Application of the mass-loading approach to understanding the impacts of mining

Briant A. Kimball, Robert L. Runkel, Katherine Walton-Day,
David A. Nimick, and Kenneth L. Bencala

Natural iron bog augmented by mining, American Fork, UT

U.S. Geological Survey
Energy, Minerals, and Environmental Health
Toxic Substances Hydrology Program
http://toxics.usgs.gov/ sites/upper_ark_page.html

USGS

Multi-Disciplinary Team

- Kimball – Mass loading (sources) / Mass transfer of reactions
- Runkel – Reactive transport model development / application
- Walton-Day – Remediation options / TMDL / fracture pathways
- Nimick – Diel cycling of metals
- Bencala – GW/SW interaction / Catchment connections
- Fuller – Biogeochemical reactions / metal bonding
- Wanty / Verplanck – Metal isotopes, rare earths, geology
- Hornberger / Cain / Croteau – Contaminant pathways to receptors

Red Mountains #1, 2, and 3

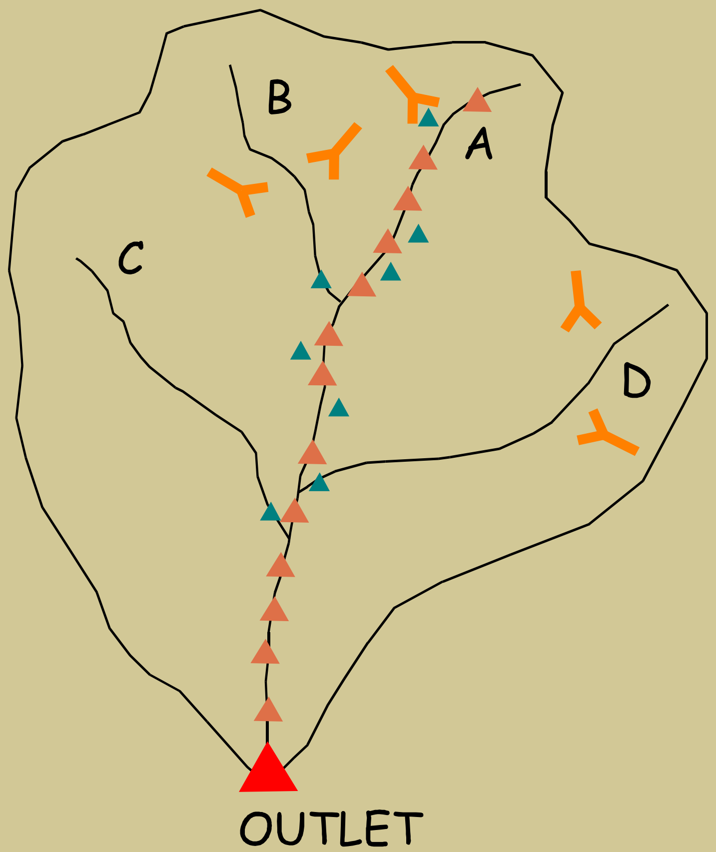
Mass-Loading Approach

- Topic: Applications of a mass-loading approach
- Question: What is the value of a quantitative approach?
- Significance: Answers for important questions

Injection of ionic tracer

Addition of dye

What do we need to know?



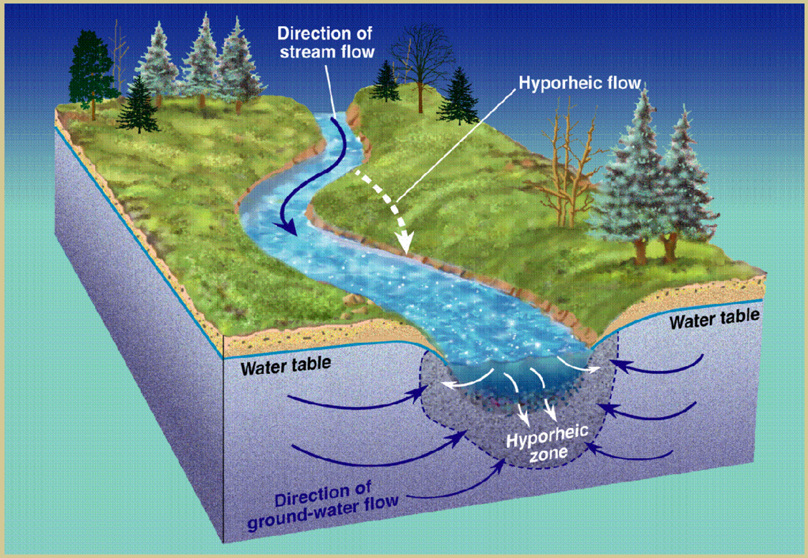
- Source identification - which sources of metals are the most significant?
- What contributions are from ARD (“background”) vs. AMD?
- What are remediation options?

- Divide stream into segments and sample inflows
- Characterization of the watershed important
  - Geology & structure
  - Ore deposit types
  - Hydrology (often missing)
  - Chemistry of inflows
- Integration of the catchment
  “The truth is in the stream”

Provide the Hydrologic Context for Synoptic Sampling

- Quantify total streamflow (stream + hyporheic) for mountain streams
- Collection of many samples for watershed-scale synoptic sampling
- Data needed for OTEQ transport simulations
- Evaluation of remediation options (TMDL)
- Dilution vs. attenuation

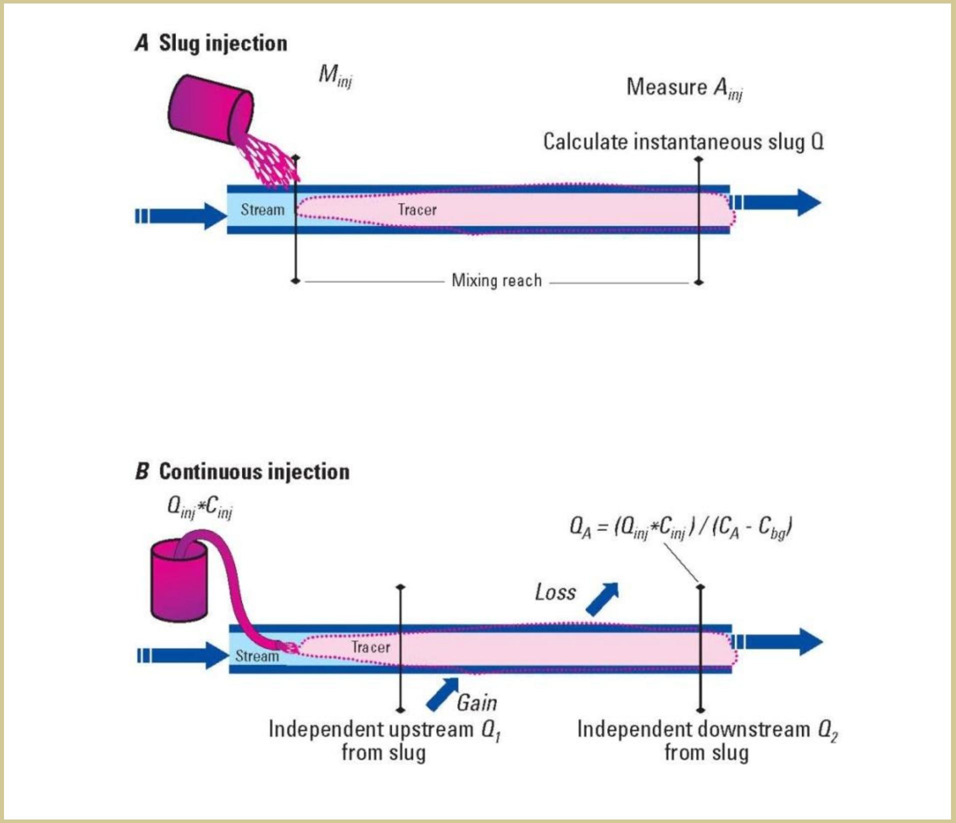
Typically studies are in upland mountain streams during baseflow conditions



