Gold King Mine Release – Analysis of Fate and Transport in the Animas and San Juan Rivers

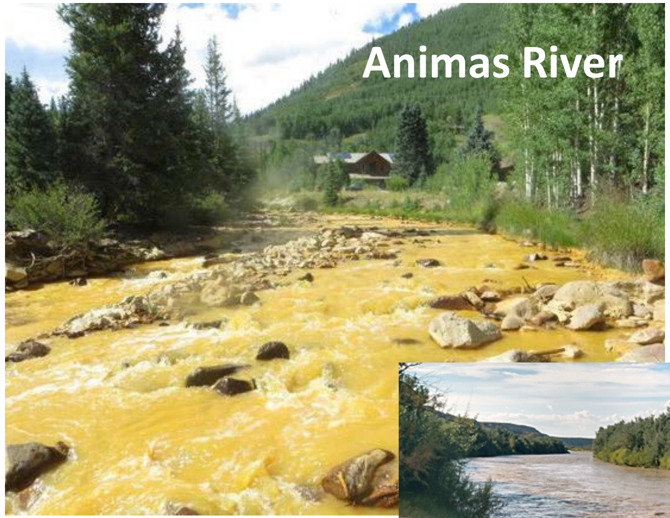
Session 3

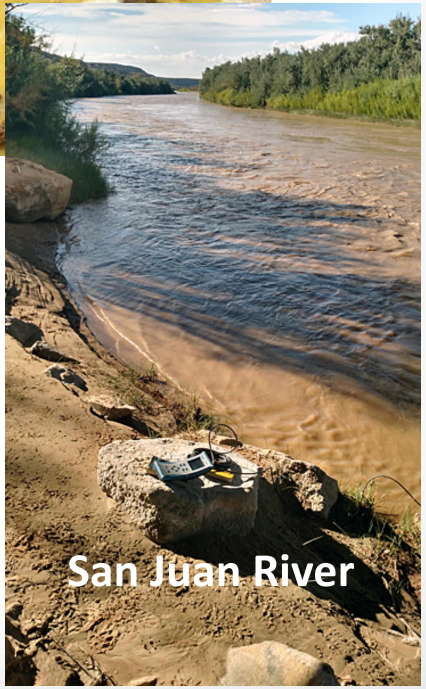
Gold King Mine Release Team
National Exposure Research Lab/ORD

June 29, 2016

Analysis Questions

- **Primary Questions**
  - How much was released and what was its makeup?
  - Where did the material in the release volume go?
  - How was water quality affected?
  - What was water user exposure to toxic metals?
  - Did any of the material stay in the river system, sequester to the streambed?
  - If so, will that material be released into the river and will it have secondary impacts after the initial spill?
  - Were groundwater drinking water or irrigation sources potentially impacted?
  - Have the rivers returned to pre-event metals levels?





Outline –Session 3

- Metals mass carried during GKM Plume
- Deposition of metals mass in the streambed
- Post-event metals in bed sediments
- Post-event metals in surface water
- Potential future entrainment of metals

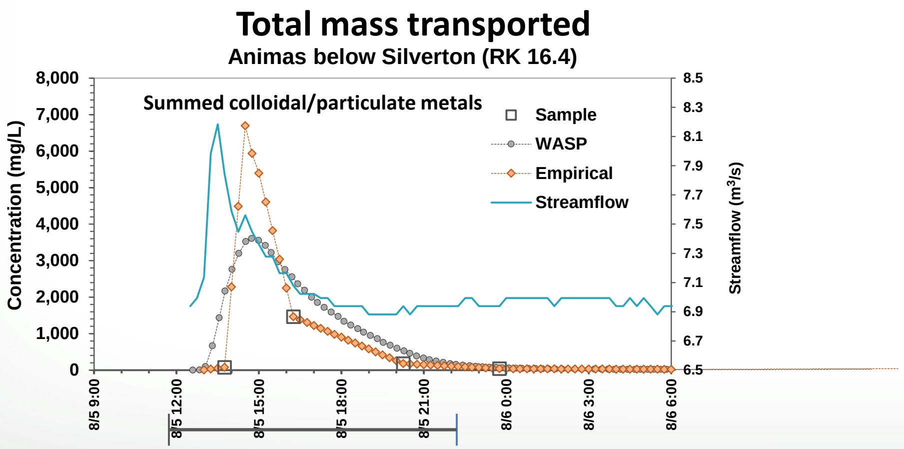
Methods

Empirical Analysis of Data

--Empirical plume model estimates metal loads and fate of mass in the Animas and San Juan River

--Statistical Analysis of field sampled sediment data

--Post event water quality trends—August to October



WASP Modeling

The "Gold King Mine WASP Model" was used to investigate long-term effects of the GKM release

- Metal concentrations in the sediments due solely to the GKM release
- How simulated metal concentrations in the sediments compare to background
- Simulated metal concentrations a year following the release to in sediments and the water column, including high, middle, and low flow

ORD Project Team

ORD/NERL Subject Experts Working on the Project

- John Washington, Geochemistry
- Chris Knightes, WASP, water quality
- Mike Cyterski, Data analysis, statistics
- Kate Sullivan, Hydrology, project lead
- Craig Barber, Fish effects
- Steve Kraemer, Groundwater
- Anne Neale, Megan Mehaffey, EnviroAtlas
- Lourdes Prieto, GIS and data acquisition

Tracking Metals Mass Transported Through the Animas River

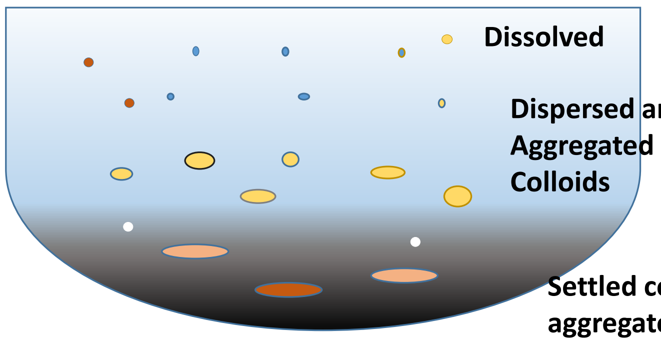
Materials sourced from:

- Contaminated soils outside GKM mine and the hillslope between -GKM and Cement Creek
- Scoured from Cement Creek and its floodplain
- Aggregated colloidal matter created from dissolved metals in the mine effluent itself

Sediment in transport a mixture:

- Larger particulates (sand/silt)
- Fine particulates (clay)
- Aggregated colloidal material of varying size, texture, and stability
- Sludge-like

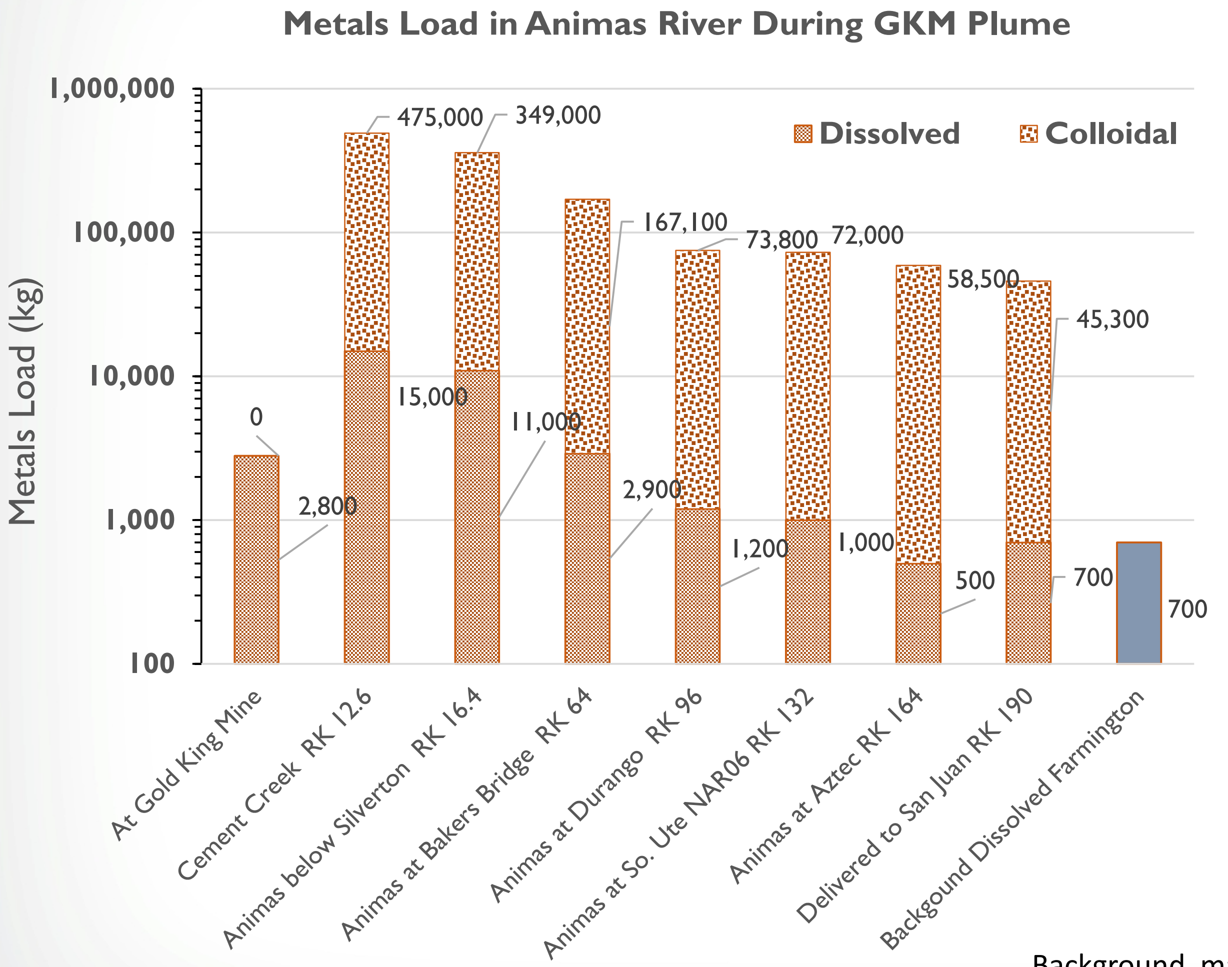
Partitioning a function of pH, metal species, time



In the streambed

- Metals bound to surfaces of rocks and sand grains
- Entrapped by microbes
- Mineralize eventually

GKM plume mass estimates-- Animas River

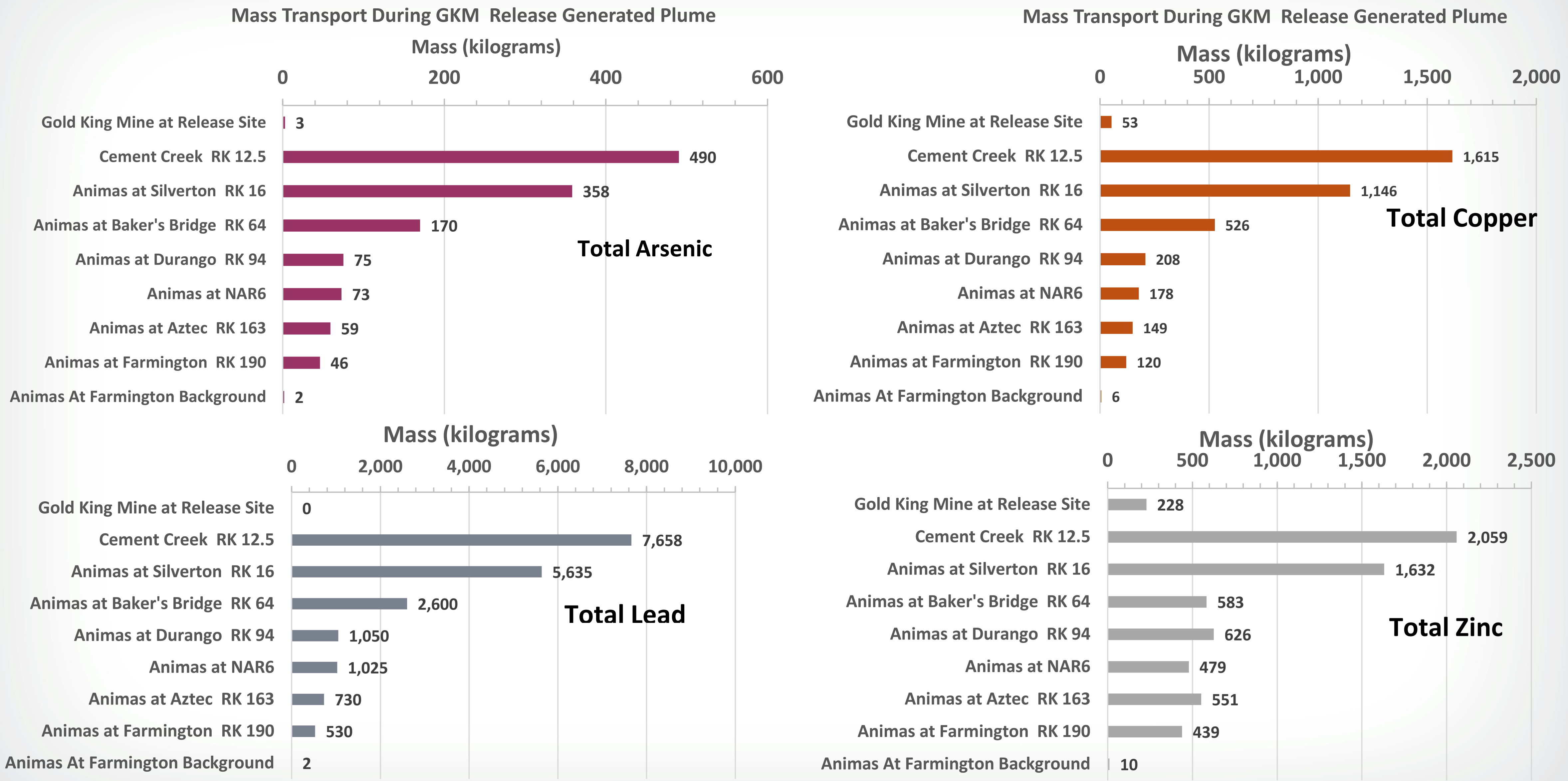


- **Metals mass carried by the river declined as the plume traveled**
  - **Dissolved → Colloidal**
  - **Colloidal → Streambed**
- **90% of the GKM metals mass delivered to the Animas from the GKM release was deposited within the Animas River**
- **~45,000 kg of colloidal/particulate was carried into the San Juan River**
- **Dissolved load at background before it left Animas system**

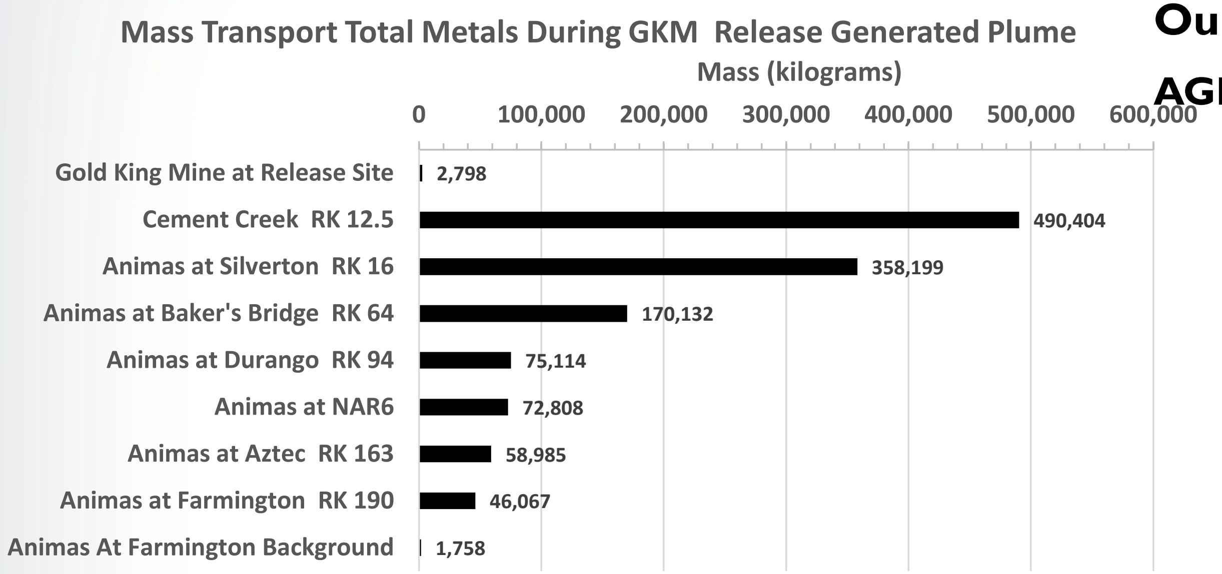
Background mass computed for plume period as constant concentration based or pre- or post plume sample for reference to plume days only

Empirical Model

Mass Transport of Individual Total Metals--Animas River



GKM plume mass estimates—Animas River

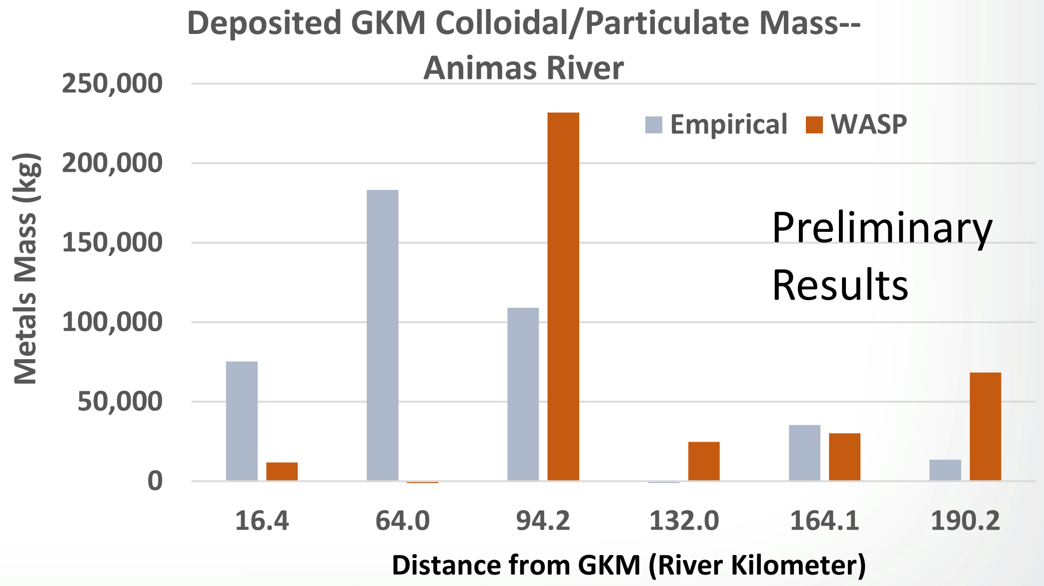


[1]*excludes major cations*

Our 2 modeling approaches Empirical and WASP

AGREED

- **The amount of metals mass released into the Animas at Cement Creek**
- **The amount of metals mass that left at Farmington**
- **Generally where mass deposited (most in Upper Animas, much less in lower Animas)**



DISAGREED

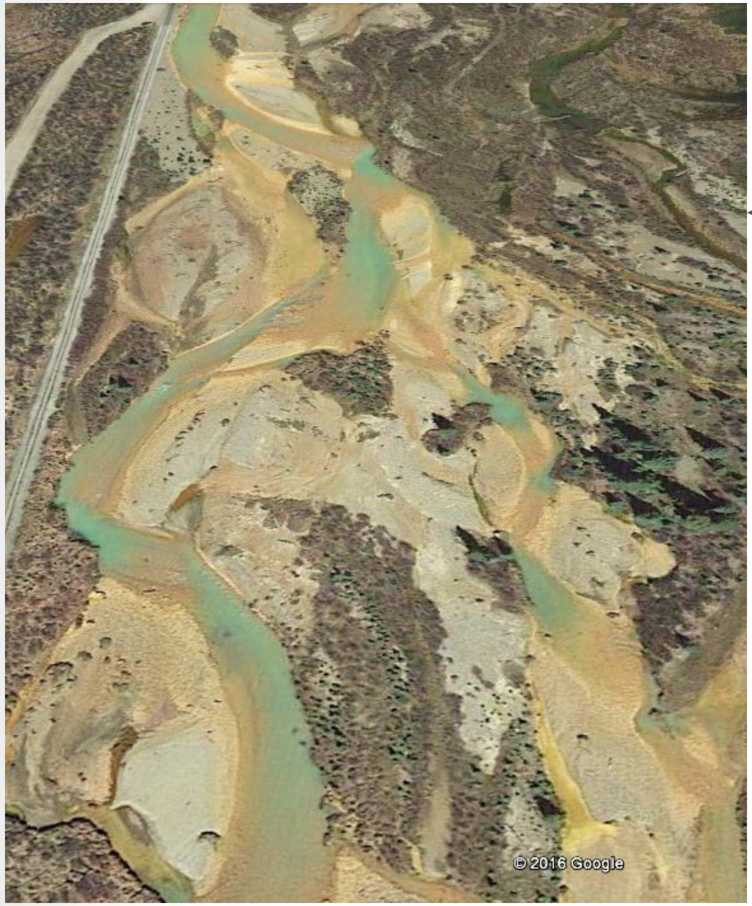
- Exactly where the colloidal/particulate mass was deposited

- Probably reflects details of topography and where the anchoring sampling location falls within the segments

The 2 models encompass uncertainty in estimating processes

Upper Animas Deposits Locations

WASP model and empirical data also suggest the majority of plume mass (≈85%) was deposited in three areas:

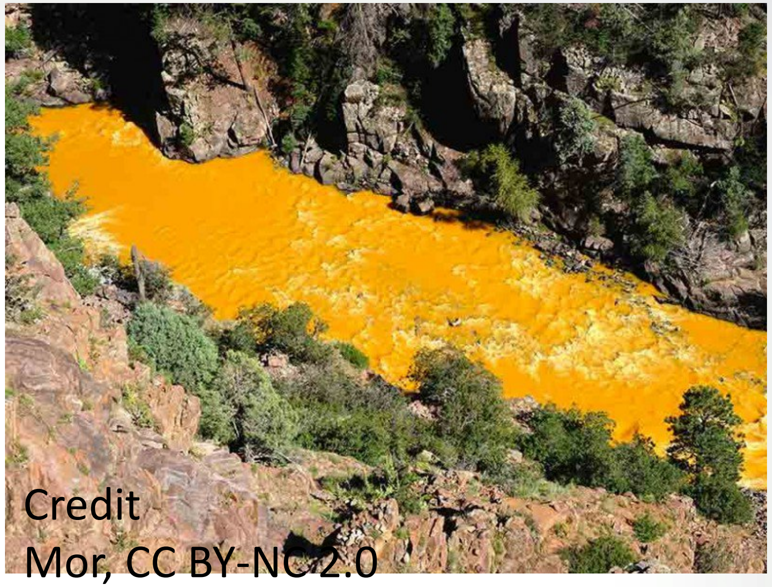


GoogleEarth

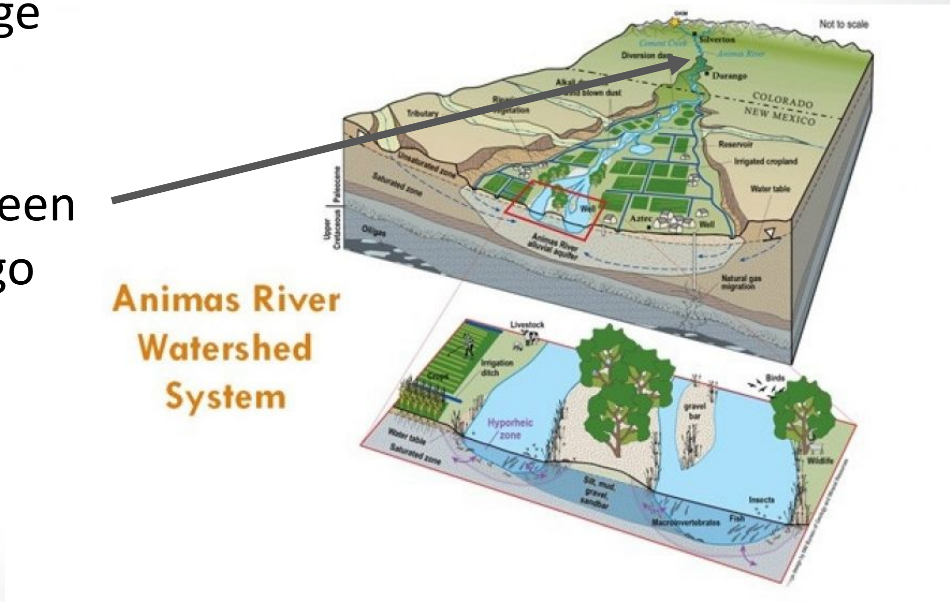
Upper Animas valley between Cement/Animas confluence and start of canyon below Silverton (27%) (~4 km)

