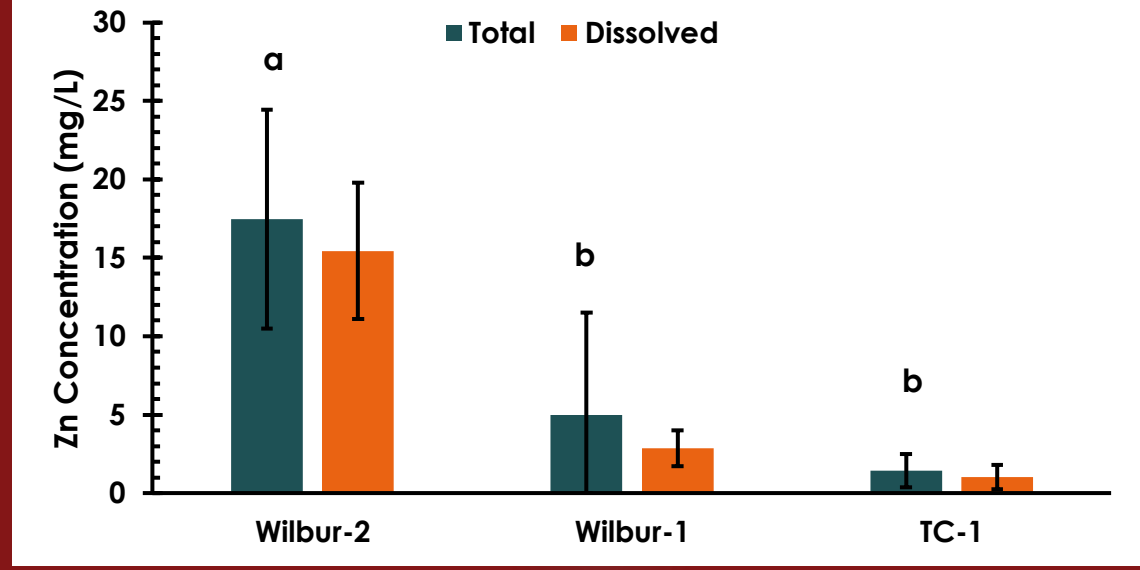


Wilbur Water Quality



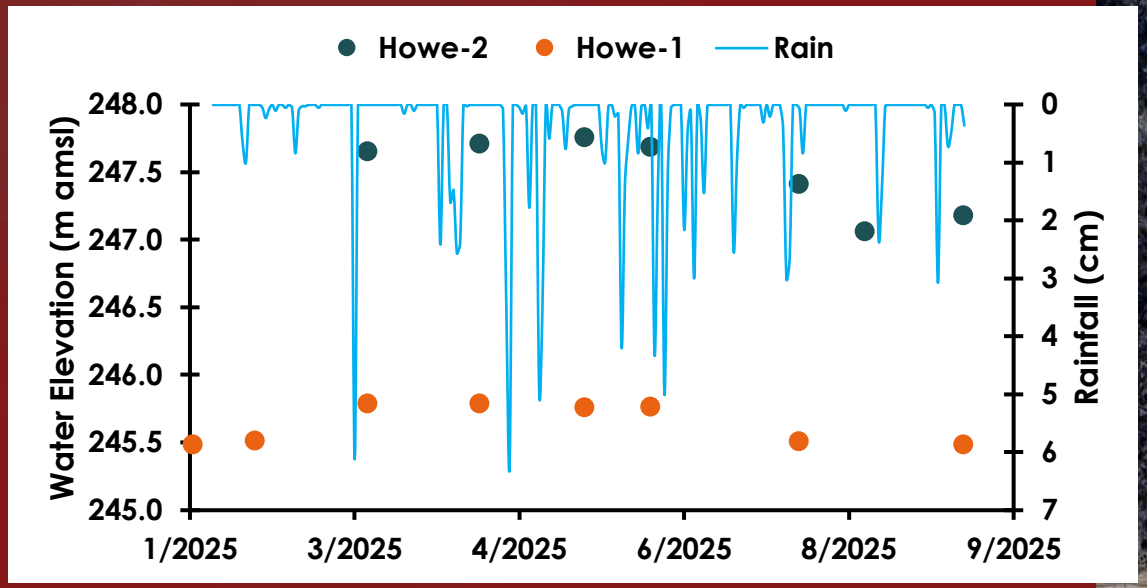




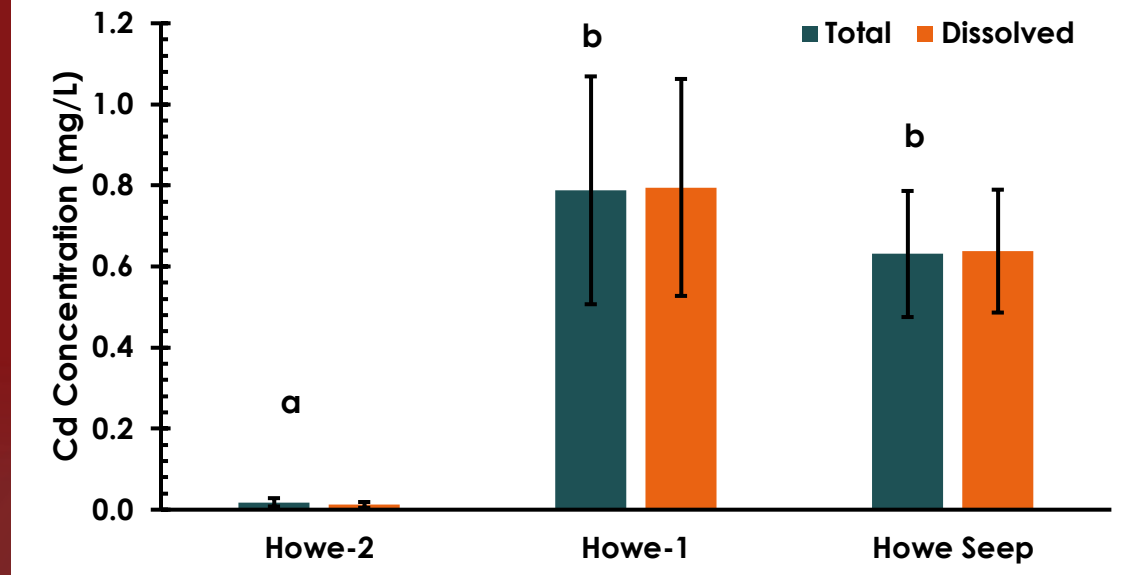


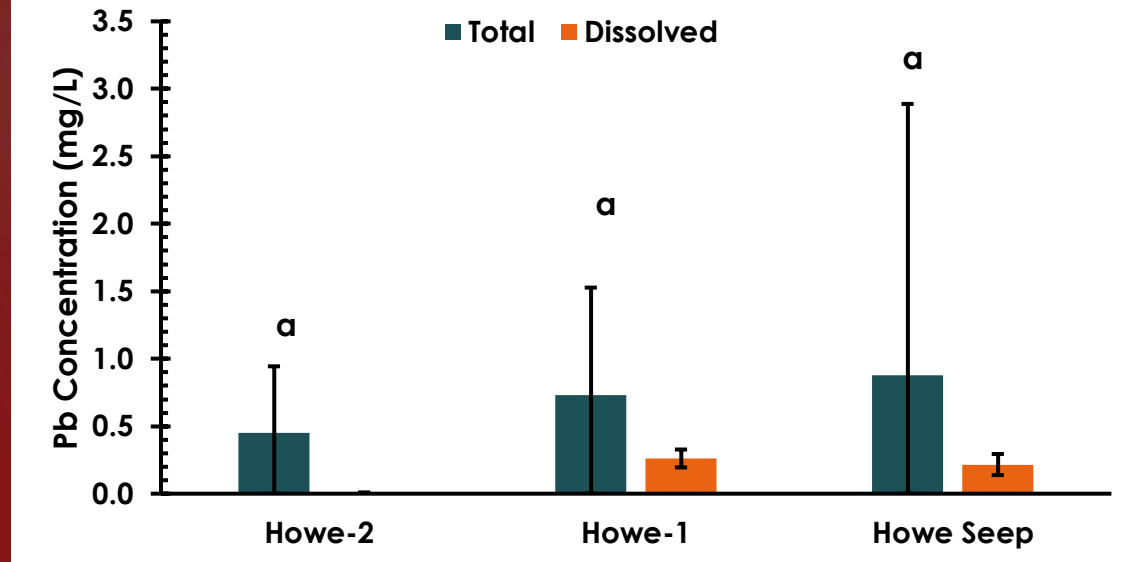
Study Areas – Howe

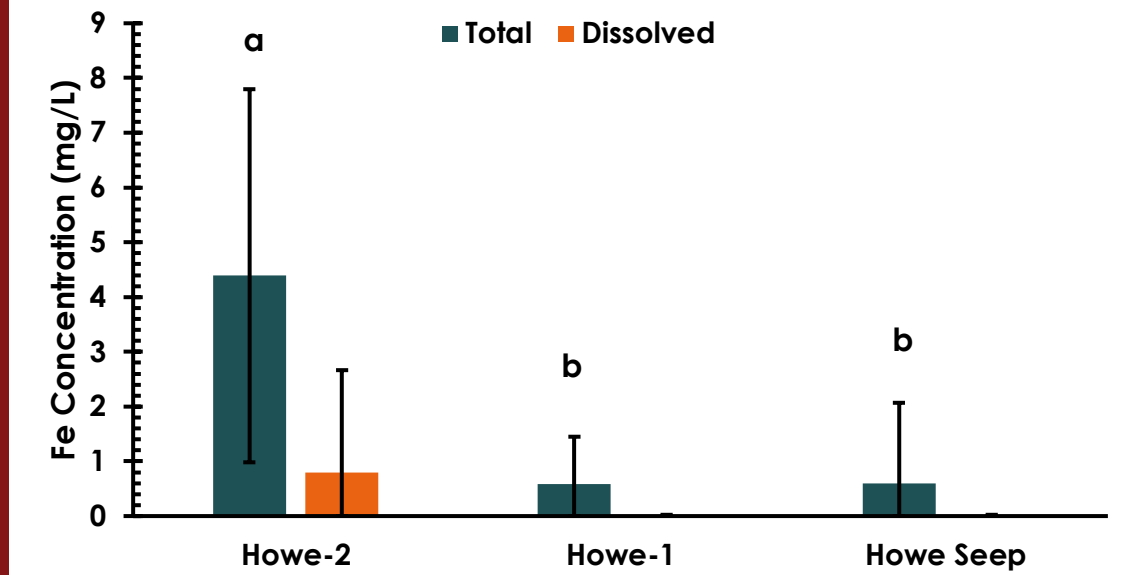
- Partial remediation
  - Two wells
  - Seep from base of mine waste pile
  - Autosampler