Must quantify the hydrology to understand the variation of in-stream chemistry

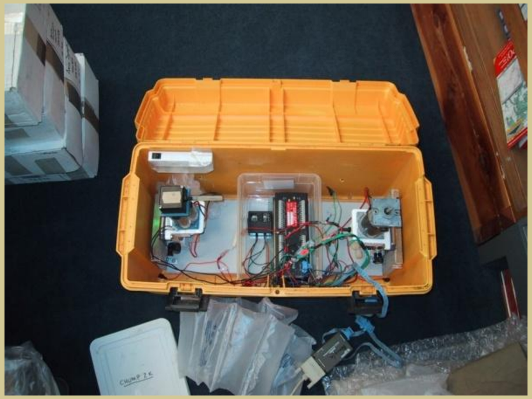
Types of tracers and additions

- Ionic tracers
  - Low pH: LiCl, LiBr
  - High pH: NaBr, NaCl
- Tracer additions
  - "Slug"
    - Known mass + response
    - Gives loss/ gain
  - Continuous
    - Known rate and concentration
    - Gain only



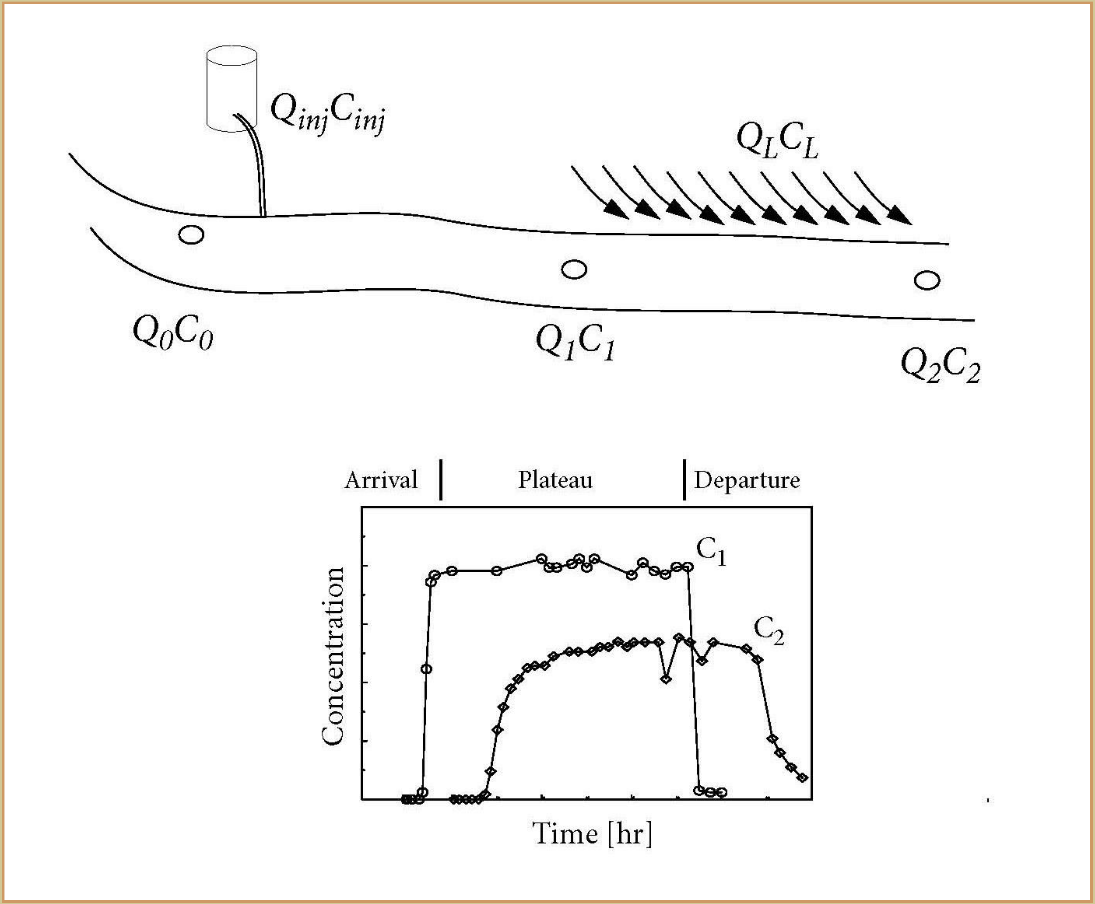
Adding the salt

Pump setup for tracer injection



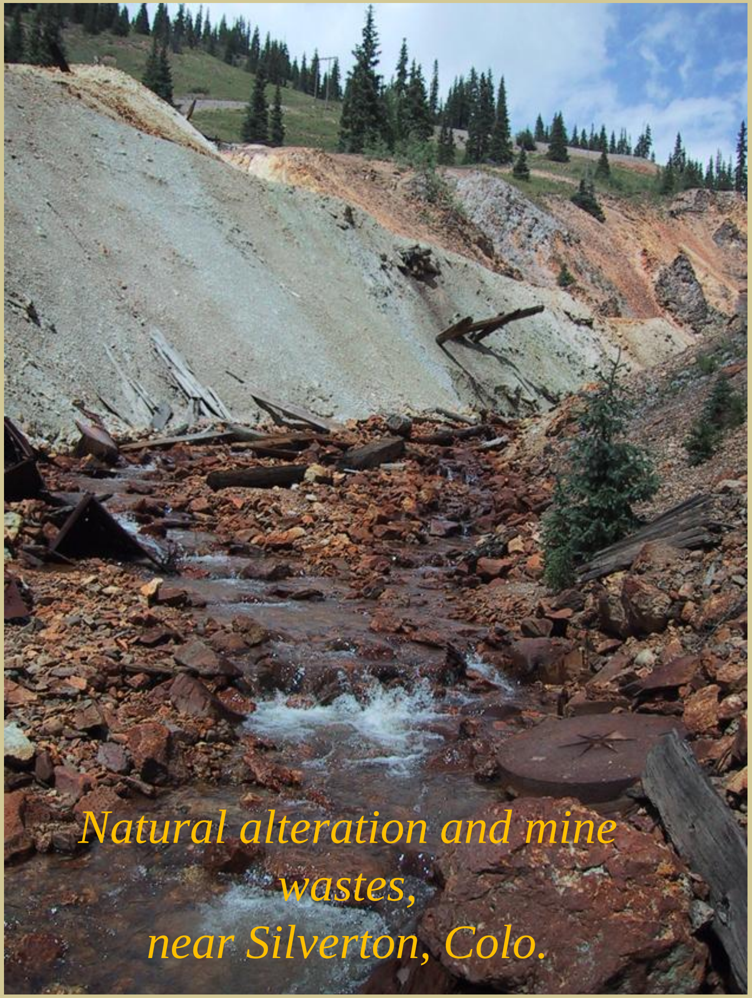
- Continuous injection of ionic tracer
- Metered pump
  - Pulse every 6 seconds
  - Data logger counts revolutions; adjusts voltage
  - Allows for a constant injection rate despite battery change
- Synoptic sampling at "plateau" after down-valley flow is "saturated" with tracer

Quantify stream hydrodynamics



- Magnitude of stream flow, Q, from plateau
- Travel time gives velocity (Q/Area)
- Shape gives mixing (dispersion and transient storage)