In the canyon reach between Silverton and Baker's Bridge (38%) (~44 km)

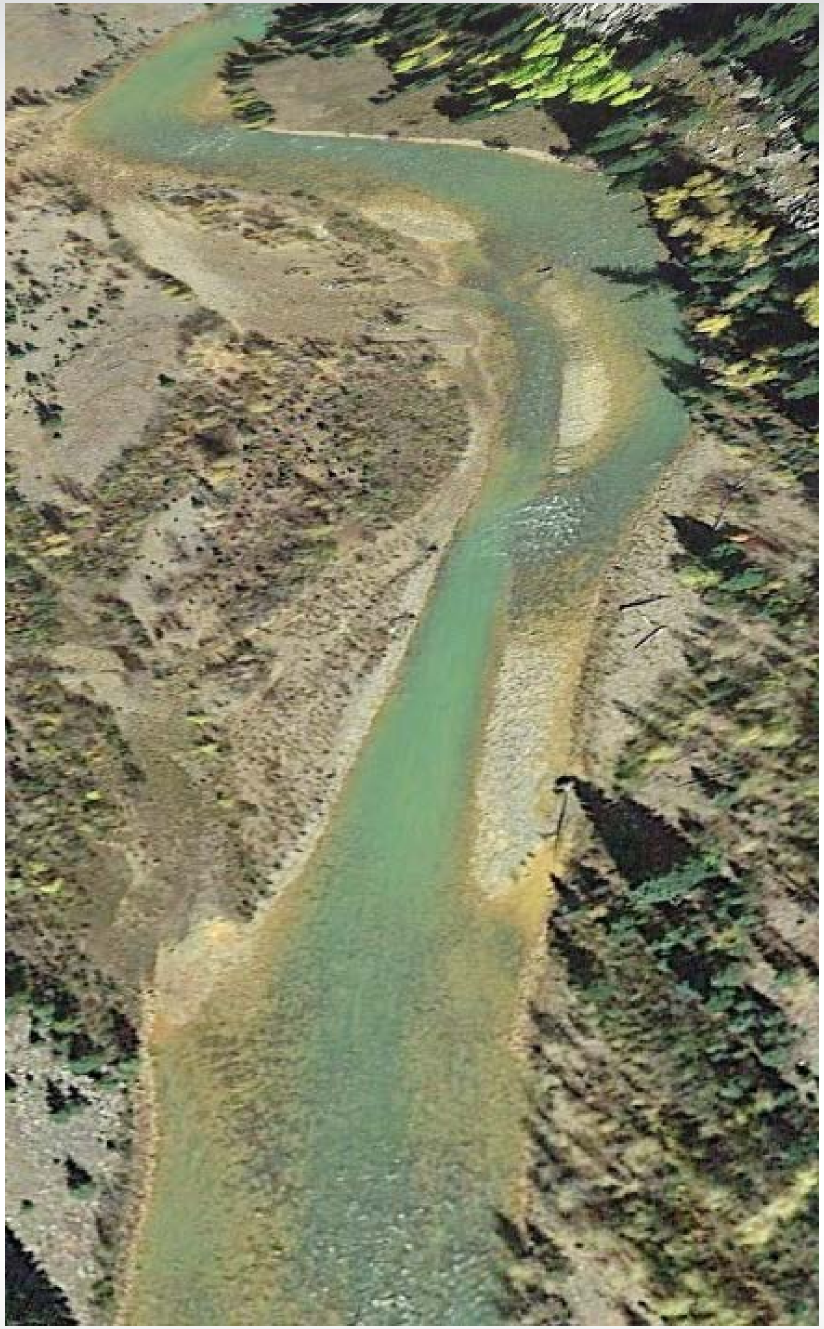
In the braided reach between Baker's Bridge and Durango (20%) (~30 km)



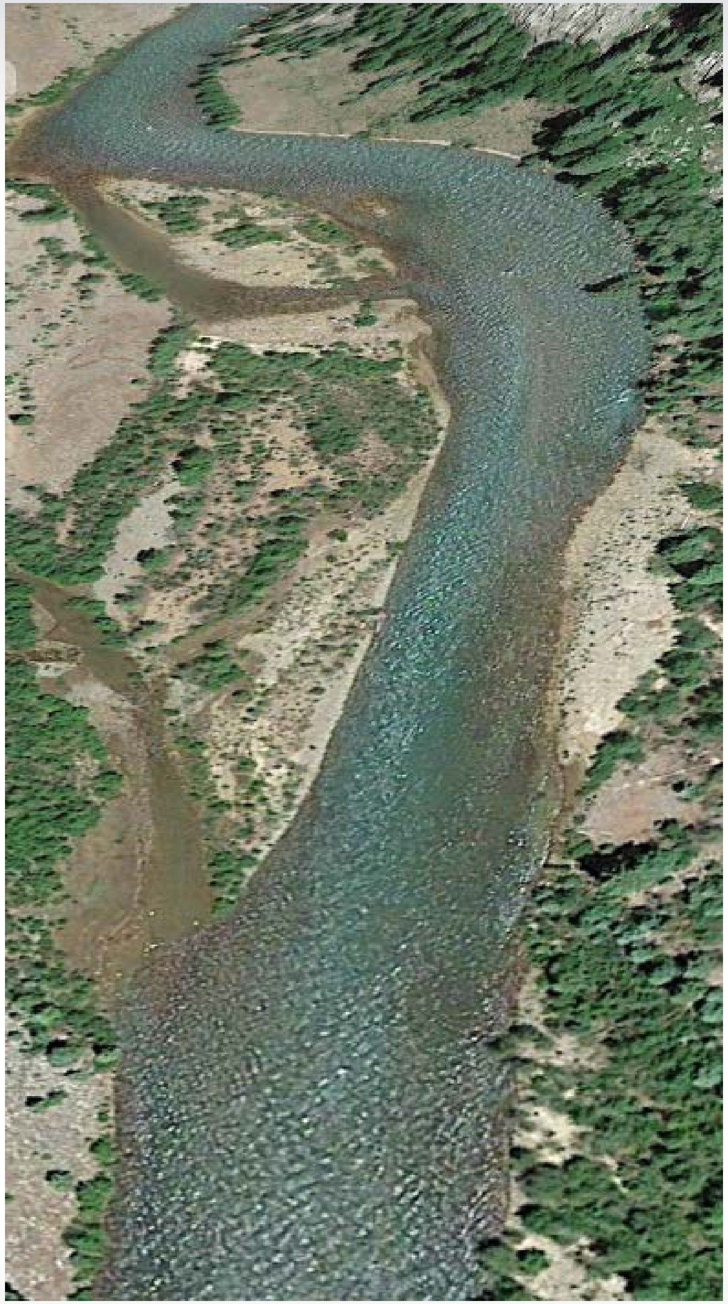
Credit
Mor, CC BY-NC 2.0



Yellowish deposits at channel edge and slow zones suggest GKM material on streambed



October 2015



Within the "canyon" reach 12 km downstream from A72 below Silverton

2014

GoogleEarth

About 32 km down river from A72 below Silverton

Yellowish deposits diminished but still present

October 2015

GoogleEarth

2014

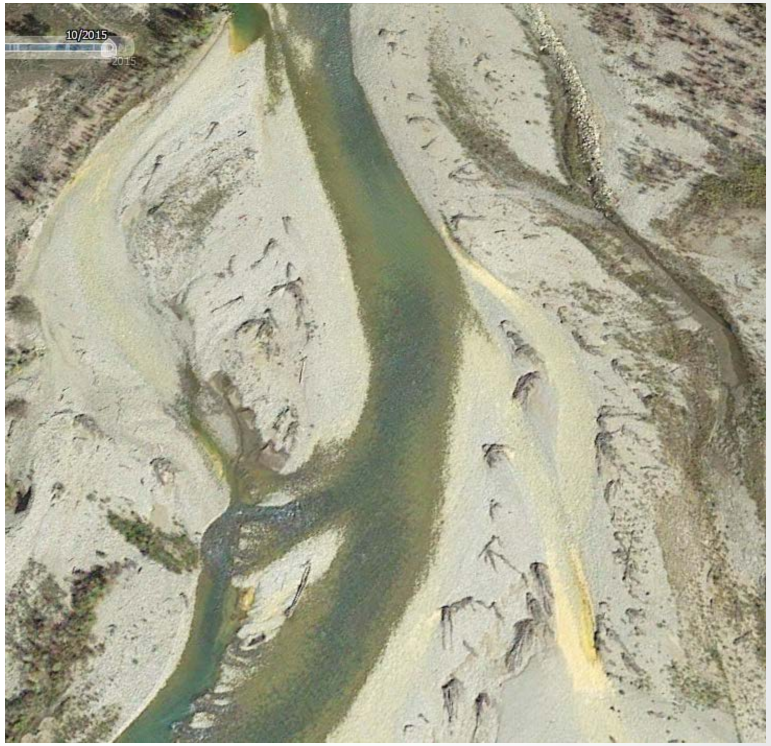
Deposited Plume Material in Streambed

Baker's Bridge Area RK 64

June 2014

Aug 2015

Oct 2015



GoogleEarth

Meandering reach upstream of city of Durango

August 2015
Post-Event

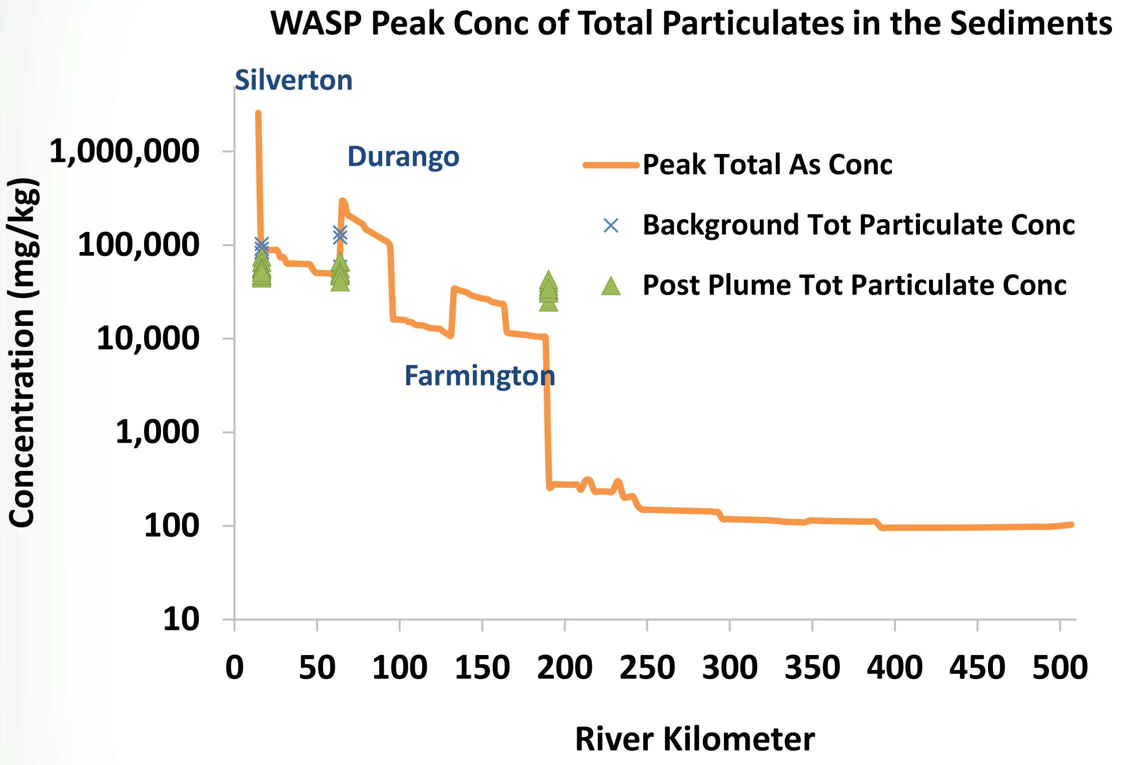
August 6, 2015

DRAFT June 29, 2016

October 2015

2014

WASP Sediment Simulation Results - Total Particulates



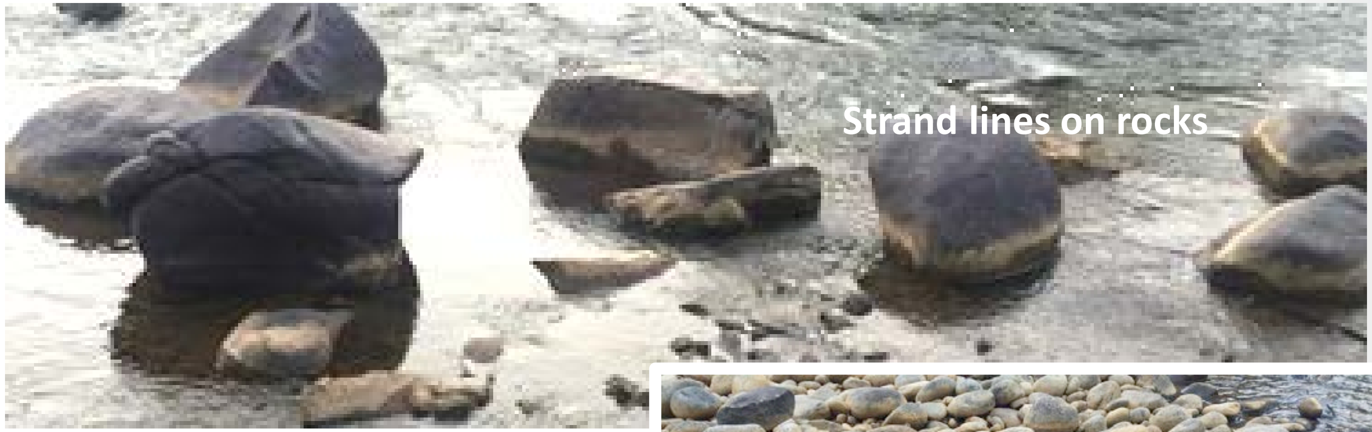
- WASP deposits most metals in three primary locations
  - Between the Cement/Animas confluence and the city of Silverton
  - In the canyon reach between Silverton and Baker's Bridge
  - Between Baker's Bridge and Durango; the velocity of the river decreased in this segment after leaving the canyon
- Background and post-plume sediment total metal concentrations are plotted at the 3 locations

WASP did not account for settling of non-metallic particulates (silts, clays), and therefore may over estimate sediment metal concentrations

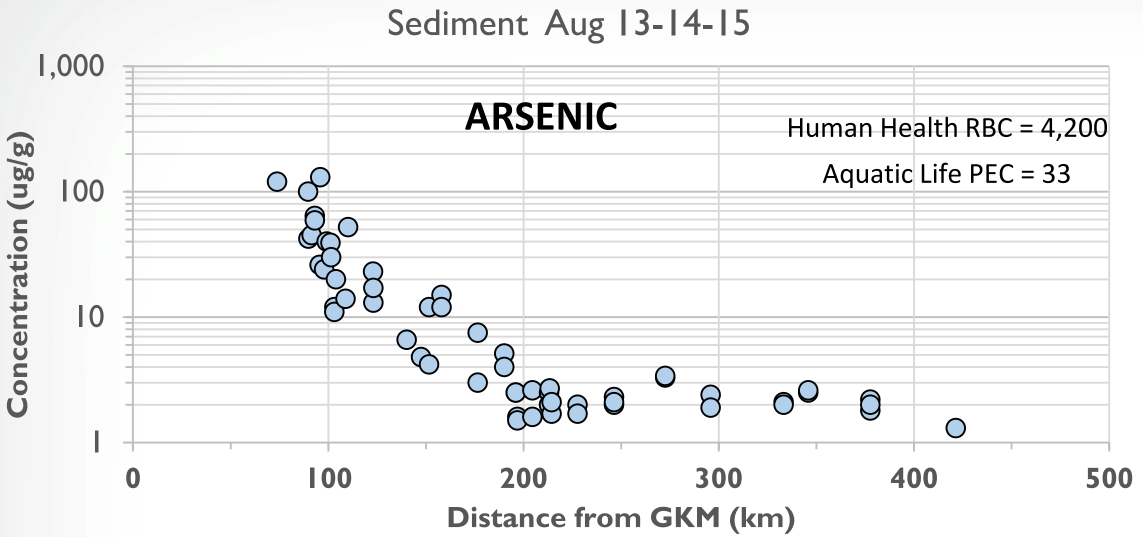
Deposited Plume Material in Streambed

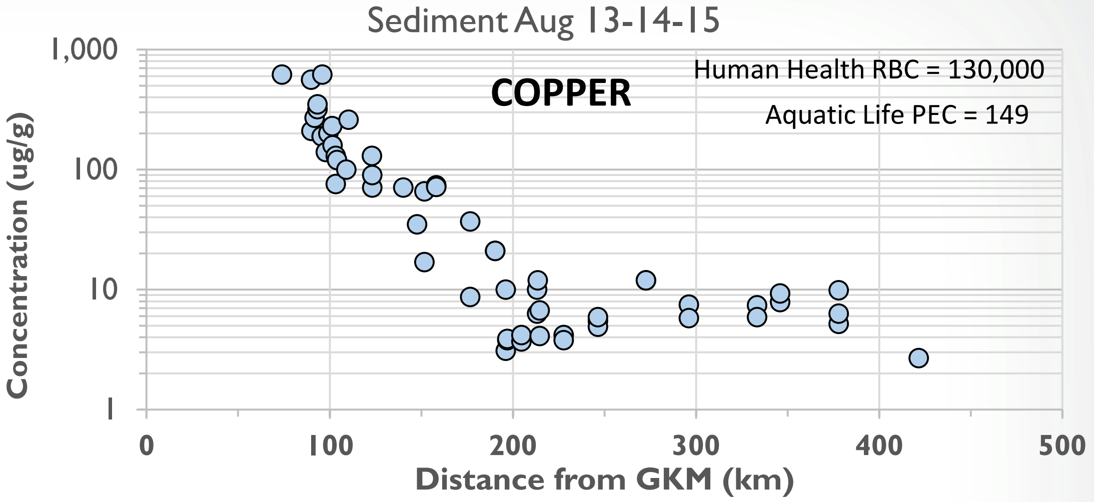
Primary research question:

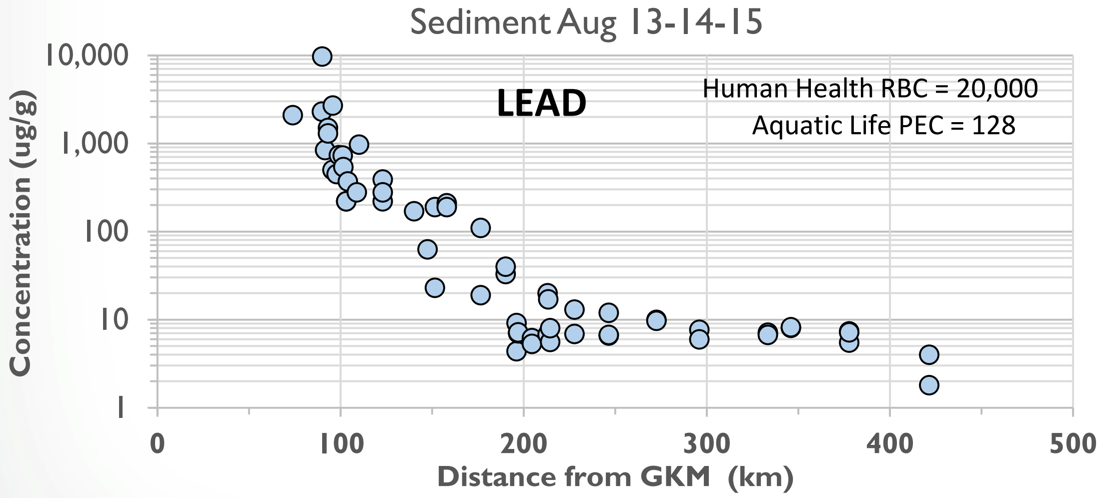
How did the GKM deposits affect metals concentrations in the streambed already known to be contaminated with AMD from the headwaters region?

