Forensic Geochemistry

Chasing the Last 1% of Copper Loadings Downstream of a Legacy Site

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Presentation Outline

- Introduction / Background
- Context and Study Objectives
- Study Design
- Lines of Evidence
- Conceptual Loadings Model
- Results Summary
- Outcomes

- Former base metal mine site
- Operations in the mid 1950's, via open pit and U/G
- Mountain terrain, rapid spring freshet
- Two main creeks, downstream of the former open pit and waste rock piles

Site Overview

- Numerous remedial actions have been completed in the North Creek drainage system
- Remediation Efforts – 1995 - 1999
  - The 7000 Dam, 6930 Adit, Upper Pump Station, Waste Rock Removal, Diversion & Collection Ditches
  - Removal of debris flow material that contained elevated copper contents along North Creek

Site Overview

Remediation Efforts – 2003 - 2006

- Collection and treatment of North Creek Seeps, including a cutoff wall above the Upper Pump Station, seep collection systems, pumping wells, expansion of the Upper Pump Station, construction of the Lower Pump Station.
- North Creek Pipeline to Bypass South Creek – Deferred to evaluate natural recovery following the source controls listed above
- Natural Recovery of Stream Sediments

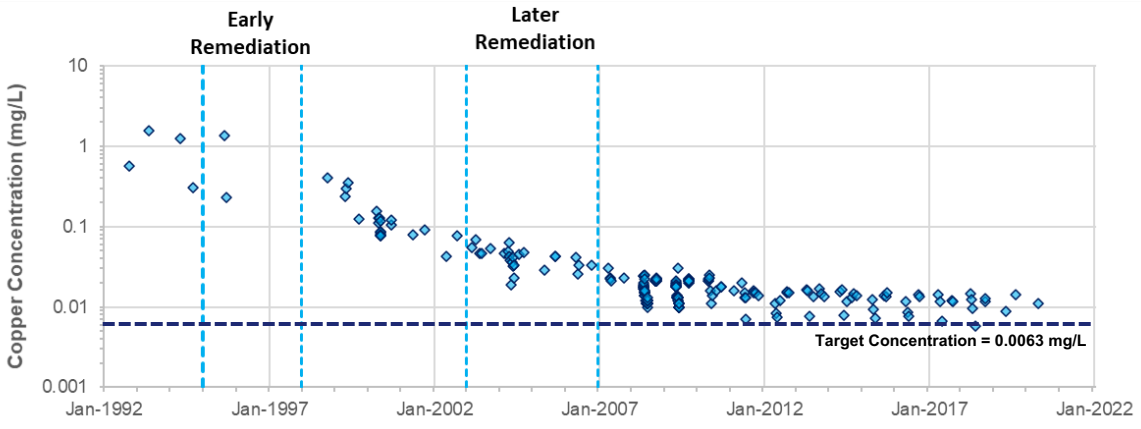
Ongoing Performance Monitoring

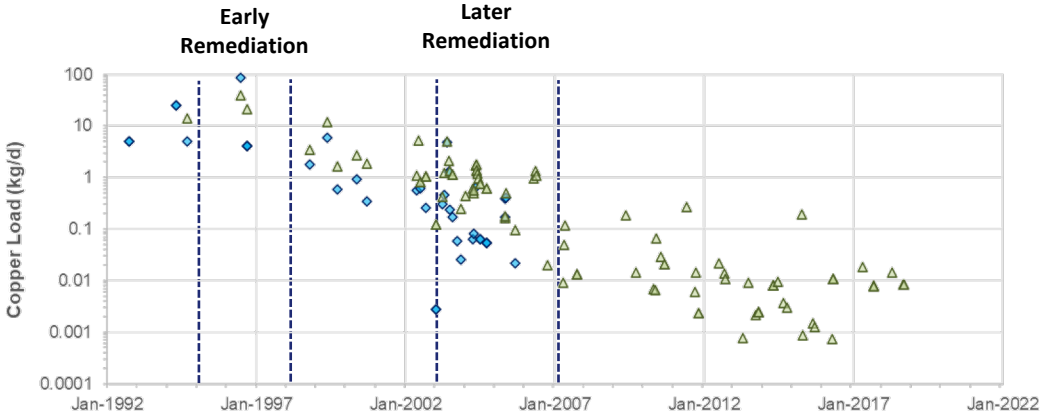
- Following the implementation of the earlier remediation efforts, a decline in loadings along the North Creek drainage was observed, with further reductions observed following additional efforts, as completed in 2006.

- An overall reduction of over 99% of the copper loadings at the mouth of North Creek was estimated over the period 1996 through 2014.

Water Quality in North Creek

Current vs. Historical





Study Objectives

- Evaluate potential sources of copper loadings in the North and South Creeks, including a quantitative measure of the forms of copper present.
- Identify potential actionable sources vs. diffuse sources
  - Actionable – point sources able to be acted upon (e.g. hotspots or specific seepage sources that could be acted upon and provide a material reduction in loading)
  - Diffuse sources – dispersed source area (e.g. along substantial portions of the drainage system)
- Provide information to support management strategies, including potential remedial strategies for sources that may be actionable.