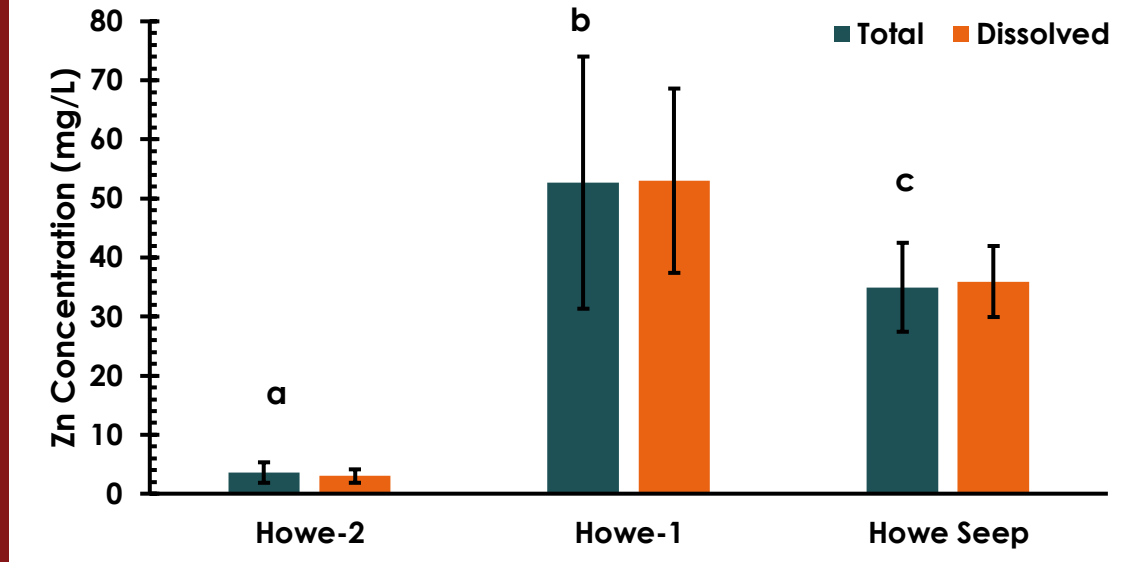


Howe Water Quality



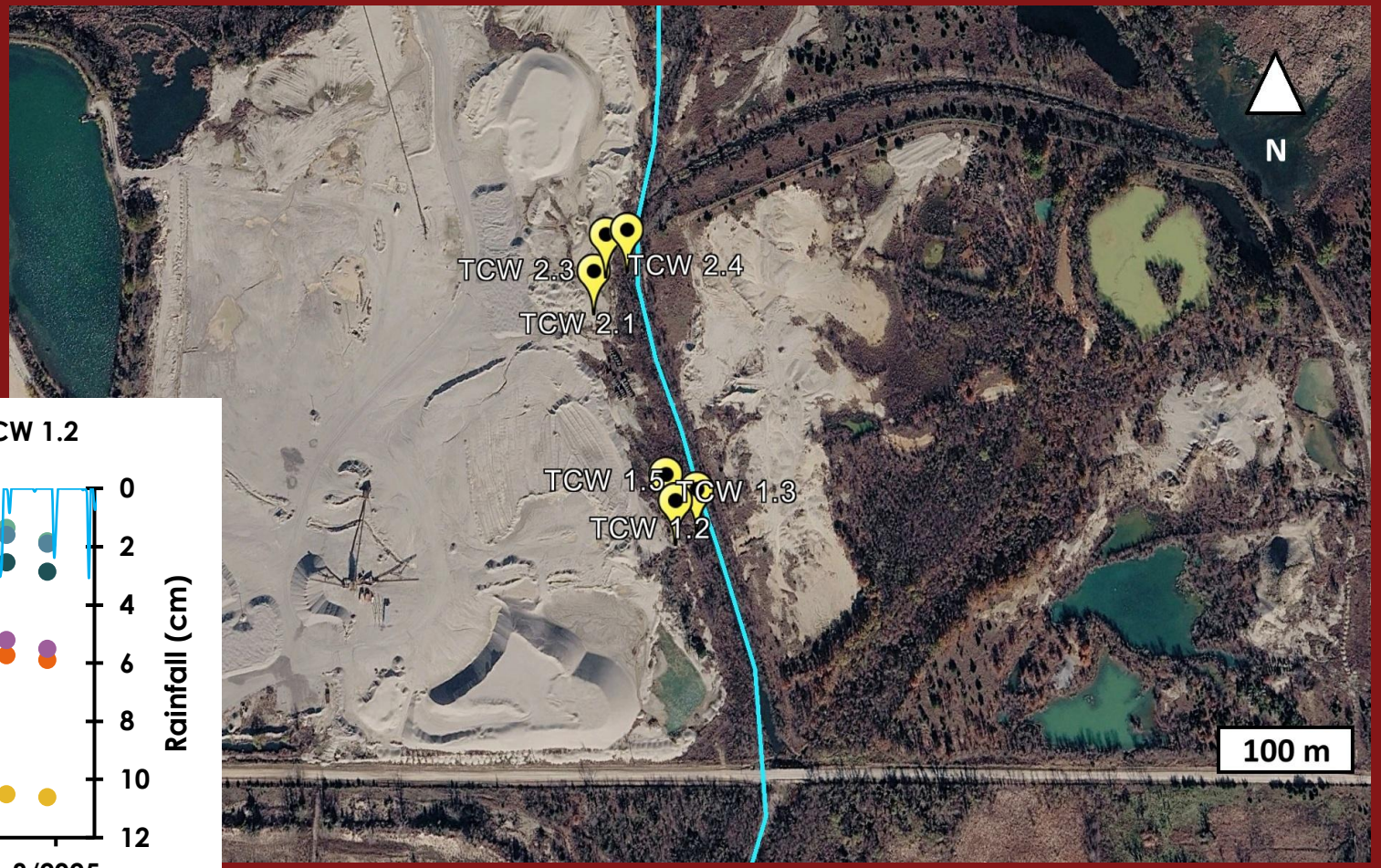


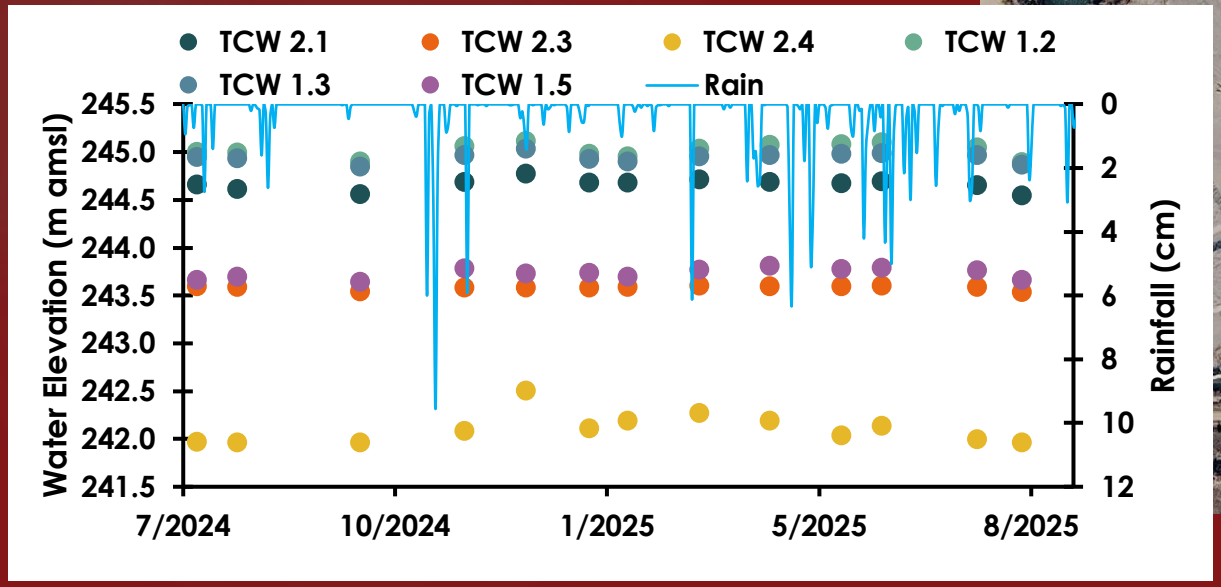




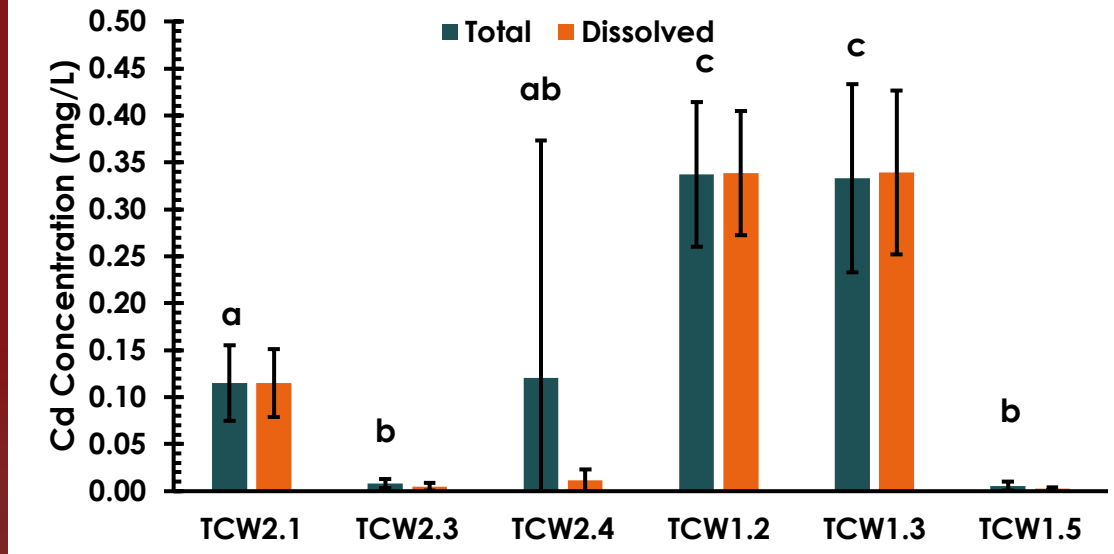
Study Areas – Admiralty

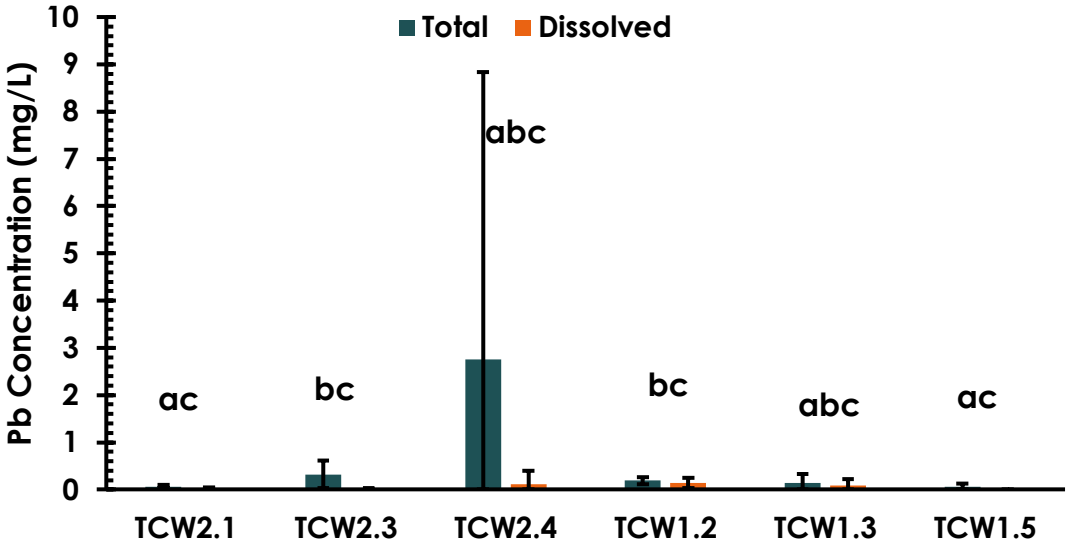
- Sieving and selective removal
  - Six wells
  - Autosampler

