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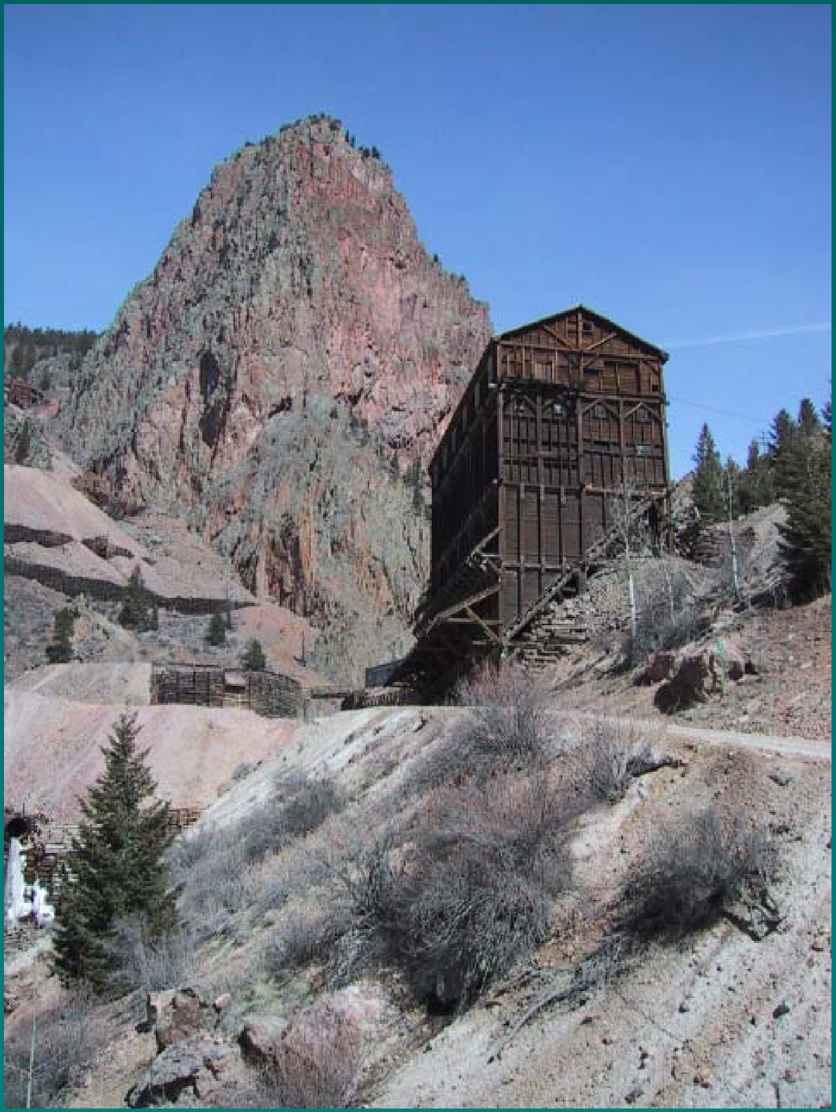

The Use of Mass Loading Studies to Identify Sources of Trace Metal Inflow to Streams Affected by Historical Mining—A Potential Exploration Tool

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

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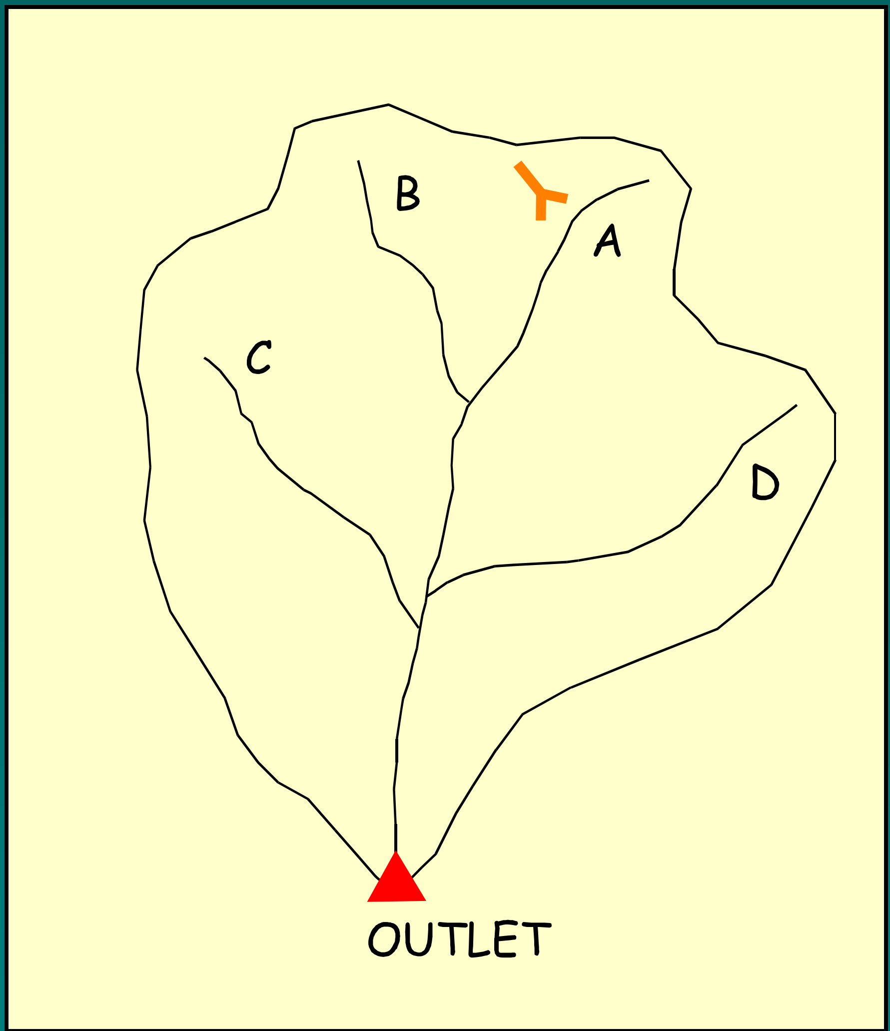
Traditional view of a watershed



- Reconnaissance
- "Integrator" site
  - Chemical Weathering
  - Loads and seasonal variation
  - Processes on a watershed scale
- Long-term monitoring
- Trends
- Anomalous watershed

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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

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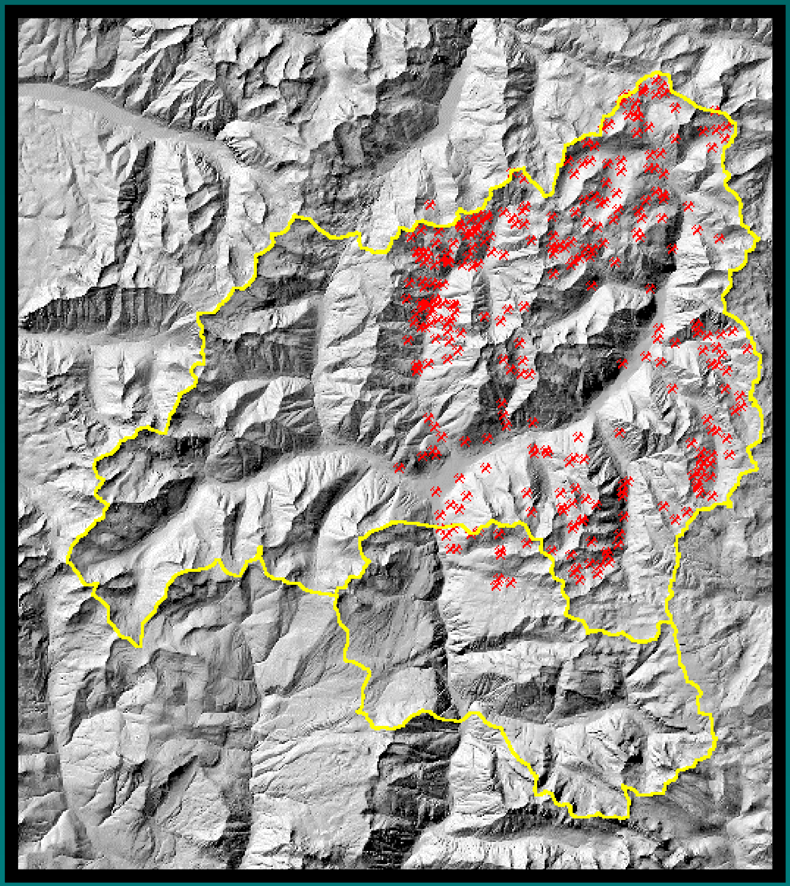
What if our questions are about sources within a watershed?



- 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)

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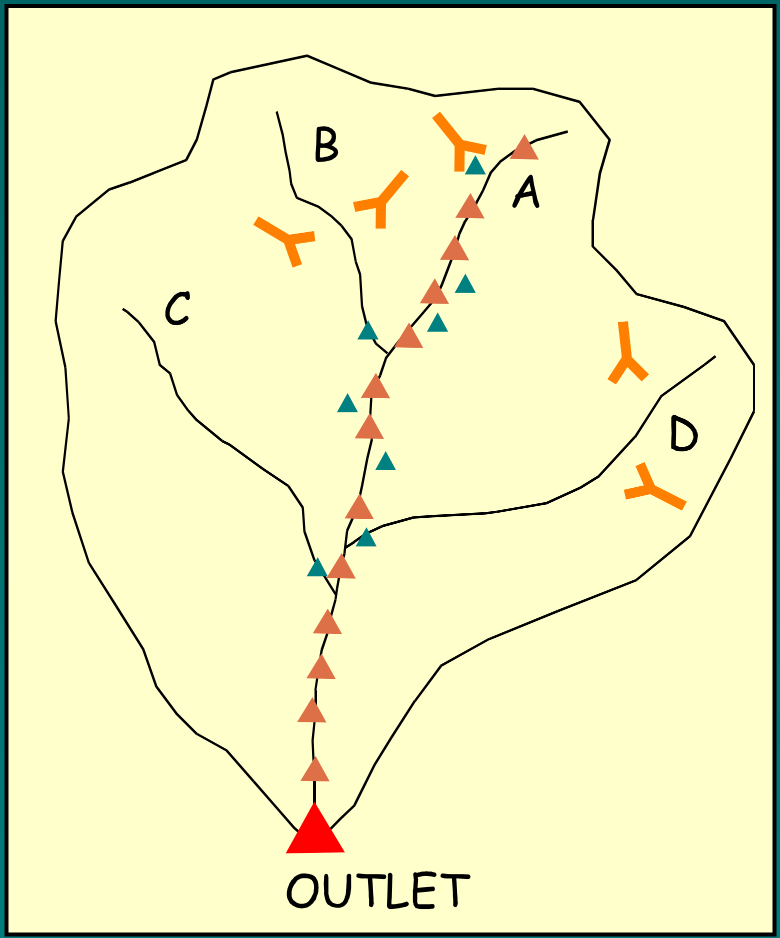
What do we need to know?