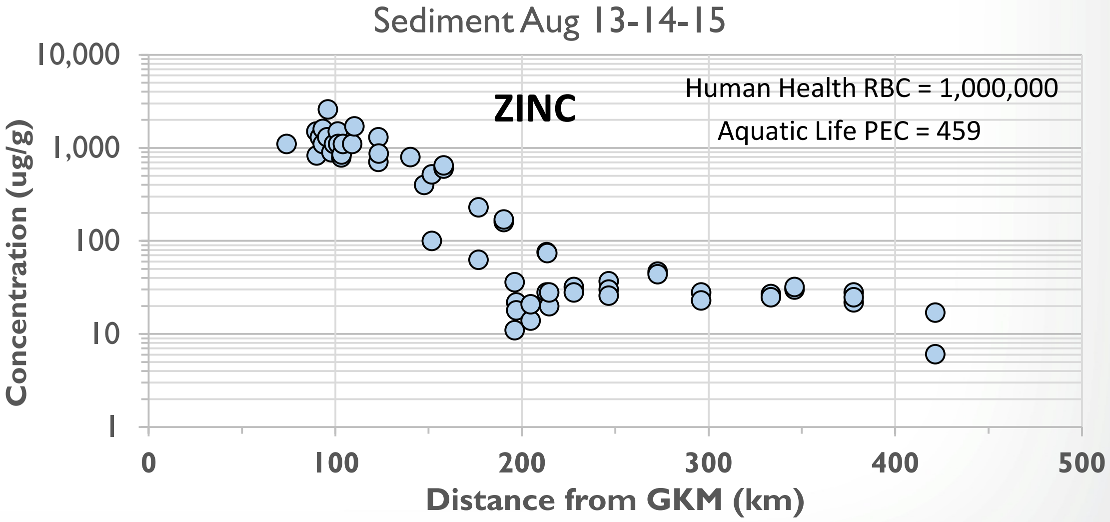


Streambed Metal Concentrations - Animas and San Juan Rivers





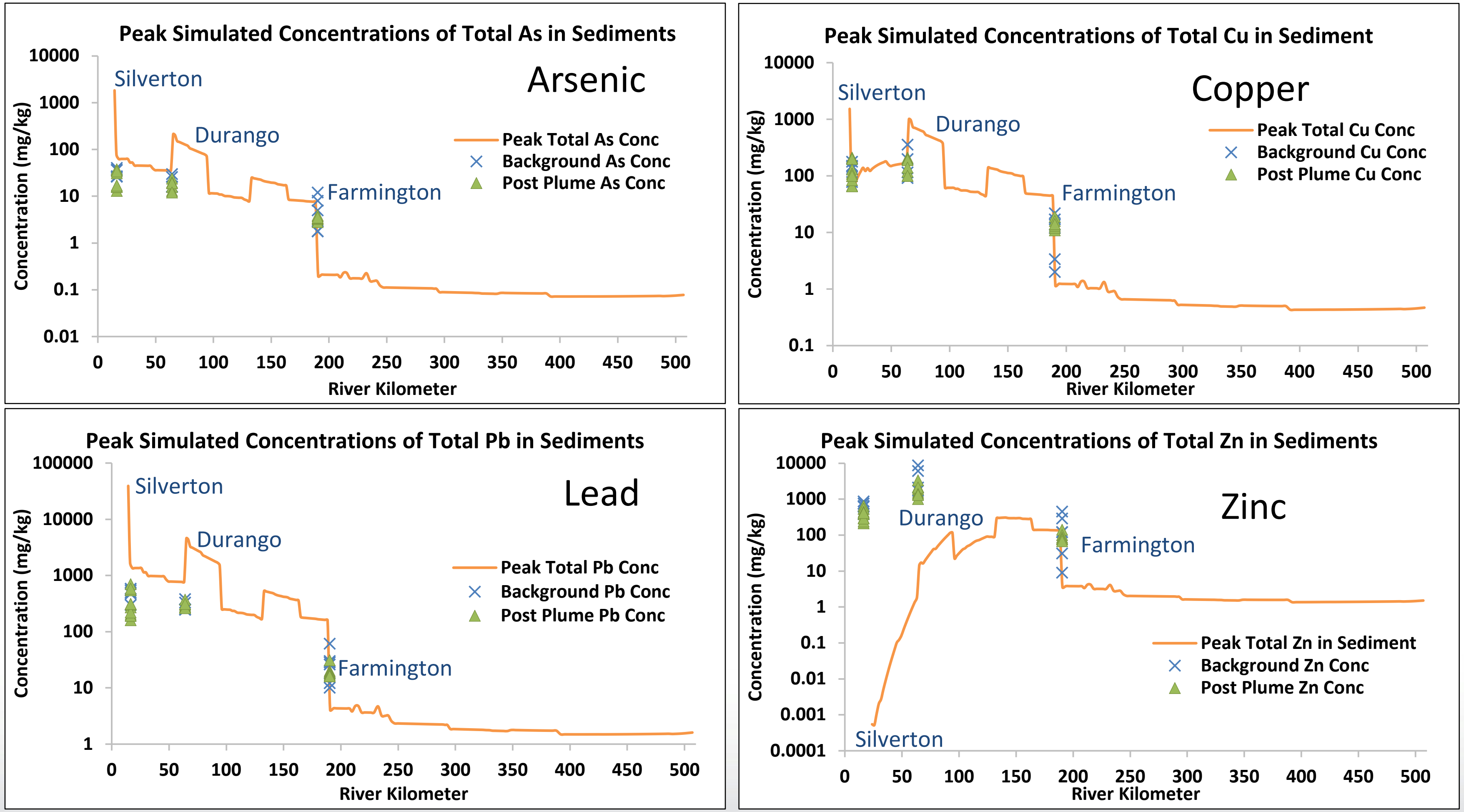




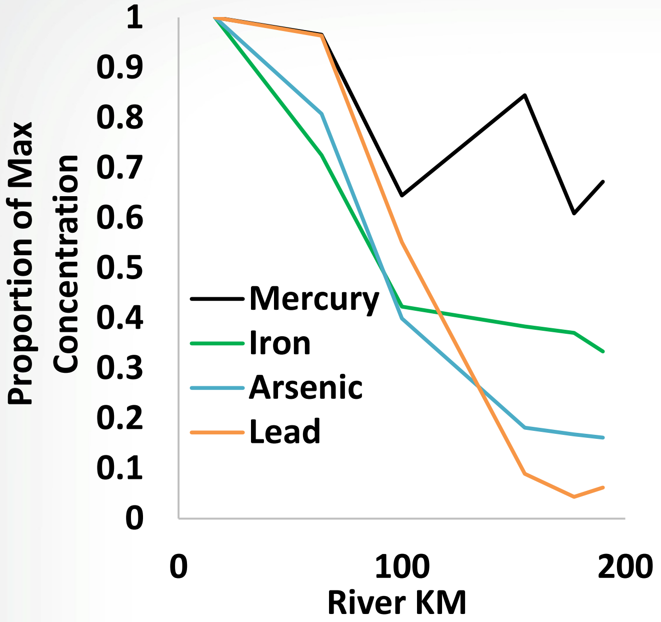
Sediment samples collected soon after the GKM Plume

Sediment Simulation Results for Individual Metals

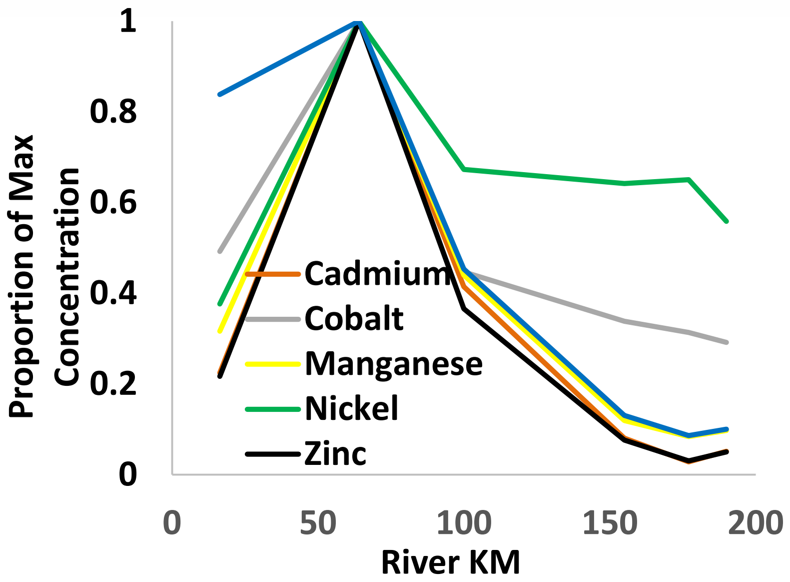
- **Arsenic, Copper and Lead: simulations suggest these metals settled upstream at Silverton and between Bakers Bridge and Durango**
- **Zinc traveled farther in dissolved form, forming colloidal solids over 60 km distance before settling in the Durango area**



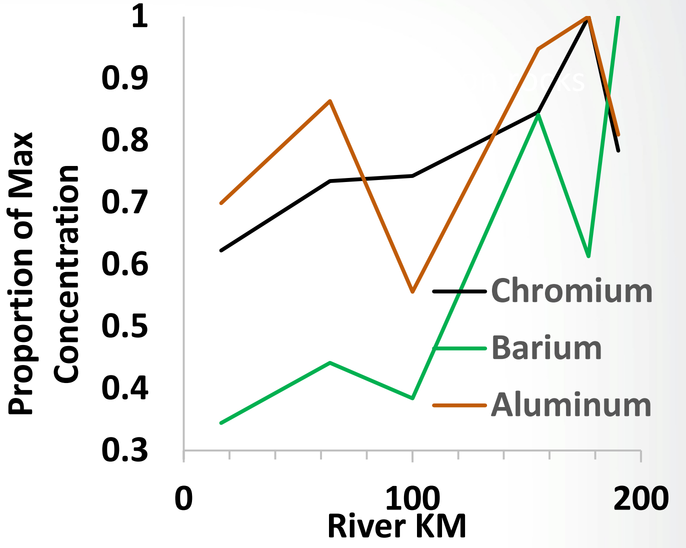
Longitudinal patterns of sediment concentrations vary by metal



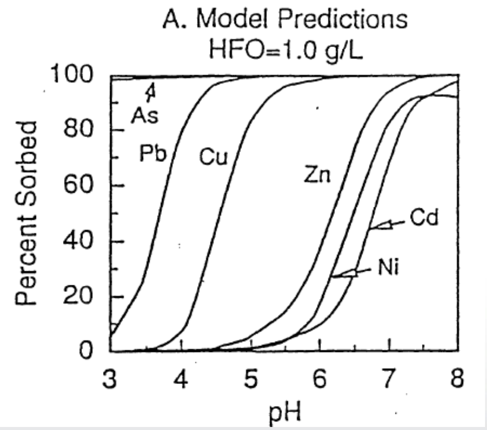
Metals that sorb at low pH have highest concentrations in first 60 km



Those with higher pH sorption travel farther before deposition



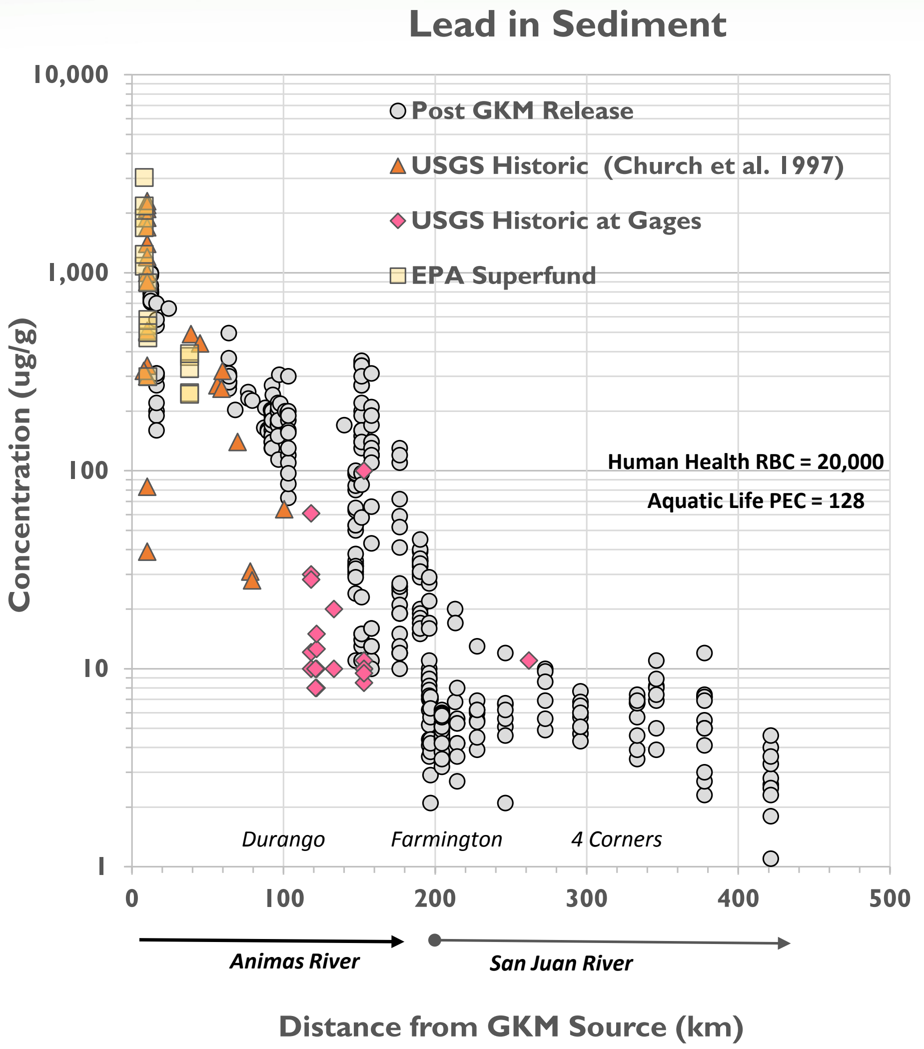
Some increase moving downstream suggesting other sources or processes

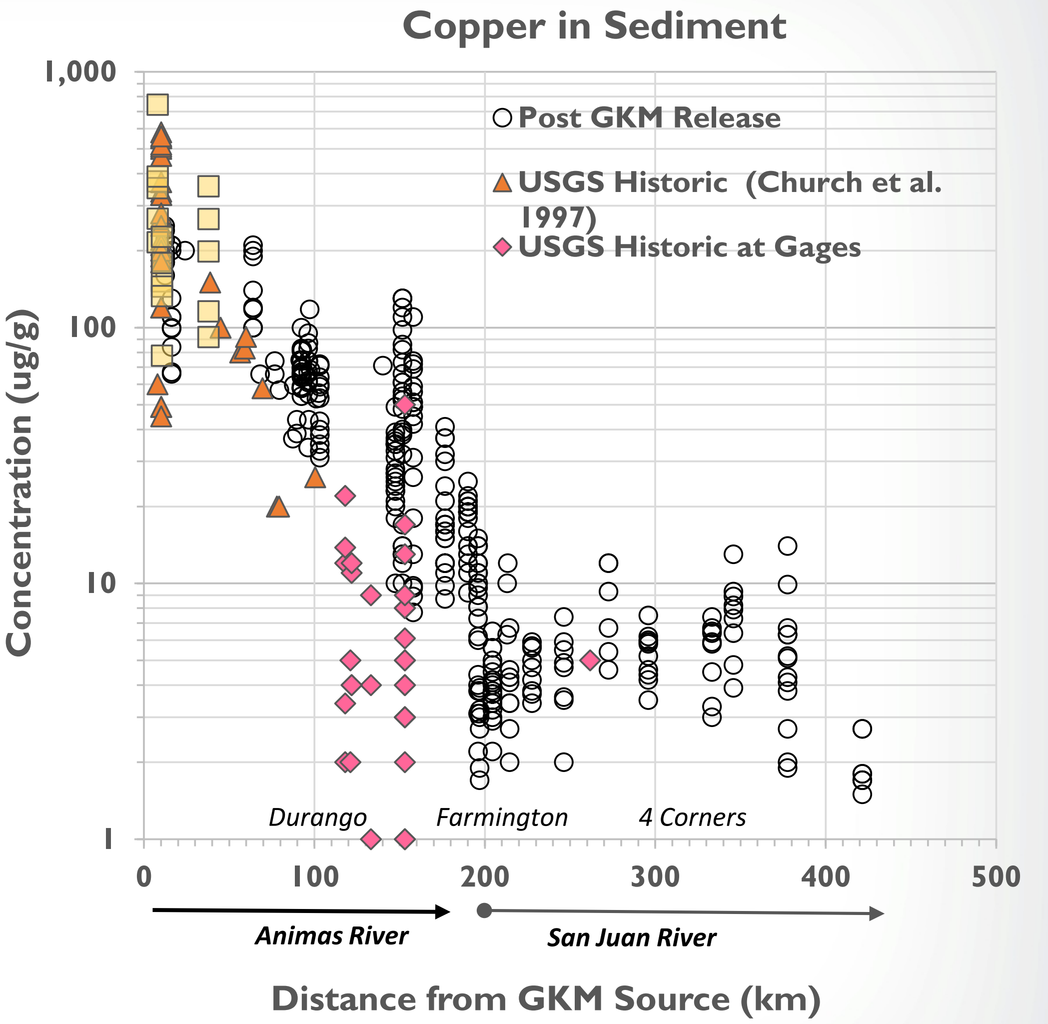


Deposition patterns appear to follow pattern of sorption pH implying time and distance to formation of solid precipitates

Post-Event and Historic Sediment Concentrations

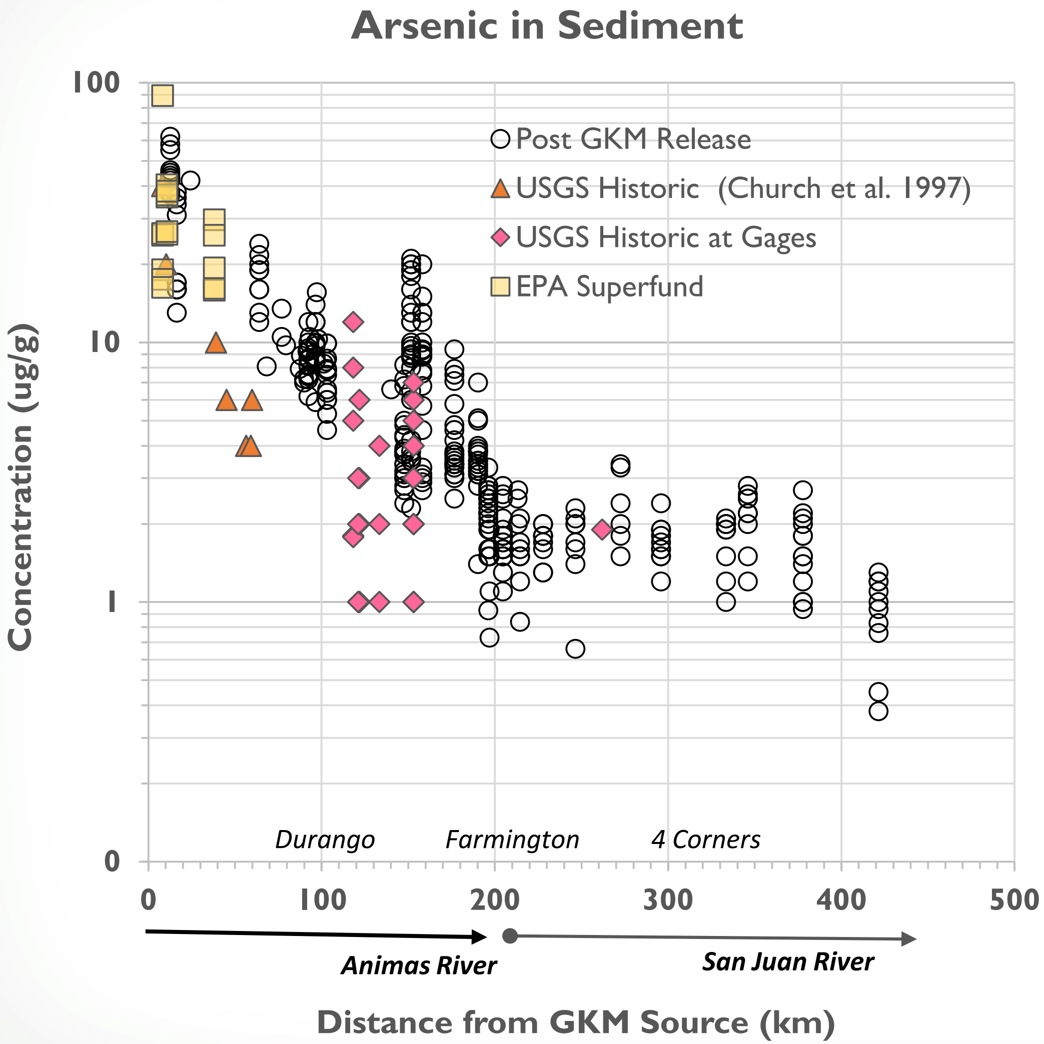
- Historic patterns of metals contamination shows strongly declining trend from Animas headwaters where AMD contamination originates from hundreds of mines
- Post GKM event concentrations are generally within the same range as historic observations

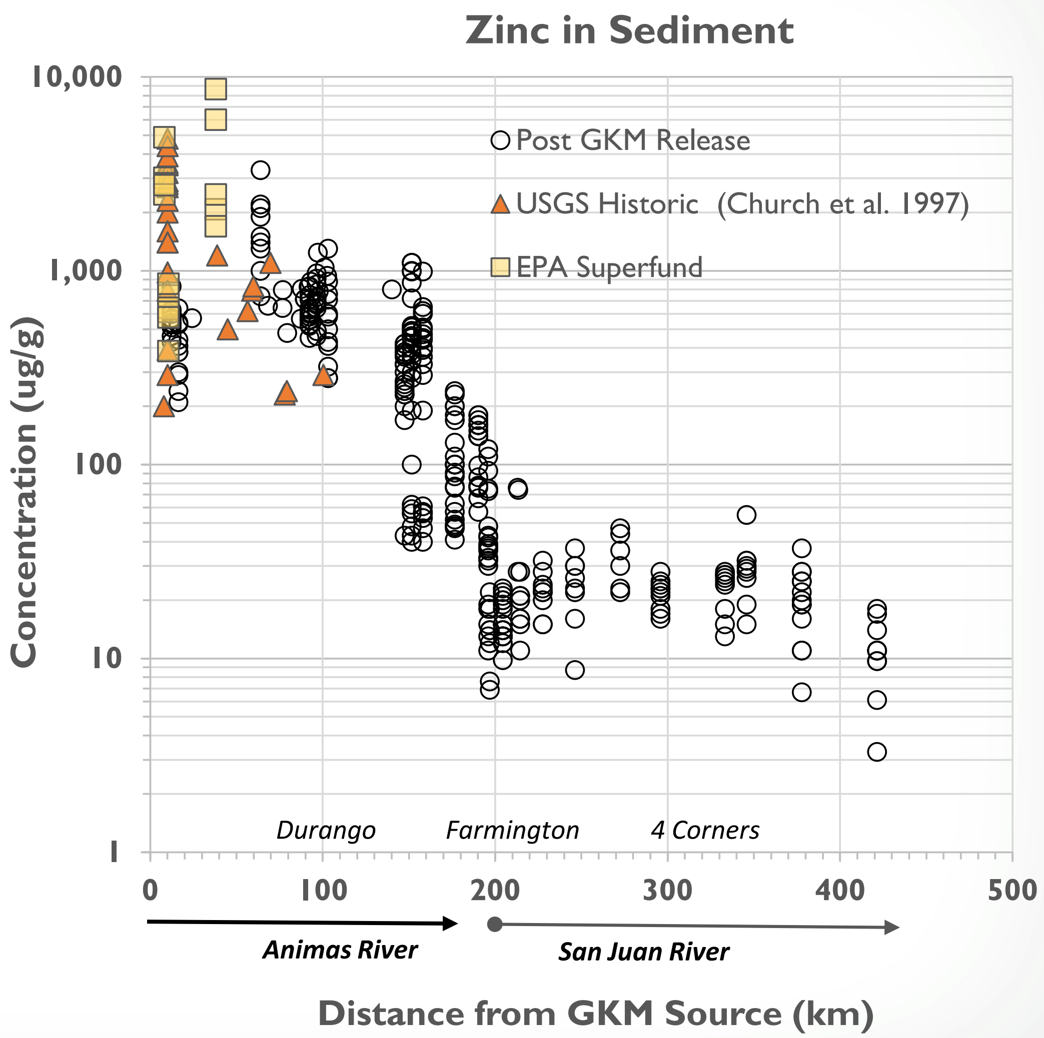




Many more locations were sampled during the GKM Plume

Post Event and Historic Sediment Concentrations

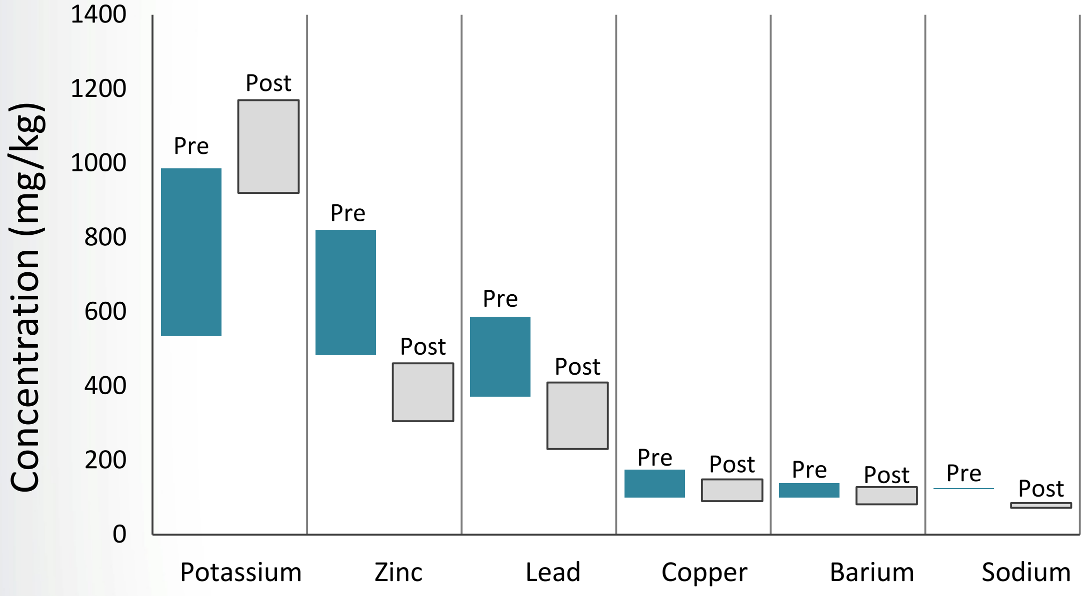




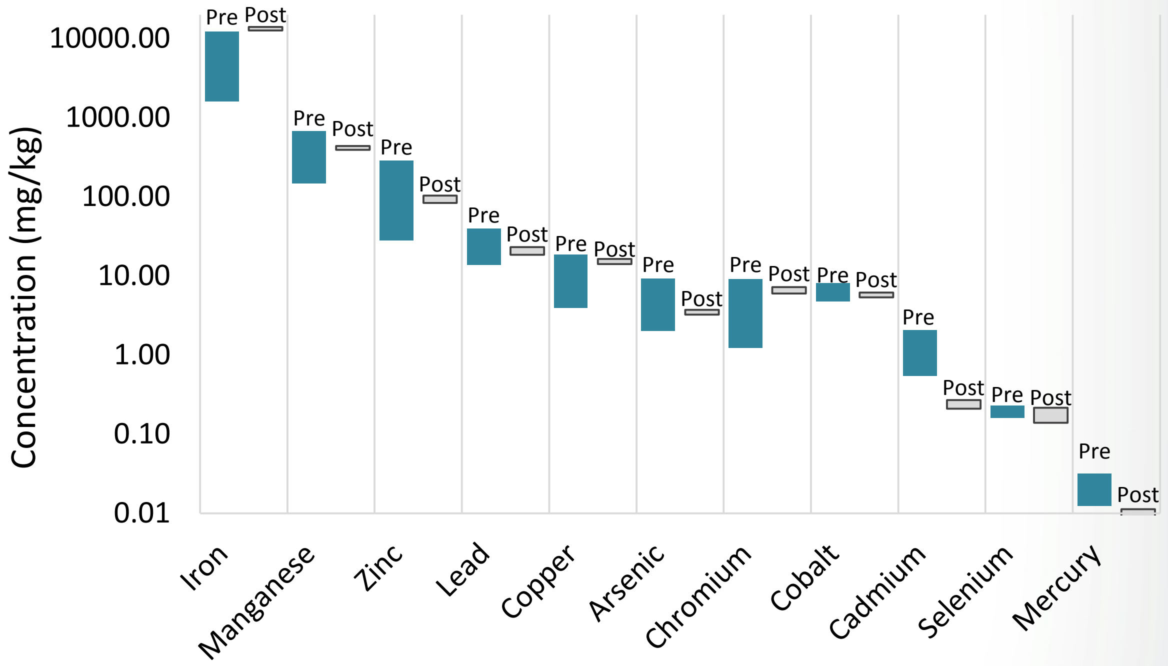
Pre-Event to Post-Event Sediment Statistical Comparisons

Comparison of 95% confidence intervals for post-event and pre-event means: multiple metals, 3 sampling locations in Animas River

Pre-Event: Superfund samples from Silverton, 2012-2014



Pre-Event: USGS samples at Farmington, 1994-2007



Dark blue bars represent a 95% confidence interval for the mean concentration of pre-event samples, lighter grey bars represent a 95% confidence interval for the mean of post-event (through October) samples.