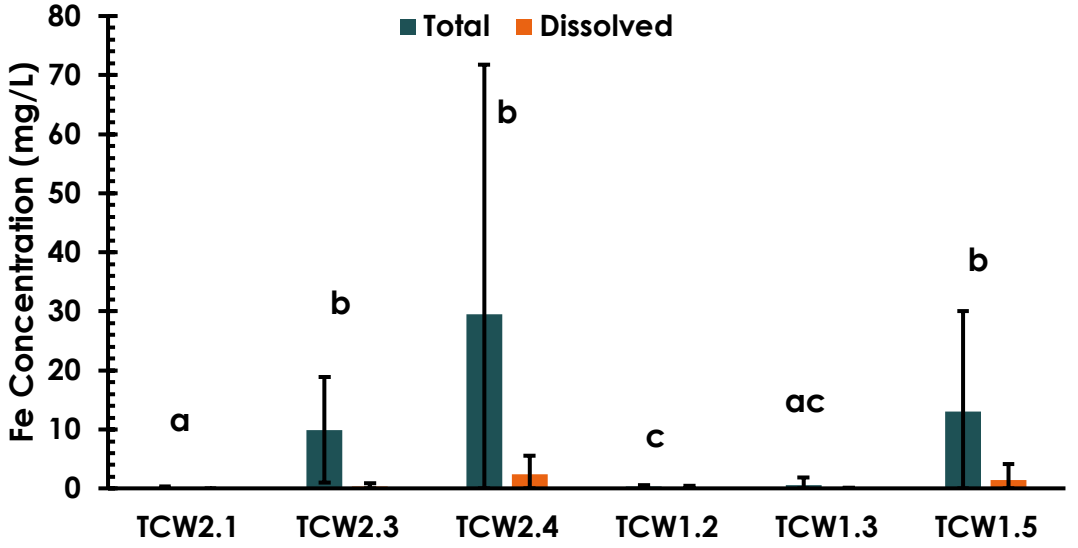


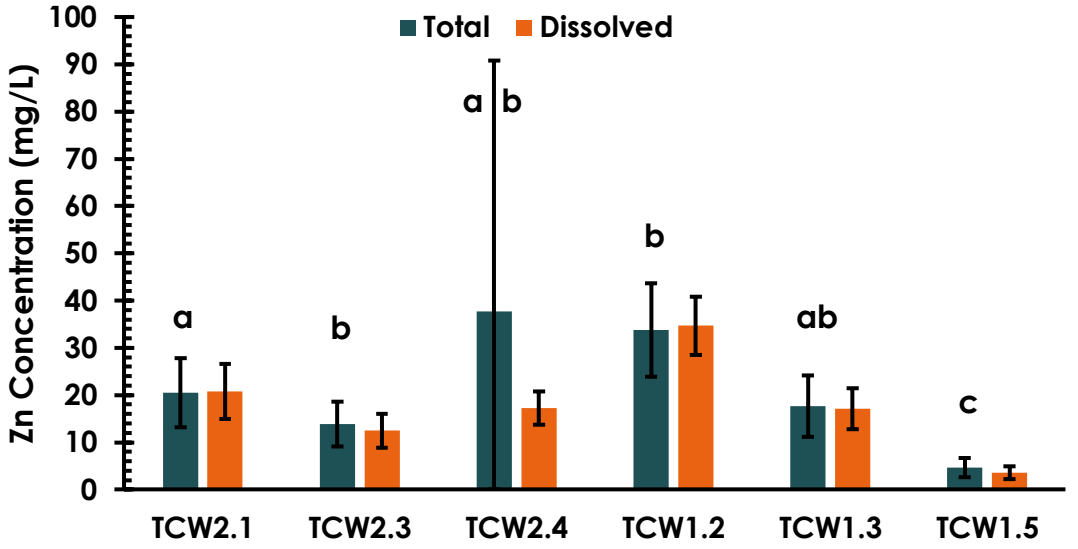


Admiralty Water Quality



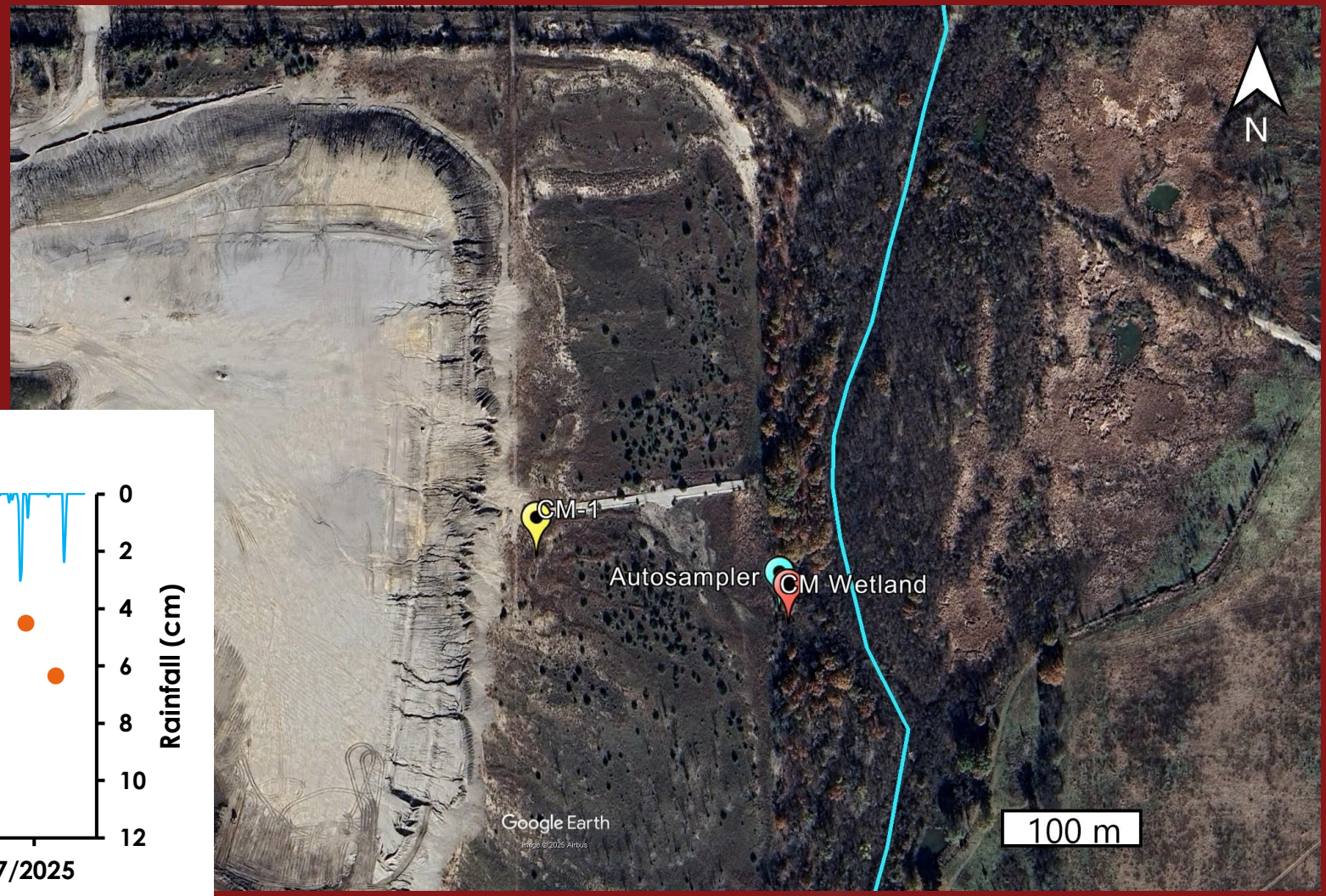


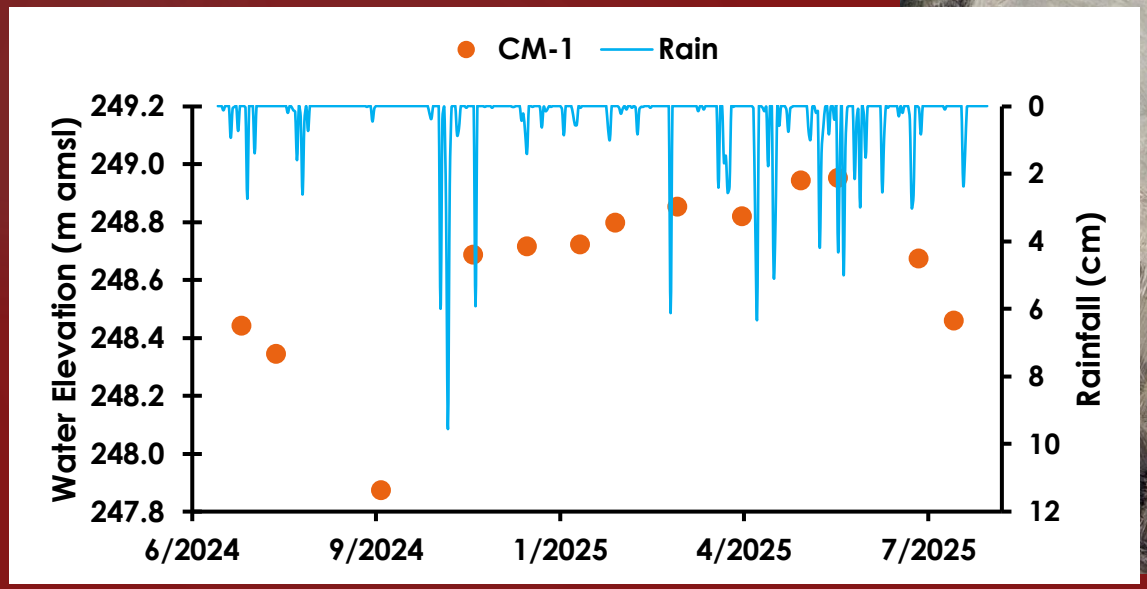