- 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

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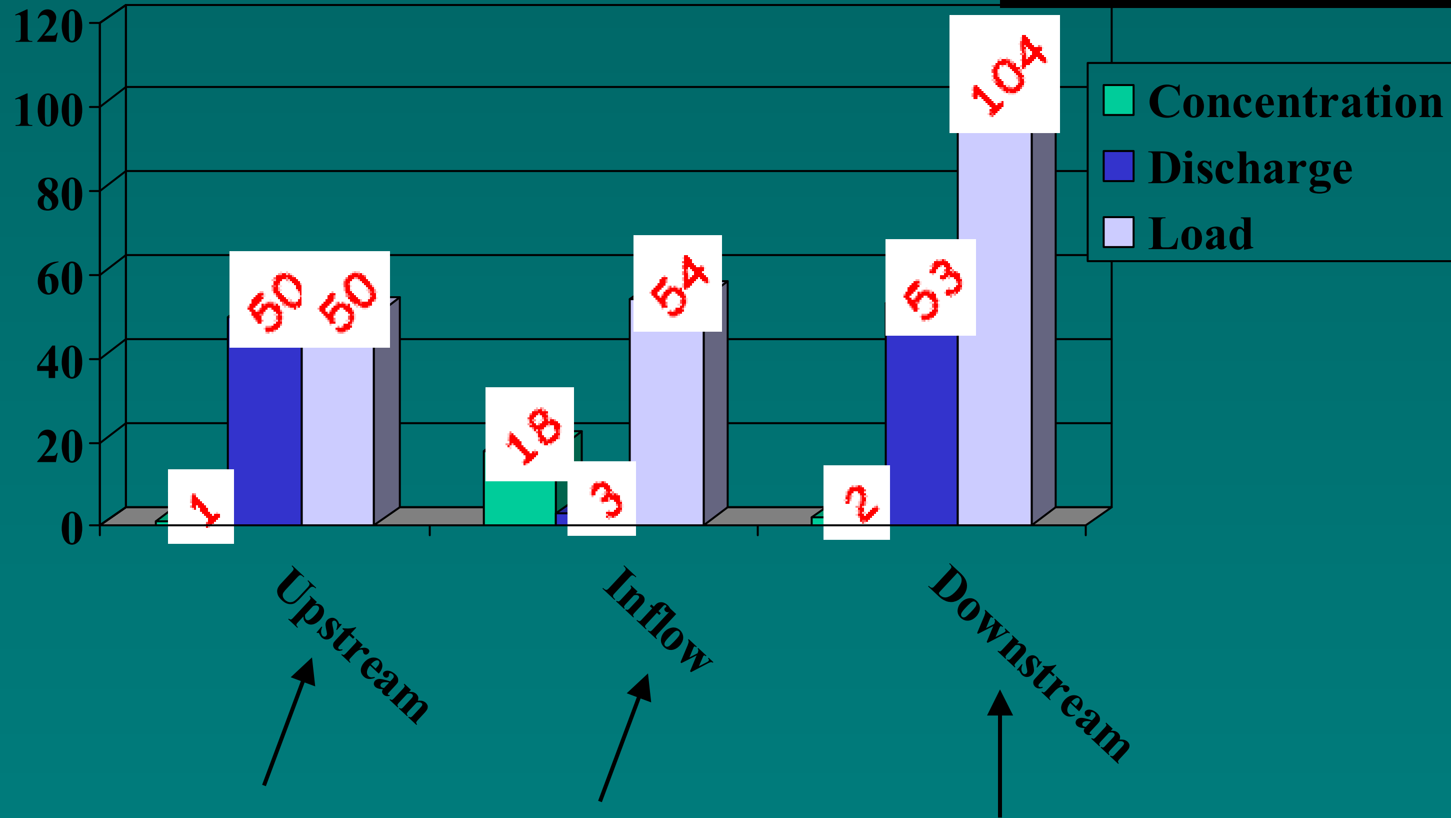
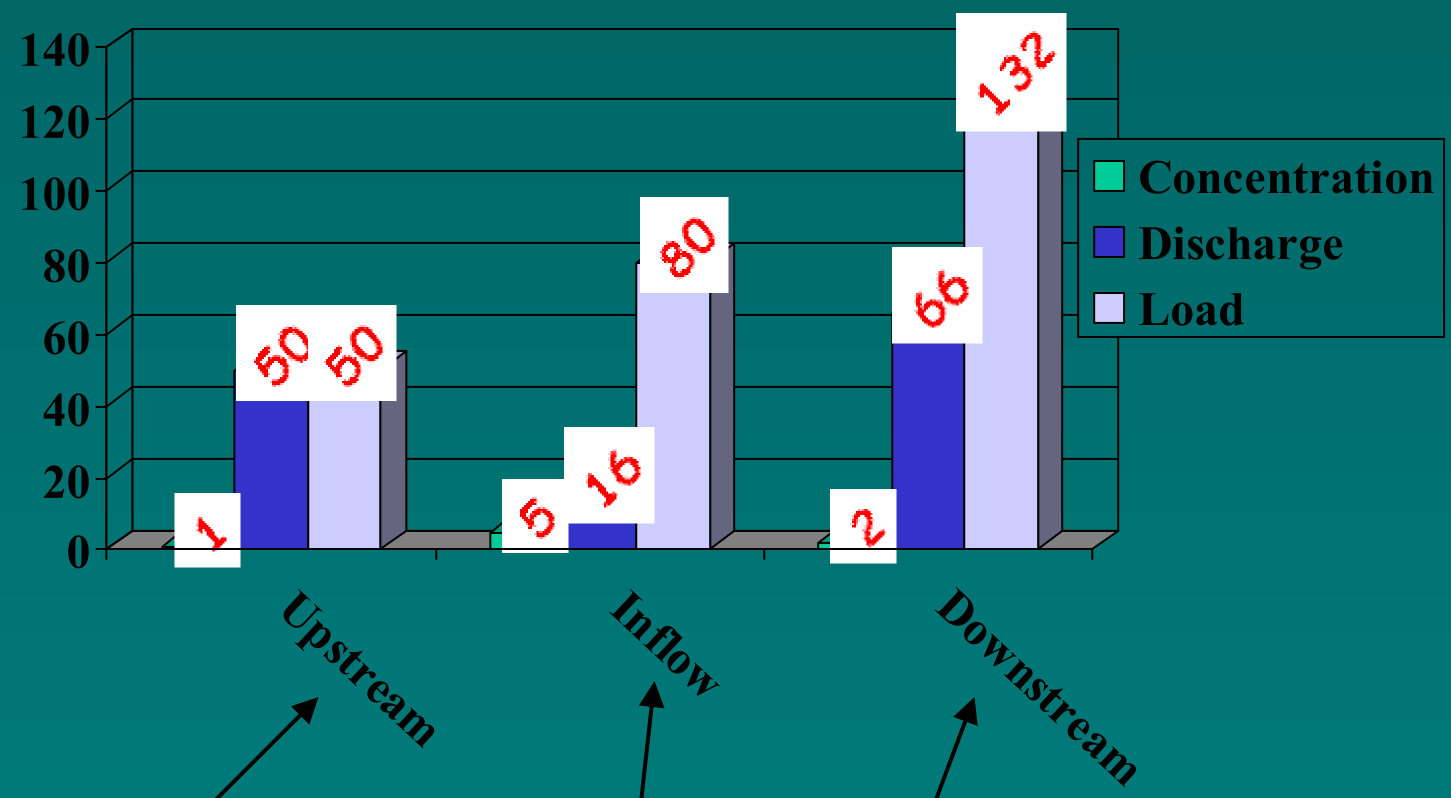
Why do we need loads for "ranking" sources?

Load = *C***Q***



$$C_AQ_A + C_I(Q_B\text{-}Q_A) = C_BQ_B$$

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

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Walk the Stream

- Fe,Al, or Mn-rich seeps
- Fe-"Bogs"
- Flocculent
- Ferricrete
- Faults, sheer zones
- Map geology

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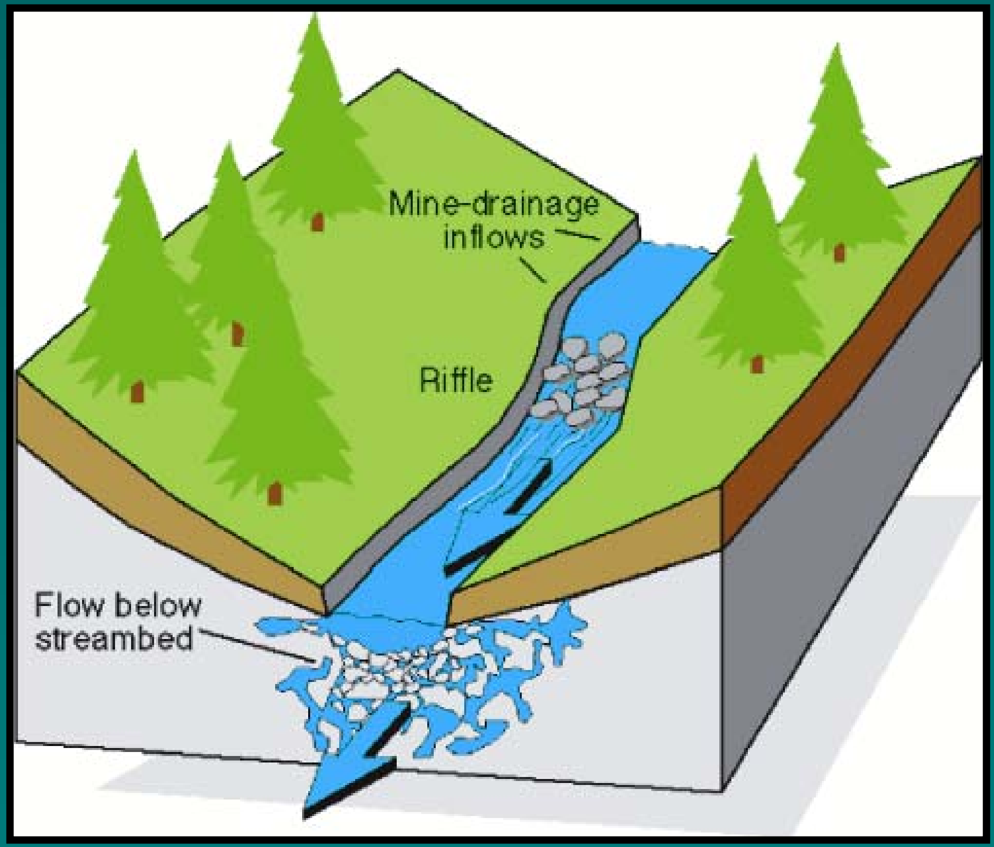
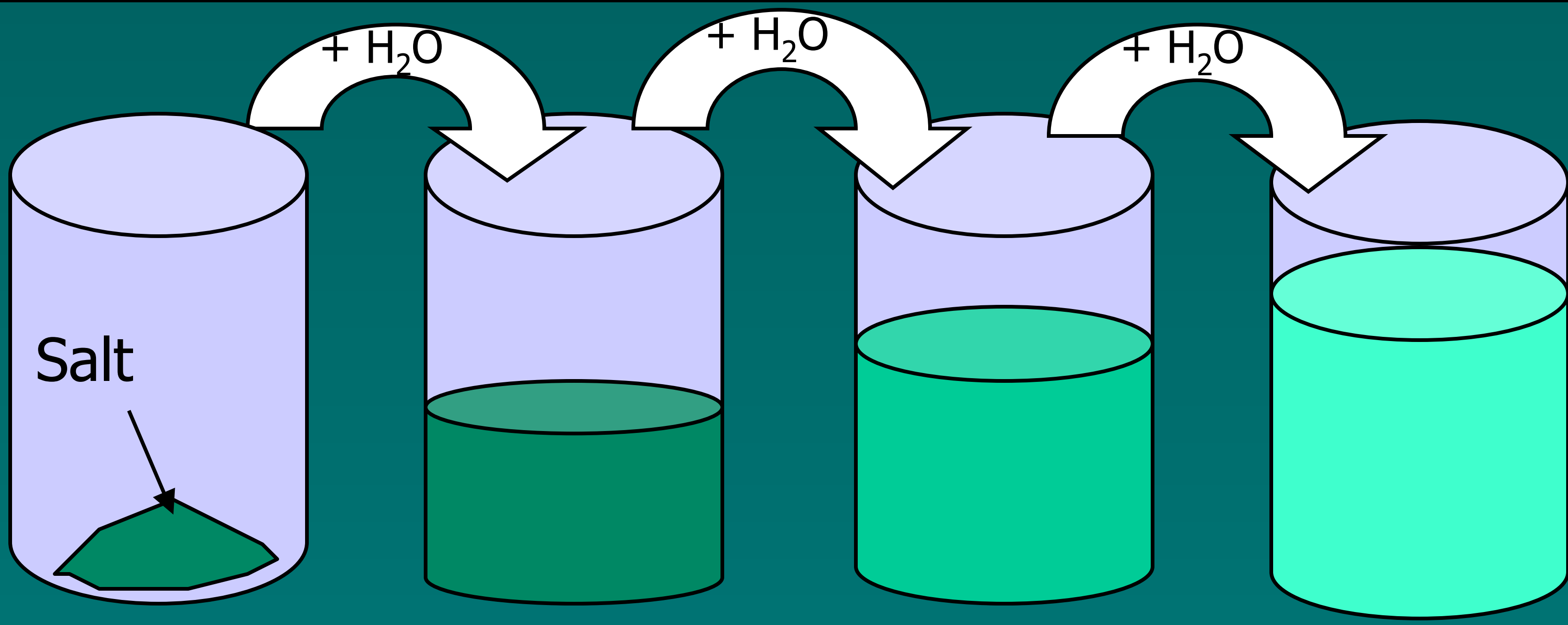
Why use a tracer for streamflow?