Sample Sizes:
Silverton: Pre-Event (5), Post-Event (12)
Baker's Bridge: Pre-Event (4), Post-Event (9)
Farmington: Pre-Event (6), Post-Event (45)

Summary of Pre to Post-Event Sediment Comparisons

Sample Sizes:
Silverton: Pre-Event (5), Post-Event (12)
Baker's Bridge: Pre-Event (4), Post-Event (9)
Farmington: Pre-Event (6), Post-Event (45)

Metal	Silverton	Baker's Bridge	Farmington
Aluminum	0.01	0.35	
Antimony	0.01	< 0.0001	
Arsenic	0.01	0.28	0.6
Barium	0.34	0.31	
Beryllium	< 0.0001	0.2	
Cadmium	0.03	0.39	0.008
Calcium	0.11	0.05	
Chromium	0.39	0.38	0.24
Cobalt	0.4	0.51	0.61
Copper	0.5	0.6	0.2
Iron	0.02	0.18	0.09
Lead	0.04	0.96	0.72
Magnesium	0.18	0.31	
Manganese	0.14	0.53	0.51
Mercury	0.86	0.79	0.01
Nickel	0.44	0.54	
Potassium	0.09	0.1	
Selenium	0.81	0.72	0.15
Silver	0.04	0.3	
Sodium	< 0.0001	0.006	
Thallium	0.39	0.9	
Vanadium	0.35	0.13	
Zinc	0.02	0.15	0.93

OBSERVATIONS:

- **Longitudinal patterns of sediment metal concentrations are similar to USGS historic data**
- **No post-event sediment metal concentration means are significantly greater than pre-event means**
- **Despite sampling and environmental heterogeneity that potentially increase variability in sampling:**
  - **Bed concentrations were already high in much of the Animas River**
  - **New GKM-related deposits did not increase them on average**

Table shows the p-values associated with two-sample t-tests on mean concentrations in pre-event and post-event samples:

- [green] Significantly Higher Pre-Event Concentration (p-value < 0.05)
- [yellow] Significantly Higher Post-Event Concentration (p-value < 0.05)
- [light grey] No Difference in Pre-Event vs Post-Event Concentrations (p-value > 0.05)
- [dark grey] No Data

Tests based on log_{10} concentration

Deposited Plume Material in Streambed

Does this result concerning bed sediment make sense, given the large amount of deposition during the GKM plume?

River Segment	Segment Length (cm)	Segment Width (cm)	Sediment Bulk Density (kg/cm3)	Segment 5-cm Depth Sediment Weight (kg)	Pre-Event Metal Conc (g/kg)	5-cm Depth Sediment Metal Weight (kg)	Estimated Plume-Deposited Metal (kg)	Plume Metal Deposits as % of Total
Cement to Silverton	2,500,000	1,000	0.0015	18,750,000	80	1,500,000	130,000	9-22
Silverton to Bakers Bridge	50,000,000	2,000	0.0015	750,000,000	80	60,000,000	190,000	0.3–0.8
Bakers Bridge to Durango	30,000,000	5,000	0.0015	1,125,000,000	40	45,000,000	100,000	0.2–0.6

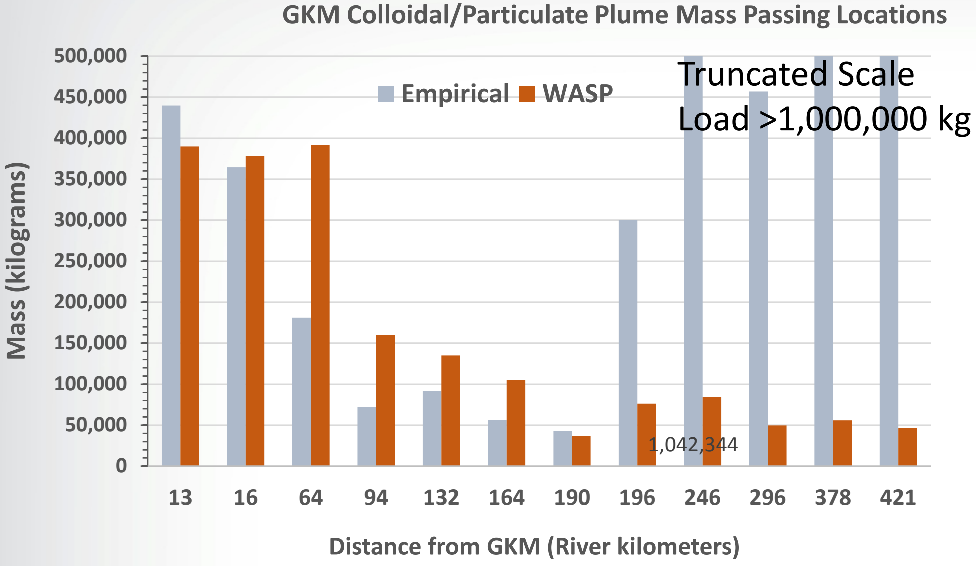
Unit Block of Sediment
1m x 1m x 5 cm
Weight ≈ 75 kg

Bulk Density = 0.0015 kg/cm^3

Unit block of sediment composed of 8% metal at Silverton and Baker's Bridge, 4% metal at Durango

Range covers calculation between 2-5cm sample depth

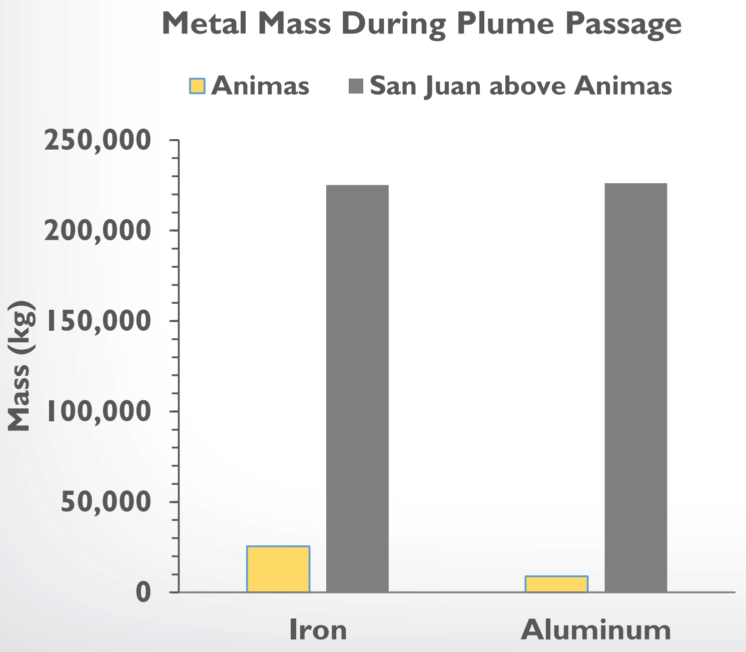
Mass of Sediment in the San Juan River

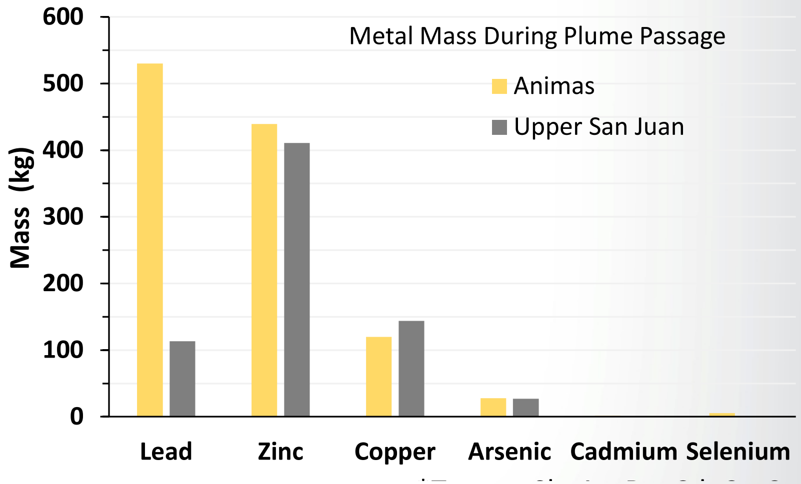


- WASP represents only GKM plume
- Empirical includes measured metals in background from upper San Juan and plume
- Particulate load transported during the GKM plume increased significantly when the Animas joined the San Juan

OBSERVATIONS:

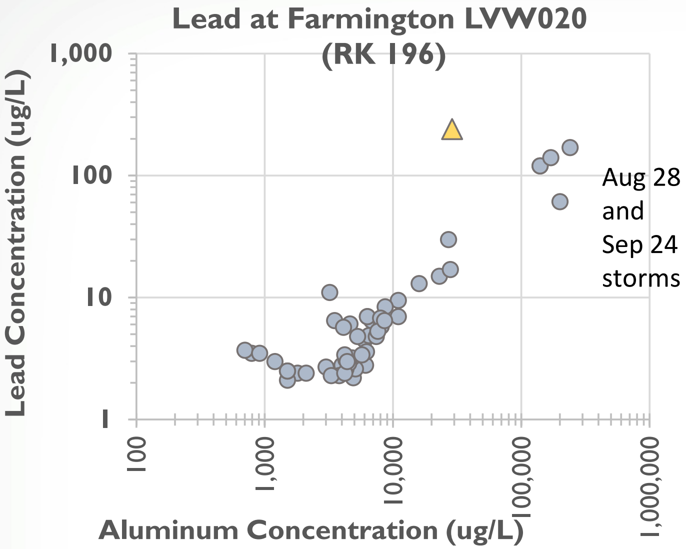
- ~45,000 kg delivered with plume increased to 300,000 kg in San Juan at Farmington
- Most of the SJ load was aluminum and iron associated with suspended sediments
- High metals load in San Juan diluted effects of the GKM plume and made it more difficult to detect

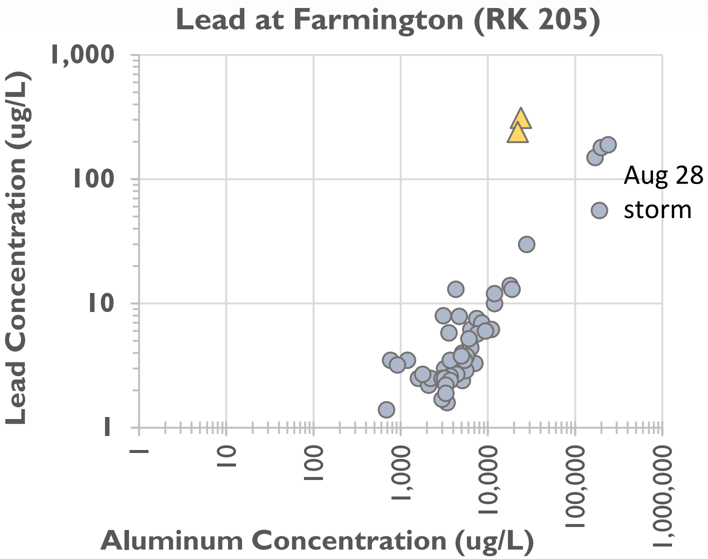


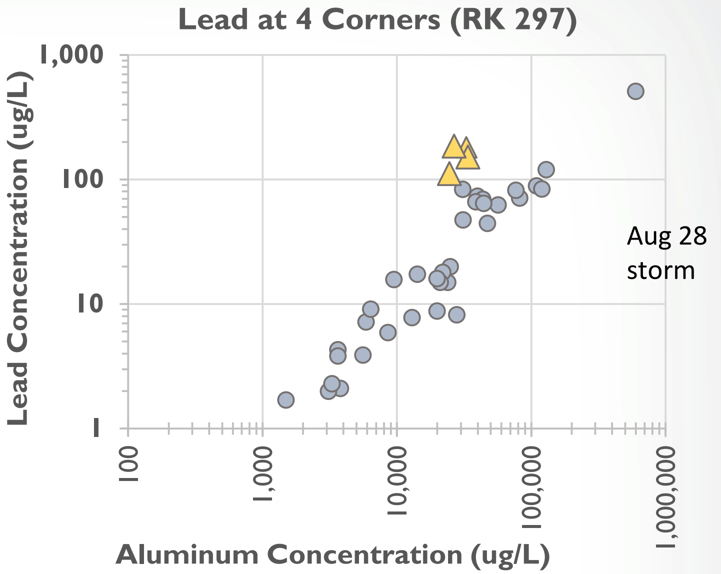


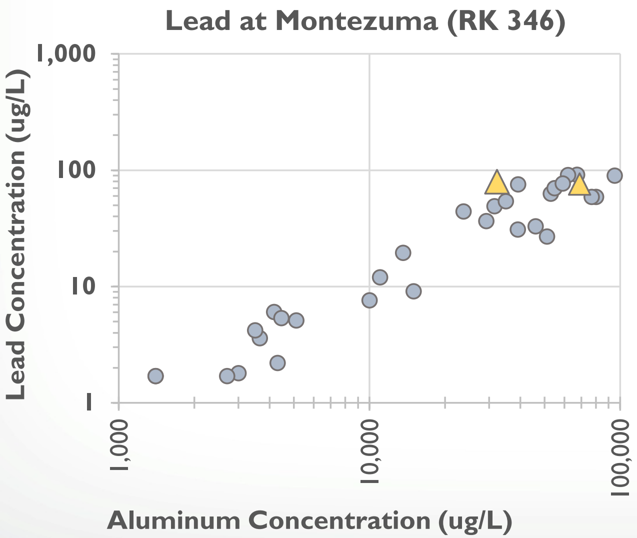
Several metals notably high in GKM: Total Lead (+416 kg) Total Selenium (+5 kg)

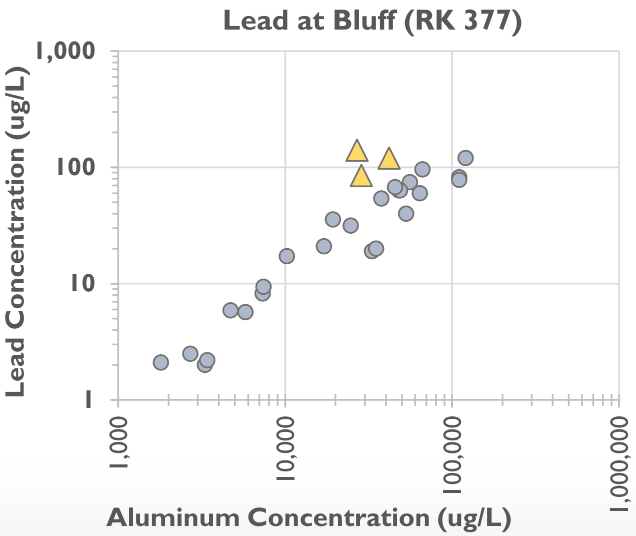
Correlation of Metals and Aluminum Concentration During the Plume At Sites Along the San Juan River

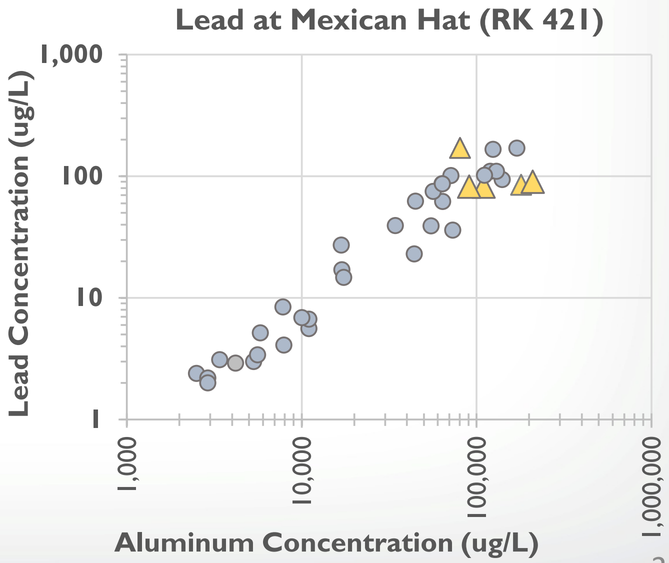




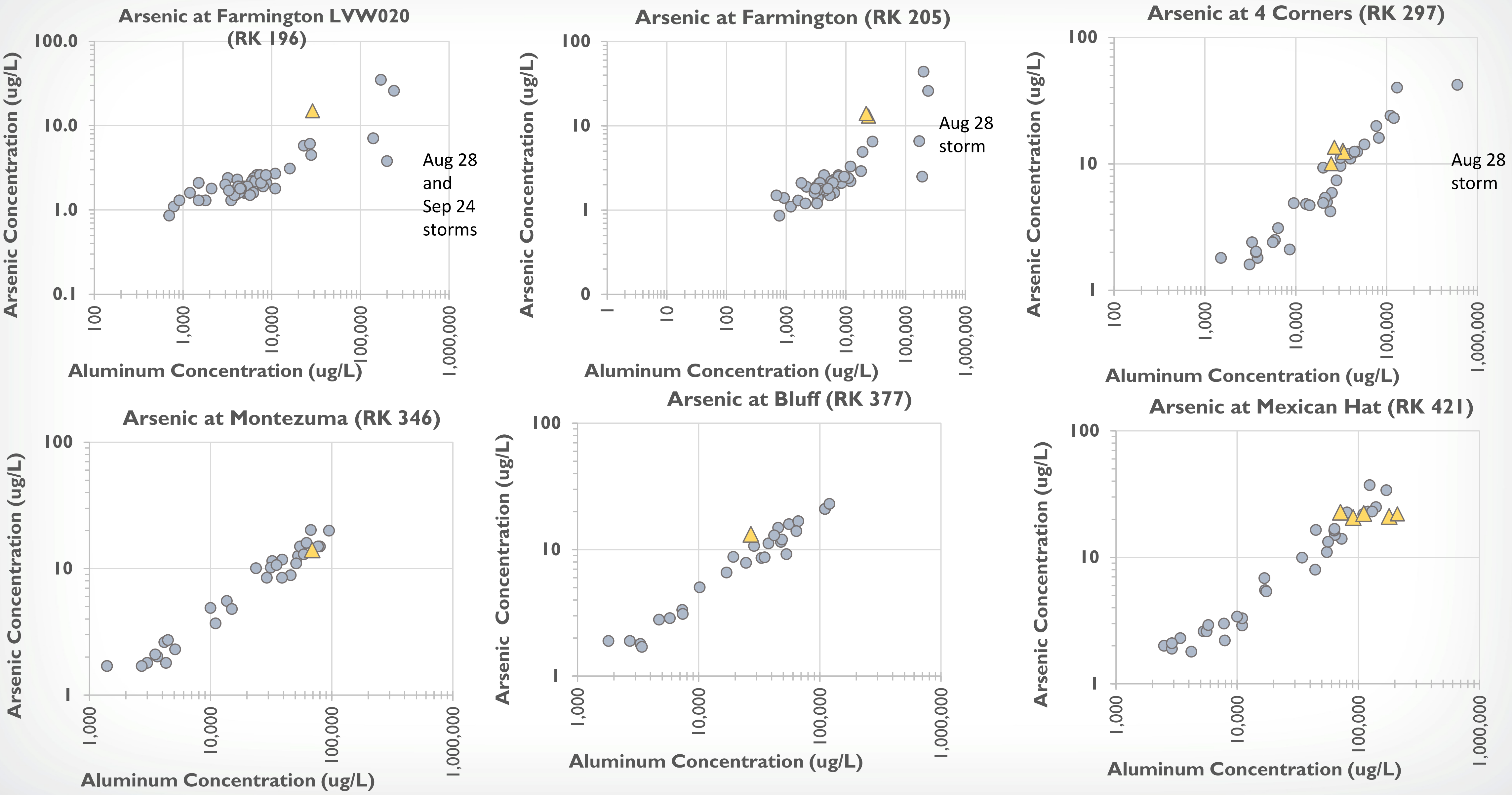






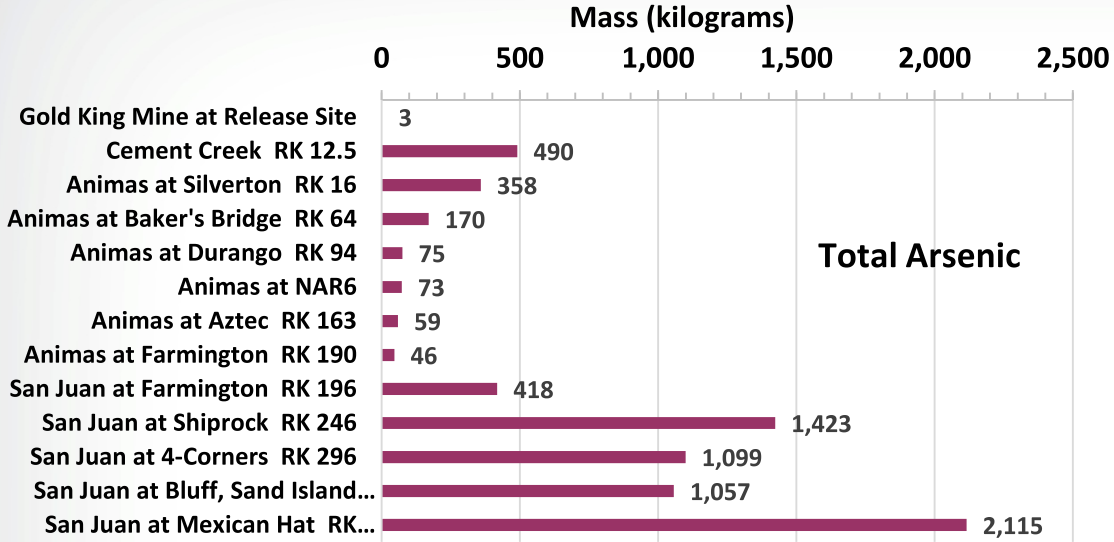


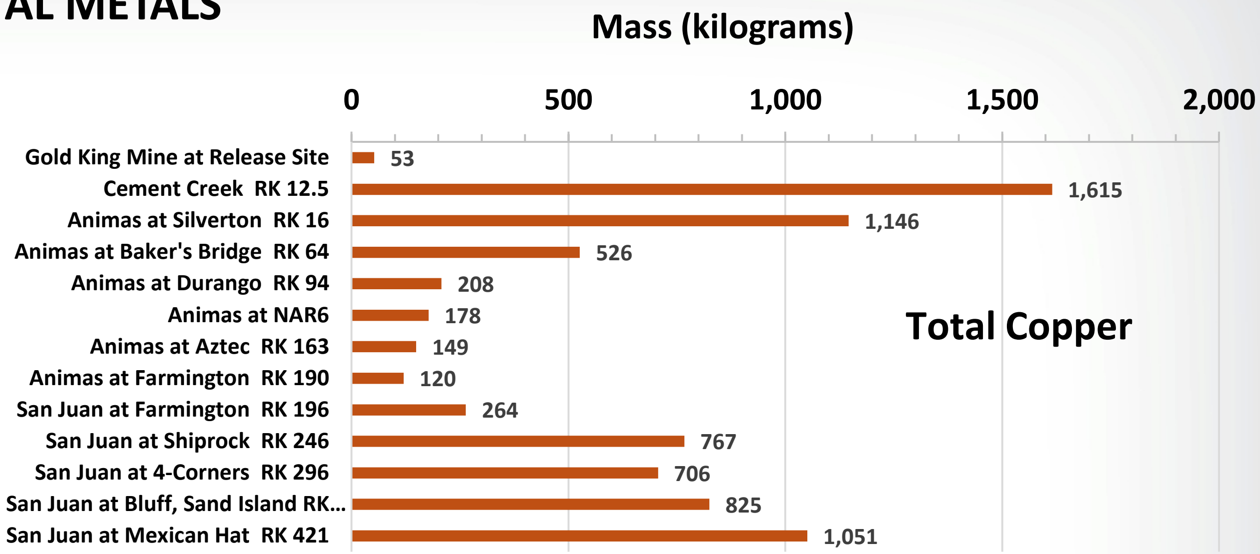
Correlation of Metals and Aluminum Concentration During the Plume At Sites Along the San Juan River