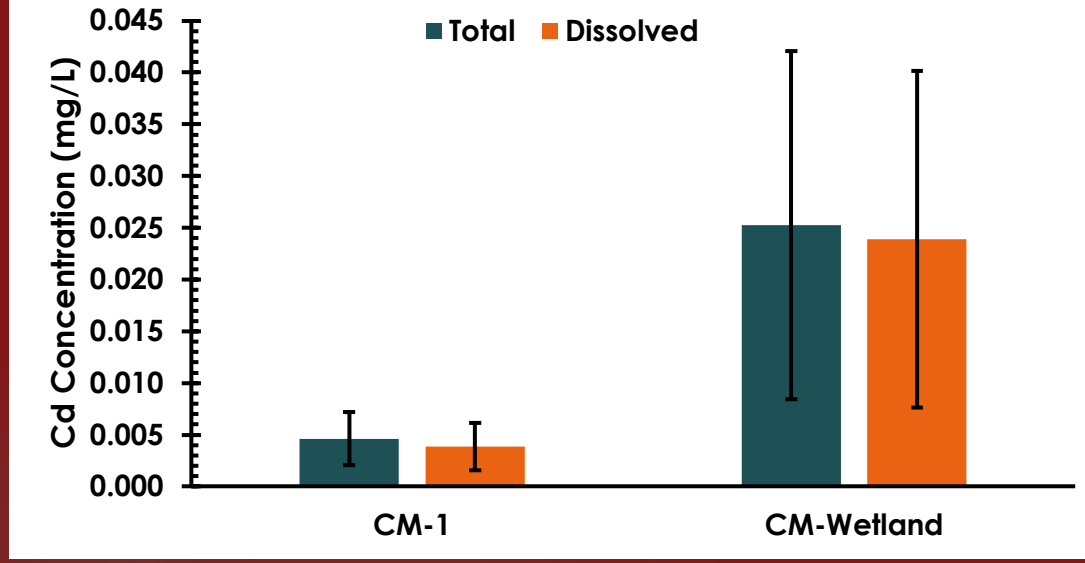
Study Areas – Central Mill

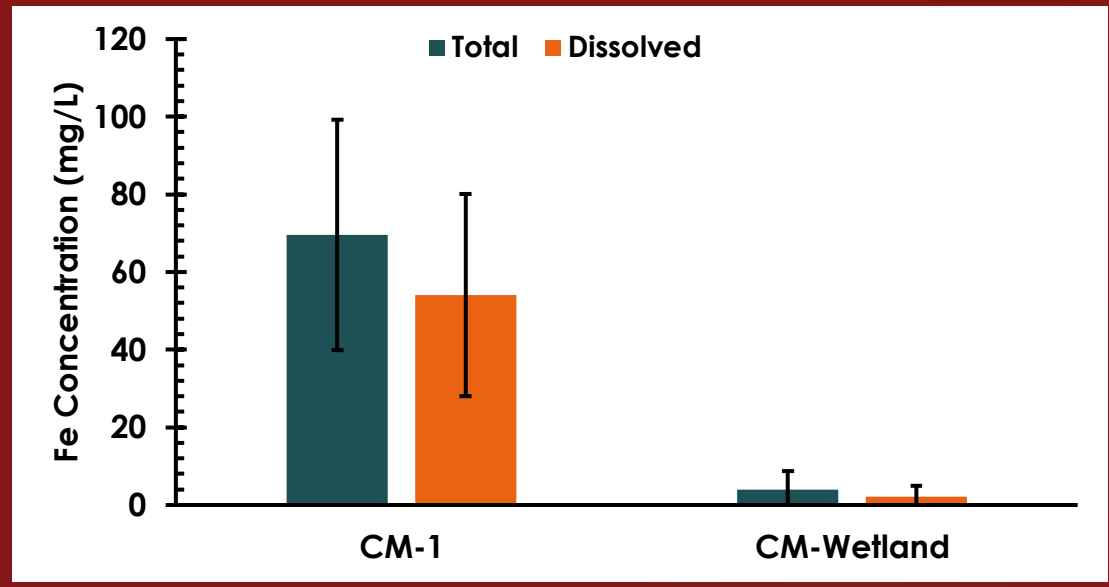
- Tailings impoundment
  - One well
  - Autosampler