- 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. H_2O = 0
Conc. Salt = NA

Mass Salt = 4
Vol. H_2O = 4
Conc. Salt = 1

Mass Salt = 4
Vol. H_2O = 6
Conc. Salt = 0.67

Mass Salt = 4
Vol. H_2O = 8
Conc. Salt = 0.5

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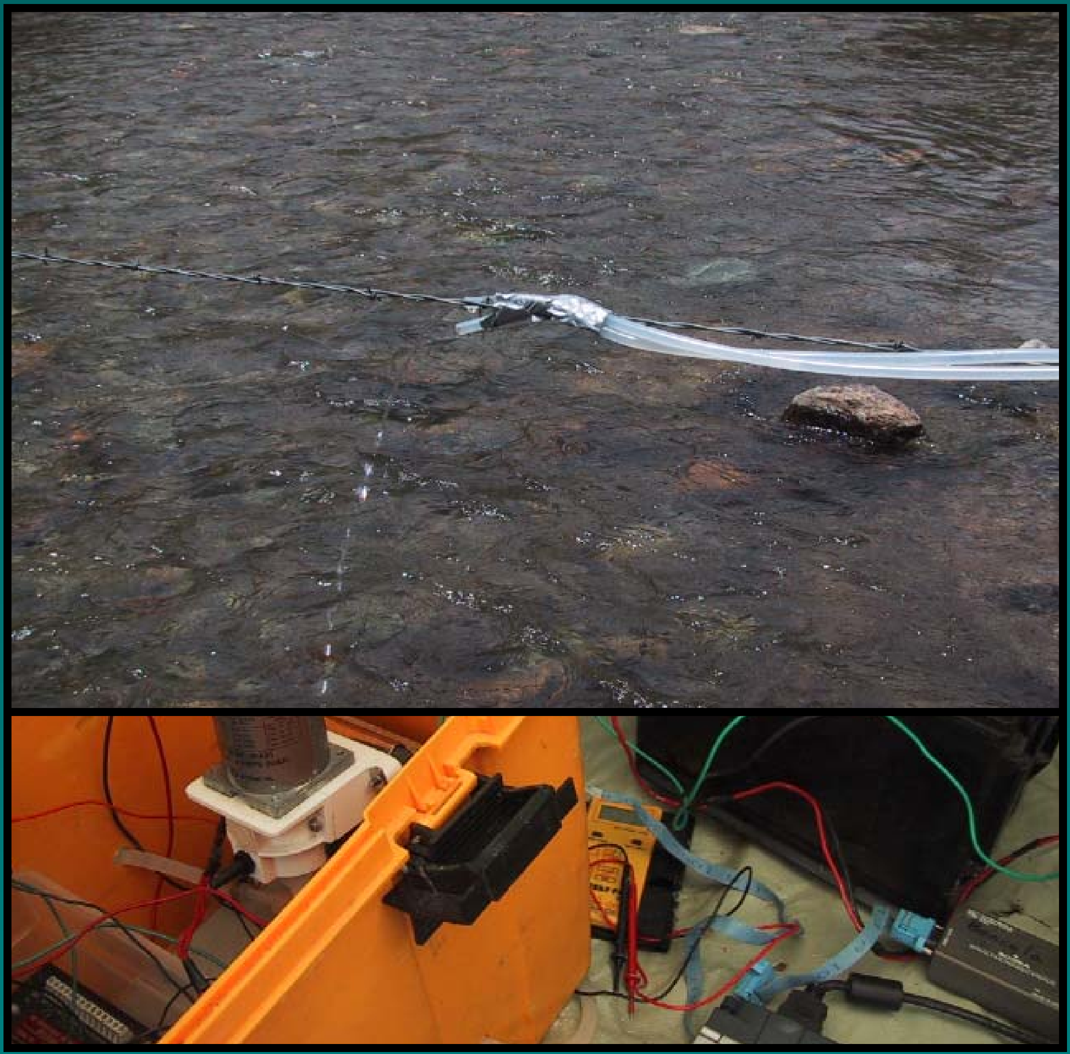
Adding the salt



- 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

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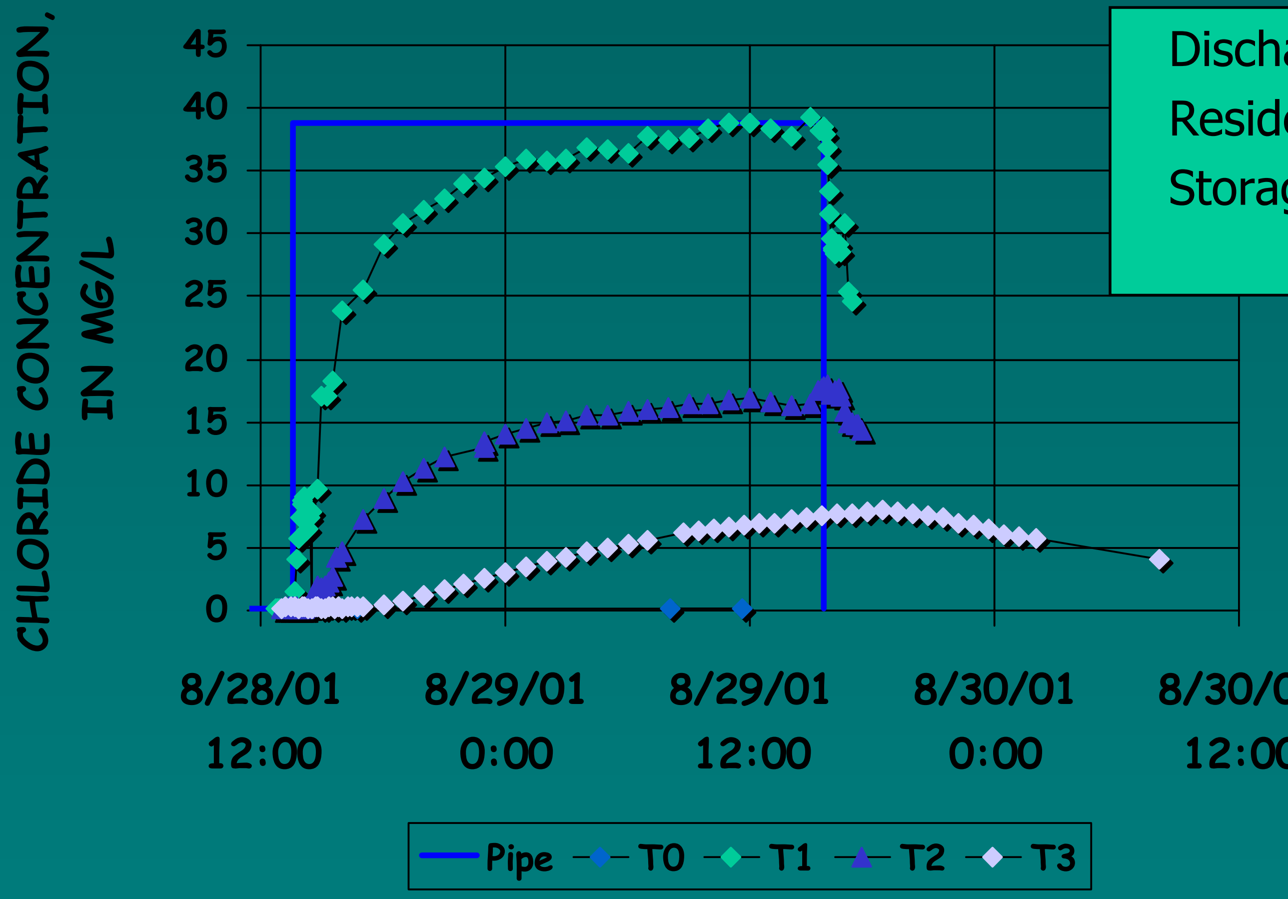
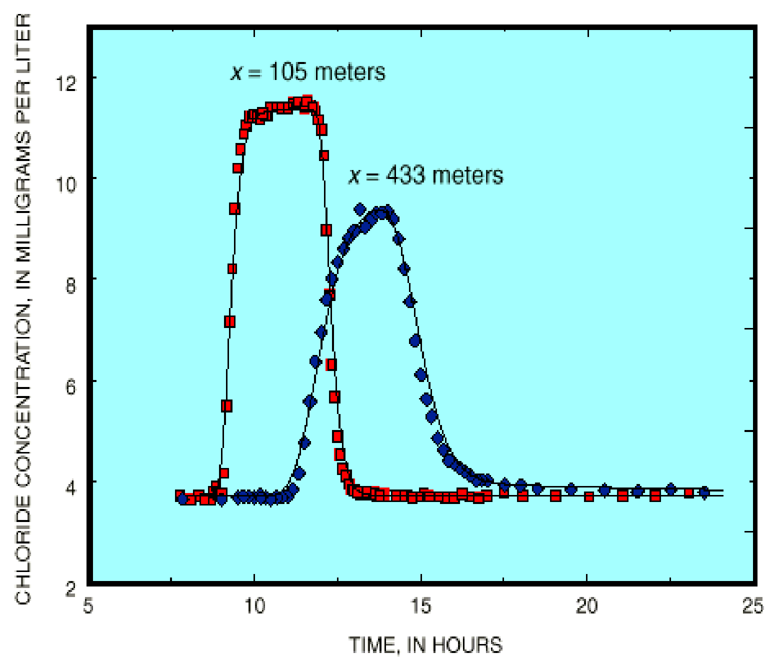
Tracer injection – Temporal view