Field Investigation Plan

Fall 2019 / Spring 2020

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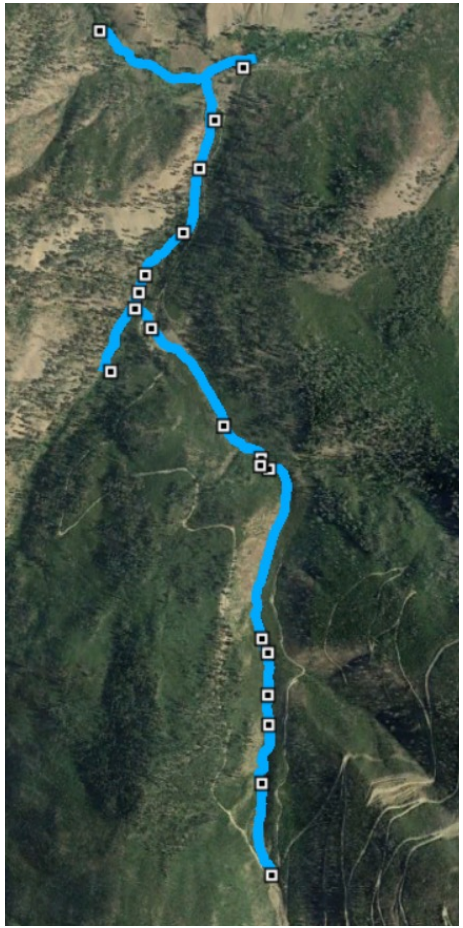
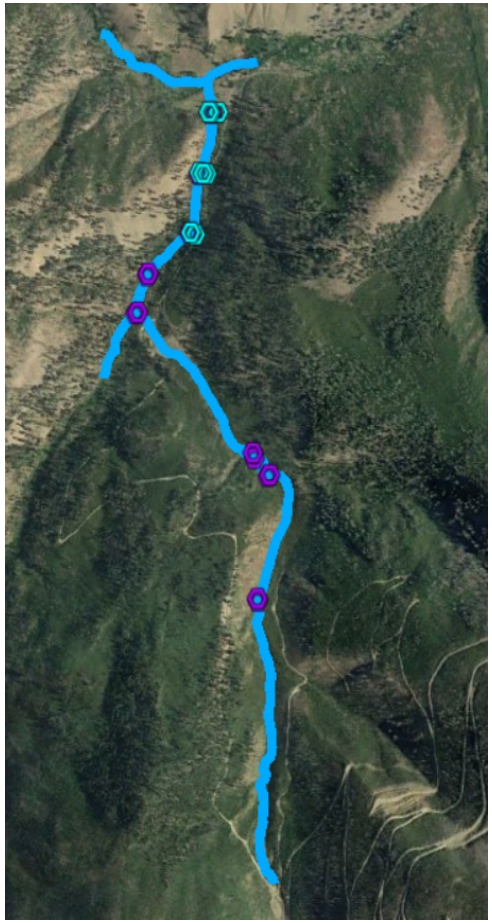
Field Investigation Plan

Potential Loadings Pathway	Proposed Sampling Approach	Estimated Stations (Min)[1]
Surface Water	Synoptic Sampling	Up to 10 - 15 Stations (includes routine stations)
In-Stream and Wetted Perimeter Sediments	Vertical Profile Samples Grab Samples	Up to 4 Areas 2-3 Samples per Area
	Porewater Selective Extraction	Up to 4 Areas 2-3 Samples per Area
Shallow Groundwater	Drive Point Piezometer Shallow Groundwater Sampling	Up to 2-3 Transects 2 Nests per Transect
	Vertical Profile Samples Laboratory Leachate and Selective Extraction	Up to 2-3 Transects Up to 2-3 samples per Transect
Overbank Deposits	XRF Measurements Core Samples Laboratory Leachate and Selective Extraction	Up to 22 Stations Up to 2 Depths per Station