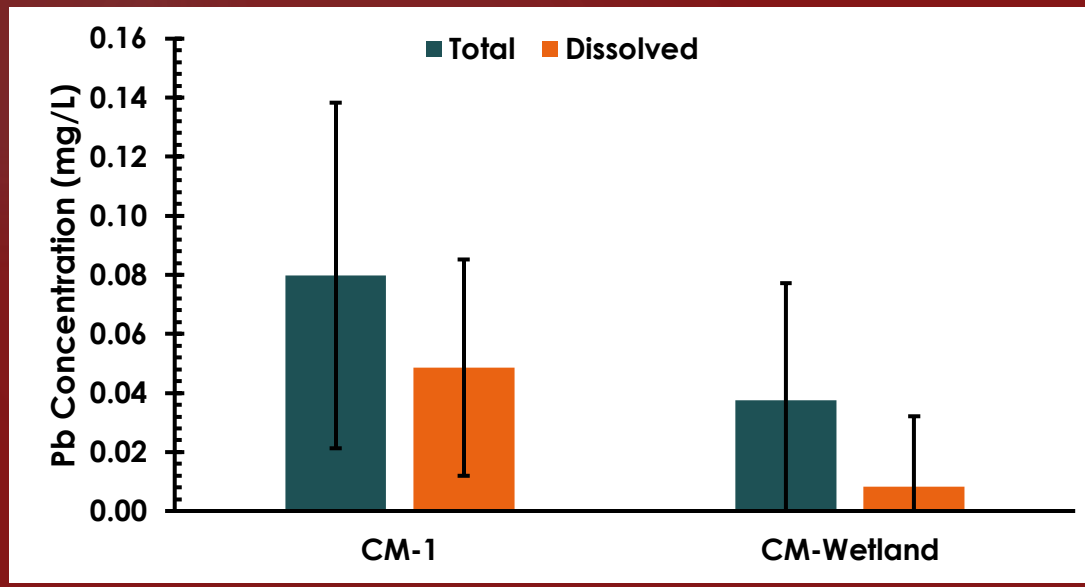


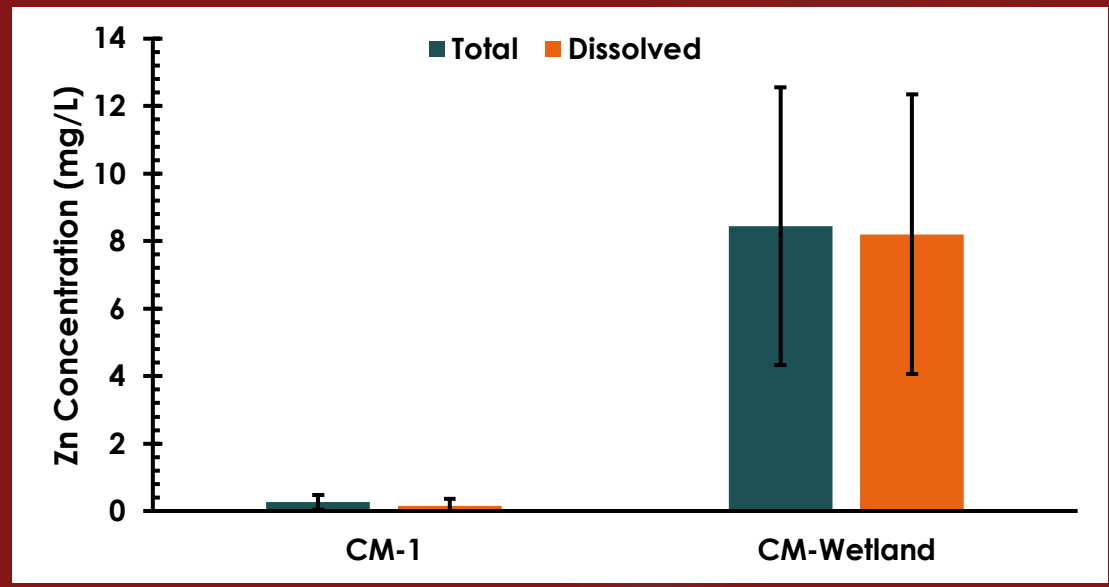


Central Mill Water Quality



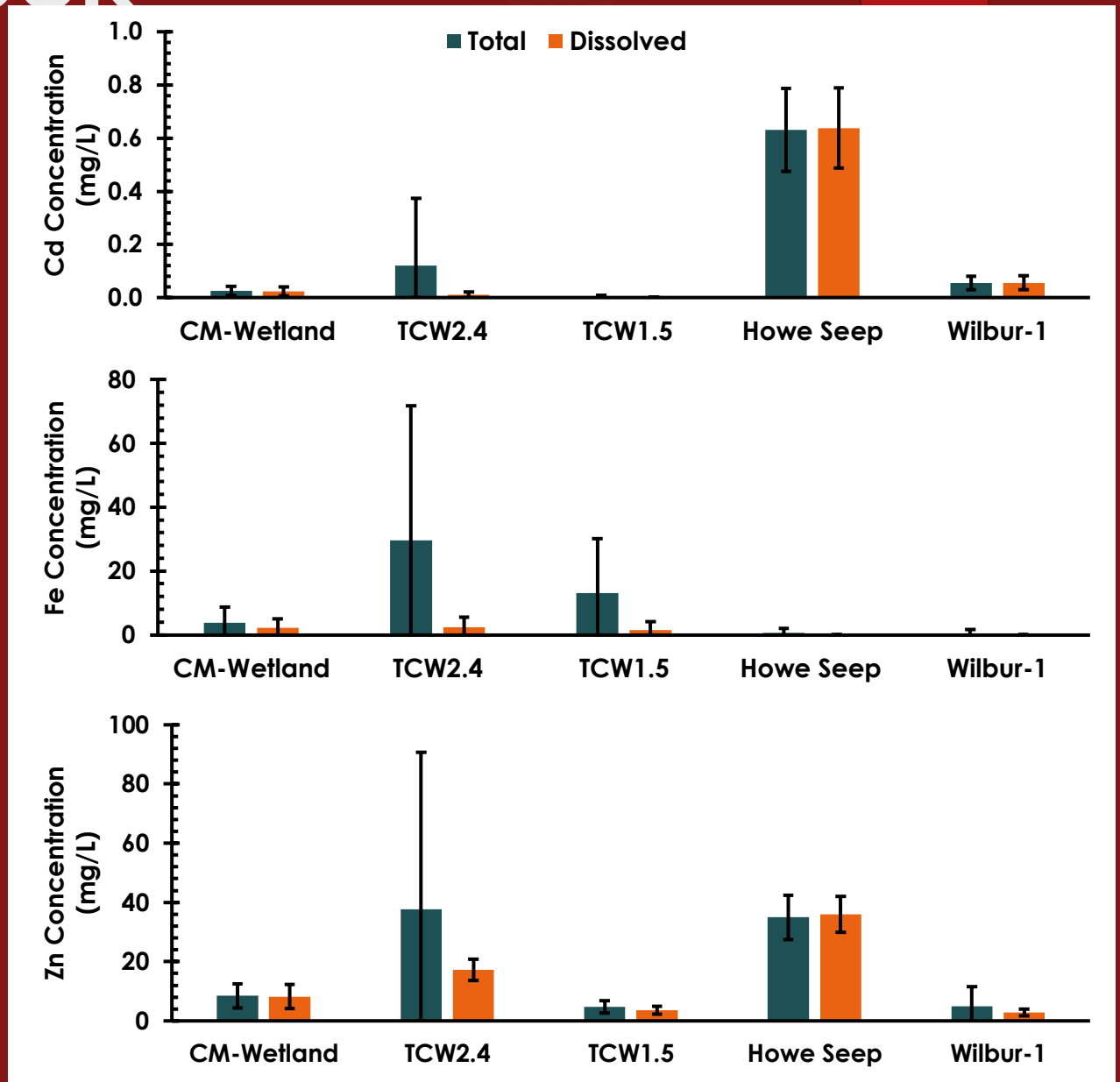






Effect on Tar Creek

- Sampling points closest to creek
  - Greatest [Cd] at Howe
  - Greatest [Fe] at Admiralty
  - Greatest [Zn] at Howe and Admiralty
  - Lead similar at all sites
- Hypothesis rejected
  - None of the examined piles clearly contributed more to metals loads
  - Results from diffuse loading indicate Admiralty is not a big contributor



Conclusions

Hypotheses Revisited

- Mine drainage seeps, when flowing, contribute most of the daily metals load to the stream as they add large volumes of water with elevated metal concentrations
- Hyporheic exchange contributes greater metal concentrations in seasons when the water table is higher than it does during drier periods due to increased infiltration and reductive dissolution
- Metals loading to the stream from mine waste processed by size sorting will exceed loading from unprocessed waste rock and tailings, due to concentrations of finer materials and greater exposure to oxygen, respectively

- Partially accepted. True for cadmium, iron, and lead, but not zinc
- Not accepted. Hyporheic zone neither source nor sink of metals
- Not accepted. Partially remediated mine waste responsible for more cadmium and zinc loading, no difference in lead concentrations

Future Work and Recommendations

- Removal of mine waste and treatment of mine drainage are both important
- Diffuse groundwater contributions to Tar Creek not consequential
  - Hyporheic zone may become a metals source during remediation
- Riparian buffers on mine waste protect surface water
  - Should be left as long as possible during mine waste removal

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Thank you!