Discharge
Residence time
Storage

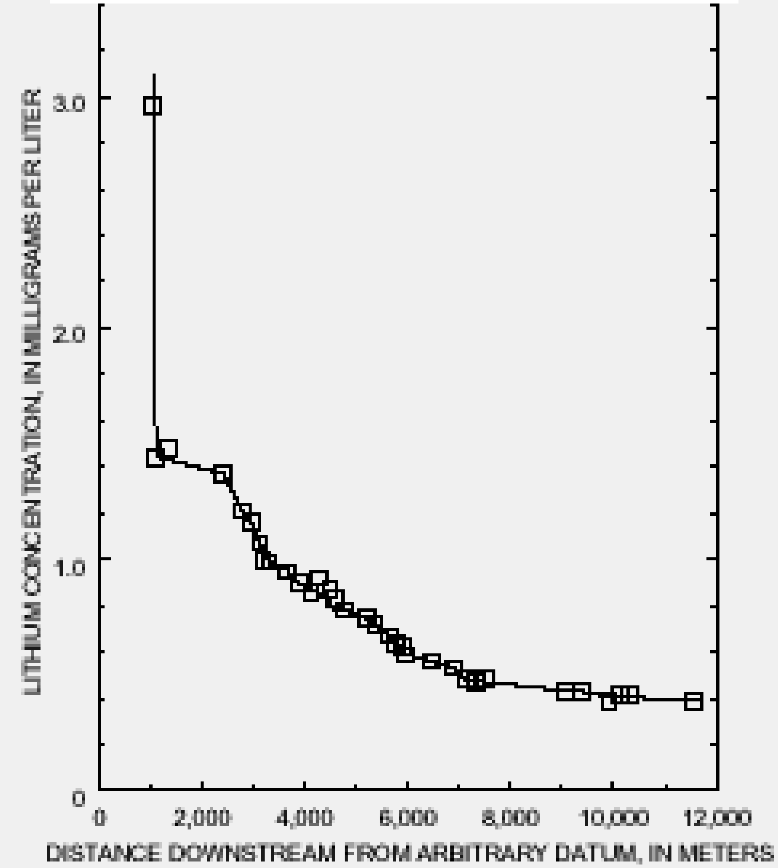
Tracer (salt) Dilution

Uvas Creek, California, USA



Temporal Profile

Cement Creek, Colorado, USA



Spatial Profile

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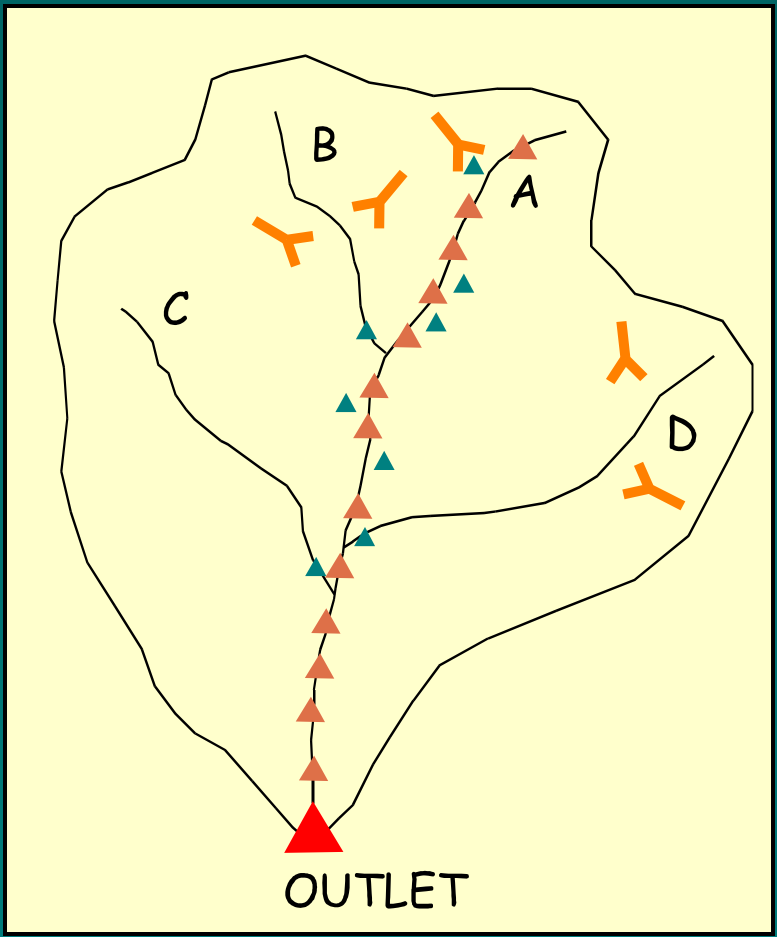
Synoptic Sampling



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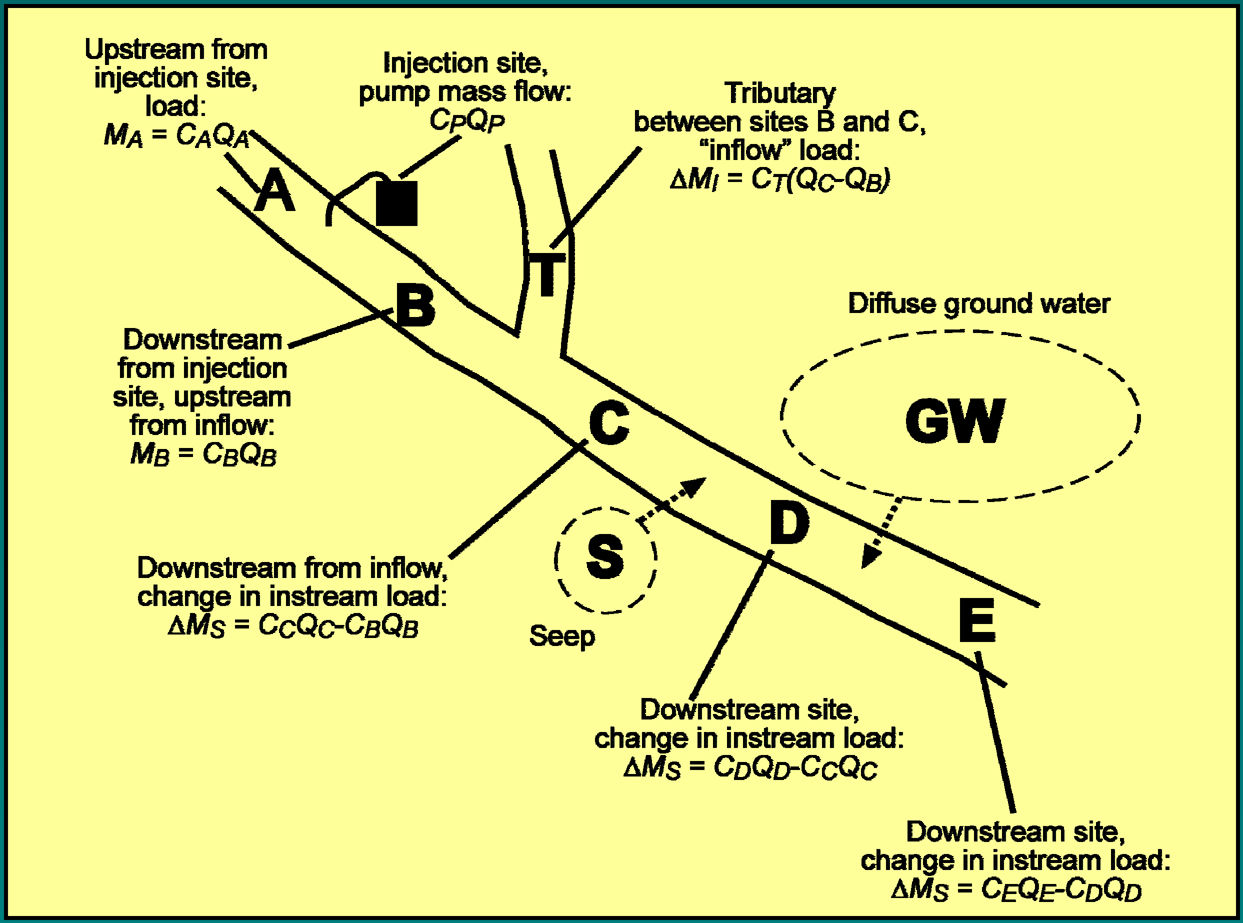
Load calculations -- Look at change between sites