Examples of Applications

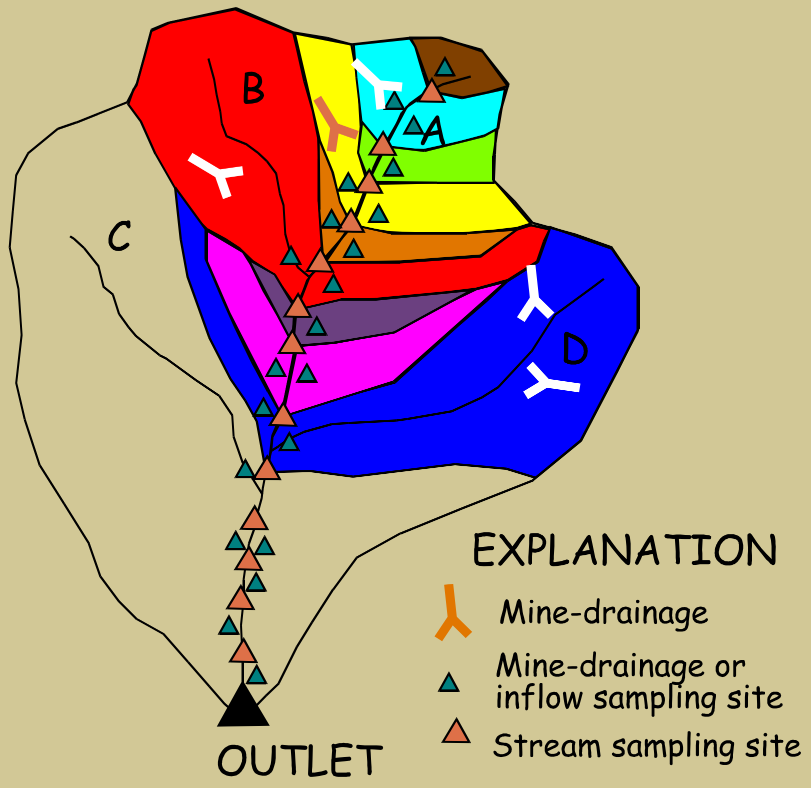


1. Reconstruct Pre-Mining Conditions – Setting Remediation Goals
2. Quantifying Remediation Options
3. Quantifying Changes in Biogeochemical Systems in Response to Remediation

1. How clean is clean?

- Setting goals for remediation – what is “fair?”
  - Rarely have pre-mining samples
  - Divide current quality into mining vs. non-mining
- Multidisciplinary approaches
  - Analog unmined catchments
  - Ferricrete / Cu
  - OTEQ application

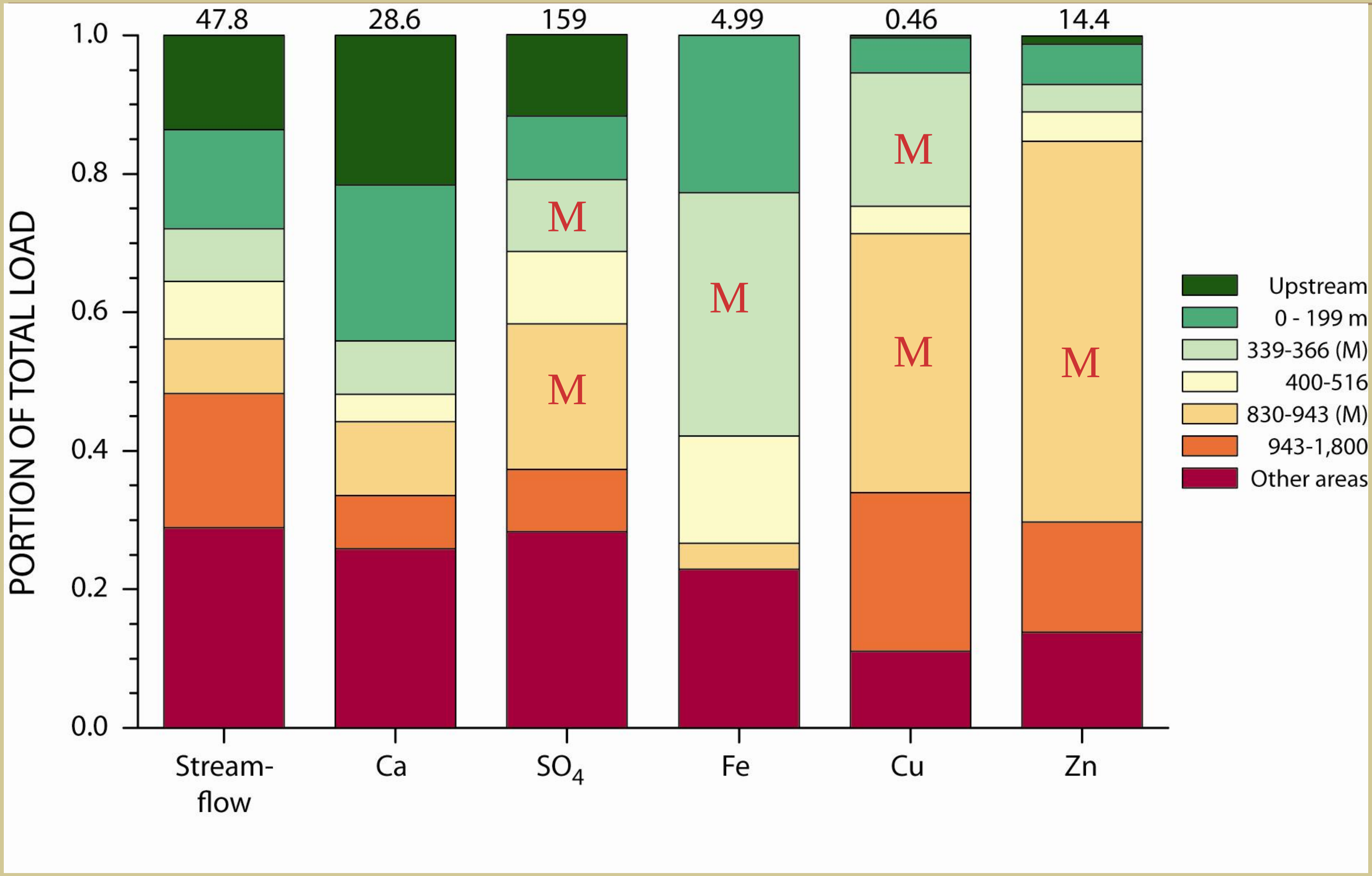
OTEQ approach



- Uses results of a mass-loading study
- Calibration of OTEQ model
- Identification of mined vs. un-mined inflows
  - Geologic constraints
  - Historical information
  - Stable isotopes of metals
- “Remove” likely mining sources in the model
- Simulate the resulting in-stream concentrations

Mined vs. Un-mined loading

L/s *kg/day*



OTEQ: One-Dimensional Transport w/ Equilibrium Chemistry

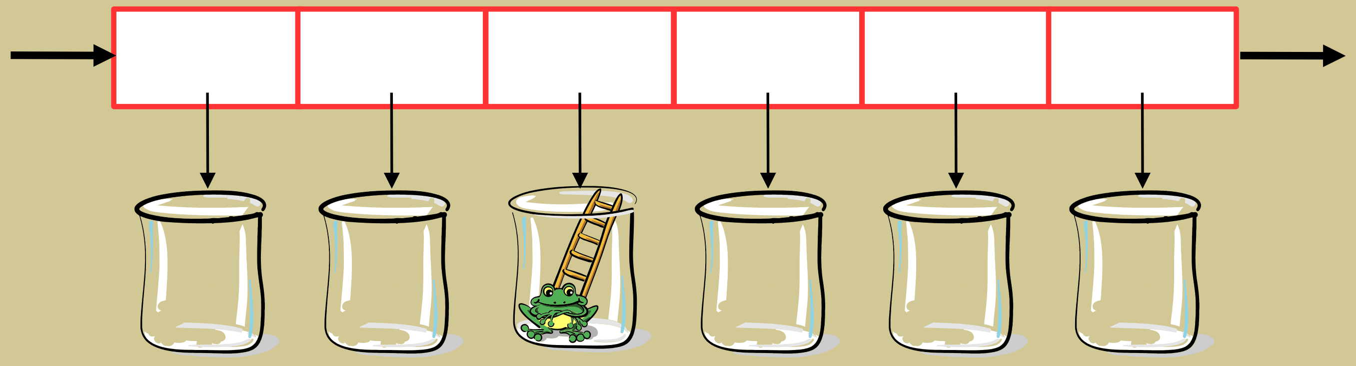
- **Couples:** Transport (OTIS)