QUESTIONS?

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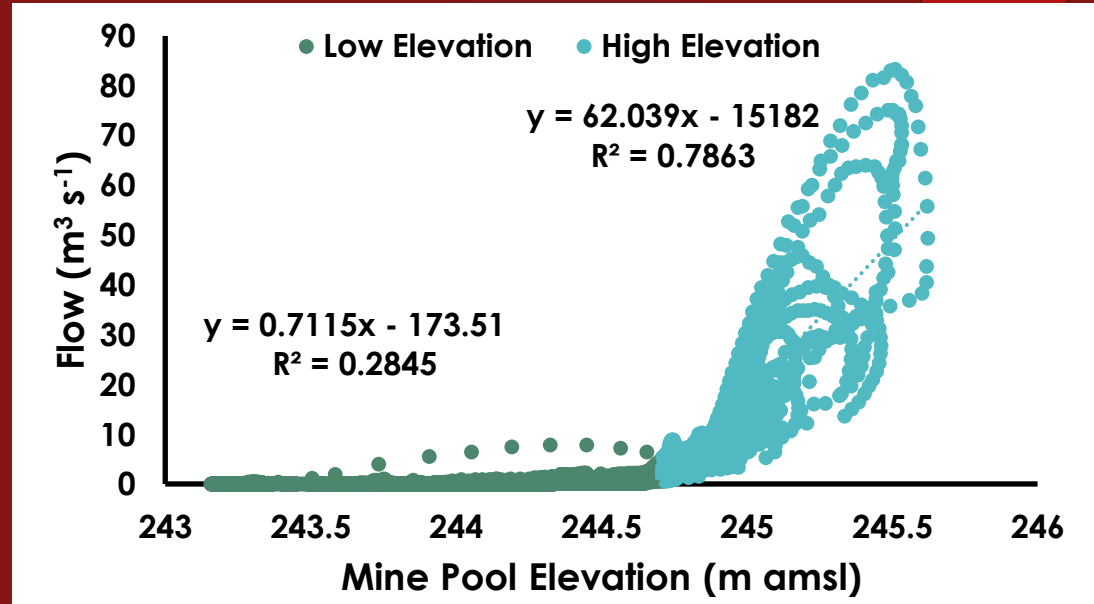
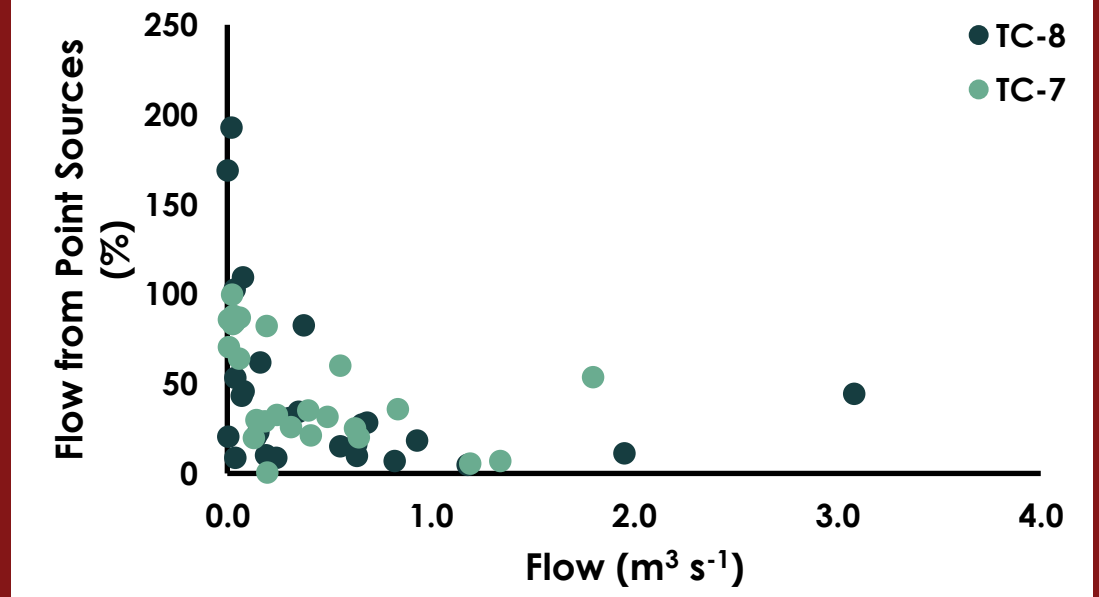
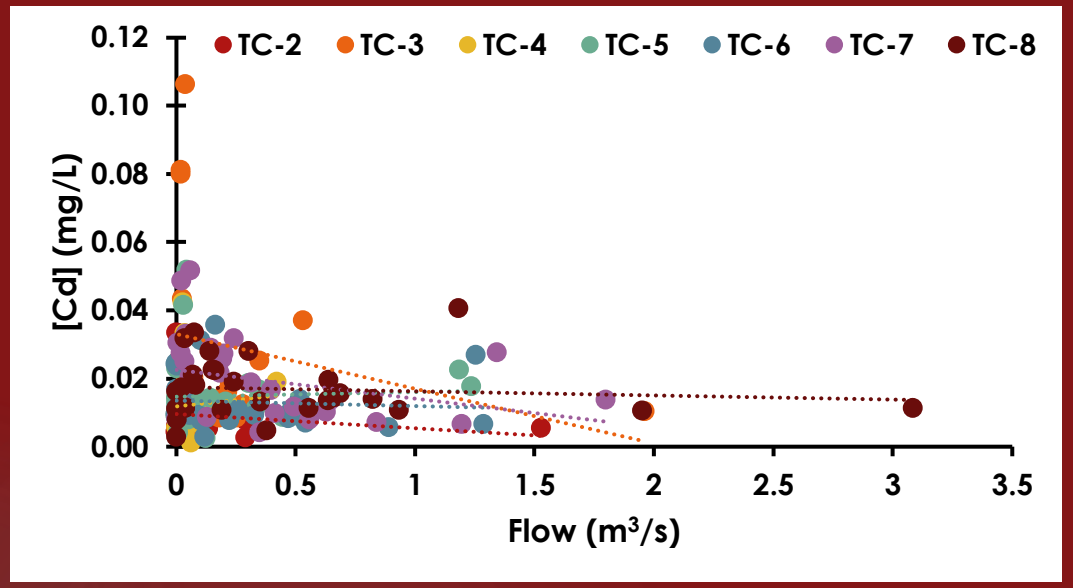
Water Quantity

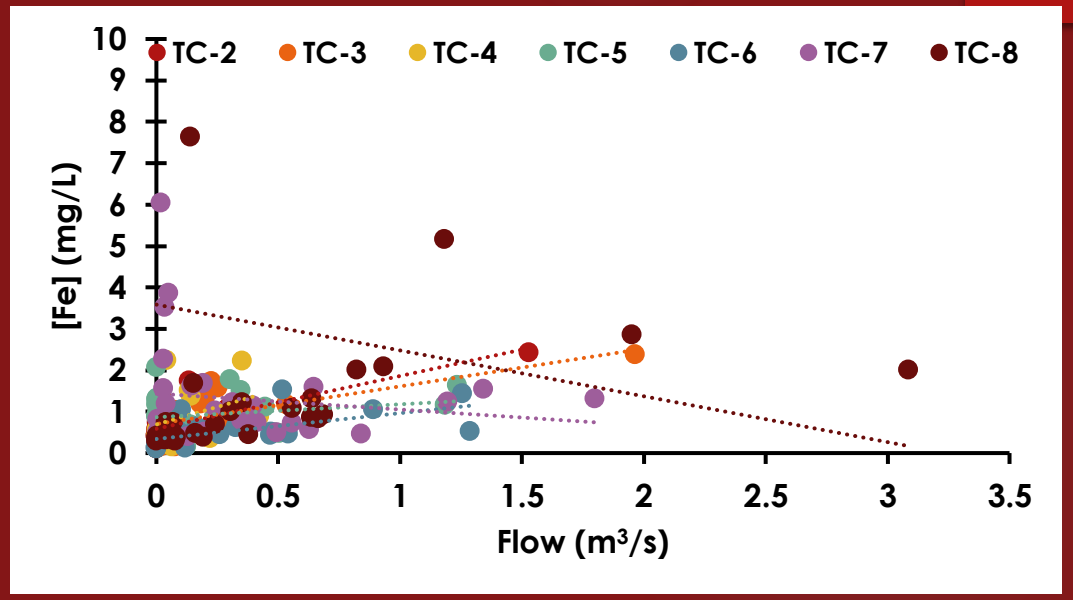
- USGS data
  - Low and high elevation relationships
  - High mine pool elevation more strongly correlated with flow
- Sampling events: flows at TC-8 between 0.001 and 3.1 m^3/s
  - 20 years of daily means from USGS – about 75th percentile
- Greater percent of flows from point sources in low flow events
  - Dry periods → low mine pool and little runoff