$M_s = QC$

$\Delta M_s = Q_B C_B - Q_A C_A$



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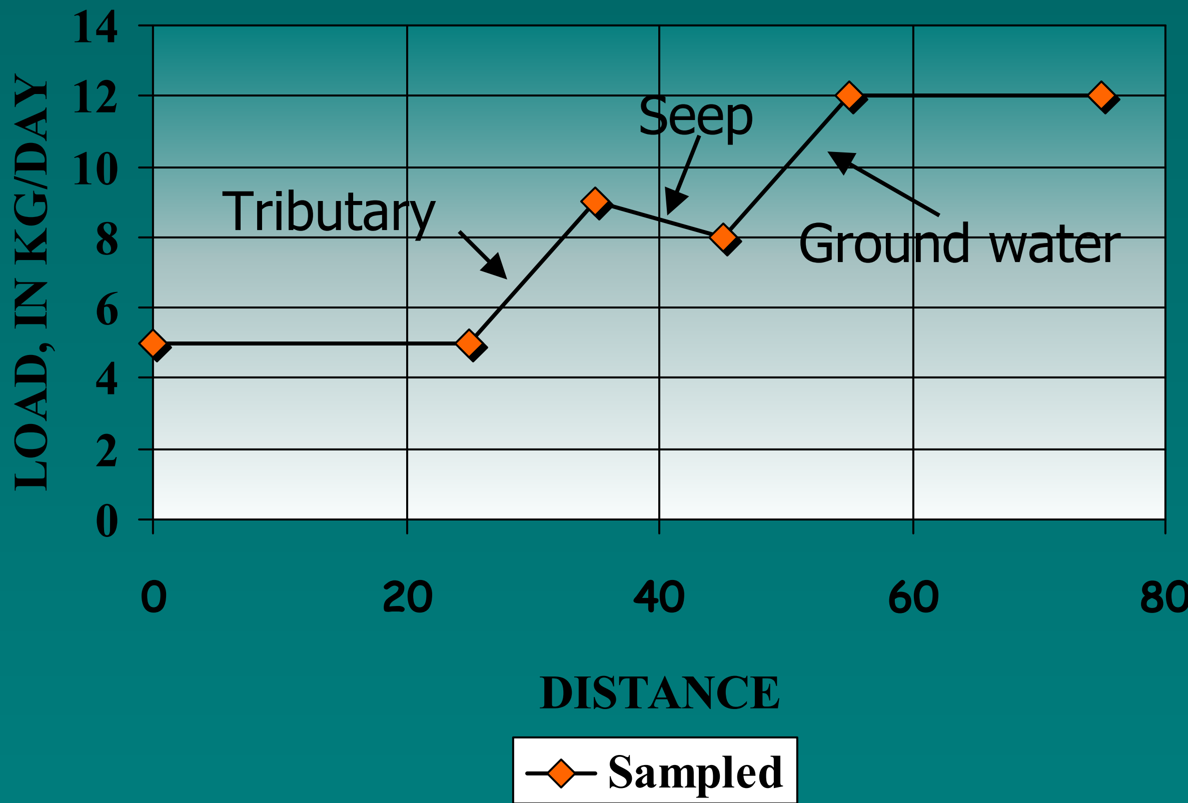
Working the data
Sampled Instream Load

$$M = Q_A C_A$$

Trib	Site	Dist	Zn	Q	Load
0	A	0	1.00	5.00	5.00
0	B	25	1.00	5.50	5.50
1	T	30	1.50	2.00	3.00
0	C	35	1.20	7.50	9.00
1	S	40	1.50	2.00	3.00
0	D	45	0.84	9.50	8.00
0	E	55	1.04	11.5	12.00
0	F	75	1.00	12.0	12.00

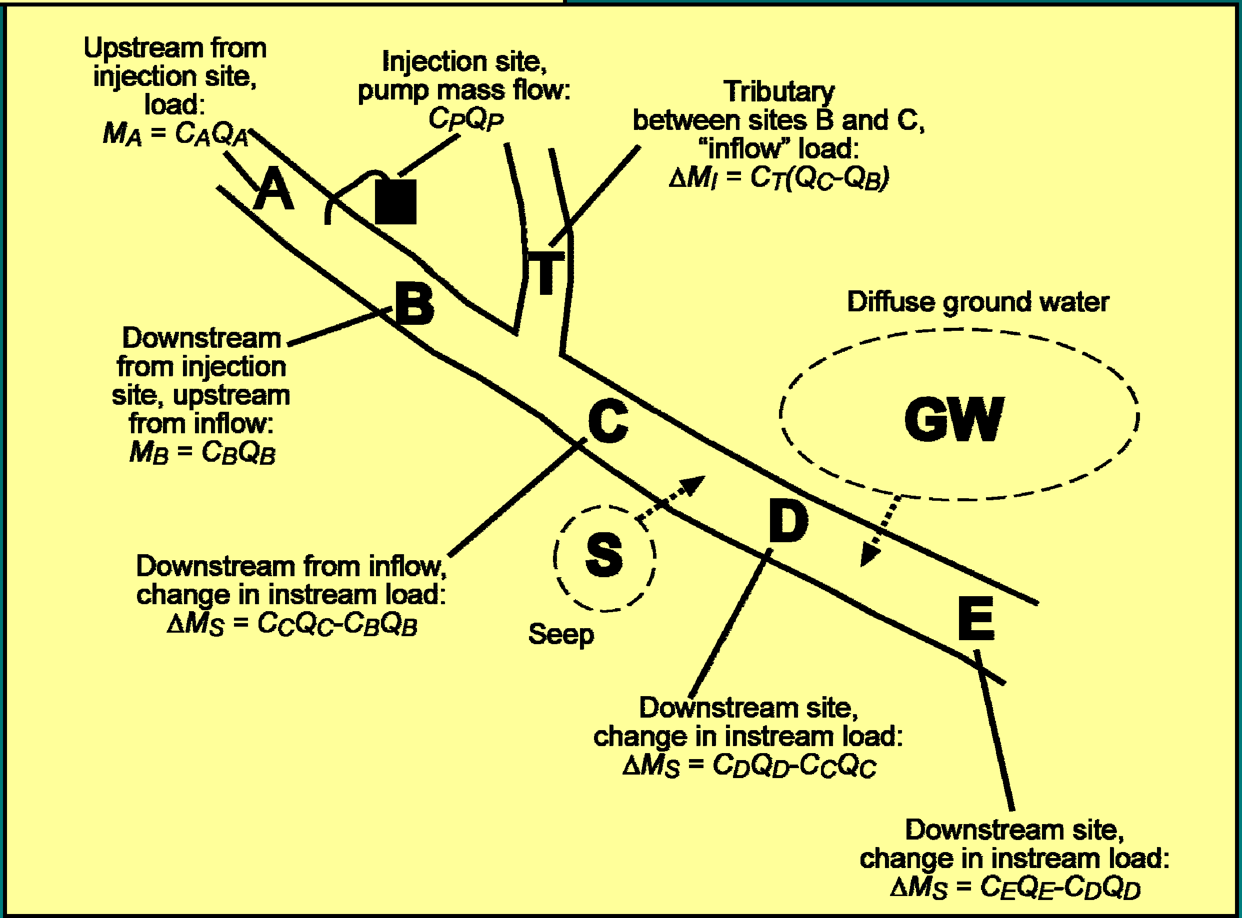
Sampled Instream Load

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



Load calculations -- Look at change between sites

$$\Delta M_S = Q_B C_B - Q_A C_A$$



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Cumulative Instream Load

$$\Delta M_S = Q_B C_B - Q_A C_A$$

$$\sum + \Delta M_S$$

Trib	Site	Dist	Zn	Q	Load	Δ Ms	Instream
0	A	0	1.00	5.00	5.00		
0	B	25	1.00	5.50	5.50	0.50	5.50
1	T	30	1.50	2.00	3.00		
0	C	35	1.20	7.50	9.00	3.50	9.00
1	S	40	1.50	2.00	3.00		
0	D	45	0.84	9.50	8.00	-1.00	9.00
0	E	55	1.04	11.5	12.00	4.00	13.00
0	F	75	1.00	12.0	12.00	0.00	13.00

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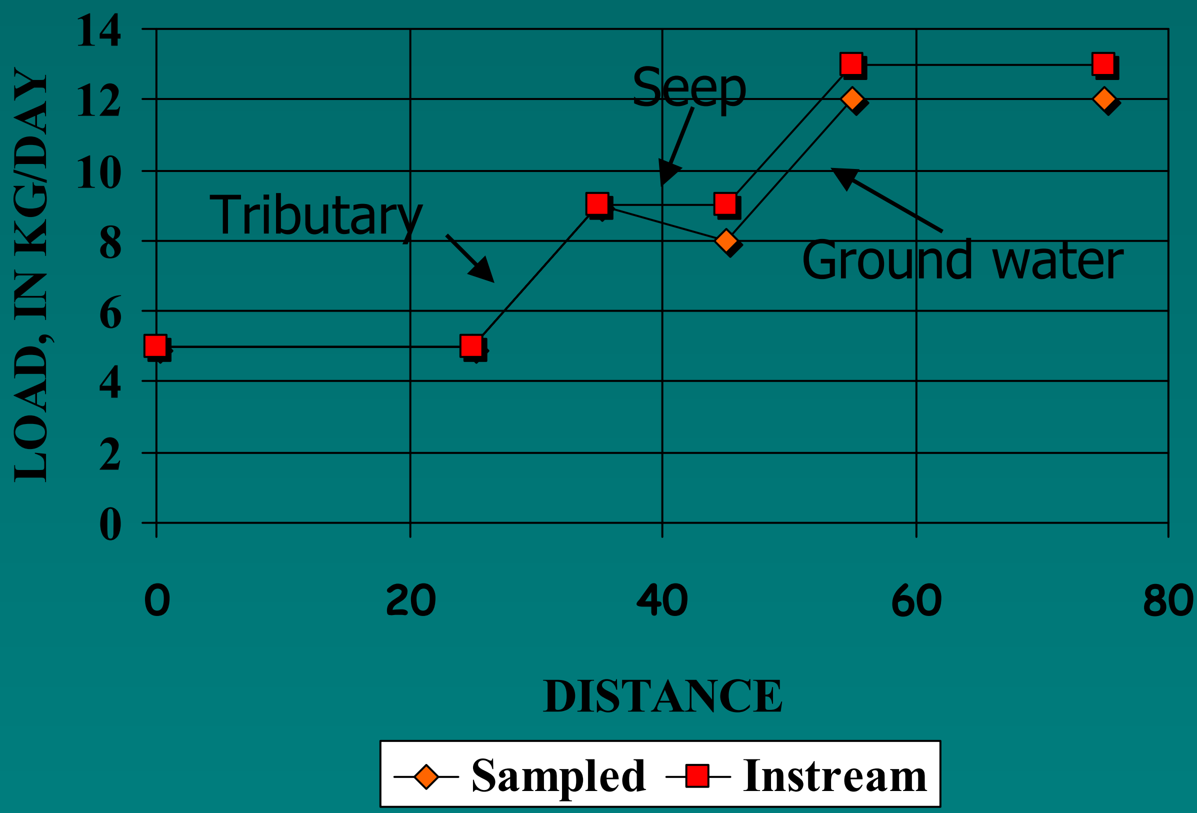
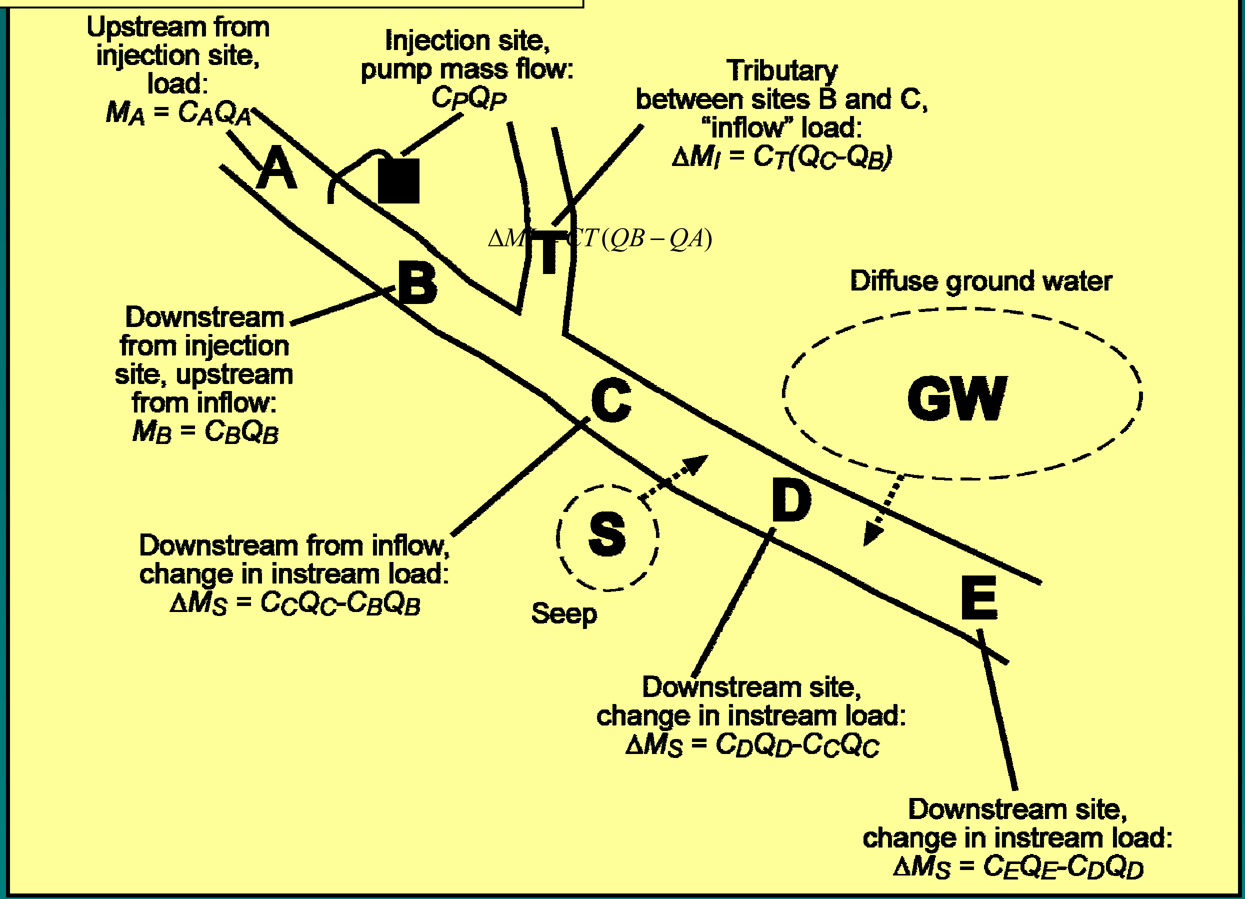
Cumulative instream load