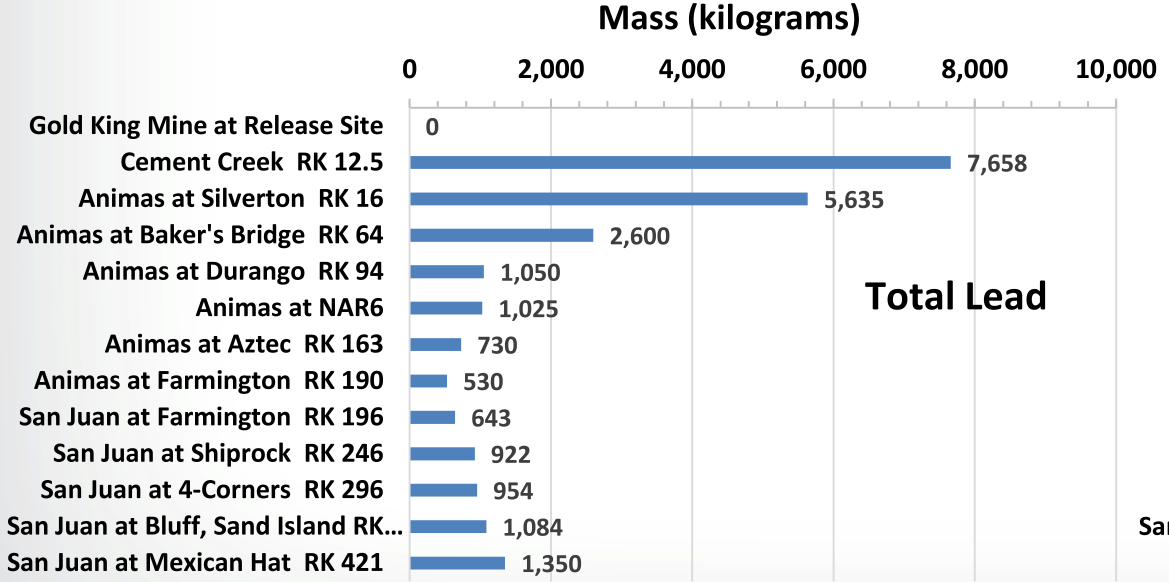


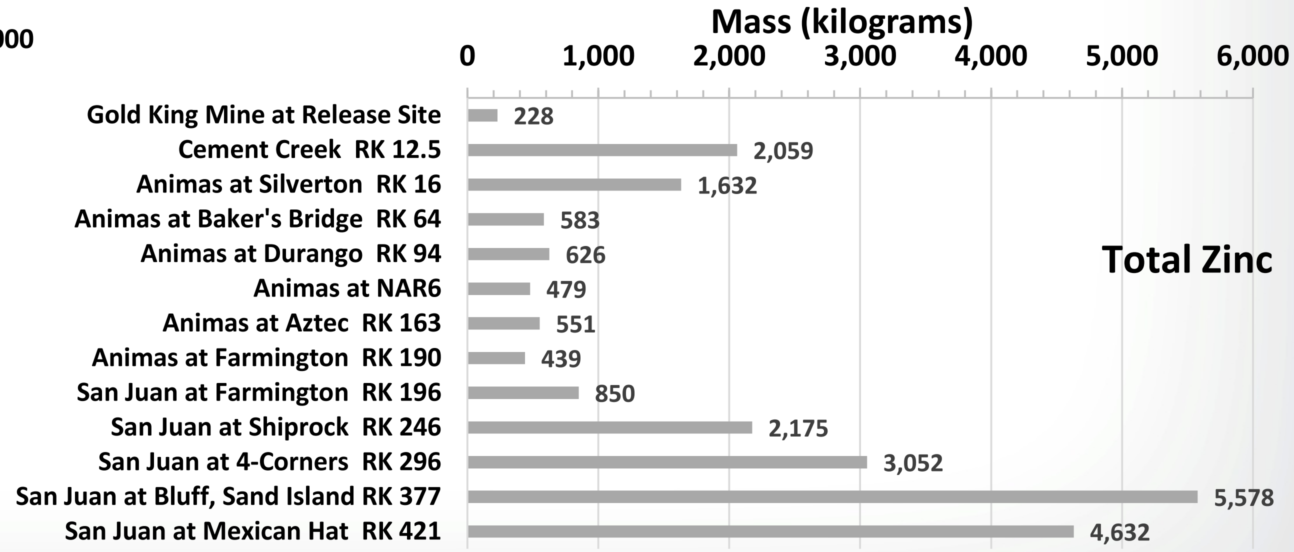
Mass Transport During Time Period of the GKM Release-Generated Plume

TOTAL METALS

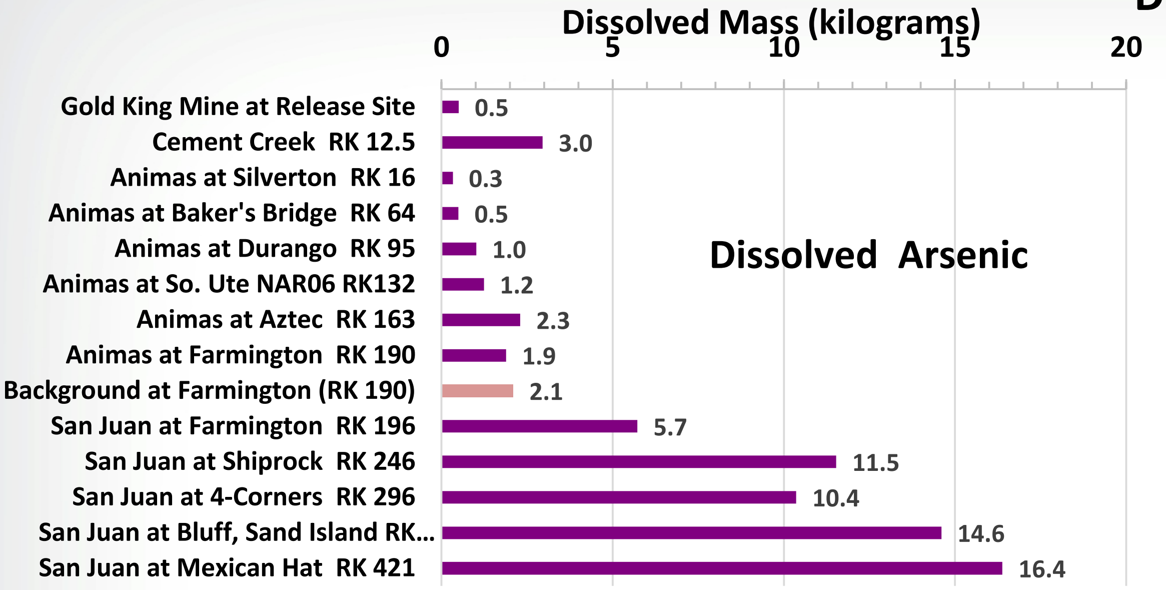


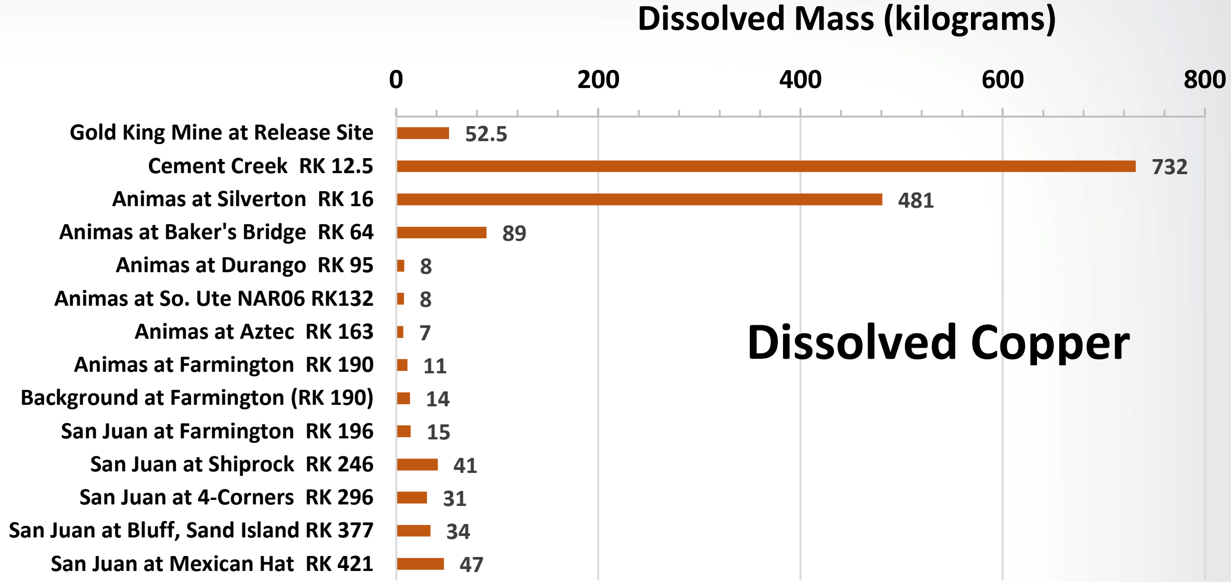


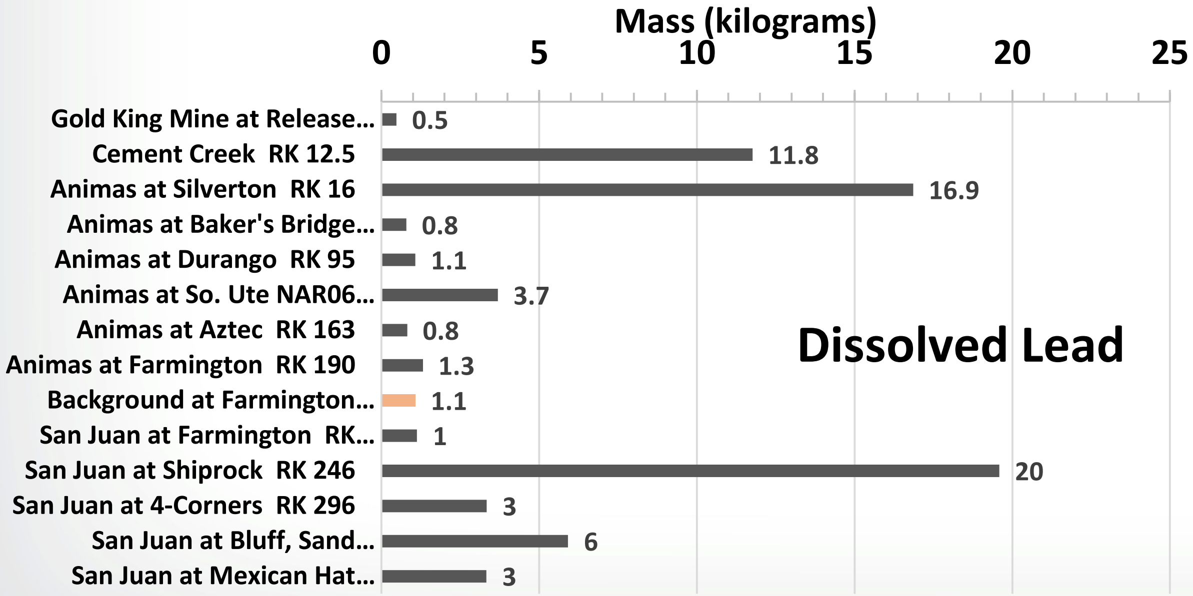


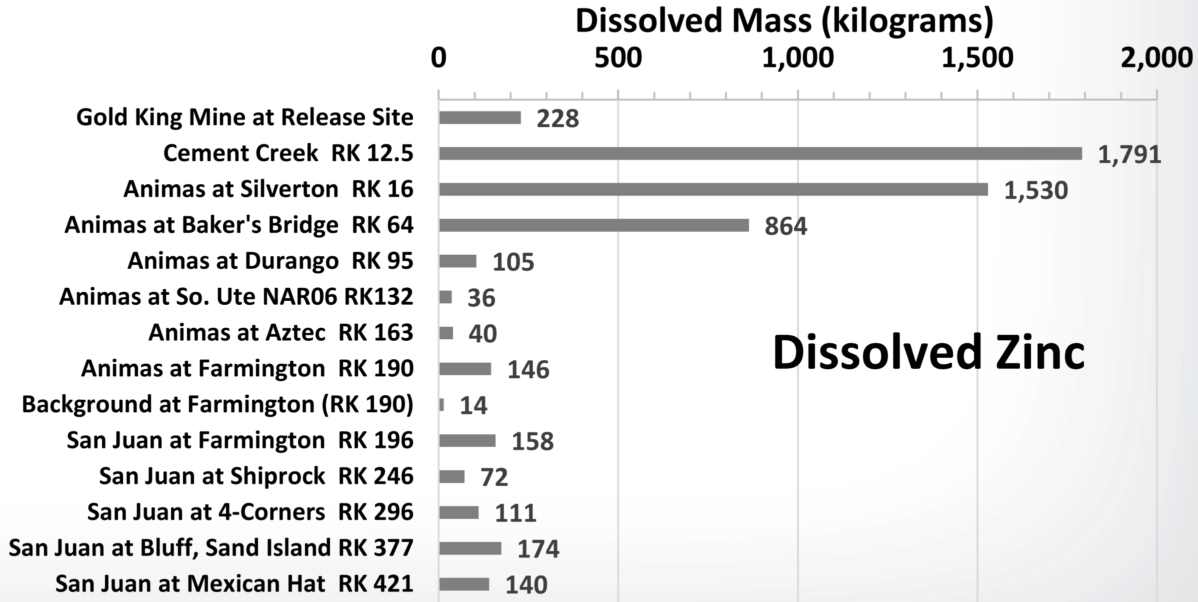


Mass Transport During Time Period of the GKM Release-Generated Plume
DISSOLVED METALS



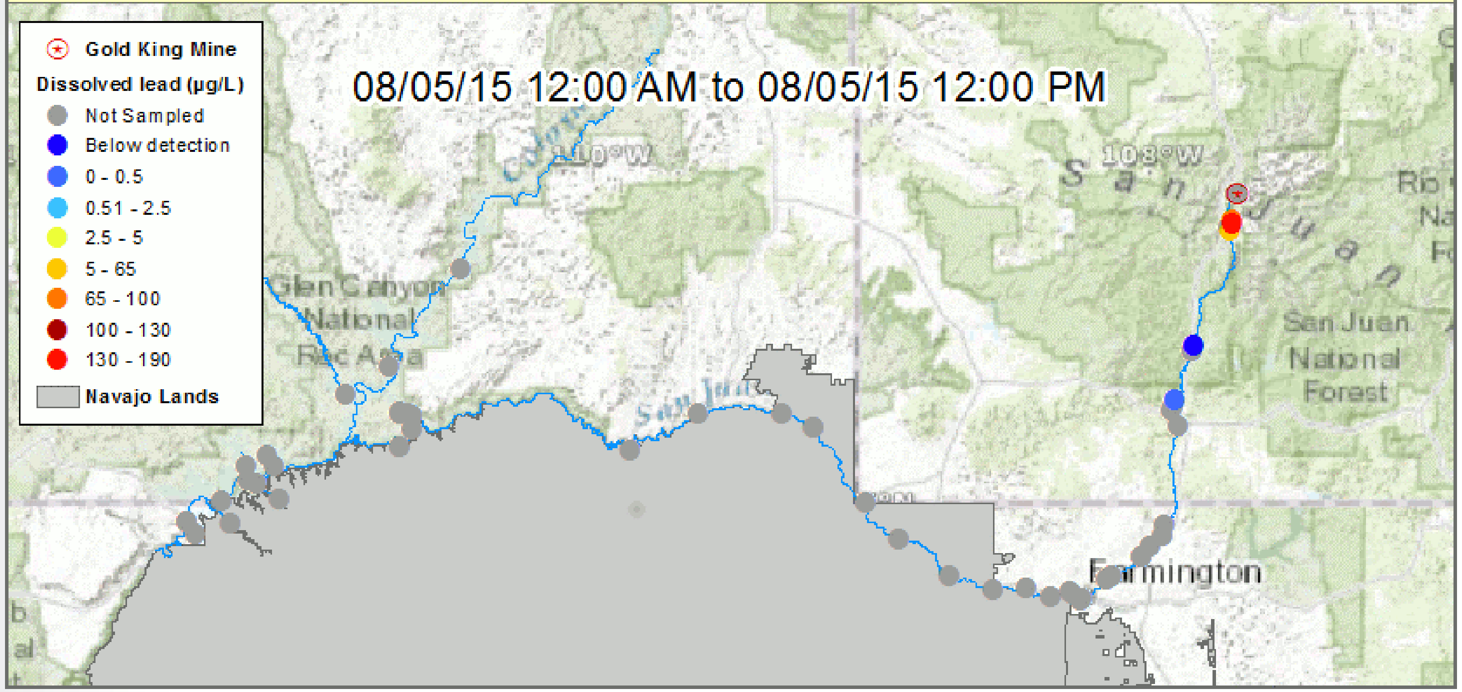


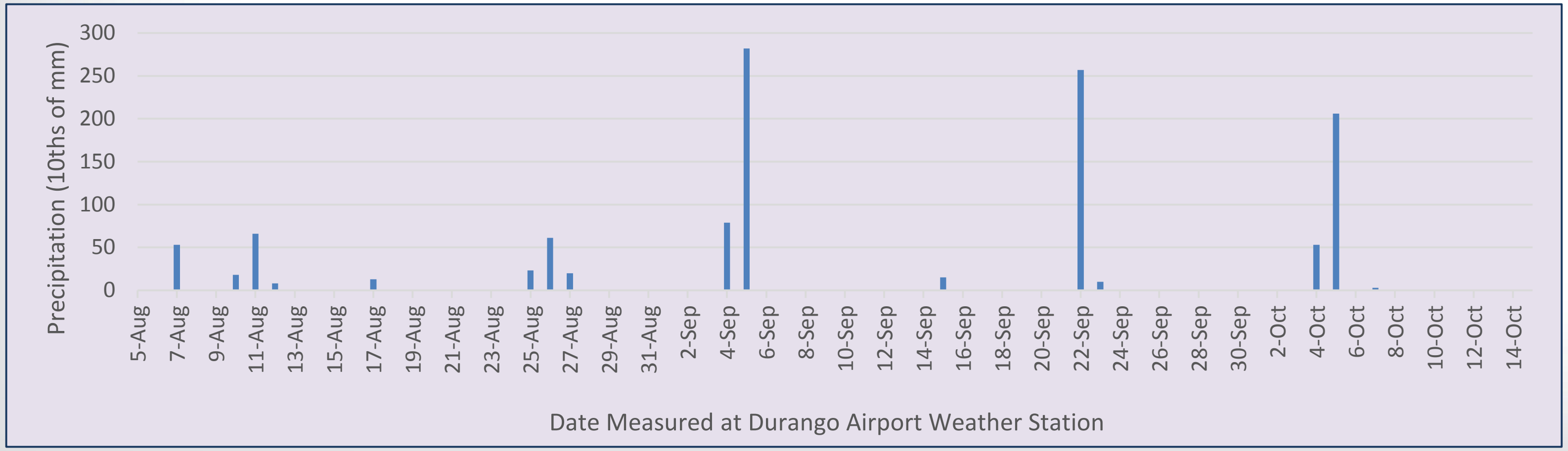




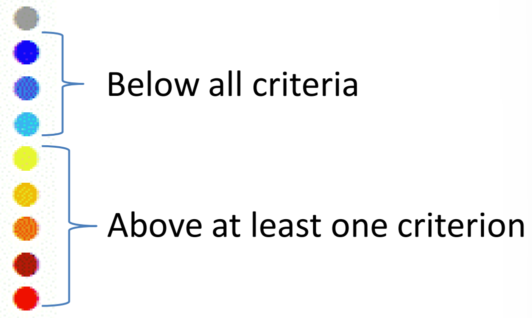
Measured Dissolved Lead Concentrations Following Gold King Mine Spill

