The Use of Mass Loading Studies to Identify Sources of Trace Metal Inflow to Streams Affected by Historical Mining—A Potential Exploration Tool

by

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Presentation Outline

• Why detailed sampling?
• Loads versus concentration
• Mass-load studies and the injection/synoptic sampling method
• Load calculations
• Examples of anomalous findings
• Summary
Traditional view of a watershed

- Reconnaissance
- "Integrator" site
  - Chemical Weathering
  - Loads and seasonal variation
  - Processes on a watershed scale
- Long-term monitoring
- Trends
- Anomalous watershed
What are the questions for mass-loading analysis?

- Where are the greatest sources of loading occurring?
- Are there ground-water sources of metal loading?
- Are there multi-element sources of ground-water loading to the stream?
- Are there ground water sources of indicator elements to the stream?

Confluence of Cement Creek and the Animas River, Animas River Basin, Colorado, USA
What if our questions are about sources within a watershed?

- Usually a lot of chemical data on possible sources
  - “Site by site”
  - Regional geology
- Integrator site cannot answer questions about relative importance
- Little information on stream flow (discharge)
What do we need to know?

- What sources are the most significant?
- Need spatial detail at specific locations
- Divide stream into segments and sample inflows
- Watershed characterization
  - Geology and structure
  - Deposit types
  - Hydrology
  - Chemistry and location of inflow to stream
Why do we need loads for “ranking” sources?

Load = \( C \times Q \)

\[ C_A Q_A + C_I (Q_B - Q_A) = C_B Q_B \]
Not always the highest concentration

\[ C_A Q_A + C_I (Q_B - Q_A) = C_B Q_B \]
Mass-Loading Studies: The Method

- Walk the stream
- Inject salt (for hydrology, streamflow)
- Collect synoptic samples
- Calculate streamflow
- Calculate loads
- Calculate relative loads
Walk the Stream

- Fe, Al, or Mn-rich seeps
- Fe-”Bogs”
- Flocculent
- Ferricrete
- Faults, sheer zones
- Map geology
Why use a tracer for streamflow?

- Total (stream + hyporheic) flow for mountain streams
- Collection of many samples for watershed-scale synoptic sampling
  - Locate **anomalous** inflow
  - Evaluate **premining** baseline conditions
  - Evaluate remediation options
Tracer (salt) Dilution

- Mass Salt = 4
  Vol. H₂O = 0
  Conc. Salt = NA

- Mass Salt = 4
  Vol. H₂O = 4
  Conc. Salt = 1

- Mass Salt = 4
  Vol. H₂O = 6
  Conc. Salt = 0.67

- Mass Salt = 4
  Vol. H₂O = 8
  Conc. Salt = 0.5

[Diagram showing dilution process with volumes and concentrations]
Adding the salt

- Continuous Injection
  - Not a "slug"
  - Long enough for steady state
- Carefully metered pump
  - Counting revolutions with data logger
  - Adjusts voltage
  - Constant per two minute period

Pump setup for tracer injection
Tracer injection – Temporal view

CHLORIDE CONCENTRATION, IN MG/L

Discharge
Residence time
Storage

Pipe T0 T1 T2 T3
Tracer (salt) Dilution

Uvas Creek, California, USA

Cement Creek, Colorado, USA

Temporal Profile

Spatial Profile
Synoptic Sampling
Load calculations --
Look at change between sites

\[ M_s = QC \]

\[ \Delta M_s = Q_B C_B - Q_A C_A \]
Working the data
Sampled Instream Load

\[ M = Q_A C_A \]

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1. “Basic data” from the study
2. Shows increase and decrease of load

Sampled Instream Load

- Tributary
- Seep
- Ground water

LOAD, IN KG/DAY

DISTANCE

Sampled

USGS
Load calculations --
Look at change between sites

$$\Delta M_S = Q_B C_B - Q_A C_A$$
Cumulative Instream Load

\[ \Delta M_s = Q_B C_B - Q_A C_A \]
\[ \sum +\Delta M_s \]

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Cumulative instream load

1. Cumulative sum of positive
2. Best estimate of total load to stream

LOAD, IN KG/DAY

DISTANCE

Demand

Sampled

Instream

Seep

Tributary

Ground water

USGS
Load calculations --
Cumulative Inflow Load

\[ \Delta M_I = C_T (Q_C - Q_B) \]
Cumulative inflow load

\[ \Delta M_I = C_T (Q_B - Q_A) \]

\[ \sum \Delta M_I \]

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Cumulative Inflow Load

1. Cumulative sum of inflow load
2. Best estimate of sampled load

LOAD, IN KG/DAY

DISTANCE

- Sampled
- Instream
- Inflow

Cumulative Inflow Load Graph

- Tributary
- Seep
- Ground water
What did we get?

- Which sites cause the greatest loading (watershed view)?
- Are there ground-water or "non-point" sources of metals (watershed and site characterization)?
- Are changes due to chemical reaction (natural attenuation) or to dilution?
Map of the contiguous United States showing western states where mass-loading studies have been conducted
Little Cottonwood, Utah

1. Sharp increase → distinct sources

- Vein deposits
  - Mine tunnels
  - Bulkhead
- Mountain leaking

![Graph showing zinc load and distance in meters with three lines representing Instream, Total, and Inflow.]
Cement Creek, Colorado

1. Broad increase → regional alteration
2. Unsampled versus sampled inflow

![Graph showing dissolved zinc load vs. distance.](image)
Watershed-scale comparison -- Zinc

- Surface water versus ground water
Integrating the geologic sources

- Mineral Creek, Cement Creek, Colorado
- Loadings are tied to geologic sources
- Alteration zones
  - Acid-sulfate zone
  - Quartz-sericite-pyrite
  - Propylitic alteration

Alteration map by Dana Bove (USGS)
Watershed-scale comparison – Multi-element

Surface Inflow

Unsampled Inflow
Watershed characterization is integrated in the stream

- Results are a “road map” for potential followup work
- Trace-metal-rich ground water inflows indicate mineralized or altered zones, or hydraulically conductive fractures that intersect such zones
- Construct flow paths from metal-rich inflows to sources
- Overlay maps of geology, fractures, alteration, geophysics, then drill....
Caveat Emptor!!

- Method has not been tested for exploration
- Method is not a “Stand-Alone” technique: part of an “Integrated” (geology, structure, hydrology, etc.) investigation
- Special considerations needed for loosing streams, or streams with loosing reaches
Summary

- Mass-loading studies (hydrogeochemical technique)
- Results can locate ground-water input to stream (single-element, multi-element, indicator elements)
- Combined with other data (geology, geophysics) may help locate deposits
- Premining baseline and water-quality assessment