Surface Water - Synoptic



Groundwater

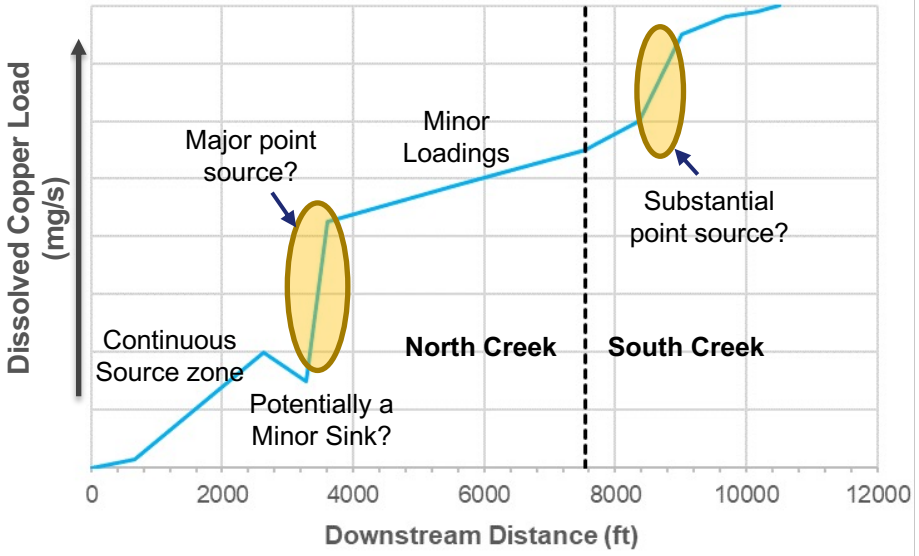


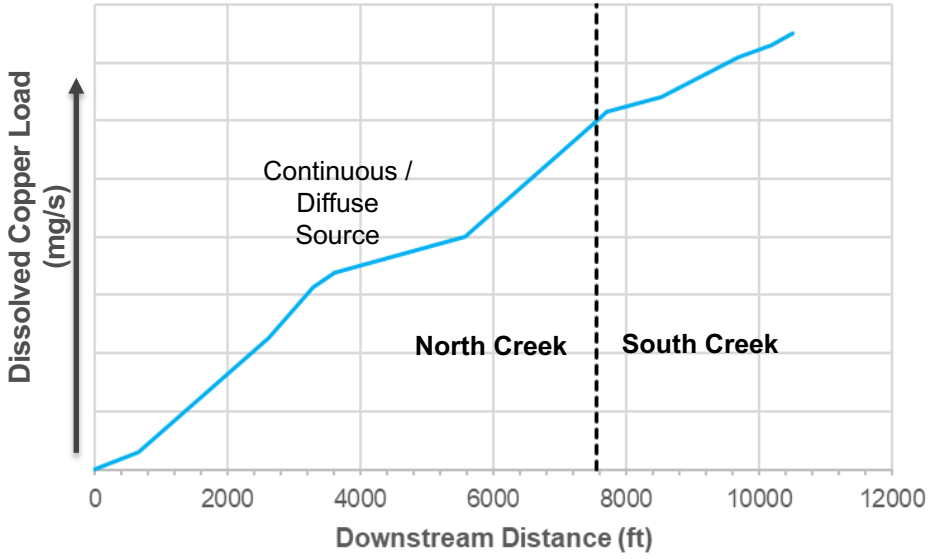
2019

Historical

Evaluating Lines of Evidence

Point Sources or Diffuse Loadings?





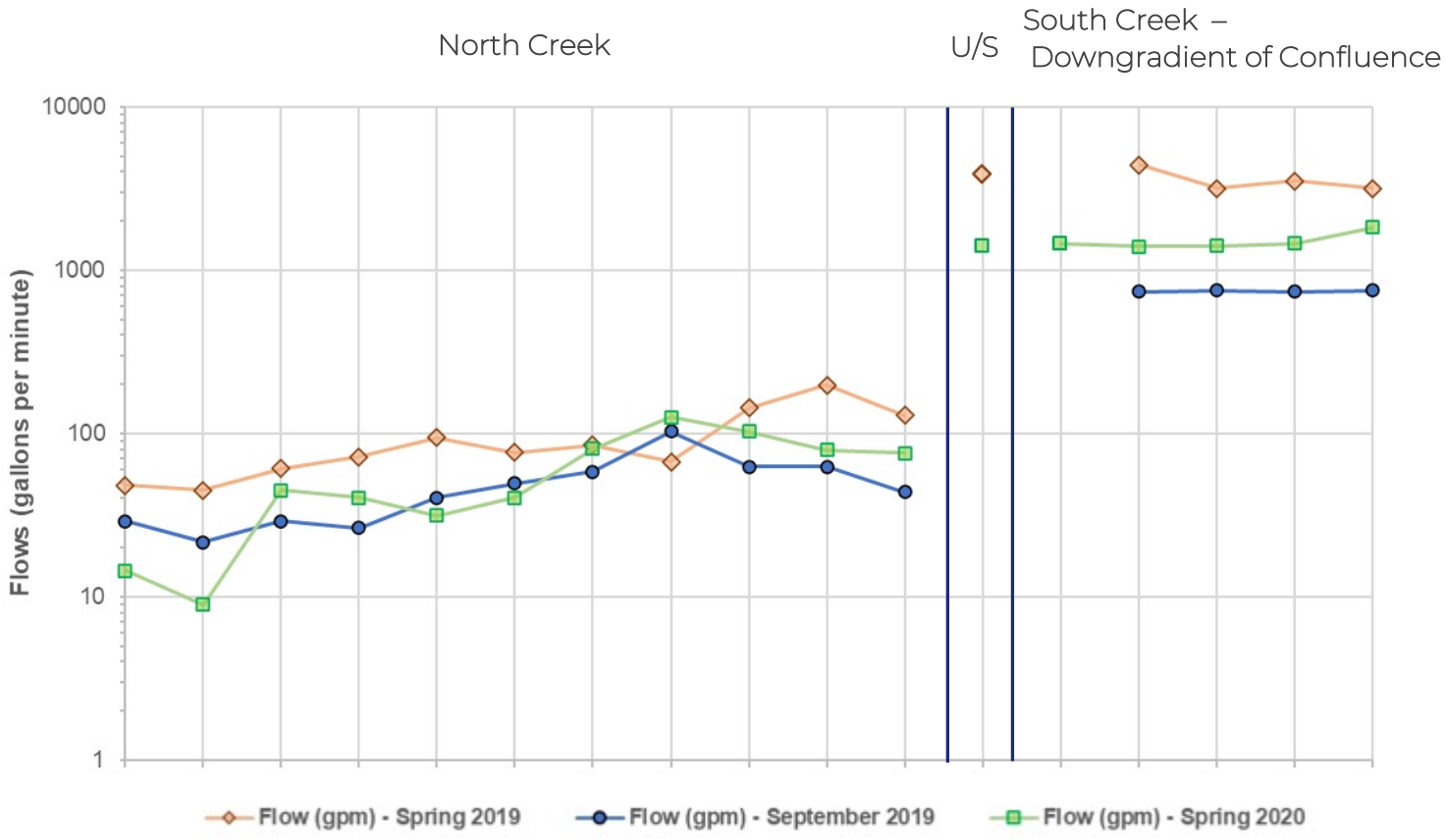
Overview of Study Outcomes

- Copper loadings in South Creek have naturally recovered over time
- Majority of copper loadings associated with South Creek, with minor amounts in North Creek
- Pipeline to re-route North Creek therefore not a clear solution to loadings removal in South Creek
- Copper inventory remains in the solids and appears to be dispersed across the nearby South Creek overbank materials
- No apparent actionable (point) sources were observed
- Preliminary recovery estimates in South Creek on the order of decades
- Large-scale efforts would be required to remove and dispose of the affected soils and would adversely affect the existing creek system