12-hour maximums





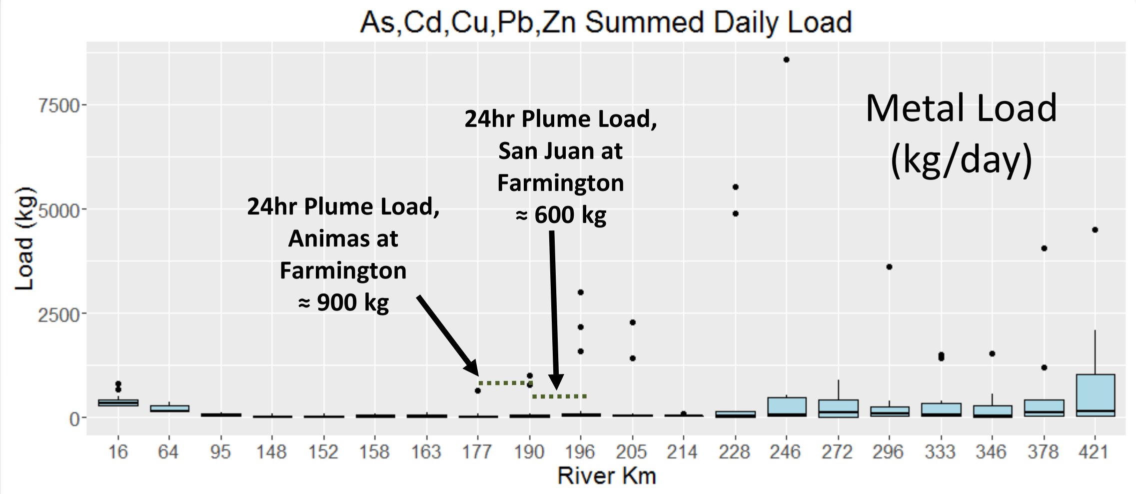
0.5 ug/L Pre-event concentrations
2.5 ug/L National Aquatic Life Criteria Chronic
5 ug/L Region 6 & 9 - Aquatic Life Criteria Chronic
65 ug/L National Aquatic Life Criteria Acute
100 ug/L Livestock Criteria
130 ug/L Region 6 & 9 - Aquatic Life Acute
200 ug/L Recreational Screening Level

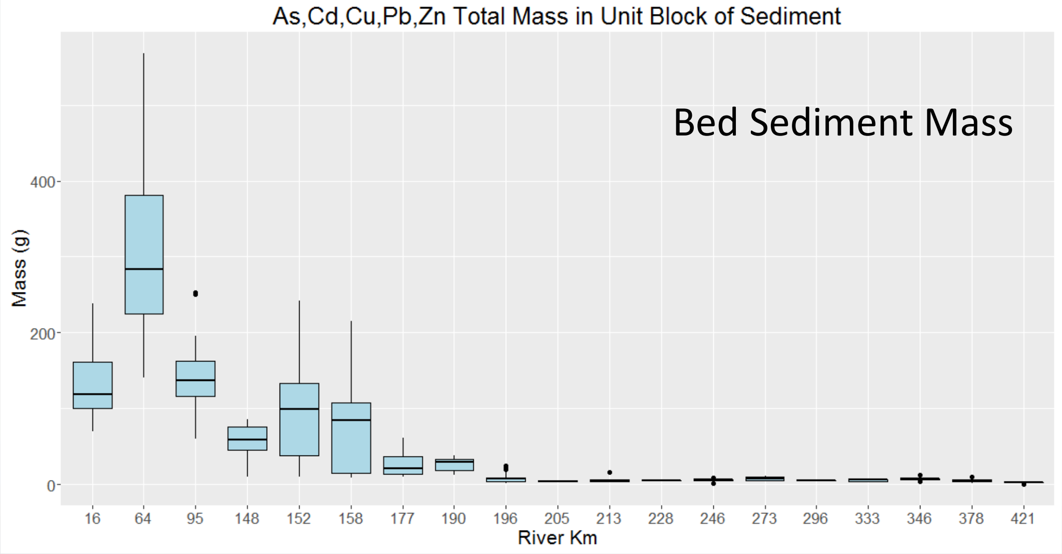


Notes:

- Grey dots represent locations that were sampled at some point between 8/5 and 10/15, so grey dot indicates no sample taken during corresponding 12 hr period
- Color of dot represents maximum result based on samples over 12-hr period
- Spikes seem to coincide with rain events (see precip chart)

Metals in the San Juan River





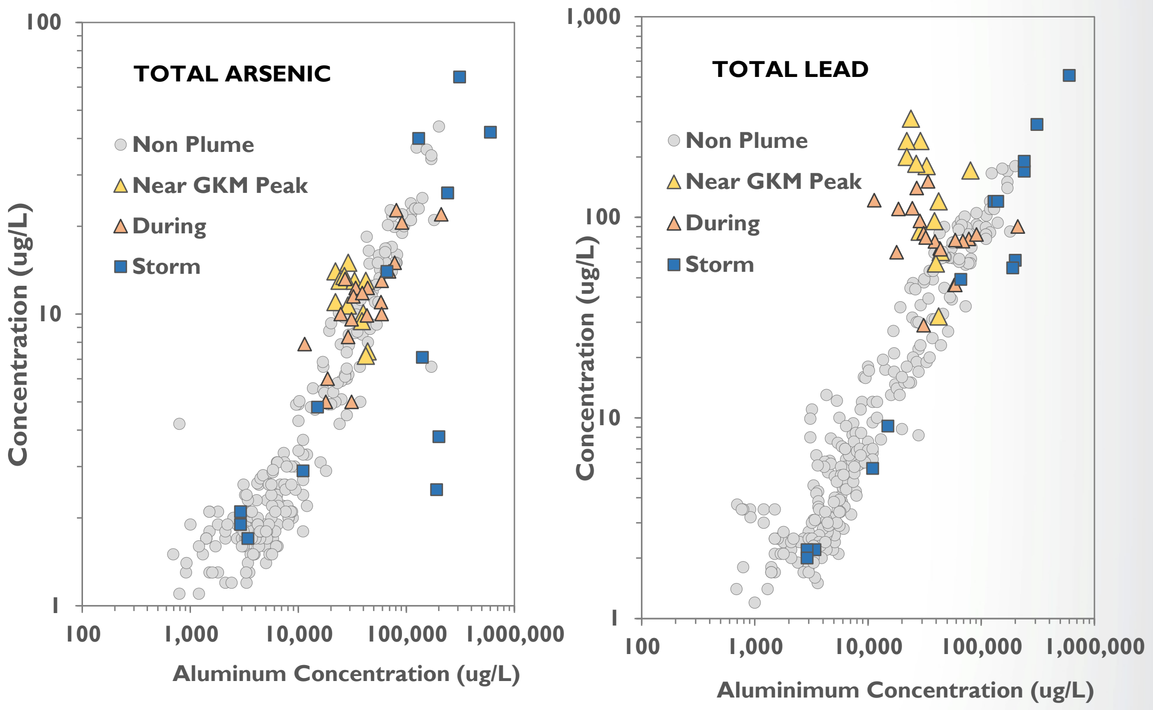
- **During the 2-month period after the GKM release, and during the GKM plume, total metal concentrations and daily loads were larger in the San Juan River than in the Animas River and tended to increase in the downstream direction**
- **Post-event monitoring has shown that water concentrations of some metals are high in the San Juan River relative to water quality criteria during storm events (e.g. Aug 27, Sept 6 and Sep 26)**
- **Although there are large amounts of metals sorbed to suspended sediments transported through the San Juan River, metals concentrations in bed sediments are low compared to those in the Animas River**

Data includes only post-event samples

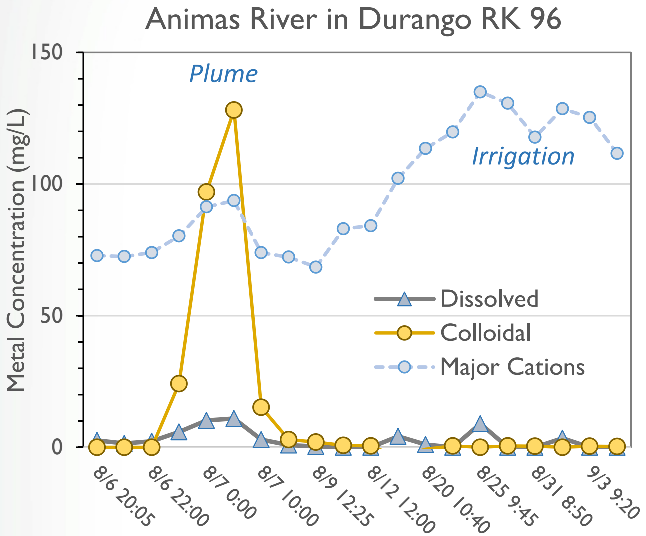
Mass of Sediment in the San Juan River

- The large metals loads in the San Juan are not due to a high level of metal contamination in the bed—in fact, concentrations are generally small
- Bed sediments are the source of high suspended sediment concentrations during storms
- Aluminum and iron are associated with sediments and their concentrations are elevated with streamflow along with suspended sediments
- The correlation graphs introduced earlier show a consistent relationship between most of the metals and aluminum/iron
- Streambed metal concentrations are high enough to account for water concentrations as flow and suspended sediments increase

Metals Correlation With Aluminum Analysis



Post Event Trends in Water Quality

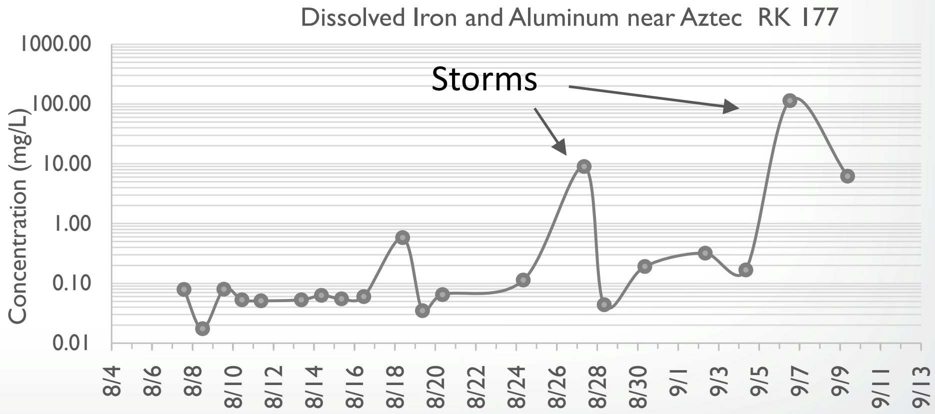


- Metals concentrations in water retreated back towards normally observed levels quickly after the GKM plume passed
- Typically, dissolved major cations including Calcium, Magnesium, Potassium, and Sodium dominate the metals content of water during summer
- Post-event adjustments to GKM water chemistry and sediment deposits possible from several sources
  - Water chemistry changes with continued/increased effluent treatment
  - Dissolution of precipitates (e.g. gypsum, gibbsite, ferrihydrite)
  - Mobilization of bed deposits in high flow events

Research Question:

Did/Will GKM release metals affect water concentrations:

- During fall months (August-October) post event?
- Spring snowmelt



Water Quality Data

Data Sources for pre-GKM event data

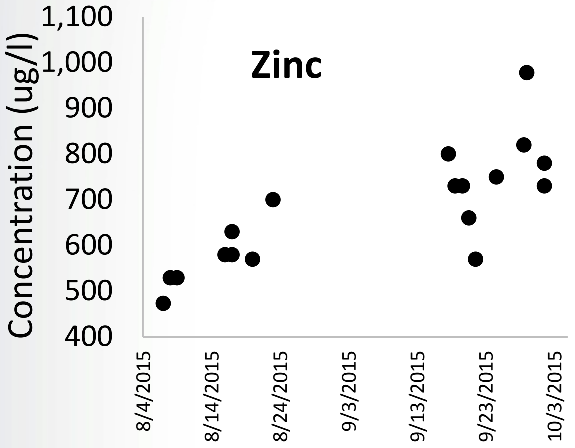
- Superfund sampling at Silverton (n≈130) and Baker's Bridge (n=5), 2012-2015
- EPA STORET data at Durango (n≈165), 2009-2014
- USGS samples at Farmington (n=12), 2006-2010

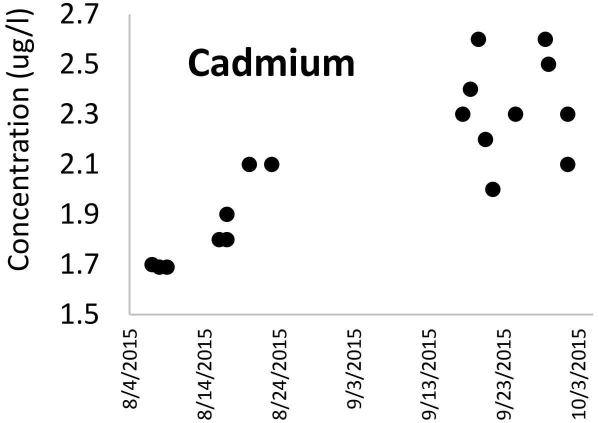
Note: USGS data were available at Silverton, Baker's Bridge, and Durango for the mid to late-1990's and early 2000's. Due to changes in managed mine geohydrology as well as AMD treatment facilities, we opted to use the most recently collected historic data (2009 to 2014) to characterize pre-event water quality.

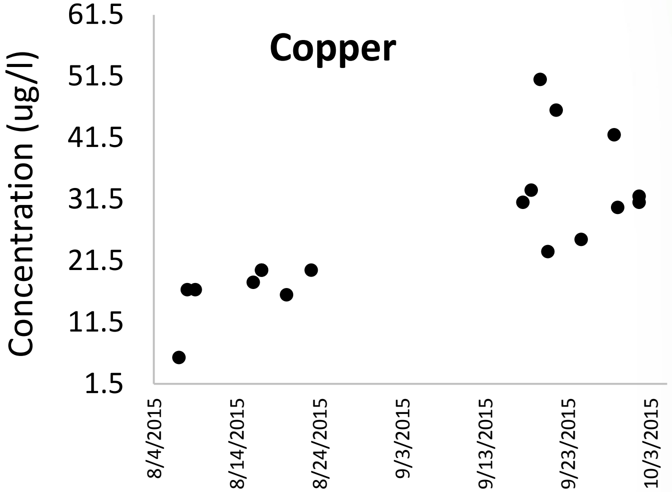
A full suite of metals (24) were not consistently measured in pre-event samples

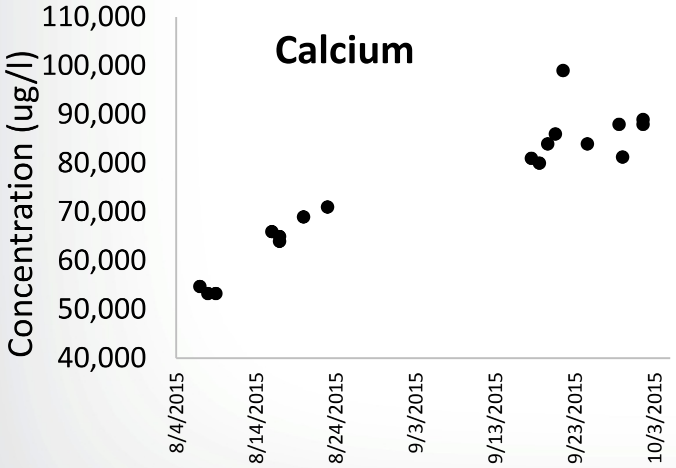
Fall 2015 Water Quality Trends at Silverton

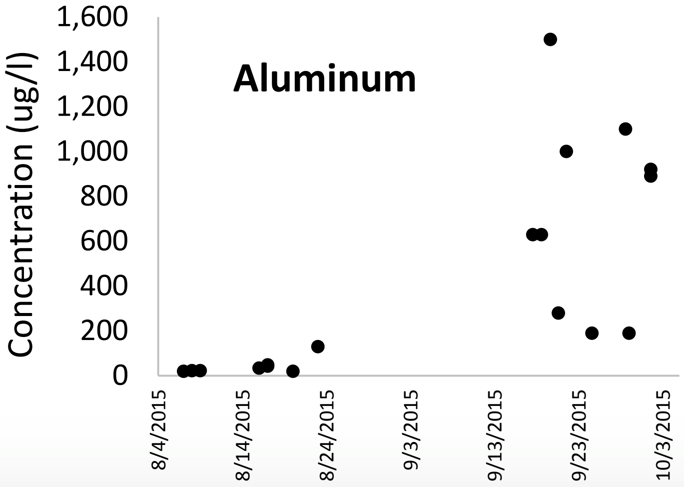
Temporal Trends in Dissolved Metals







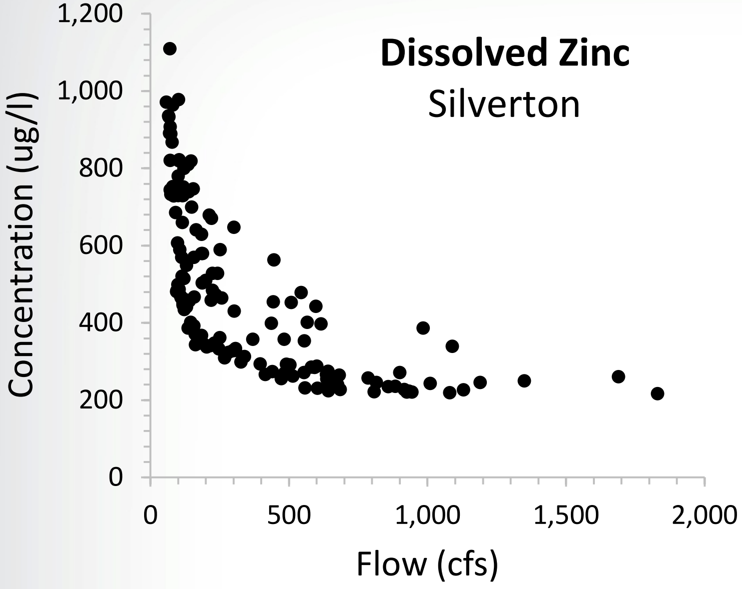


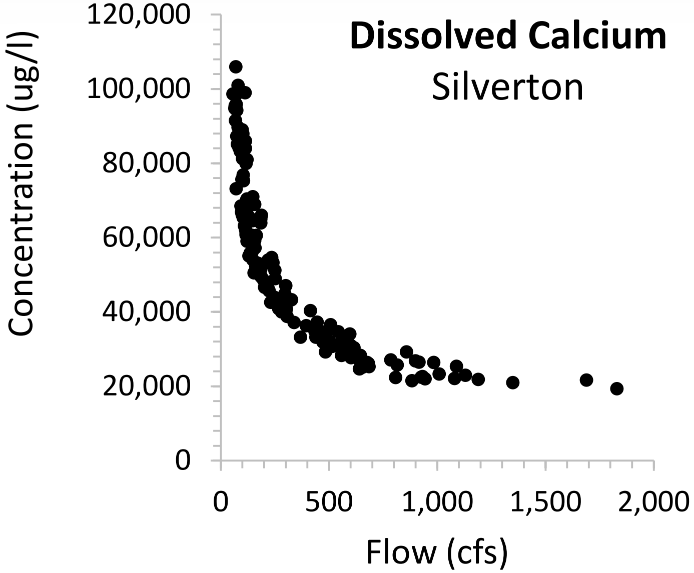


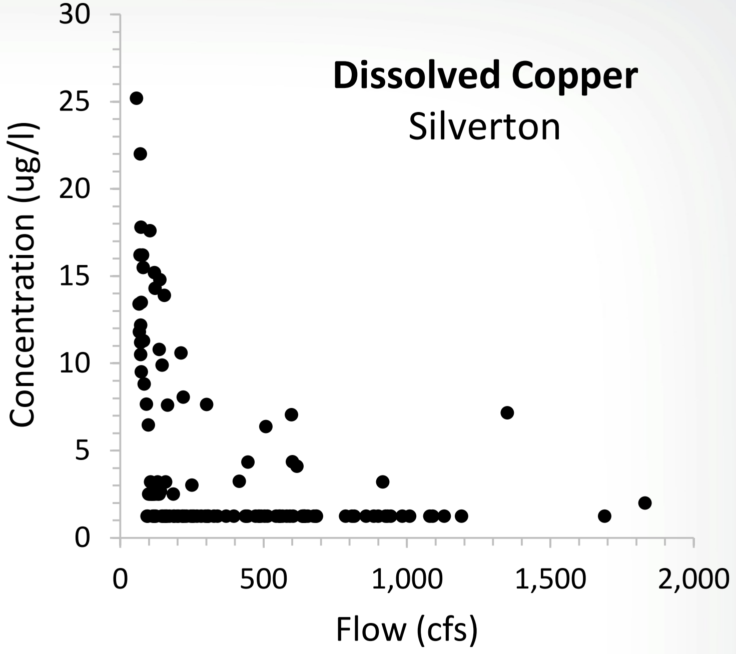
Possible Causative Factors for Increasing Trends:

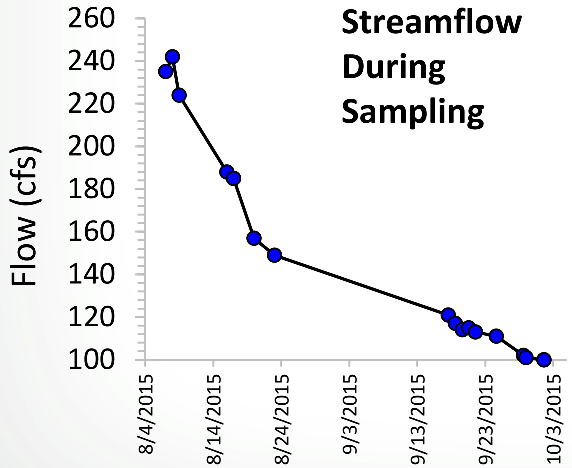
- **Dissolution from Precipitates**
- **Water Chemistry Changes**
- **Correlated to Other Factors**

Relation of Metal Concentrations to Flow





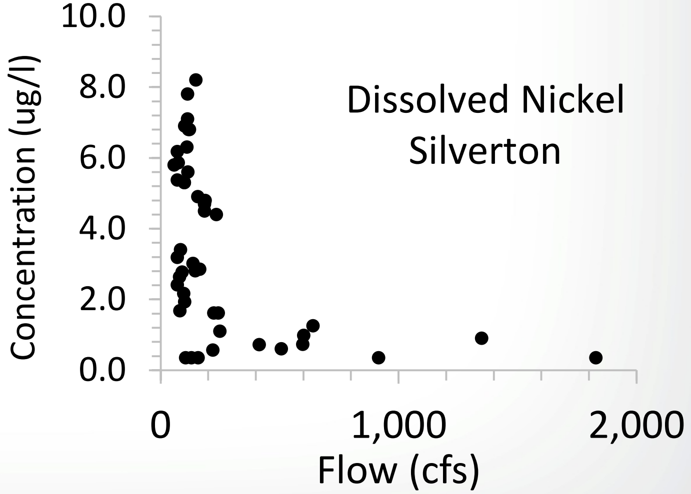




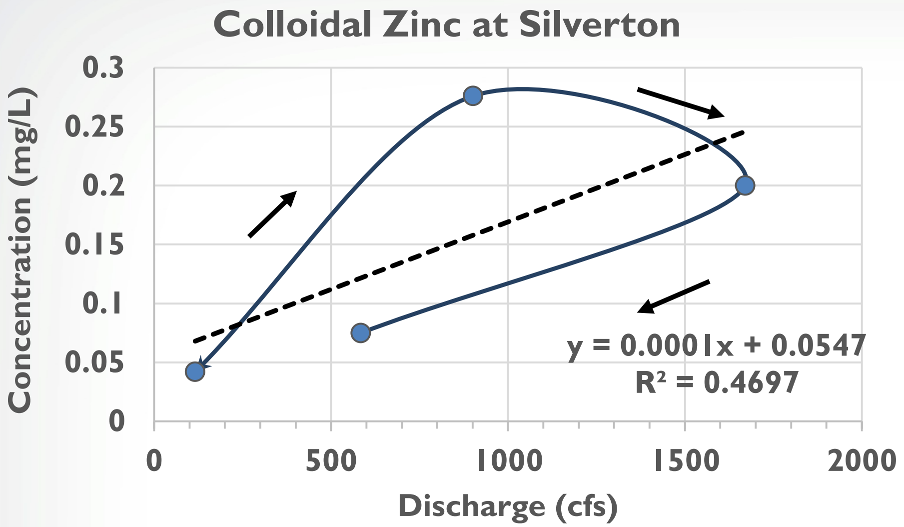
- **Dissolved metals concentrations show strong inverse relationship to streamflow**
- **Rising temporal trend in post-event dissolved metals may be explained by steadily declining flow**