$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}(AD\frac{\partial C}{\partial x}) + \frac{q_L}{A}(C_L - C) + \alpha(C_s - C)$$

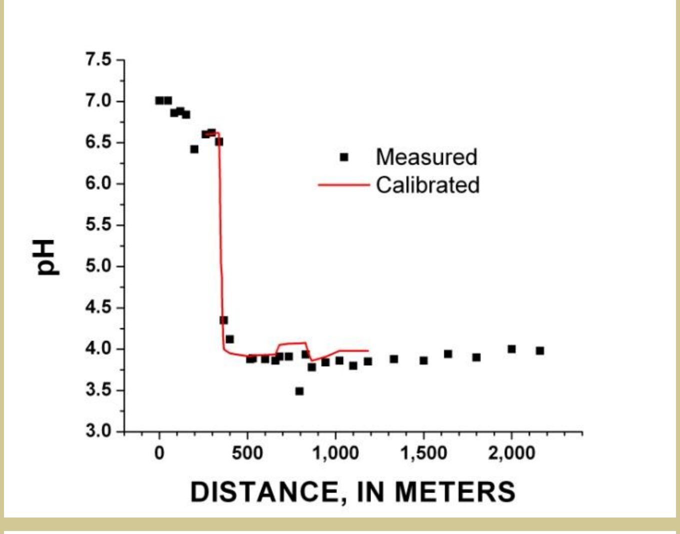
= Advection + Dispersion + Inflow + Storage

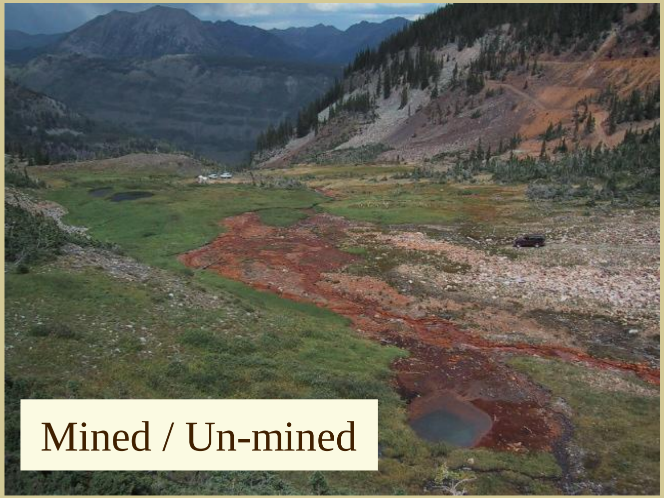
&

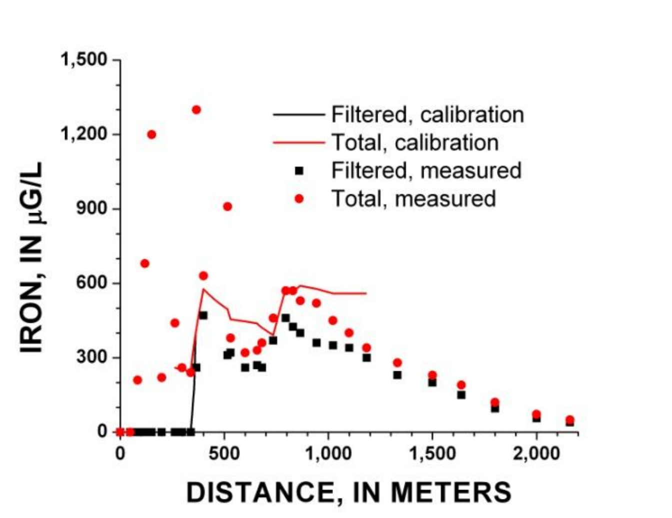
Equilibrium Chemistry (MINTEQ)