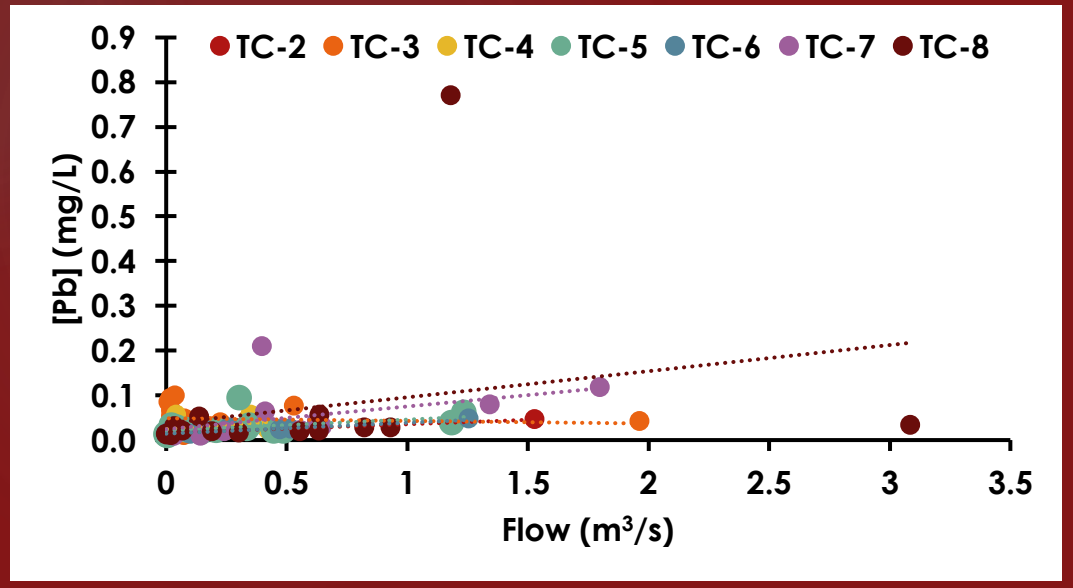


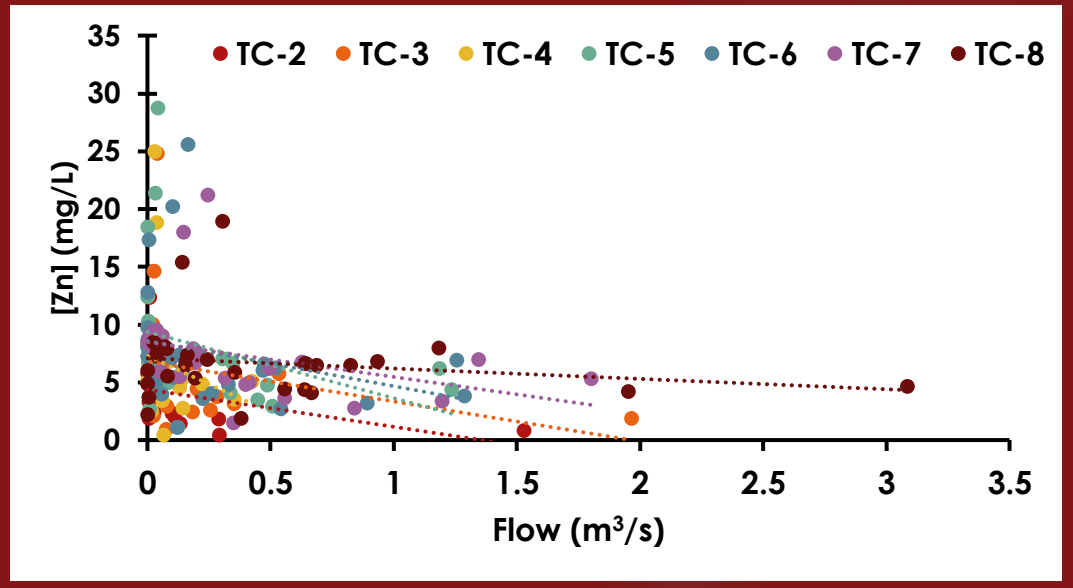


Concentration vs. Flow



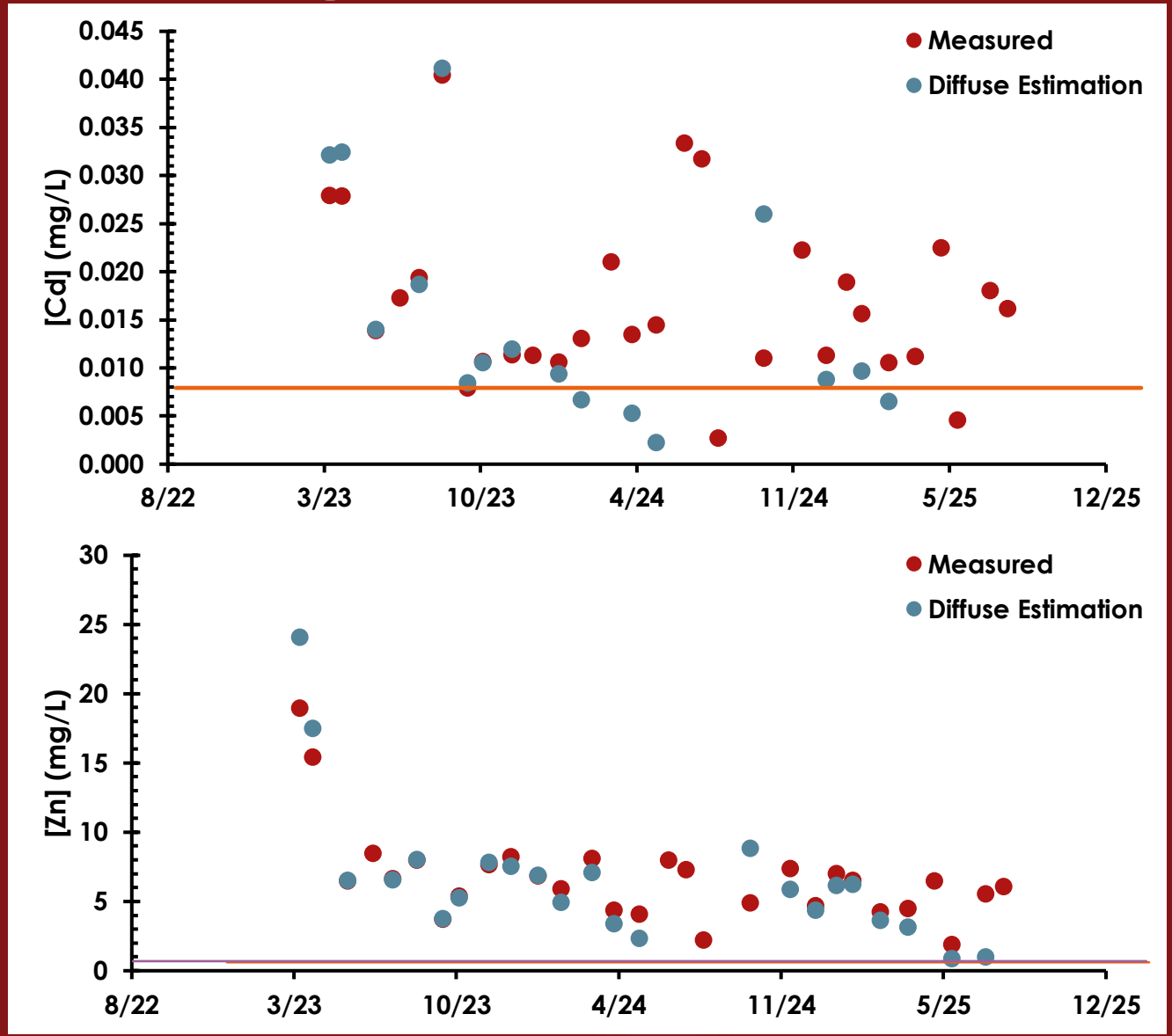






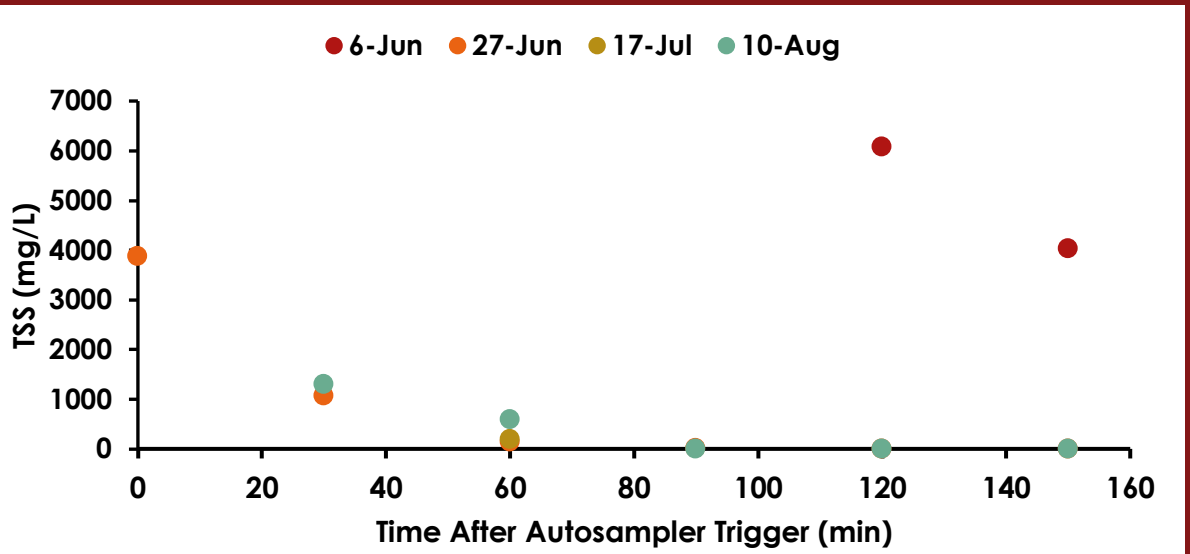
Loading: Mine Drainage vs. Runoff

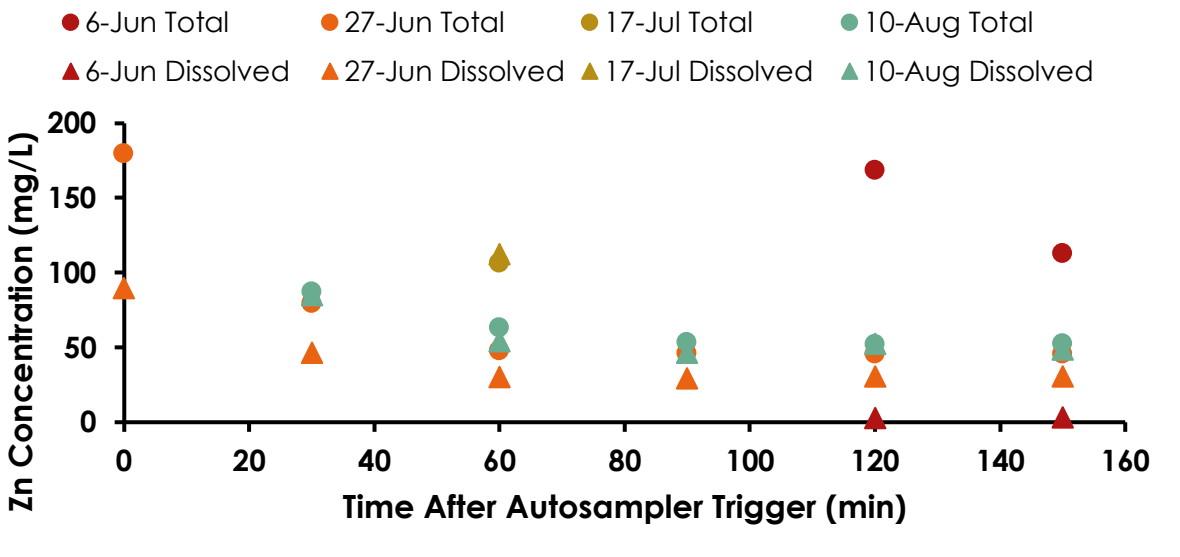
- Subtracted load from mine drainage