Lines of Evidence

Relative Loadings Contributions

Synoptic Sampling



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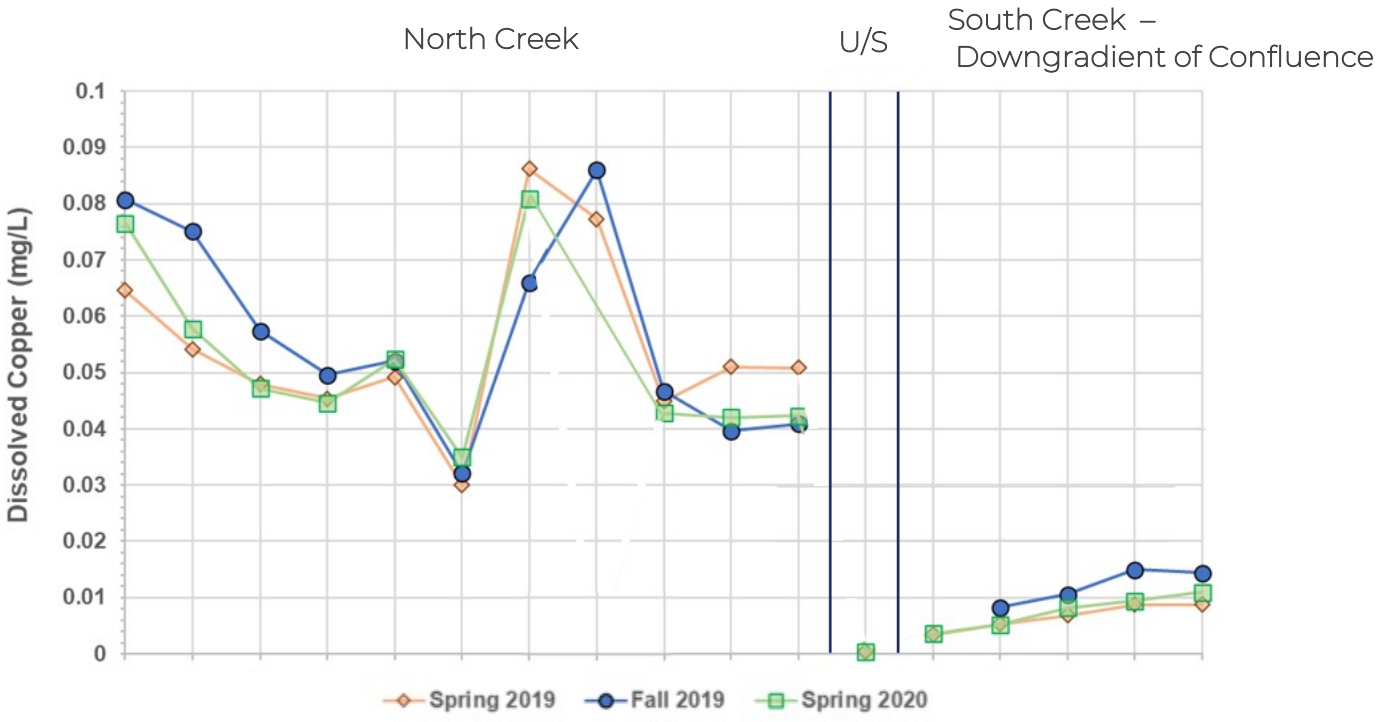
Synoptic Sampling