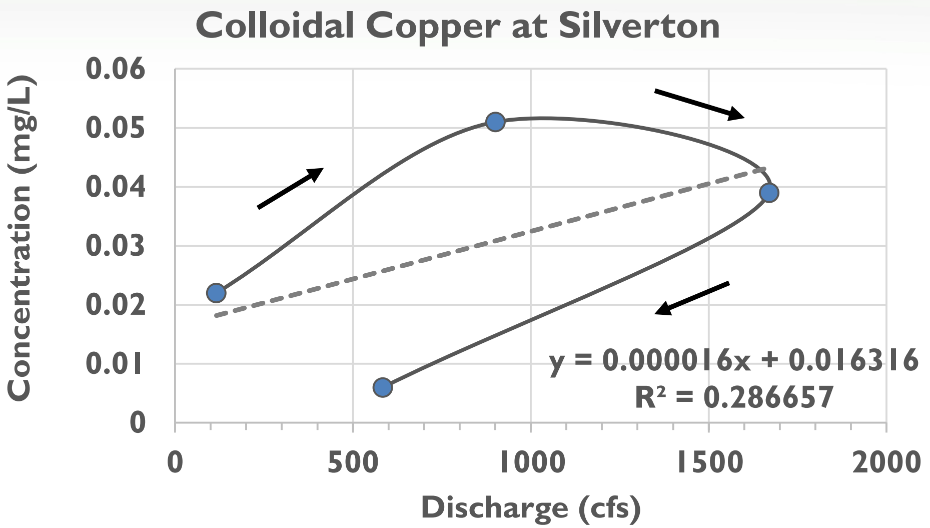
Analysis Implications:

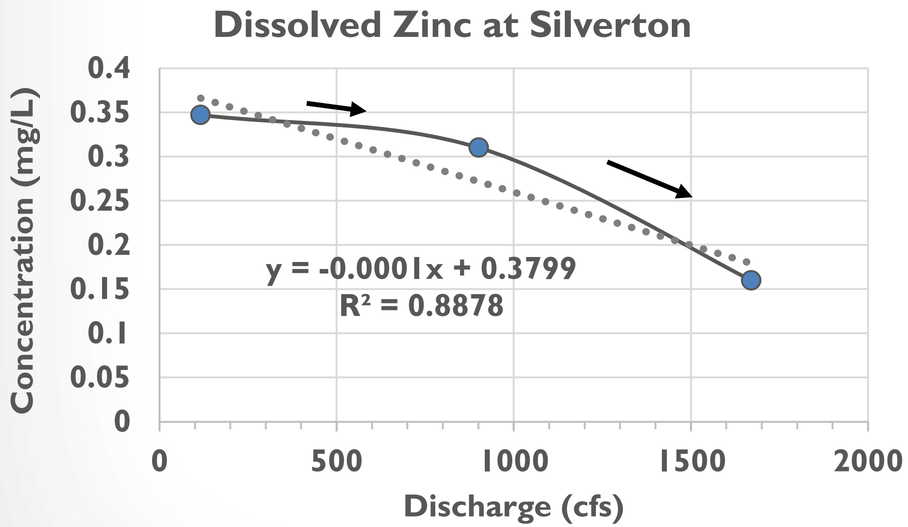
- **Restrict pre vs. post comparisons to same flow levels**
- **Historic data at flows similar to post-event period were primarily collected in spring**

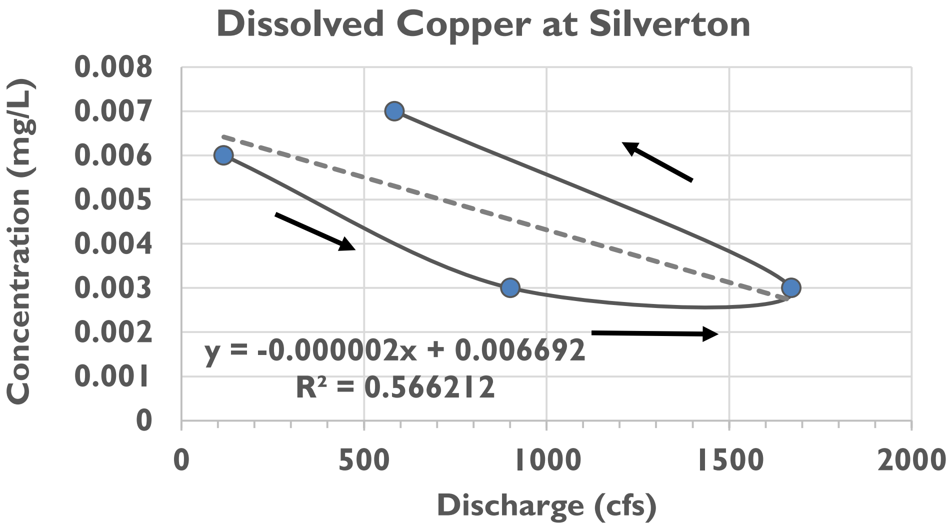


Metals Behavior in Relation To Flow During Spring Snowmelt Period







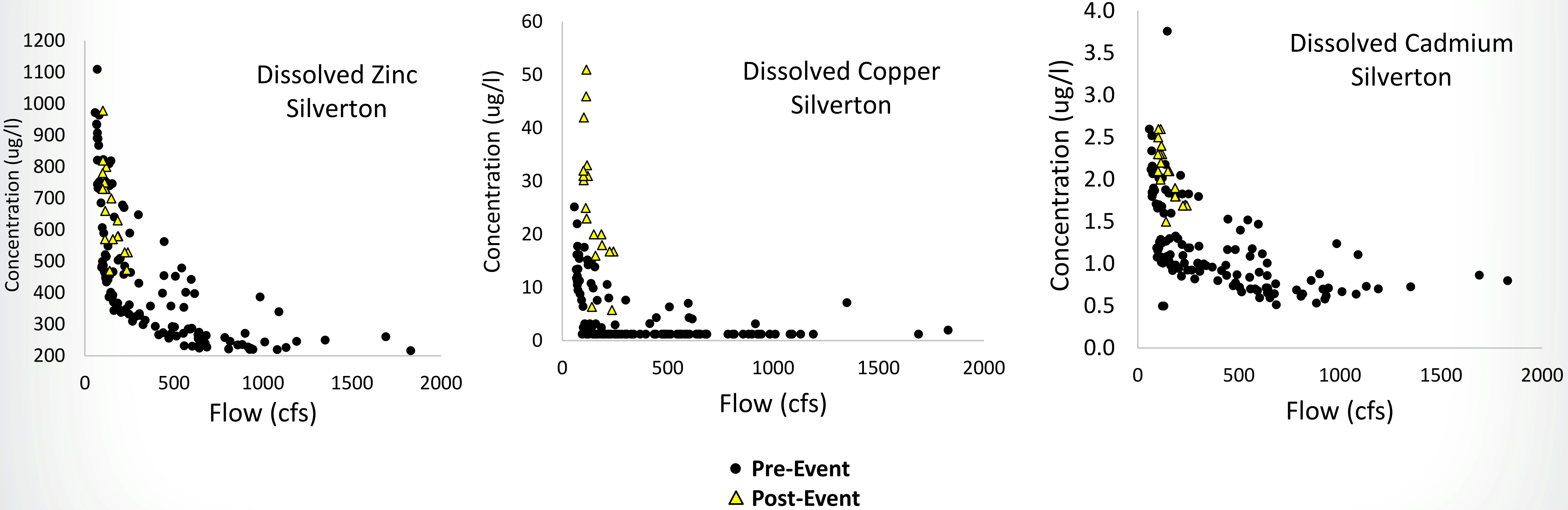


- **USGS sampled 4 times during a snowmelt season**
- **Patterns repeated at Durango and Farmington (not shown)**
- **Colloidal shows increase during snowmelt, hysteresis (particle mobilization)**
- **Dissolved shows decrease (dilution)**

USGS Sampling During Snowmelt 1995-96   Reported in Church *et al*. 1997

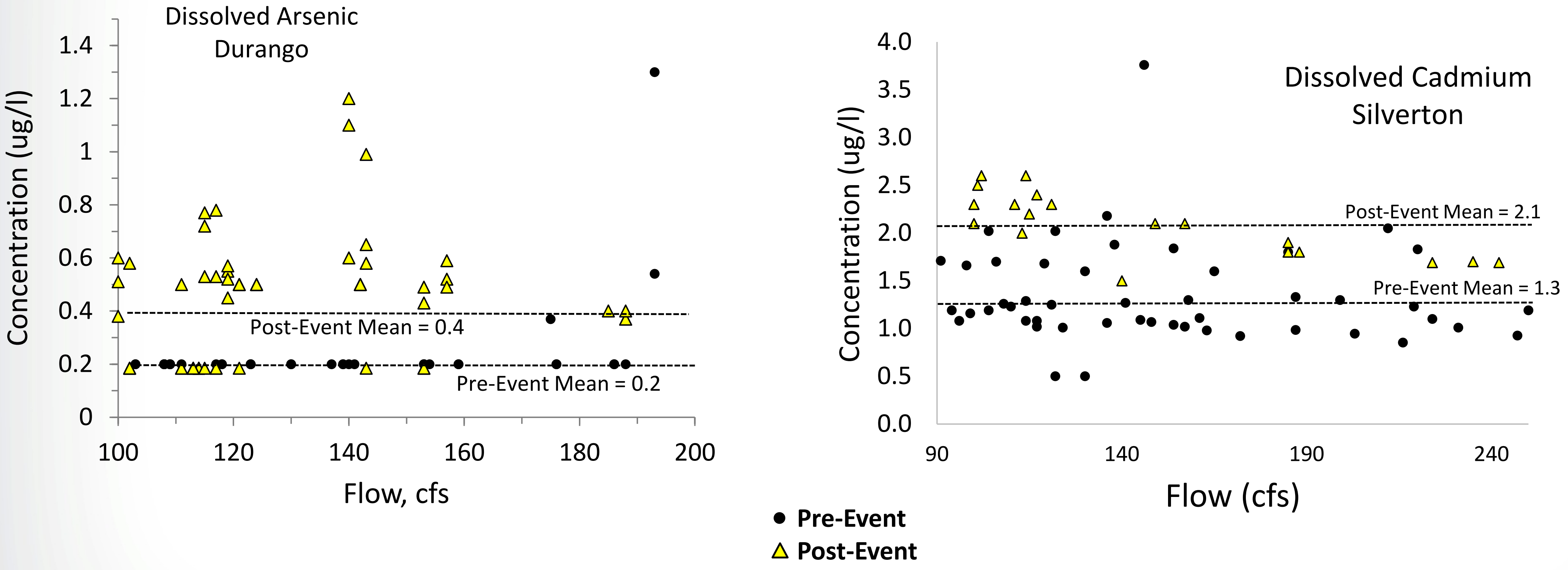
Post GKM Event Water Quality

Some dissolved metals show concentration increases around Silverton in the post-event period compared to pre-event data



Post GKM Event Water Quality

Examples of Flow-Restricted Sample Comparisons



Post GKM Event Water Quality

Sample Sizes:
Dissolved, Pre: n = 7-42
Dissolved, Post: n = 19
Total, Pre: n = 5-9
Total, Post: n = 18

- Significant Increase (p-value < 0.05)
- No change (p-value > 0.05)
- Significant Decrease (p-value < 0.05)

SILVERTON—August-October

Dissolved Concentrations:

- Majority of metals were larger
- Many statistically significant
- Notable: Aluminum, Copper, Zinc

Total Concentrations:

- Some metals larger, some smaller
- 2 statistically significant
- Notable: Copper

SILVERTON

	Metal	Pre (ug/l)	Post (ug/l)	Change	p-value
Dissolved	Aluminum	46	160	Increase	0.005
	Arsenic	0.26	0.37	Increase	0.11
	Cadmium	1.27	2.06	Increase	<0.0001
	Cobalt	4.82	7.00	Increase	0.01
	Copper	2.70	22.31	Increase	<0.0001
	Iron	1406	1509	Increase	0.71
	Lead	0.29	0.37	Increase	0.61
	Manganese	1419	1471	Increase	0.77
	Nickel	0.93	4.75	Increase	0.006
	Zinc	490	651	Increase	<0.0001
Total	Aluminum	2207	2053	Decrease	0.71
	Arsenic	0.63	1.30	Increase	0.07
	Cadmium	1.94	2.09	Increase	0.44
	Copper	26	57	Increase	<0.0001
	Iron	3038	3746	Increase	0.12
	Lead	10.26	8.55	Decrease	0.71
	Manganese	1440	1449	Increase	0.95
	Nickel	1.29	4.42	Increase	0.02
	Zinc	654	645	Decrease	0.86

Post GKM Event Water Quality

- Significant Increase (p-value < 0.05)
- No change (p-value > 0.05)
- Significant Decrease (p-value < 0.05)

Durango—August-October

Dissolved Concentrations:

- Some larger, some smaller
- Many in both categories statistically significant
- Notable: Iron, Aluminum

Total Concentrations:

- Most metals smaller
- Most statistically significant
- Notable: Aluminum, Iron, Manganese, Zinc

Sample Sizes:
Dissolved, Pre: n = 40
Dissolved, Post: n = 57
Total, Pre: n = 37
Total, Post: n = 57

DURANGO

	Metal	Pre (ug/l)	Post (ug/l)	Change	p-value
Dissolved	Aluminum	24	27	Increase	0.31
	Arsenic	0.2	0.4	Increase	<0.0001
	Cadmium	0.19	0.14	Decrease	0.047
	Copper	1.42	1.93	Increase	0.0005
	Iron	21	33	Increase	0.04
	Lead	2.92	0.34	Decrease	<0.0001
	Manganese	69	53	Decrease	0.03
	Zinc	36	29	Decrease	0.03
Total	Aluminum	152	94	Decrease	0.01
	Cadmium	0.25	0.22	Decrease	0.44
	Copper	2.67	2.99	Increase	0.42
	Iron	301	211	Decrease	0.02
	Lead	3.75	1.97	Decrease	<0.00001
	Manganese	102	83	Decrease	0.04
	Zinc	54	44	Decrease	0.04

Post GKM Event Water Quality

- Significant Increase (p-value < 0.05)
- No change (p-value > 0.05)
- Significant Decrease (p-value < 0.05)

Farmington—August-November

Dissolved Concentrations:

- Majority of metals were larger
- 4 of 10 statistically significant
- Notable: Aluminum, Iron, Zinc

Sample Sizes:
Dissolved, Pre: n = 9
Dissolved, Post: n = 16

Farmington Dissolved

Metal	Pre (ug/l)	Post (ug/l)	Change	p-value
Aluminum	9	130	Increase	<0.0001
Arsenic	0.54	0.68	Increase	0.25
Cadmium	0.05	0.11	Increase	0.16
Cobalt	0.16	0.45	Increase	0.004
Copper	2.4	2.5	Increase	0.98
Iron	8	80	Increase	0.0002
Lead	0.23	0.35	Increase	0.3
Manganese	34	28	Decrease	0.72
Nickel	1.2	2.1	Increase	0.04
Zinc	12	5	Decrease	0.09

No historic sampling of total metal concentrations available at Farmington

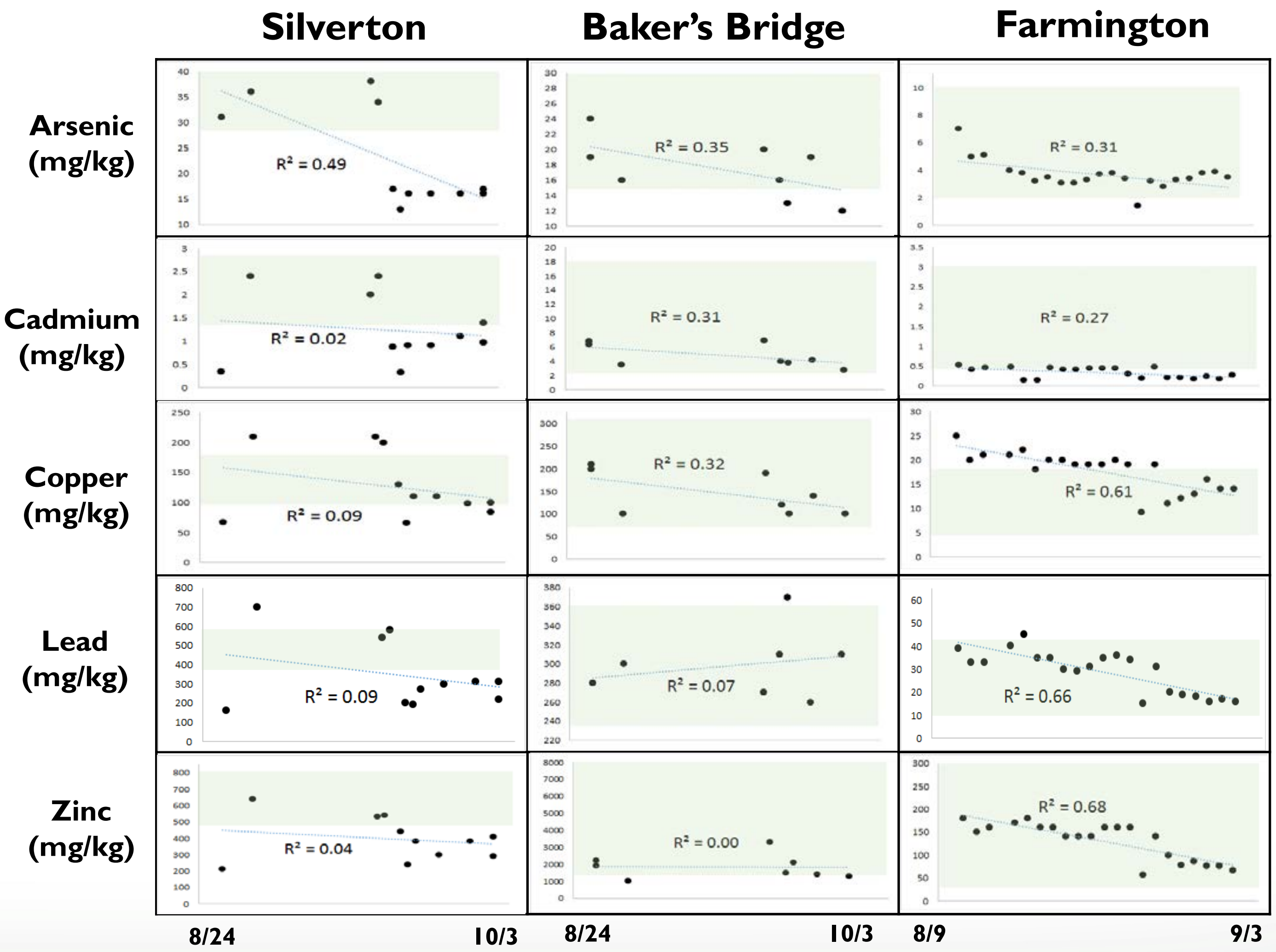
The increased dissolved concentrations of Aluminum (143 ug/l) and Iron (85 ug/l) translate to 7,000 kg and 4,000 kg of additional mass over a 60-day mean flow period

Temporal Trends in Bed Sediments

Observations:

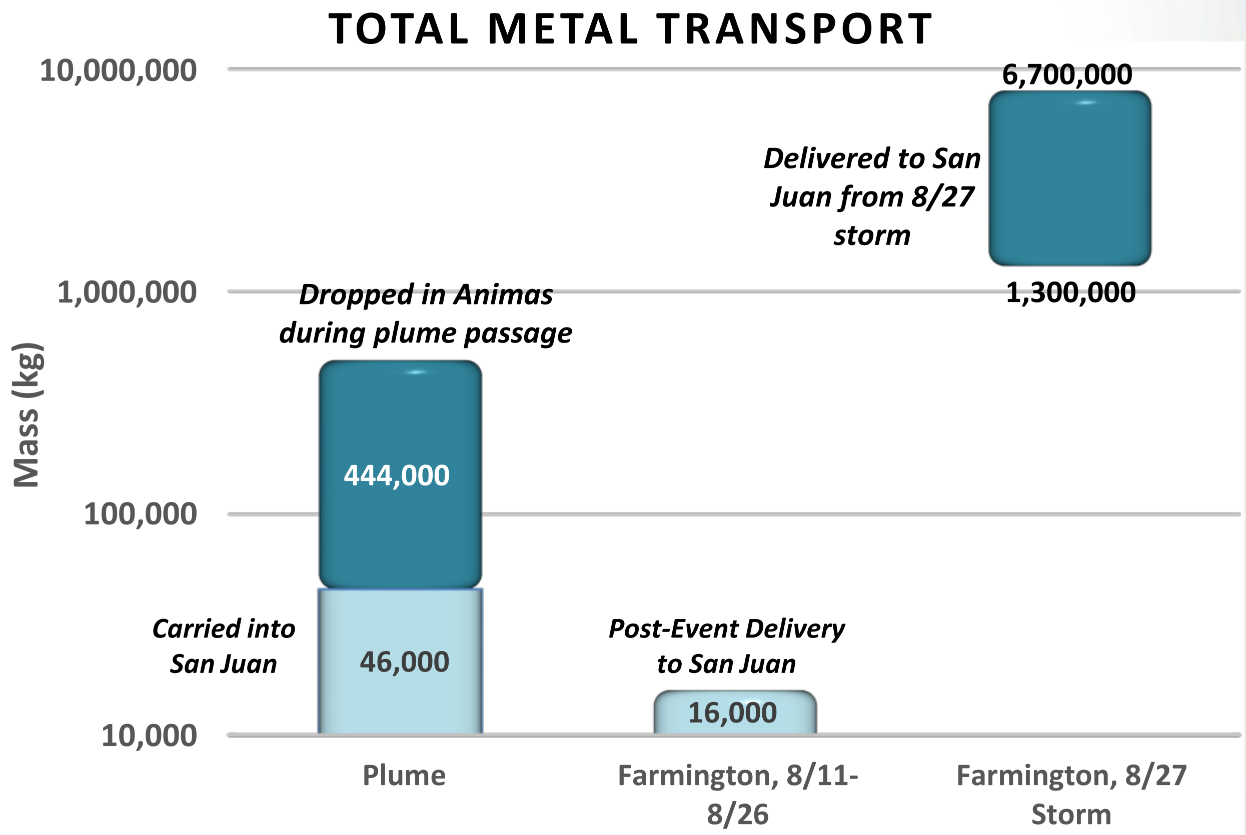
- **Some metals appear to decrease in weeks following the GKM, especially at Farmington (earlier sampling period)**
- **Concentrations not elevated relative to pre-event EPA superfund sampling; exception is Copper at Farmington in the immediate post-event samples**

Green bands represent 95% confidence interval for mean of pre-event samples



Post-GKM Event Movement of Metals Mass

- **In the two weeks following the plume passage, about 16,000 kg of metals were slowly leaked (indicated by monitoring samples)**
- **The large storm on August 27th affected the lower Animas watershed:**
  - **delivered between 1.3 and 6.7 million kg of metals to the San Juan**
  - **exceeded the ≈450,000 kg of total metals deposited in the Animas during plume passage.**



Estimated range of metals load for the August 27 storm event based on assumption of constant water concentrations (lower bound) and volumetric scaling (upper bound).