- Used remaining load to calculate concentration at new flow
- New flow = measured flow – mine drainage flow
- Concentrations of Cd and Zn would exceed OWRB guidelines at TC-8 without mine drainage contributions



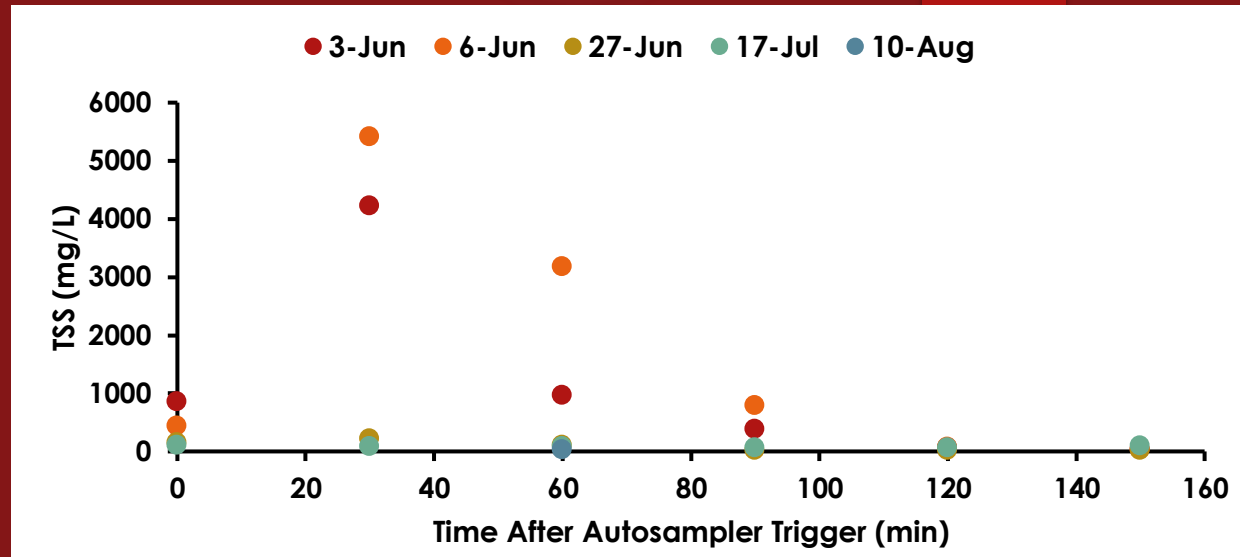
Autosamplers

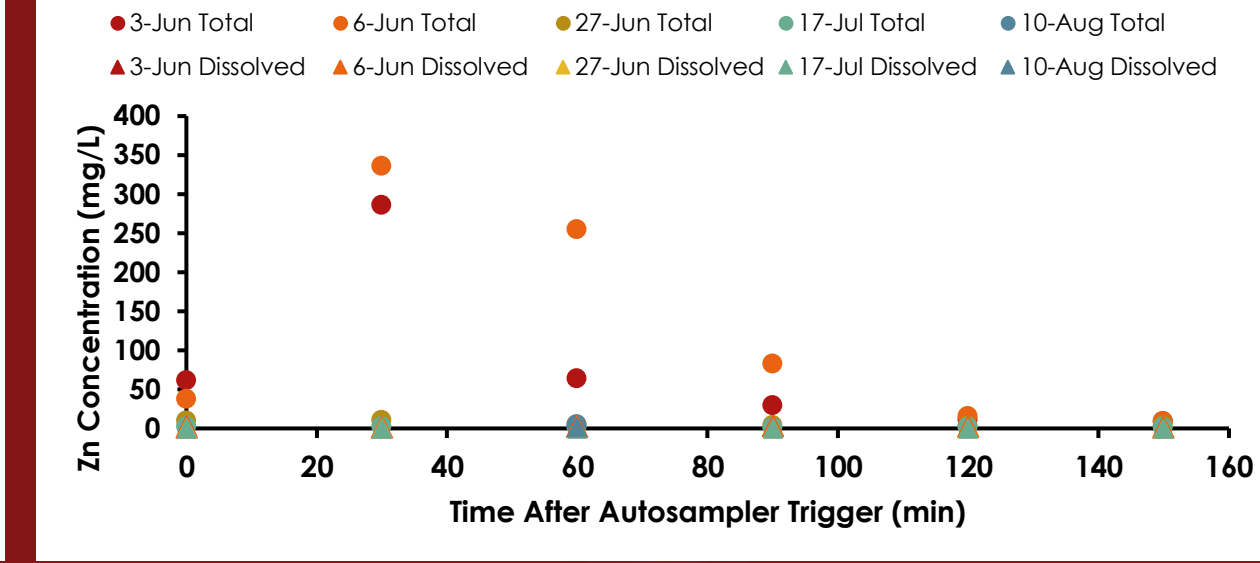
Howe





Central Mill





Water Levels