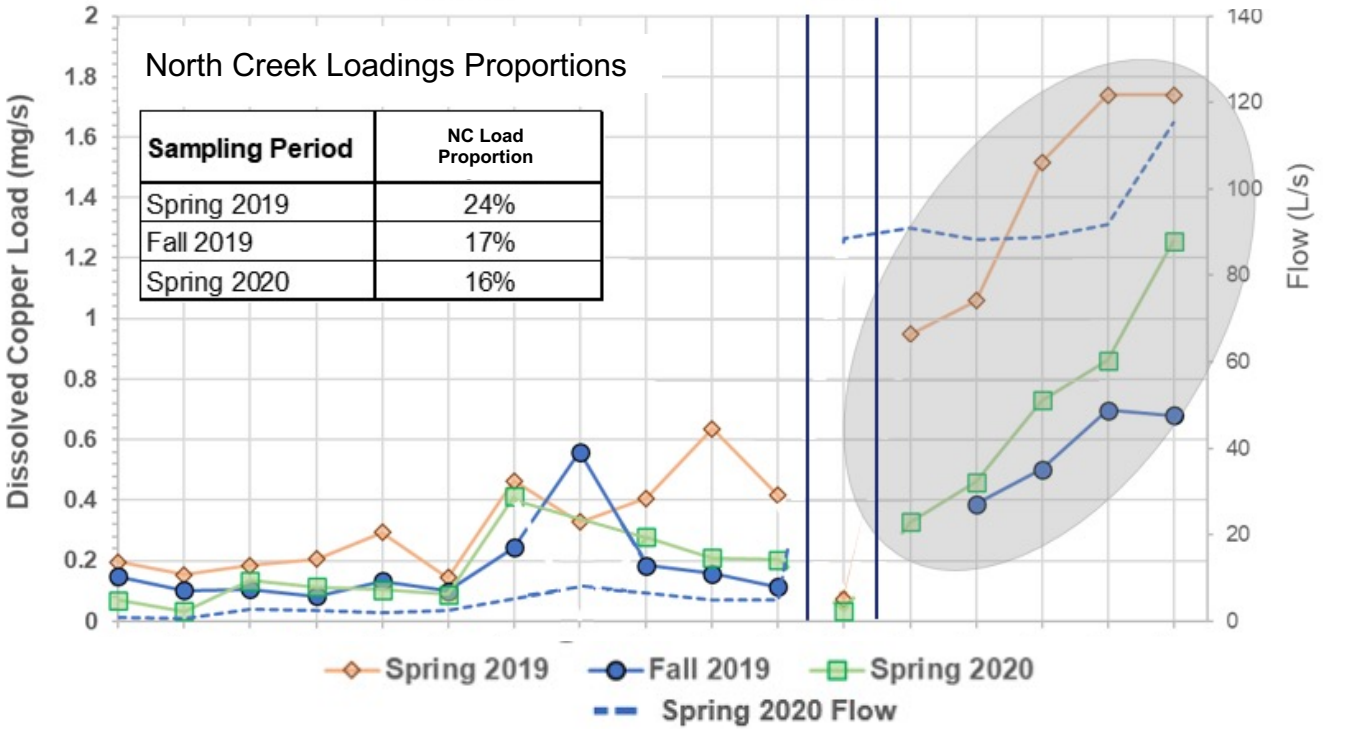


Synoptic Sampling

North Creek

U/S

South Creek – Downgradient of Confluence

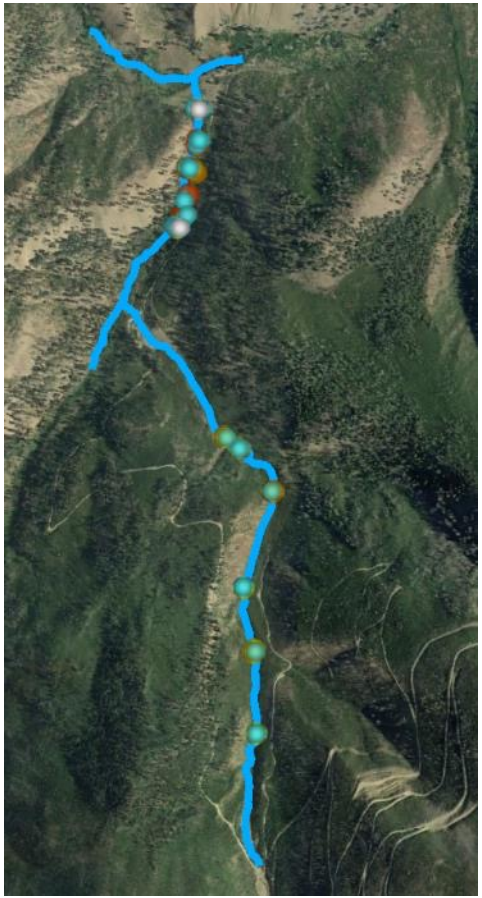


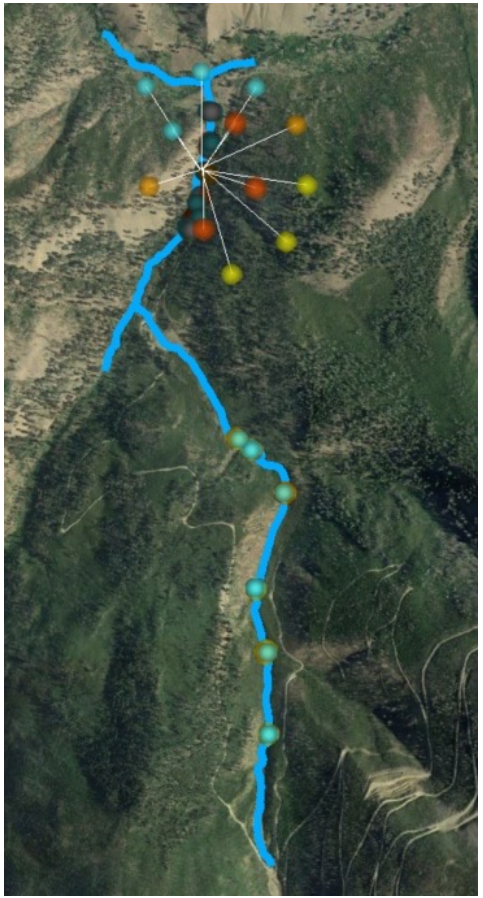
Lines of Evidence

Solids – Porewater - Groundwater Interaction

Solids Samples

Solids Content - Copper



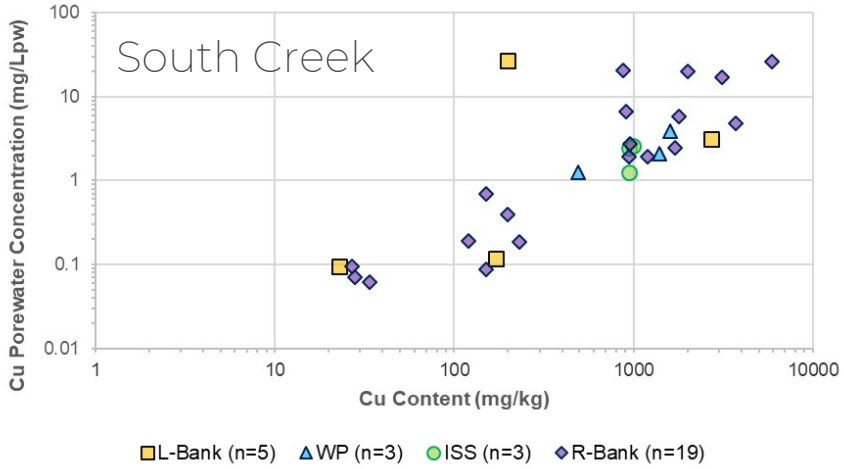


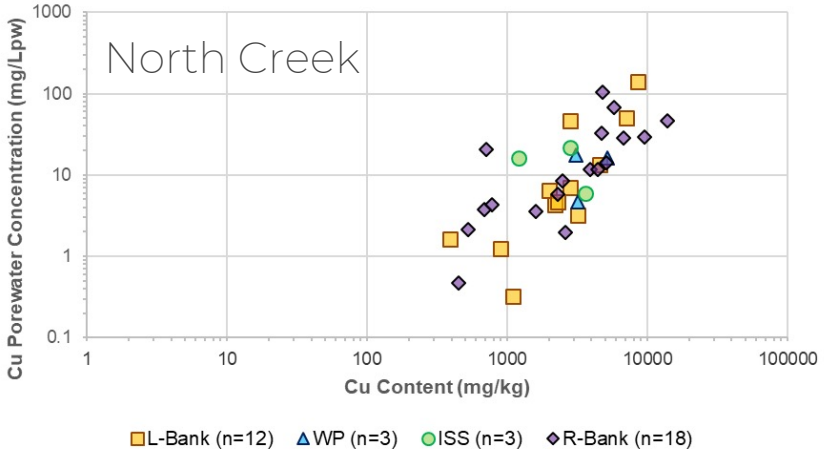
Legend