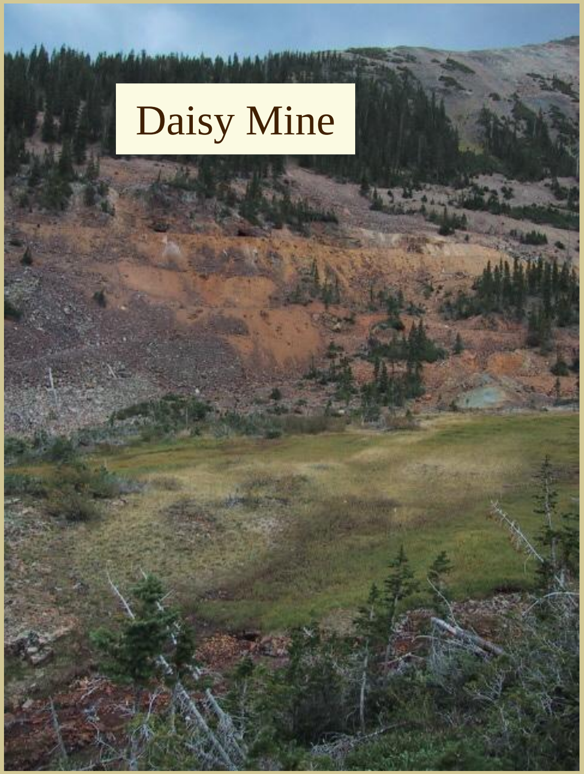
Calibration of transport model

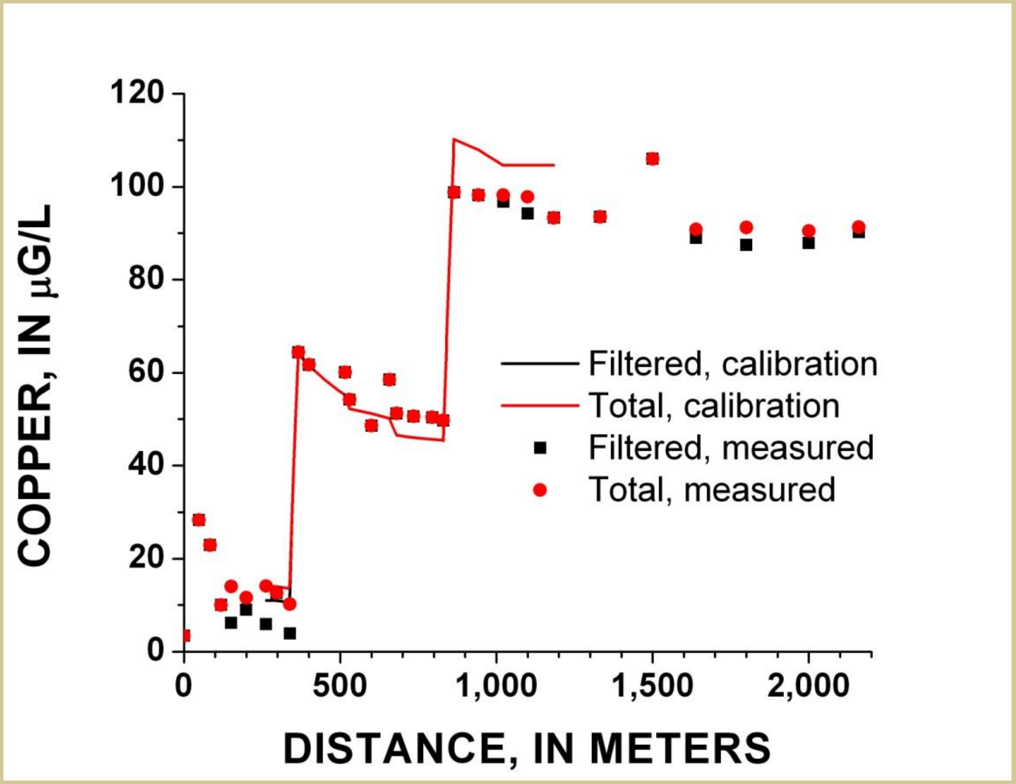




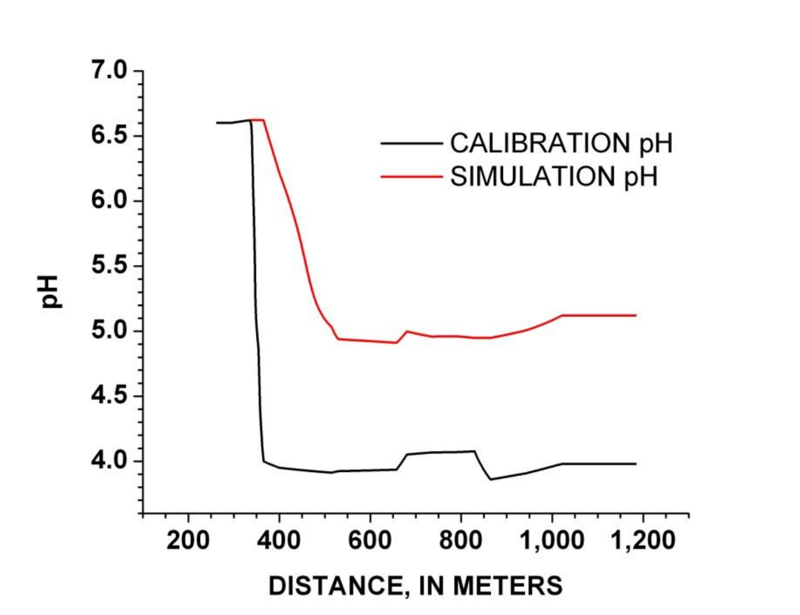


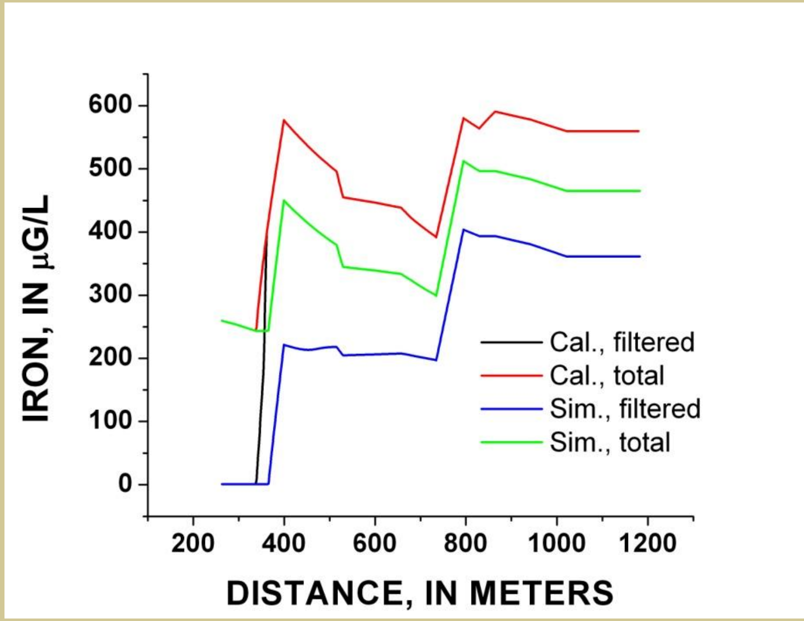
Calibration of Copper





Pre-Mining Simulation





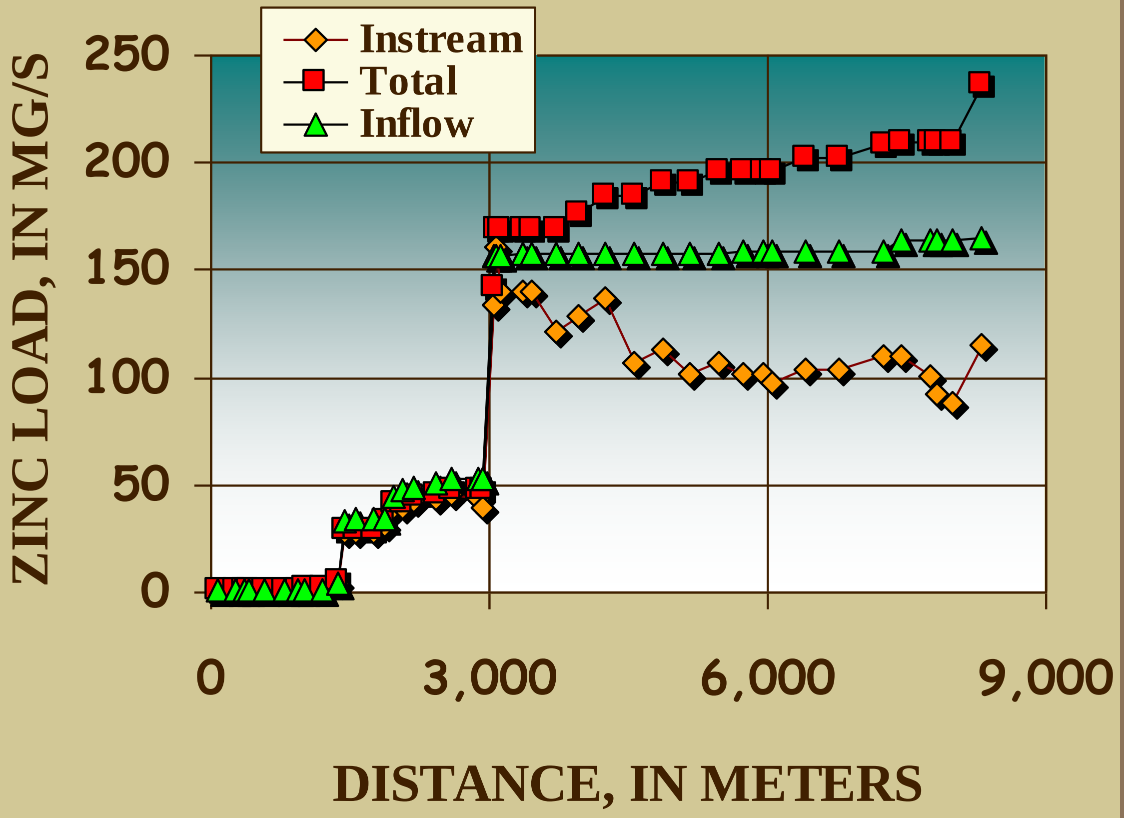
pH: 3.9 to 5.1

Fe: 560 to 360 µg/L
SO_4: 38 to 25 mg/L
Cu: 105 to 18 µg/L
Zn: 3,920 to 1,320 µg/L

Conclusion: Weathering of hydrothermally altered rocks before mining started would have prohibited certain aquatic life

2. What to do?
Little Cottonwood Creek, UT

- Main sources
  - Columbus-Rexall discharge
  - Wasatch Tunnel Bulkhead
- Mountain leaking