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



Load calculations -- Cumulative Inflow Load

$$\Delta M_I = C_T(Q_C - Q_B)$$



Cumulative inflow load

$$\Delta M_I = C_T(Q_B - Q_A)$$

$$\sum \Delta M_I$$

Trib	Site	Dist	Zn	Q	Load	Ms	Instream	Mi	Inflow
0	A	0	1.00	5.00	5.00				5.00
0	B	25	1.00	5.50	5.50	0.50	5.50		5.00
1	T	30	1.50	2.00	3.00				
0	C	35	1.20	7.50	9.00	3.50	9.00	3.00	8.00
1	S	40	1.50	2.00	3.00				
0	D	45	0.84	9.50	8.00	-1.00	9.00	3.00	11.00
0	E	55	1.04	11.5	12.00	4.00	13.00		11.00
0	F	75	1.00	12.0	12.00	0.00	13.00		11.00

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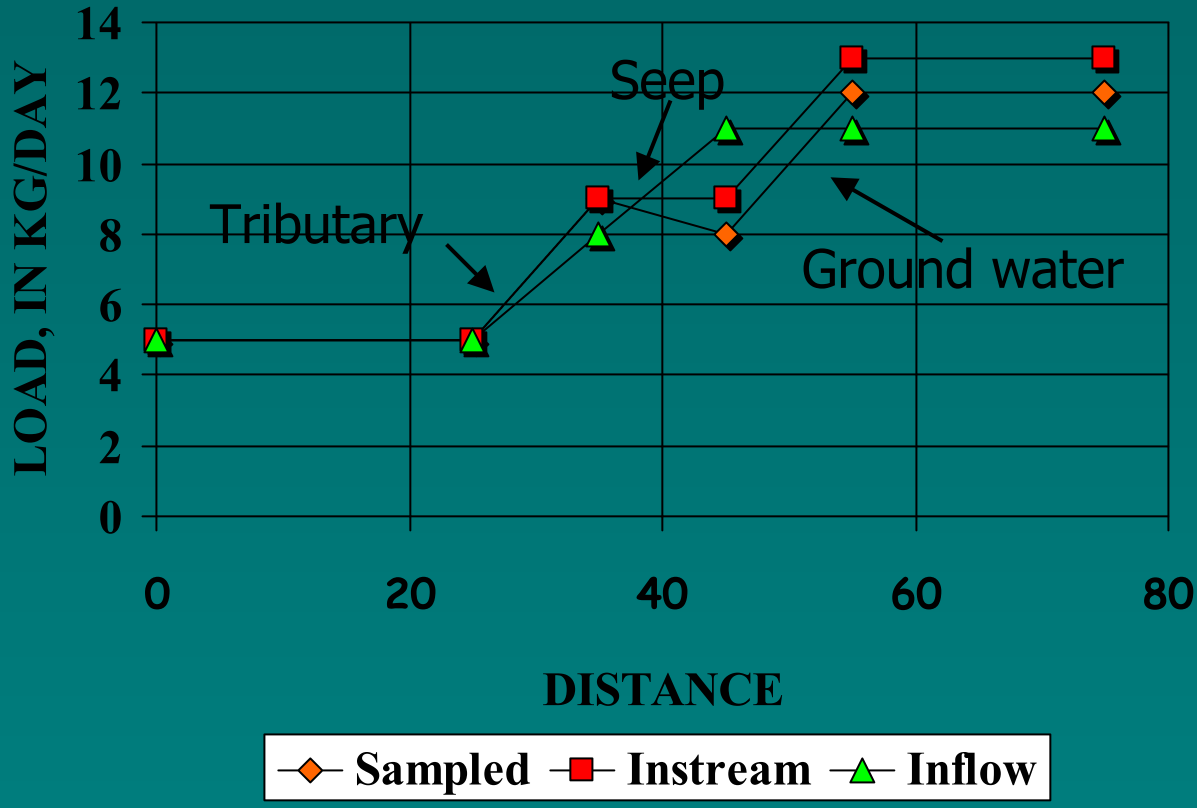
Cumulative Inflow Load

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



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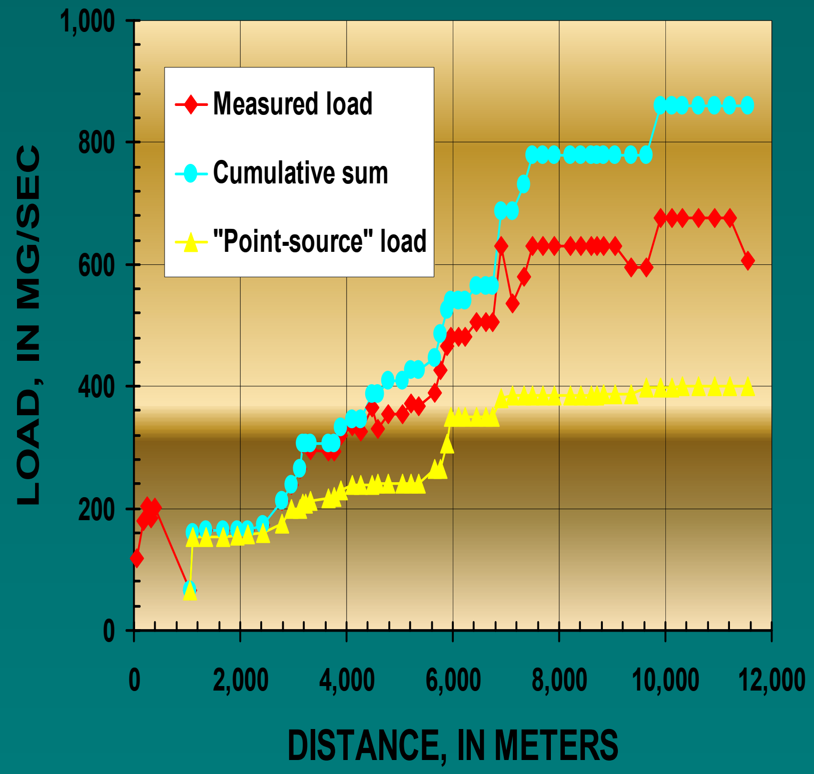
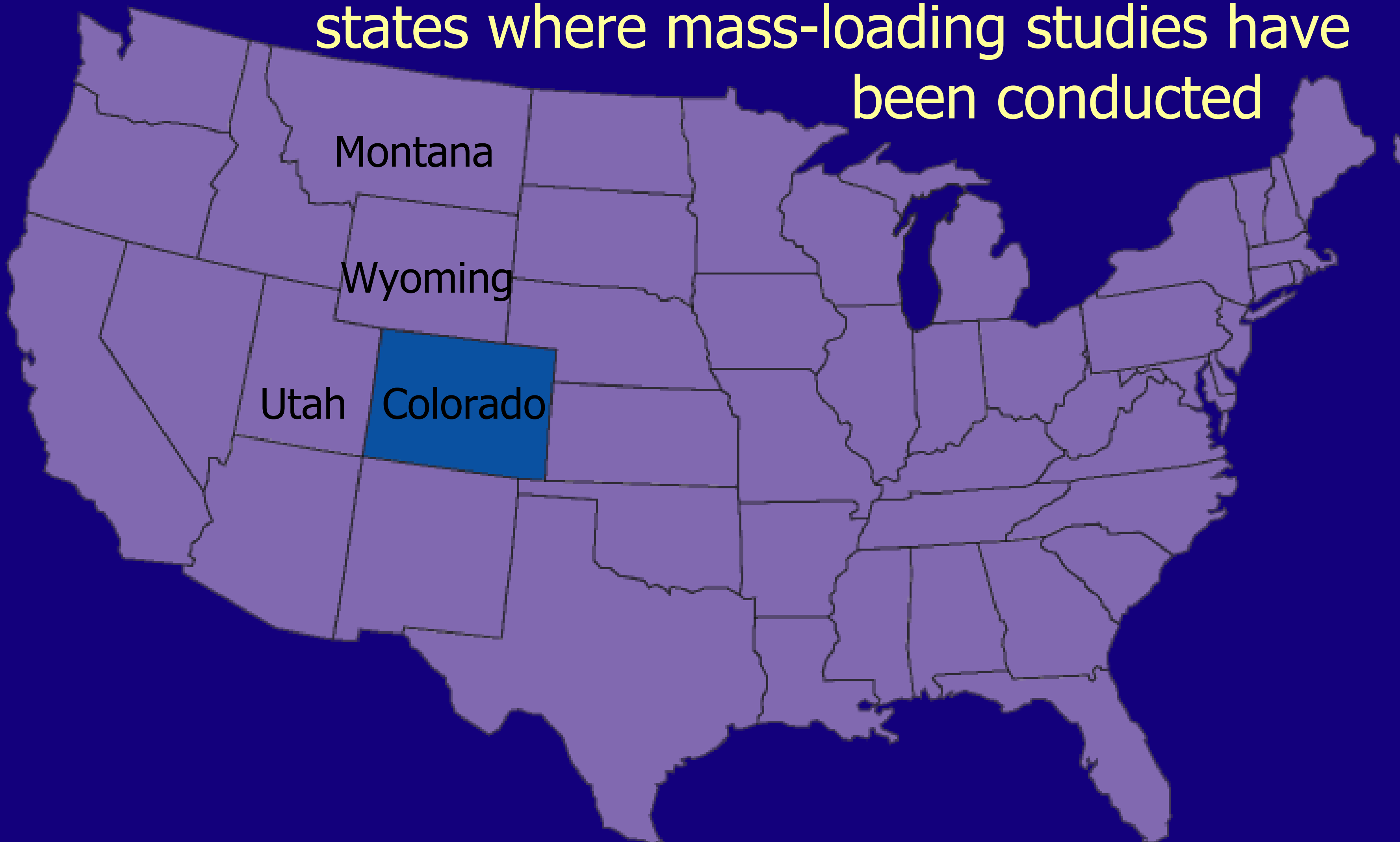
What did we get?