XRF

- < 100 mg/kg
- 100 to 1000 mg/kg
- 1000 to 2500 mg/kg
- 2500 to 10000 mg/kg
- > 10000 mg/kg

Porewater Samples

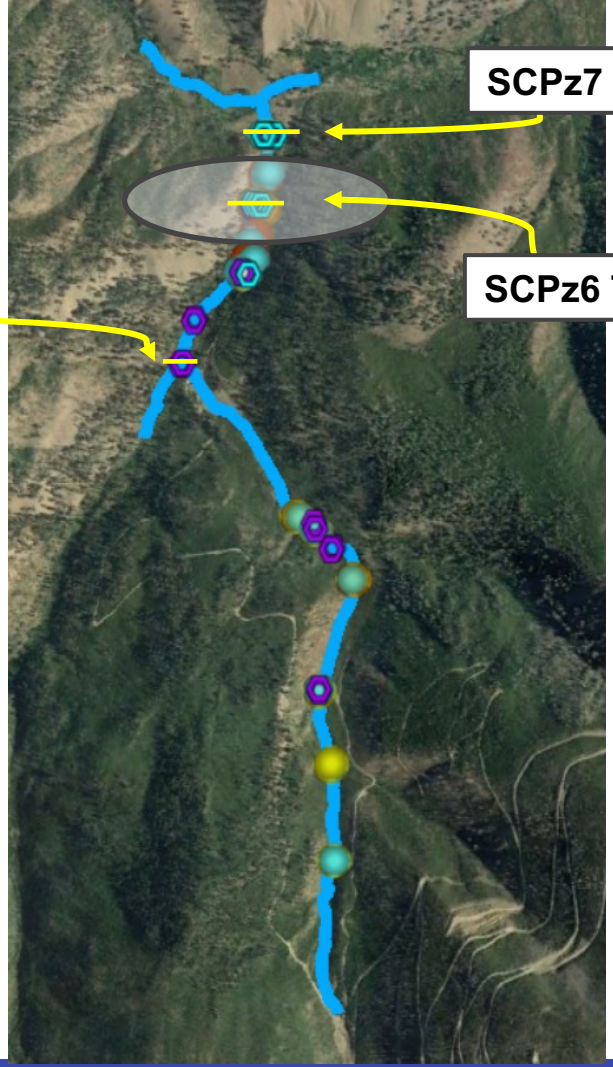
Solids - Porewater Interactions





Shallow Subsurface Water Samples

GW



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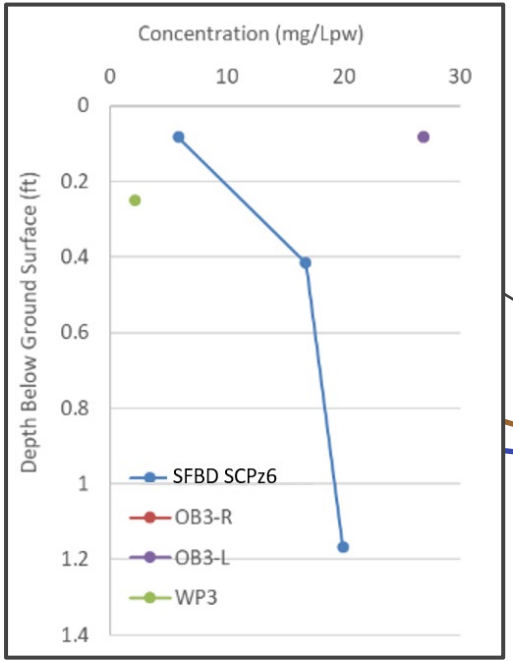
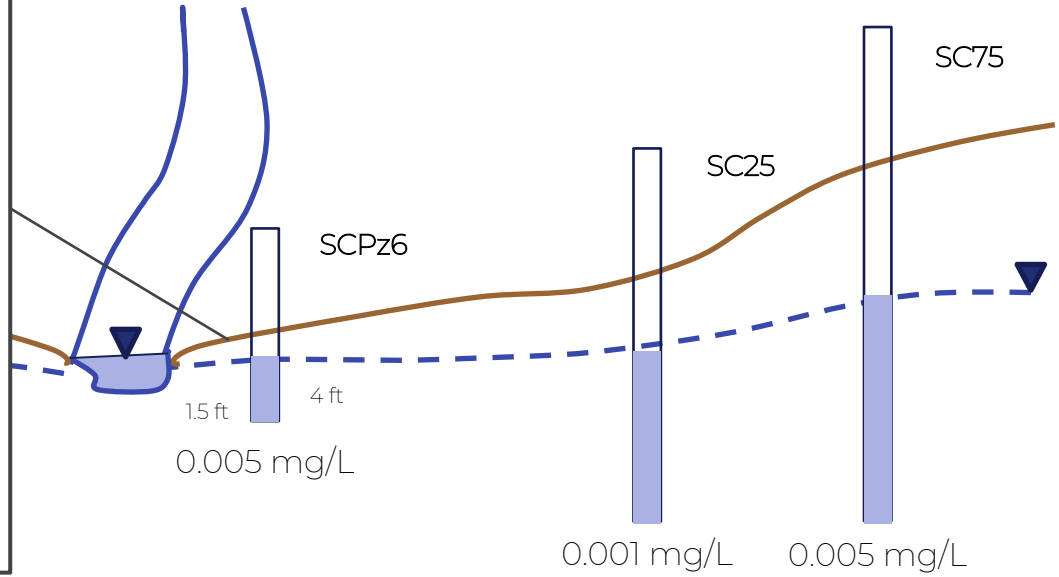
South Creek – Cross Section