Remediation Options

Columbus-Rexall discharge

- 4 levels of fen treatment

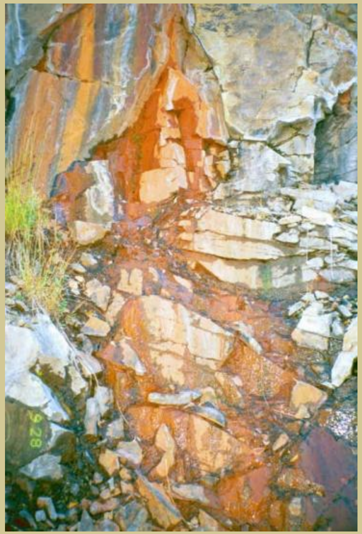
2 studies for data "on/off"

16 options
3 sites
Acute/Chronic

96 OTEQ runs

Wasatch Tunnel

- 4 levels of release from bulkhead (dilution)

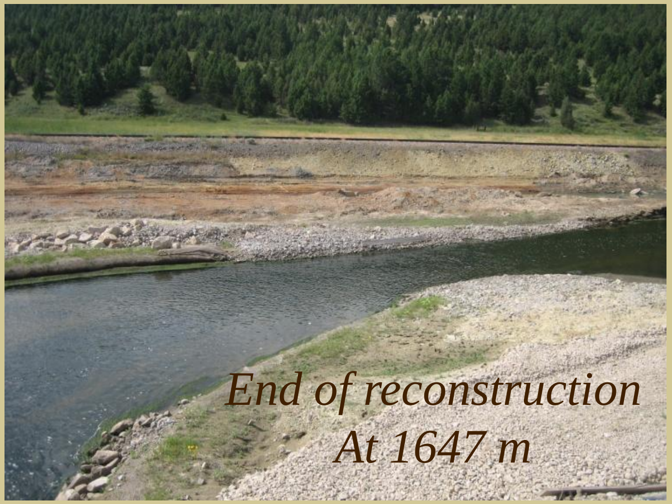


Site #3, Chronic Zn standard

Tunnel / Fen	Fen Off 2.45 mg/L Zn	Fen On 0.44 mg/L Zn	On + 20% 0.35 mg/L Zn	On + 20% + 29% more 0.25 mg/L Zn
WT 100%	51	11	10	8
WT 75 %	43	-1	-2	-4
WT 50 %	35	-15	-17	-19
WT 25 %	25	-32	-35	-37

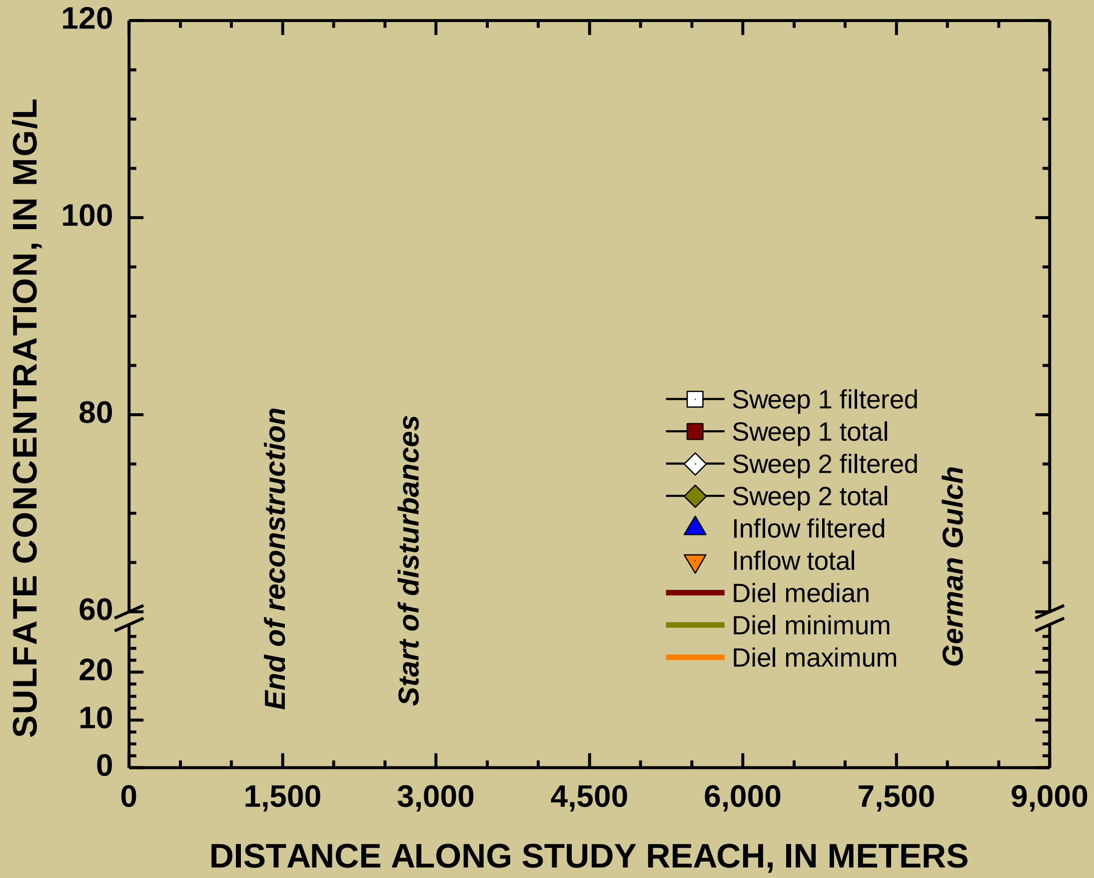
3. What happened ?

Silver Bow Creek, (Butte) MT



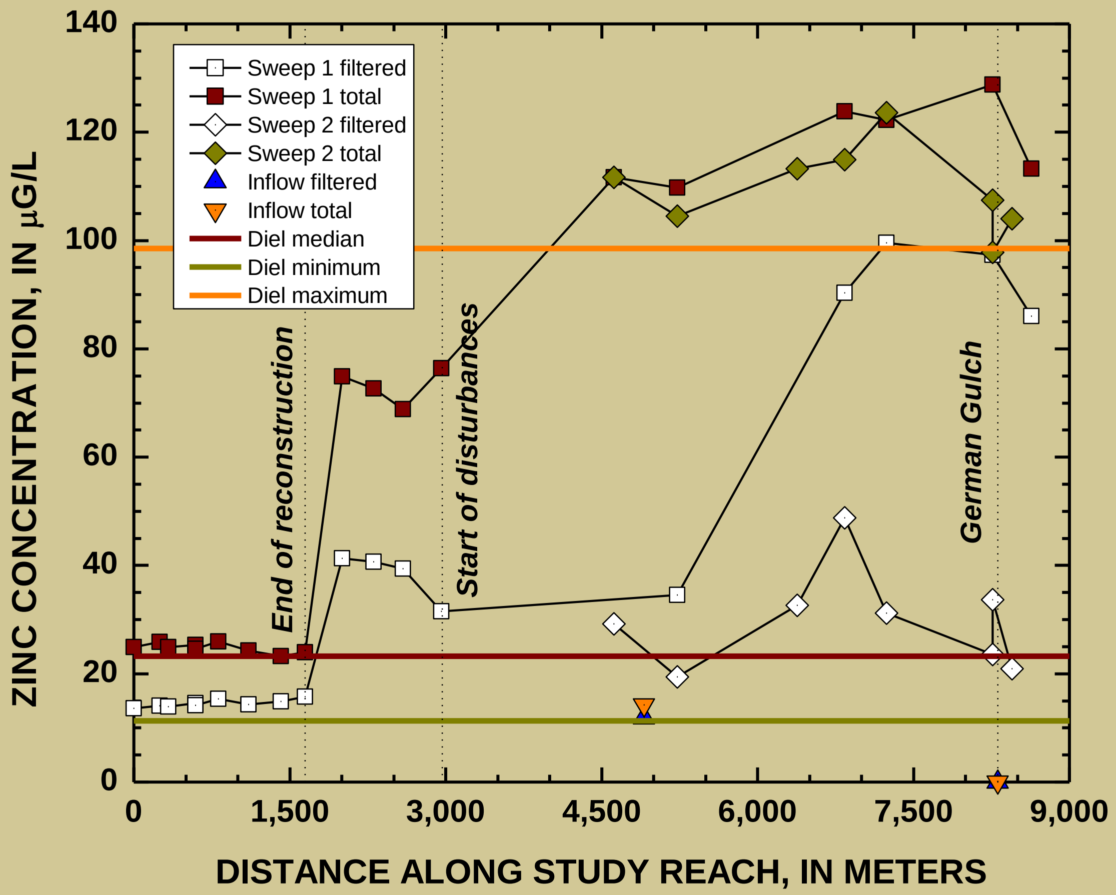
Sulfate profile

(*Range of diel samples indicated*)