- 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



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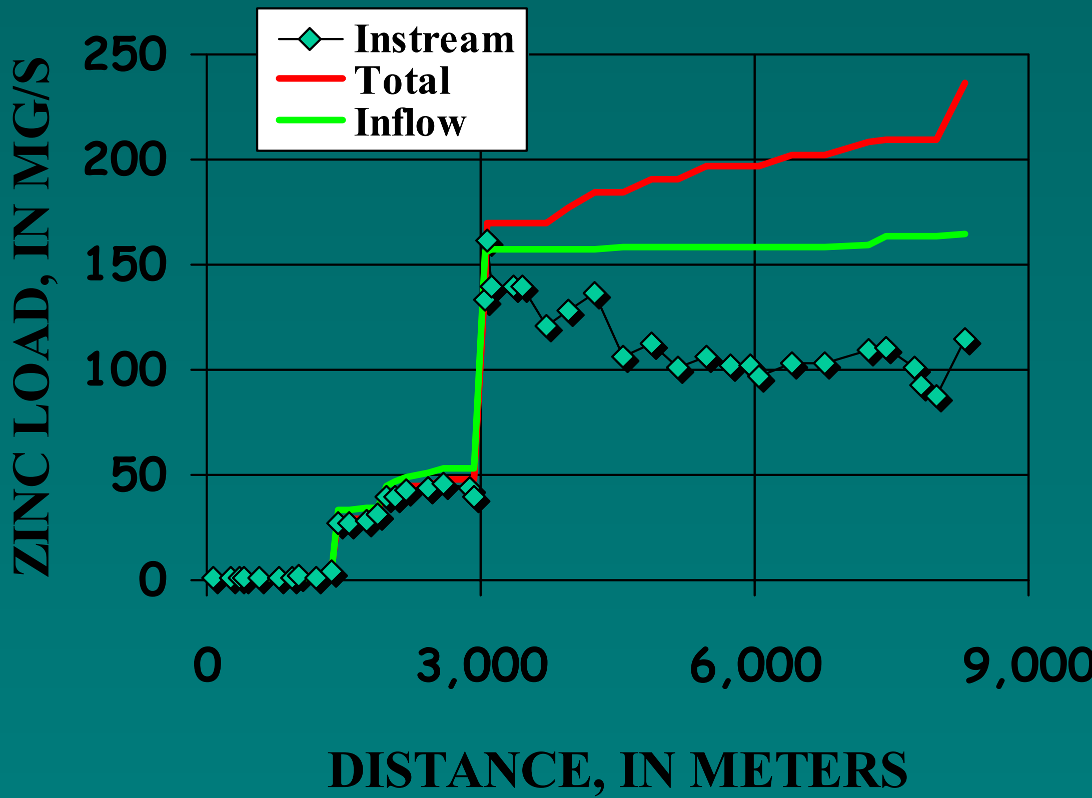
Little Cottonwood, Utah