Copper Concentrations in the Porewater and Shallow Subsurface

- Elevated in shallow porewater
- Not elevated in deeper groundwater



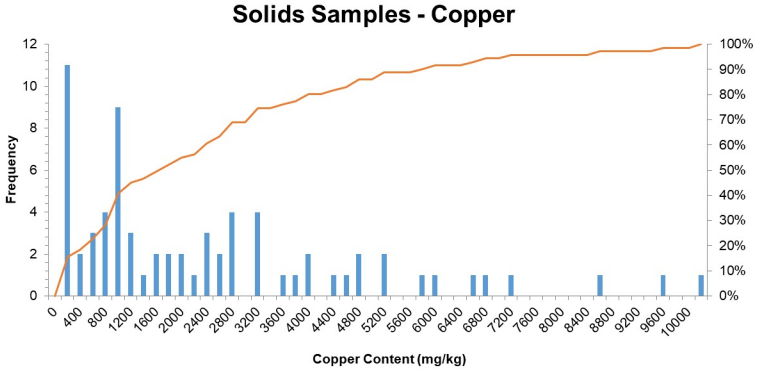


Conceptual Model

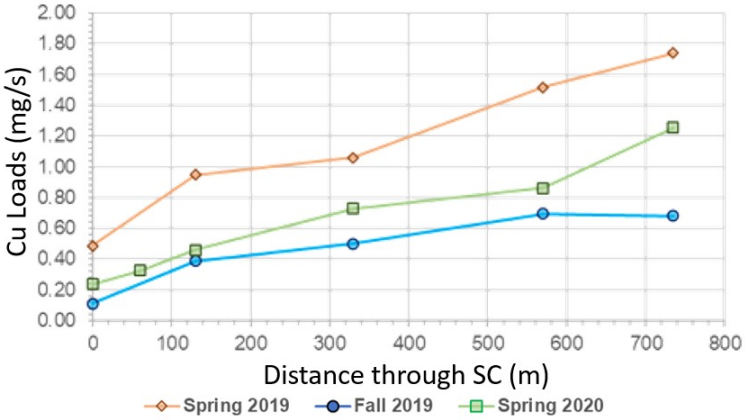
Hypotheses

CONCEPTUAL MODEL

- Inventory of copper available in the solids
  - In the 1990s tonnes of copper exiting NC each year
- SC is currently the dominant loading source
  - Approximately 30-35kg/year over past decade
- Release rate is relatively consistent with distance
- Conditions in channel not conducive to loadings
  - Rocky bottom, rapid flow
- Porewater concentrations correlated with solids contents
- Loadings are correlated with flow increases
- Groundwater does not appear to be a substantial contributor

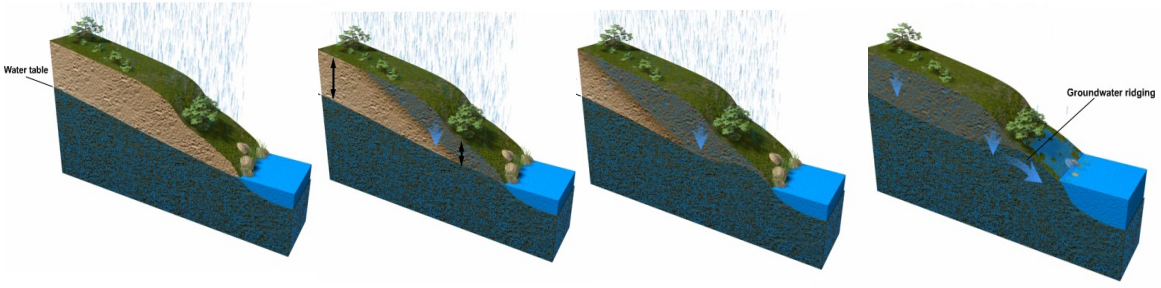


SC (2015-2020)



Conceptual Model Hypothesis

- **Higher flow periods – Groundwater Ridging**
  - Only occurs during wet / high flow conditions
  - Consequence of an elevated water table