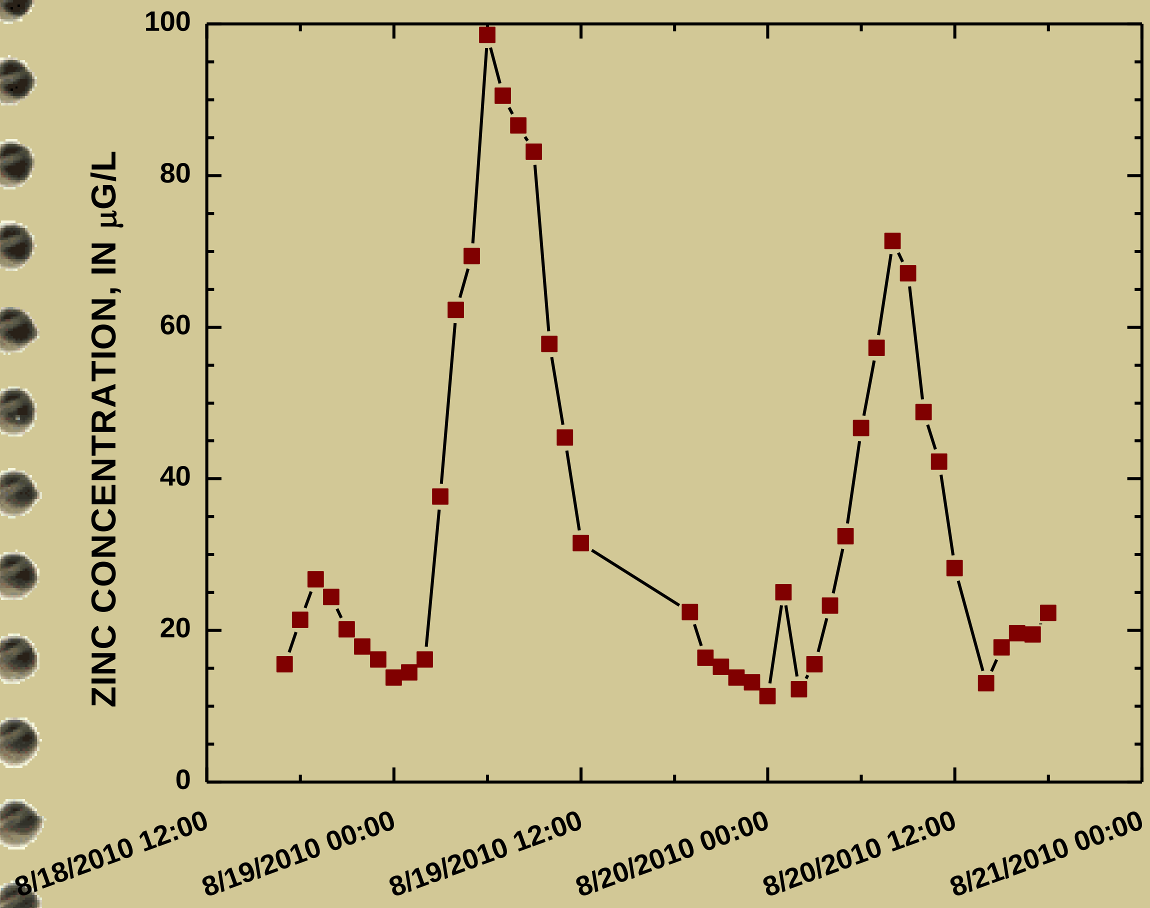
- Sulfate increases slightly downstream from reconstruction
- German Gulch dilutes the sulfate
- High sulfate concentration is a result of upstream mining
- No apparent increase from reconstruction activities between 2,967 and 4,617 m

Zinc Profile



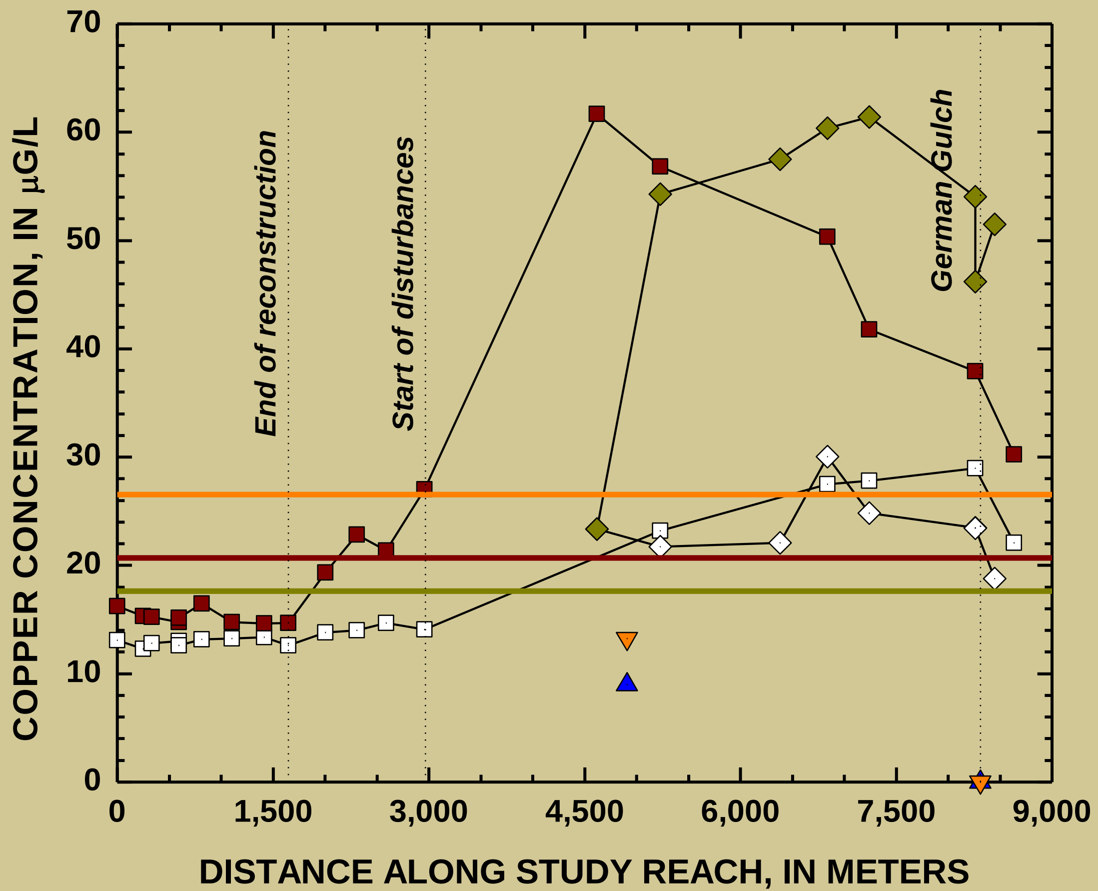
- Large increase downstream from the end of reconstruction (2,005 to 2,957 m)
- Large increase due to reconstruction activity (from 2,967 to 8,634 m)
- Substantial amount of colloidal zinc
- Temporal variation of zinc from 11.3 to 98.5 µg/L

Diel zinc variations



- Samples from auto-sampler show the large diel variation in zinc concentration
- Did not find this variation in other metals
- Manganese only showed variation on the first day - ?)