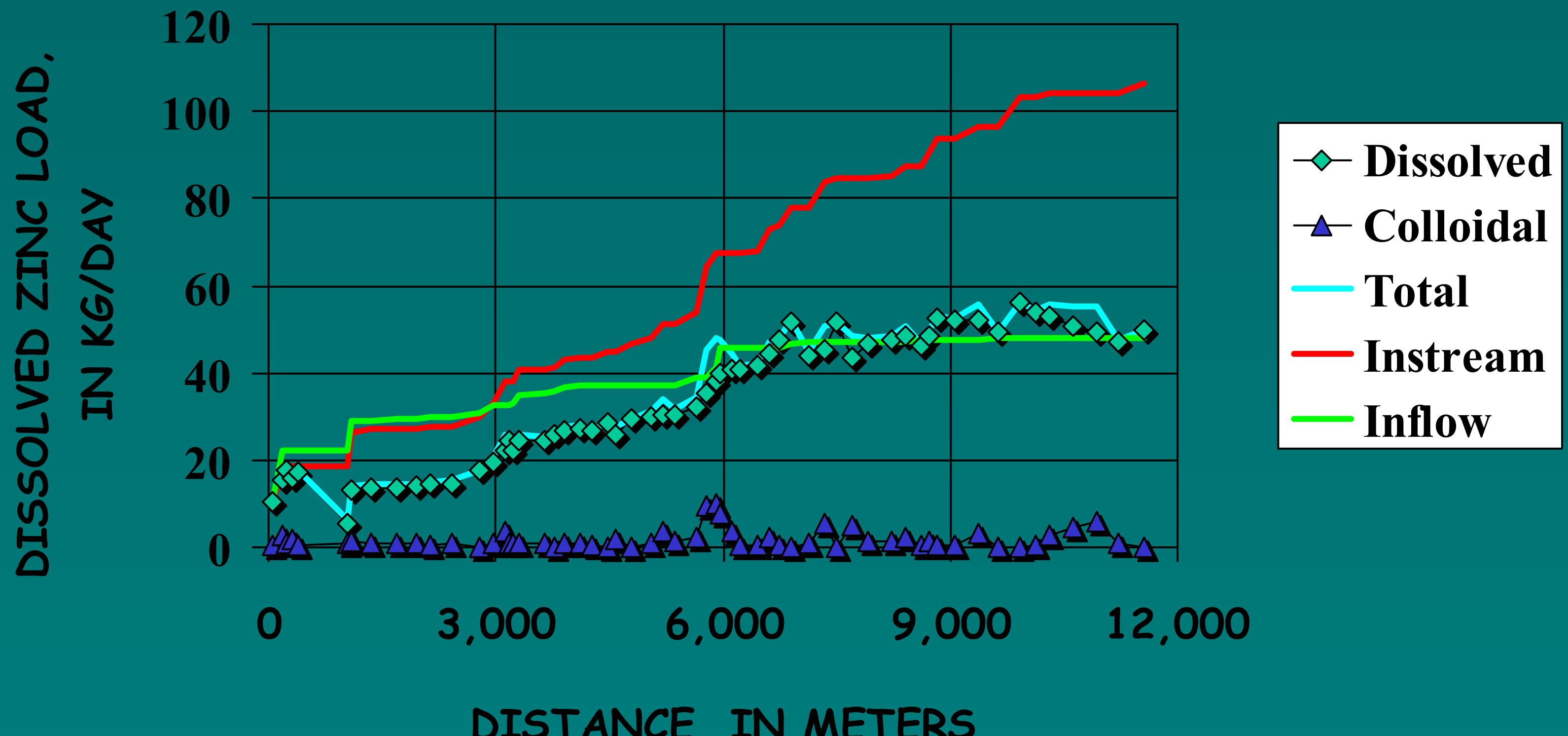
1. Sharp increase → distinct sources

- Vein deposits
  - Mine tunnels
  - Bulkhead
- Mountain leaking



Cement Creek, Colorado

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



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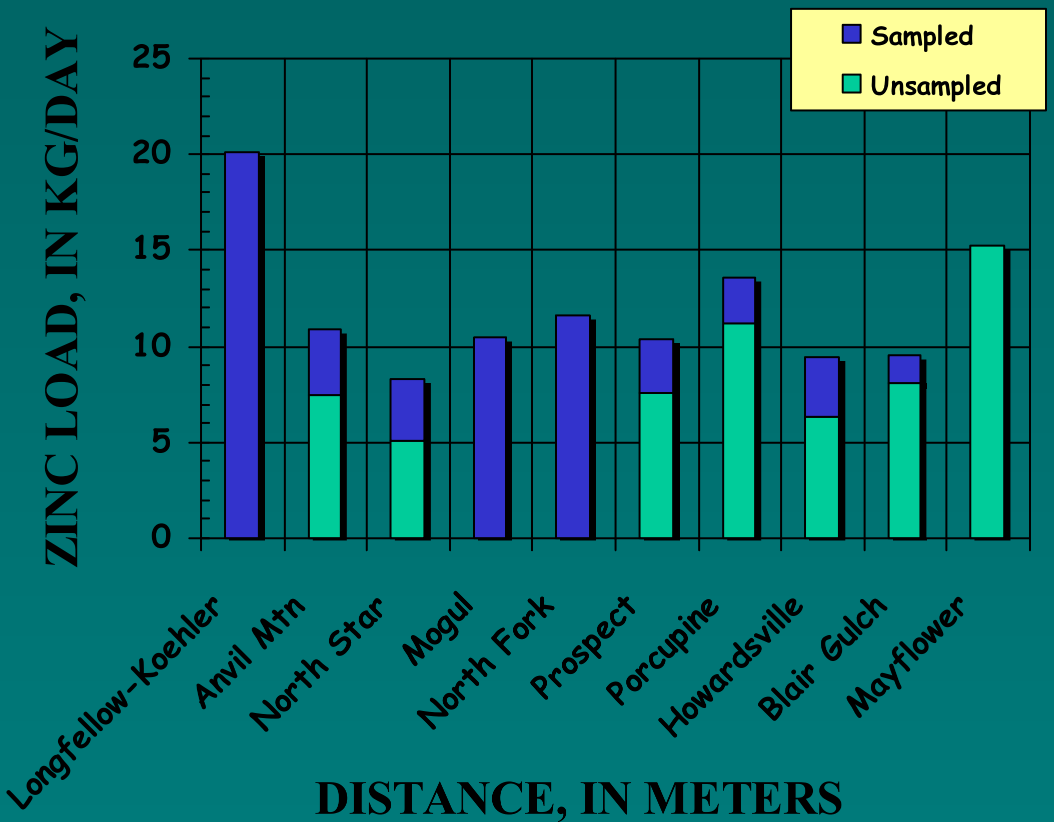
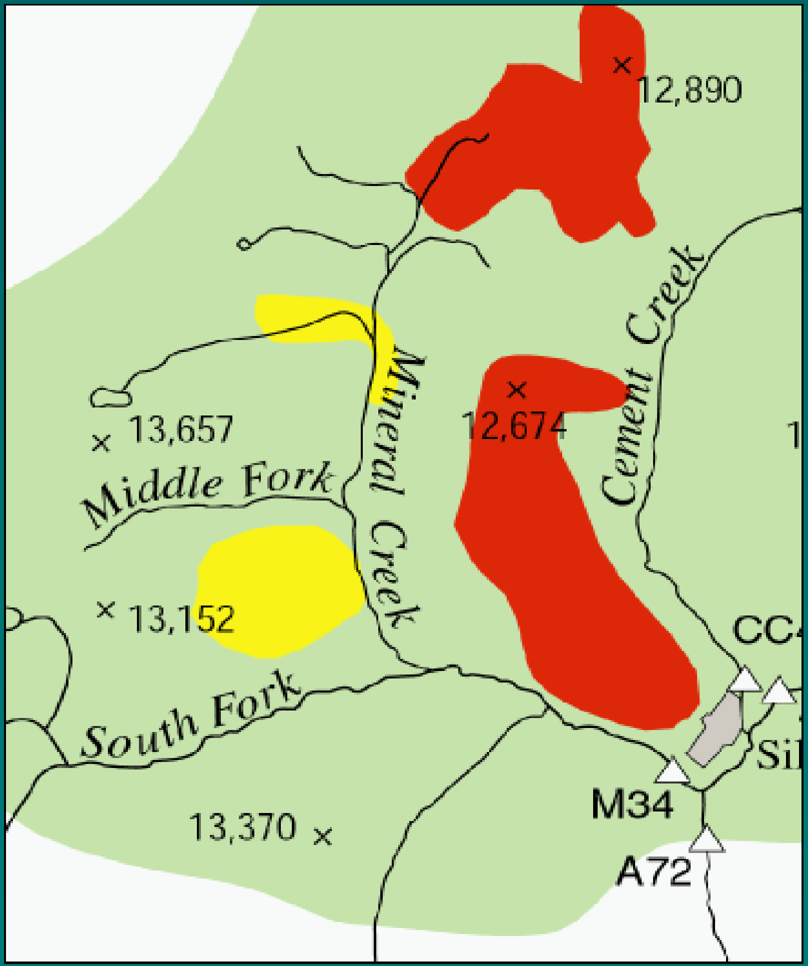
Watershed-scale comparison -- Zinc



- 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)

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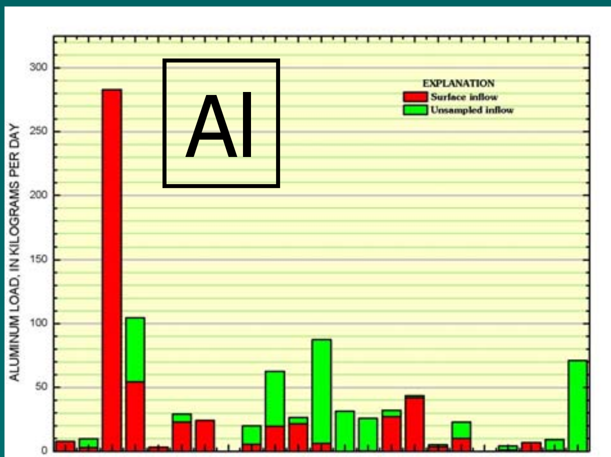
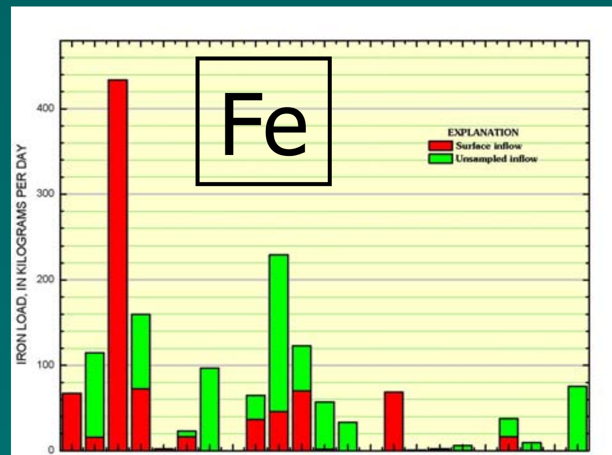
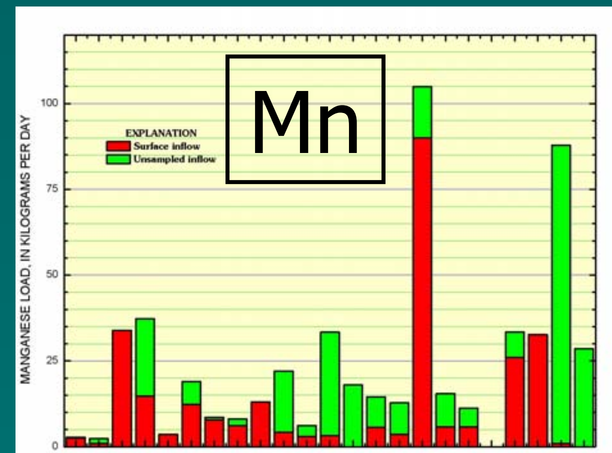
Watershed-scale comparison – Multi-element

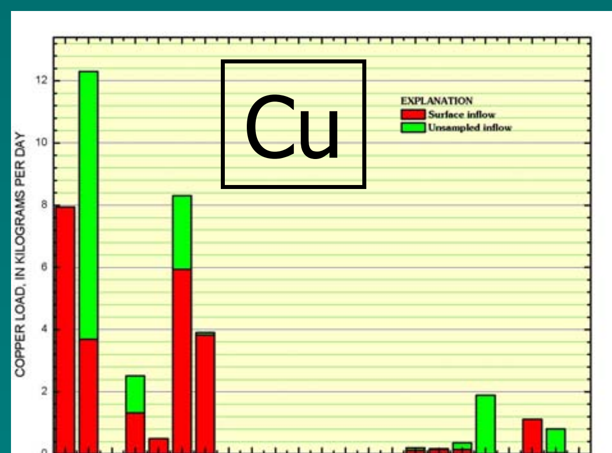


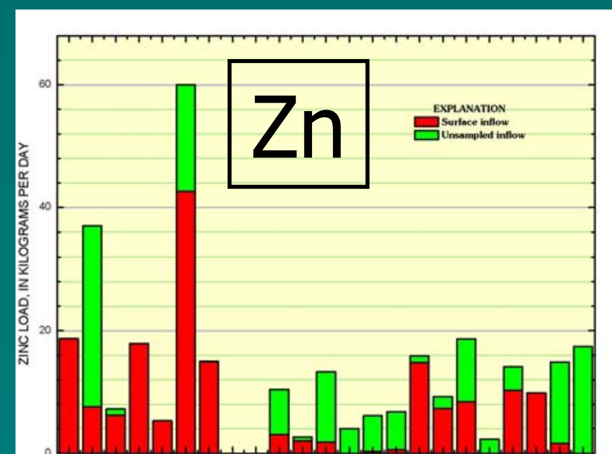




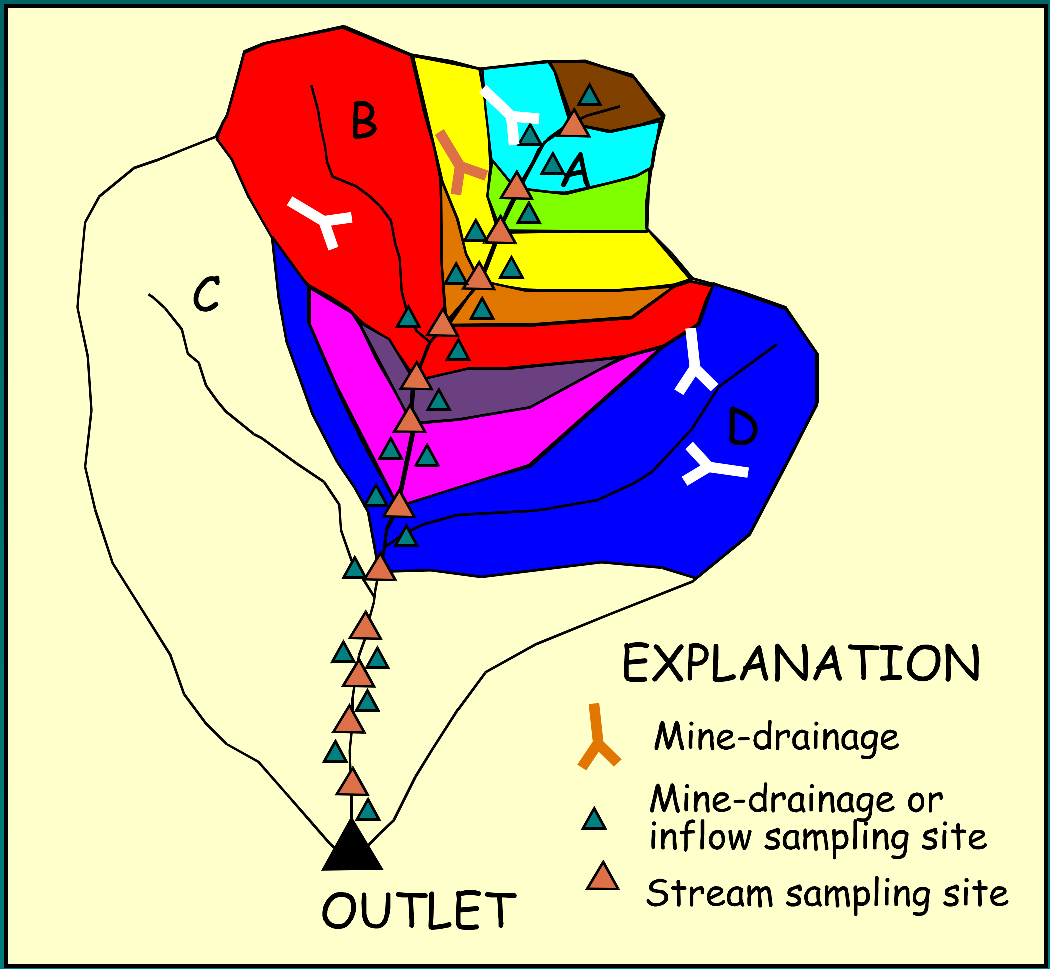
Surface Inflow

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….

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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