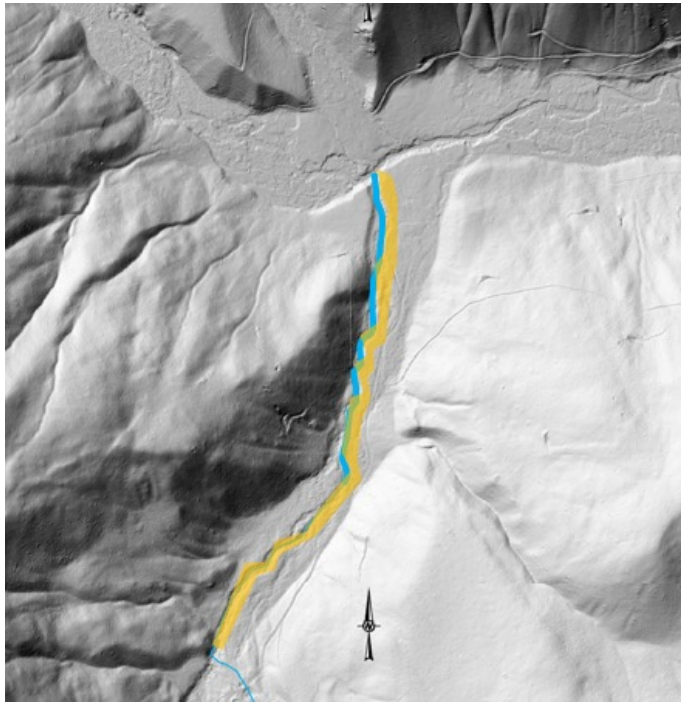


- **Lower flow periods – Direct Infiltration**
  - Highly soluble copper
  - Slow and persistent loadings from a dispersed surface load

CONCEPTUAL MODEL

Loading estimates from each conceptual model is greatly dependent on estimated extents of copper-loaded soils and proportion of SC overbank susceptible to groundwater ridging

Depths, reaches, width, solids content



Copper Loadings GW Ridging & Infiltration

Loading Rates

Spring high-flow conditions (SC loads of 1 to 1.5 mg/s):

- Higher concentration zones may account for 20-30% of loads
  - Upper range estimates include assumptions that additional, as-yet undiscovered, high concentration zones exist
- Majority of loads expected to be controlled by the more diffuse lower concentration regions

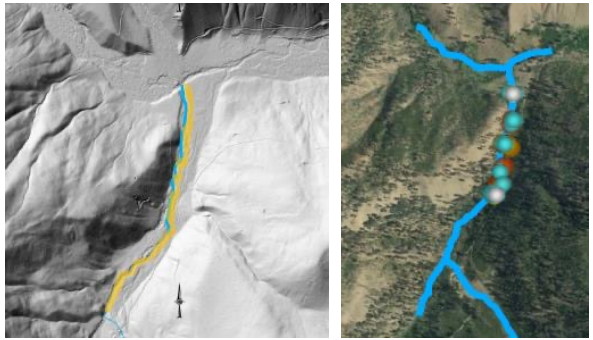
Fall low-flow conditions (SC loads of ~ 0.2 mg/s):

- High concentration zones may account for 15-30% of loads
  - Upper ranges includes assumption that additional high concentration zones exist
- Majority of loads also controlled by the more prevalent lower concentration regions

- Depth, reaches, width and representative copper contents remain a critical input

Copper Loadings

Depletion Rates



Key factors include:

- Length of stretch, width of bank, depth, representative Cu contents. rate of copper release over time

- Estimates to reach target concentration by source depletion vary substantially based on model assumptions

- Approx. 70 years to reach target concentration of 0.0063 mg/L starting at a representative Cu-content of 440 mg/kg (half of average measured value)

  - Secondary estimate of 90 years to reach target concentration starting at a representative Cu-content of 960 mg/kg (median measured value)

DISCUSSION

Copper Loadings

North Creek Summary

- Main source of loadings not associated with North Creek
- Does not seem to originate from the creek channel itself
- Does not seem to originate from a surficial point source
- Creek is deeply incised with limited banks and varied copper contents that suggests actionable sources not easily removed
- Adding a pipeline to convey loadings from North Creek would not substantially reduce the loadings in South Creek

DISCUSSION

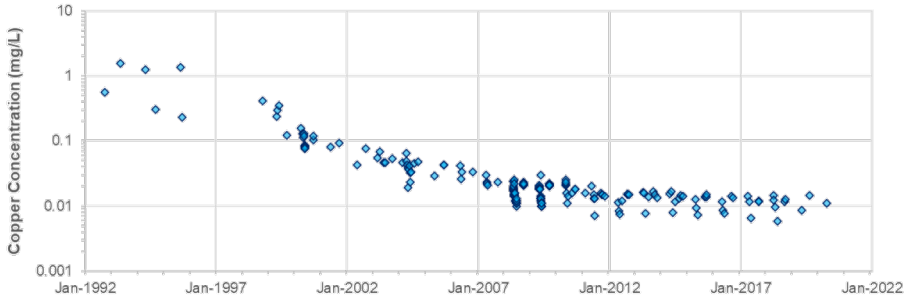
Copper Loadings
South Creek Summary

- Loadings along SC increase consistently downgradient
  - Evidence to date suggests diffuse sources of copper, rather than actionable (or single) point-sources
- However there is an inventory of copper available within the solids (estimated at several tonnes)
  - Early 1990s – tonnes of Cu exiting NC per year
  - Testing suggests these solids are relatively easily mobilized and they will continue to load into SC
  - Current release rates of approximately 30 kg/year

DISCUSSION

Copper Loadings
South Creek Summary

- Copper inventory remains in the solids and appears to be dispersed across the nearby SC banks
  - No apparent actionable (point) sources
  - Preliminary estimates of natural recovery timetables on the order of decades



  - Low solids contents (mid-100s mg/kg) necessary to meet water quality criterion
- Large-scale efforts would be required to remove and dispose of affected soils – such efforts would adversely affect the existing creek ecosystem

Thank you!

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