Copper profile



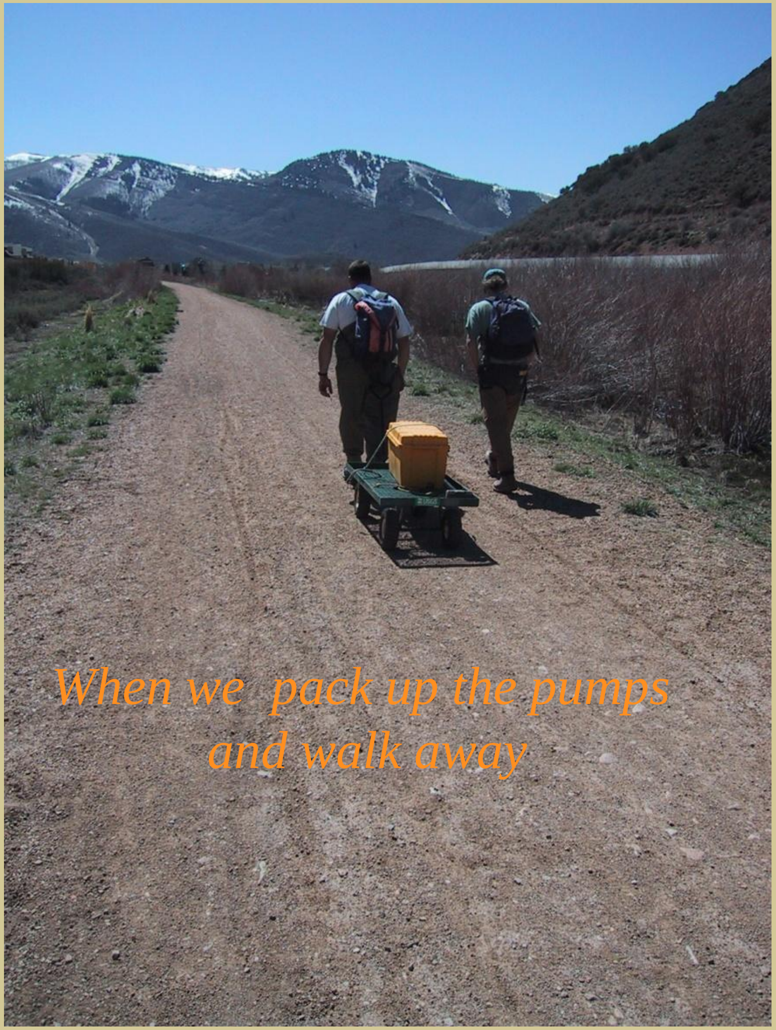
- Increase downstream from the end of reconstruction
- Increase from reconstruction activity
- Mostly colloidal copper when stirred up by construction
- Filtered copper downstream is near median of diel samples

Remediation in Silver Bow

- Low metal concentrations through LAO
- Results of reconstruction are demonstrated in the lower concentrations of metals
- Construction activity increases colloidal metal concentrations
- Returned this year to get undisturbed samples

USGS

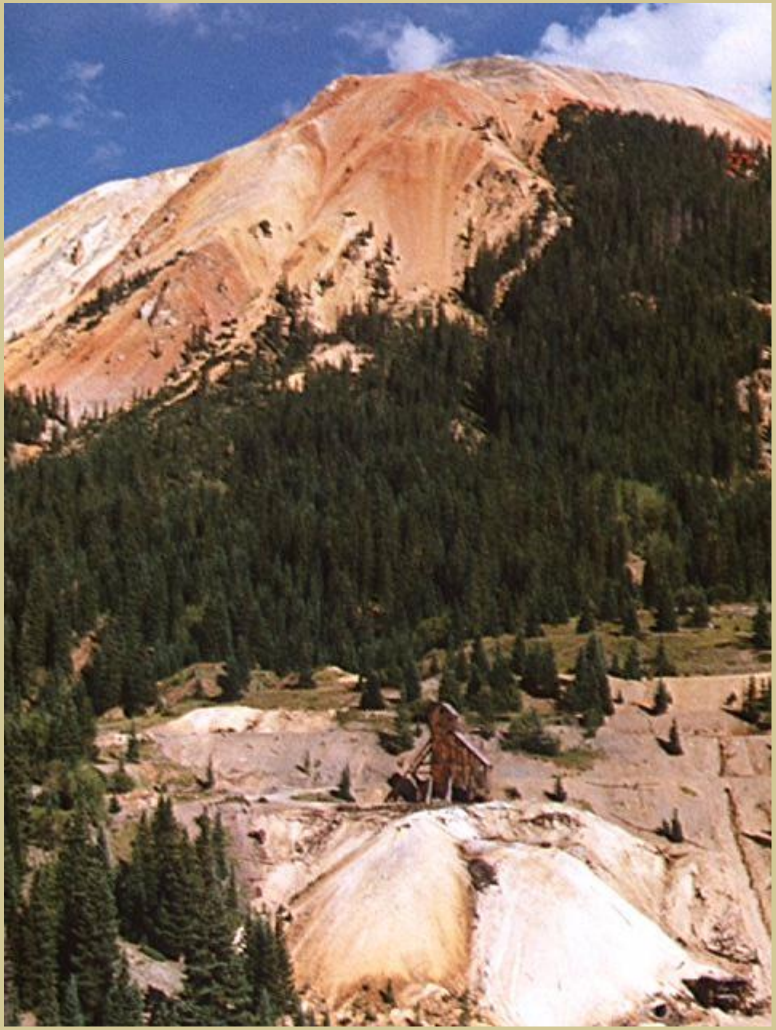
What did we get?



- Distinguish between AMD and ARD (pre-mining) giving in-stream concentrations
- Evaluation multiple remediation options (save $$$)
- Quantify what really happens with remediation
- Current application to permitting – Stibnite, ID

Contact information:
bkimball@usgs.gov
http://toxics.usgs.gov/mining

References



- Methods:

  Kimball,B.A., Runkel,R.L., Walton-Day,K., and Bencala,K.E., 2002, Assessment of metal loads in watersheds affected by acid mine drainage by using tracer injection and synoptic sampling: Cement Creek, Colorado, USA: Applied Geochemistry, v. 17, no. 9, p. 1183-1207.

  Kimball,B.A., Runkel,R.L., and Walton-Day,K., 2003, Use of field-scale experiments and reactive solute-transport modelling to evaluate remediation alternatives in streams affected by acid mine drainage, *in* Jambor, J. L., Blowes, D. W., and Ritchie, A. I. M., eds., Environmental aspects of mine wastes (31 ed.): Vancouver, British Columbia, Mineralogical Association of Canada, p. 261-282.

- Redwell Basin

  Kimball,B.A., Runkel,R.L., Wanty,R.B., and Verplanck,P.L., 2010, Reactive solute-transport simulation of pre-mining metal concentrations in mine-impacted catchments: Redwell Basin, Colorado, USA: Chemical Geology, v. 269, p. 124-136.

- Little Cottonwood Remediation

  Kimball,B.A., and Runkel,R.L., 2010, Evaluating remediation alternatives for mine drainage, Little Cottonwood Creek, Utah, USA: Environmental Earth Science, v. 60, p. 1021-1036.