Expected Metals Concentrations During Snow Melt and High Flow Events

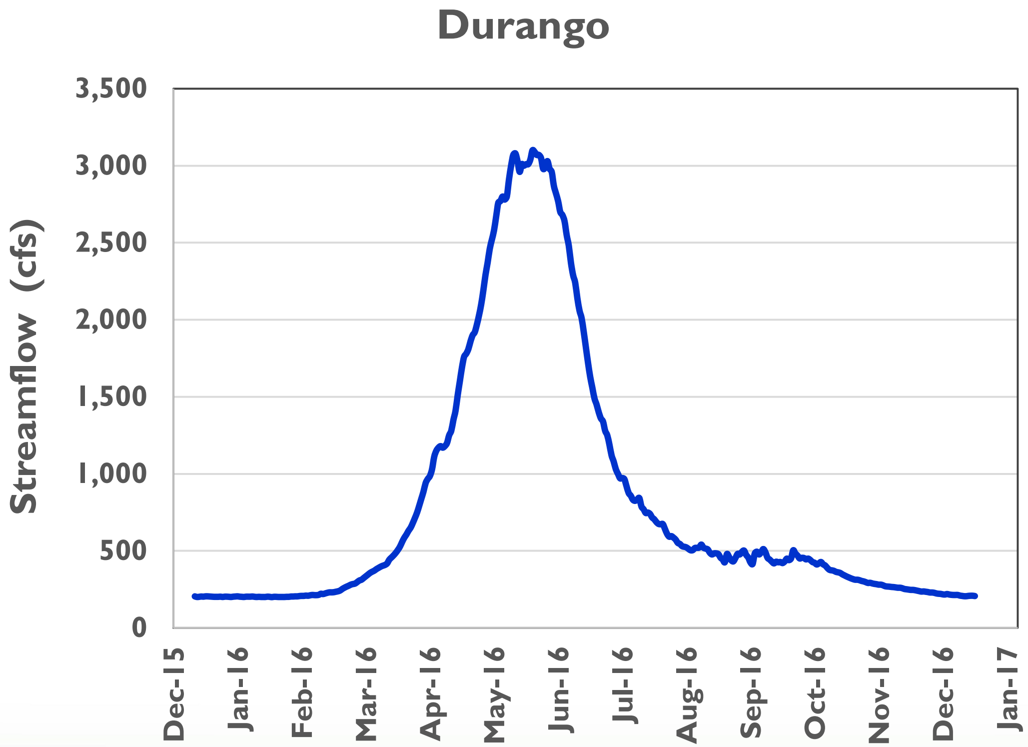
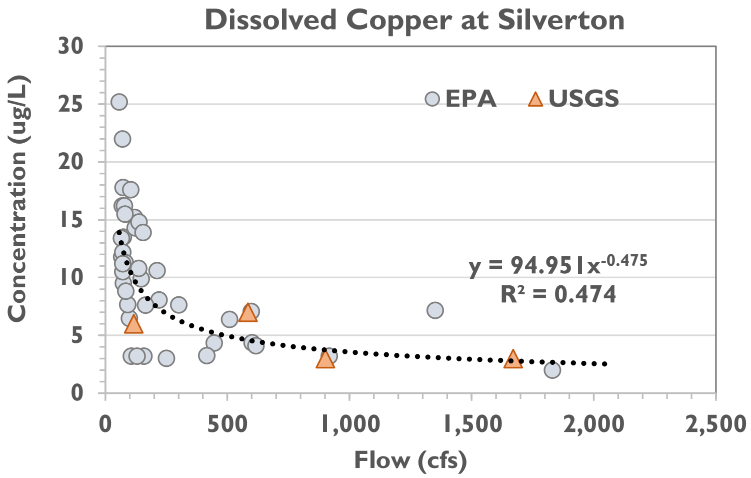
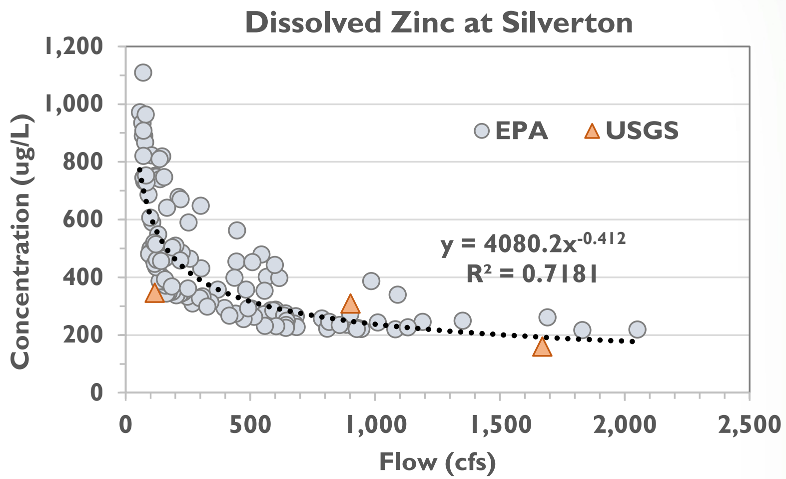


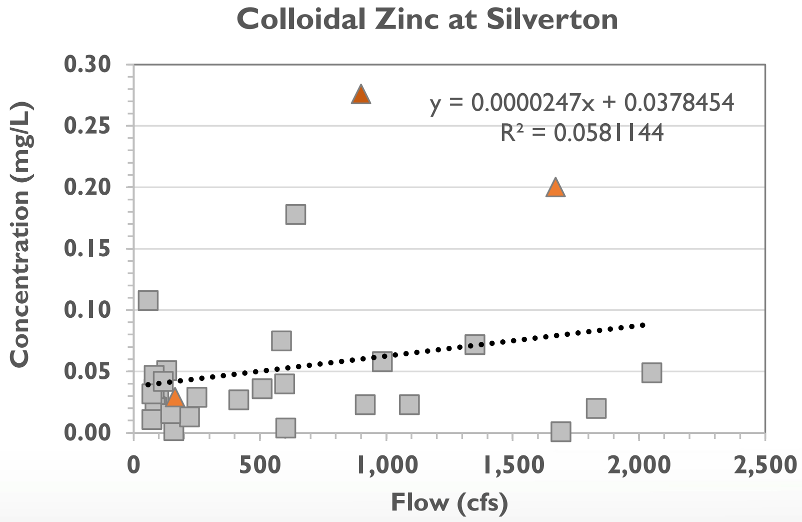
Photo: TripAdvisor.com

Empirical Method for Estimating Daily Metals Loads

- **Fit regression lines to individual metals concentrations in relation to flow**
- **Dissolved and colloidal fractions at each site**
- **Applied regression to the average daily flow at USGS gage (available as one of the flow statistics)**

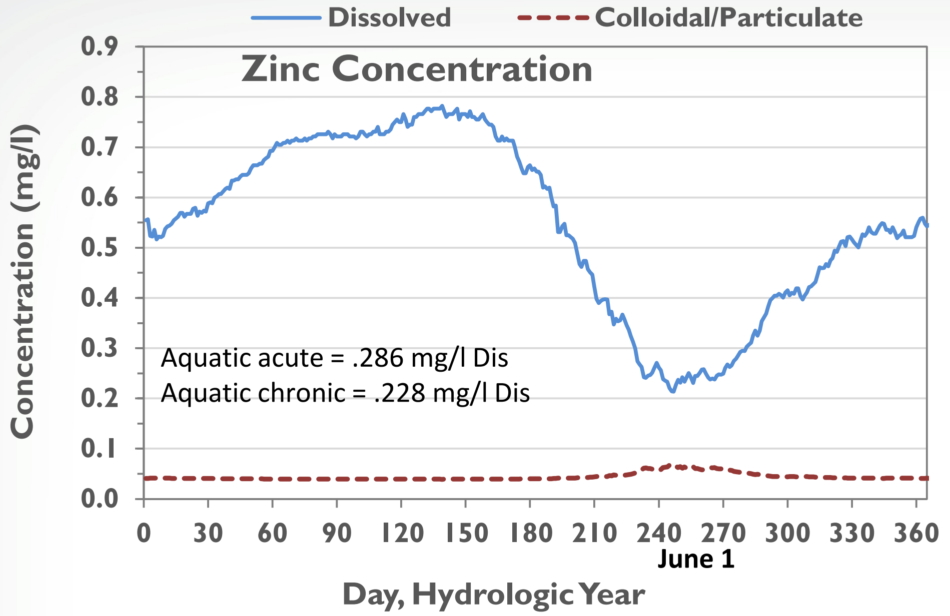


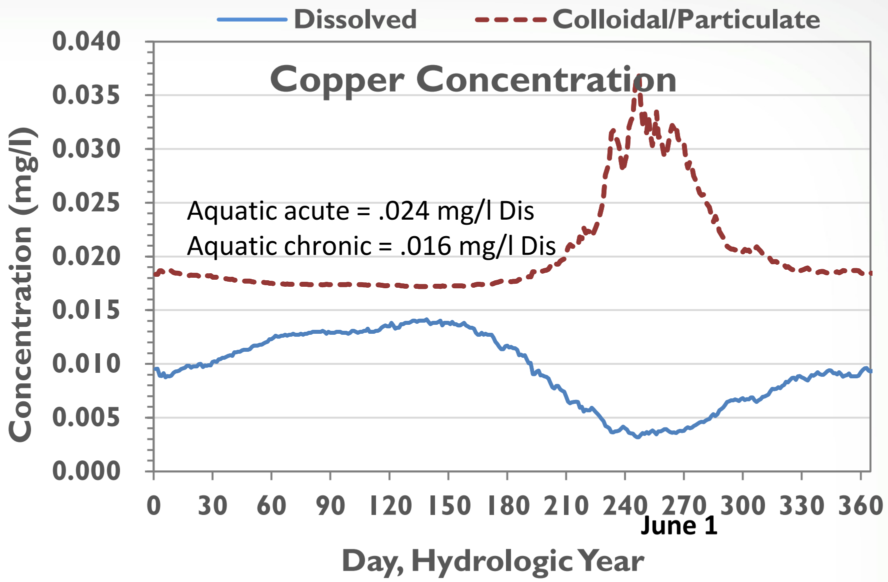


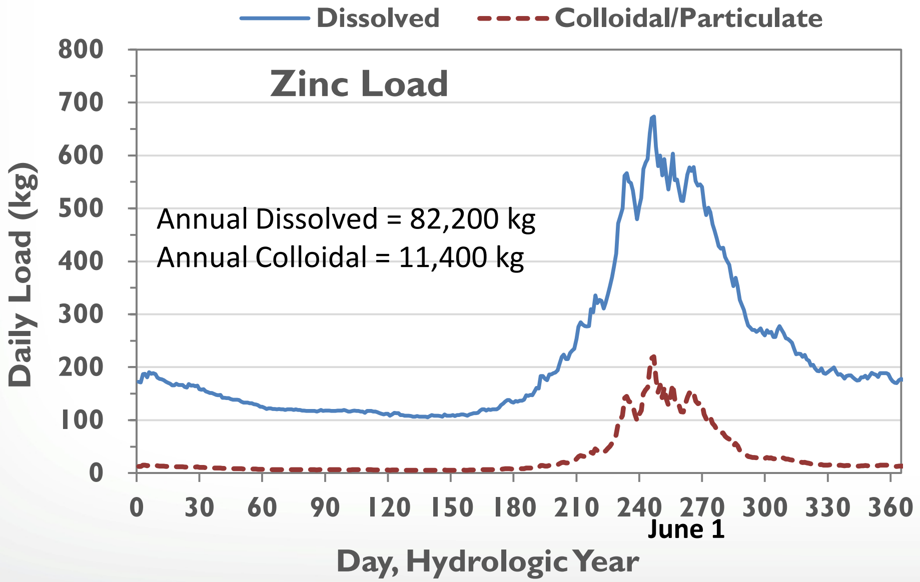


USGS data (Church et al. 1997 integrated into EPA 2009-2014 data

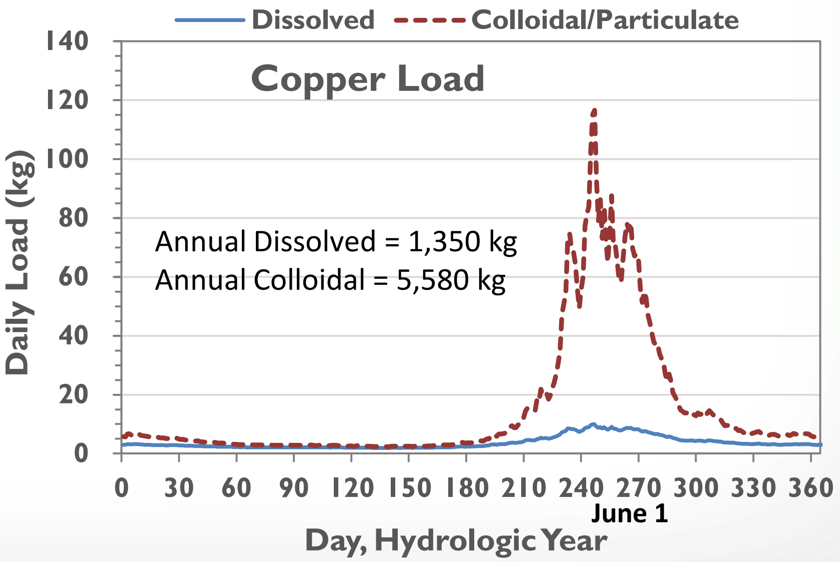
Expected Annual Metals Concentrations and Loads at Silverton





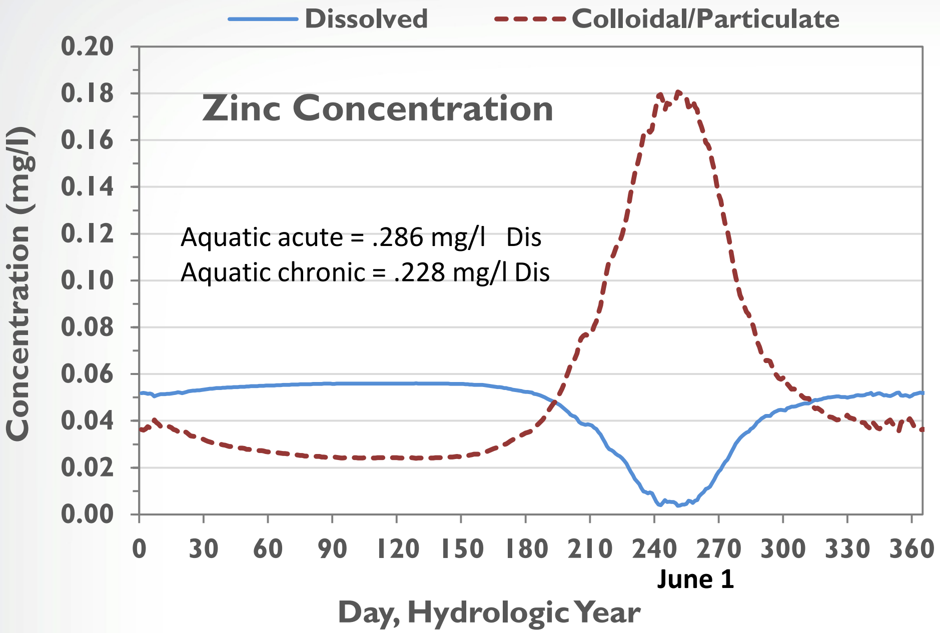


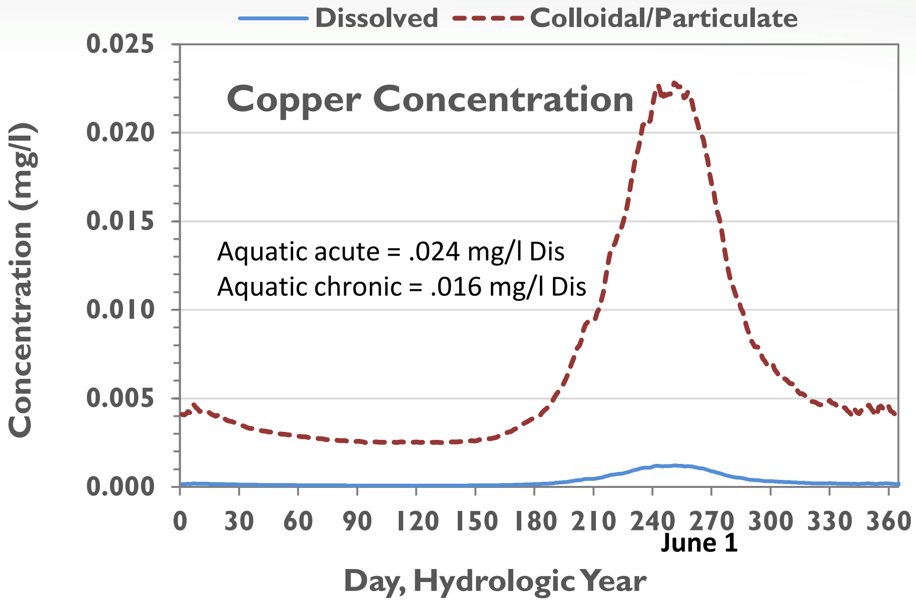
GKM = 1,630 kg 19% colloidal

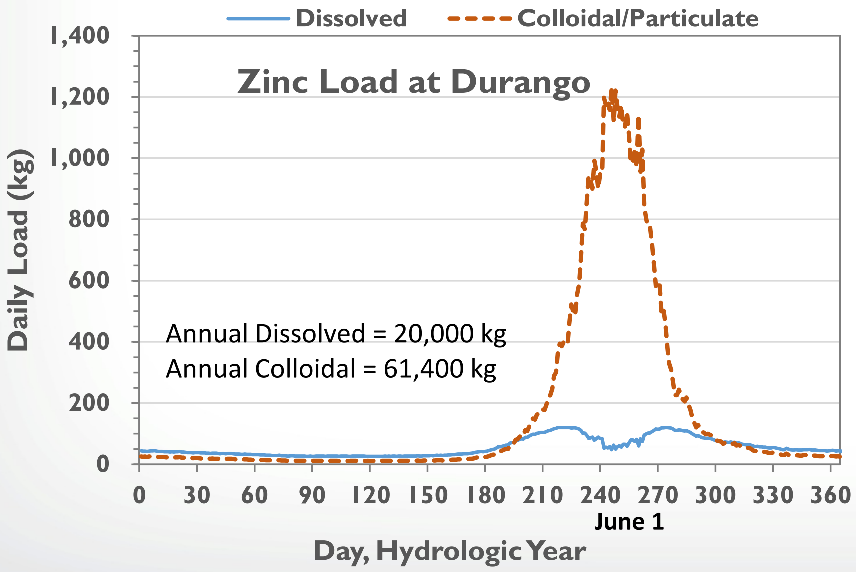


GKM = 1,150 kg 73% colloidal

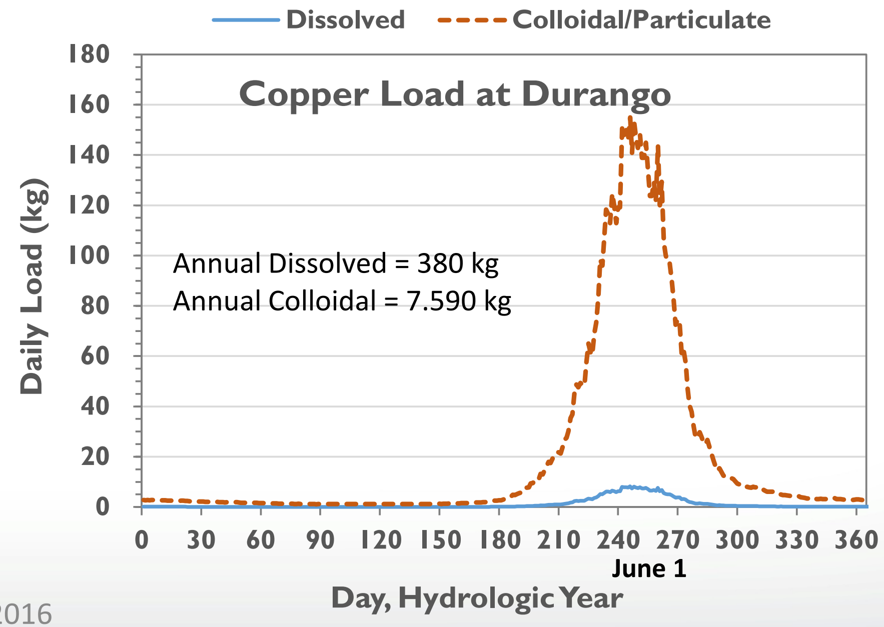
Expected Annual Metals Concentrations and Loads at Durango





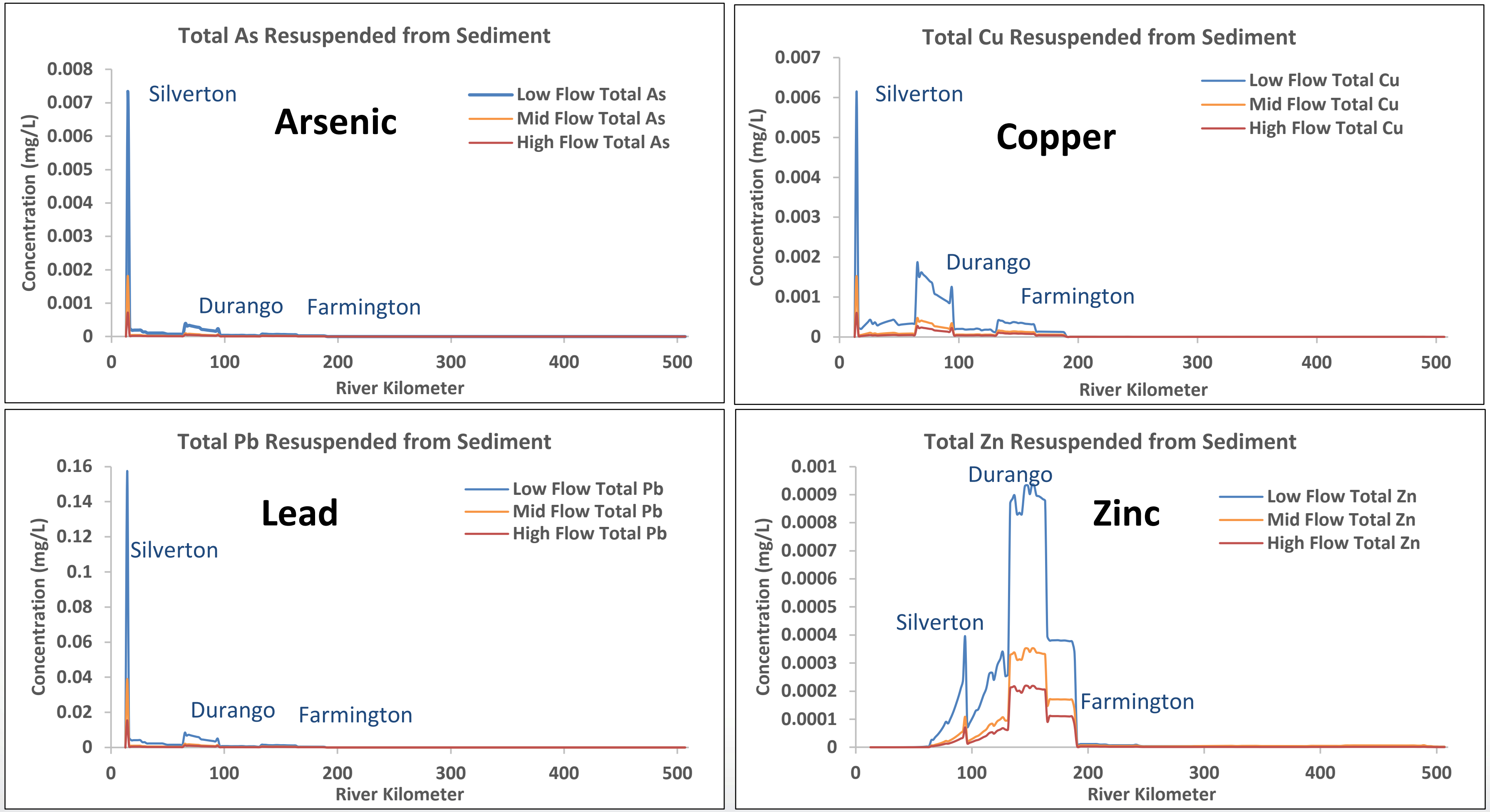


GKM = 626 kg 81% colloidal



GKM = 208 kg 96% colloidal

Resuspension Scenario



WASP simulation:

- All GKM deposited metals mixed at once into the water column
- 3 flow levels

Results:
Largest concentrations in Silverton

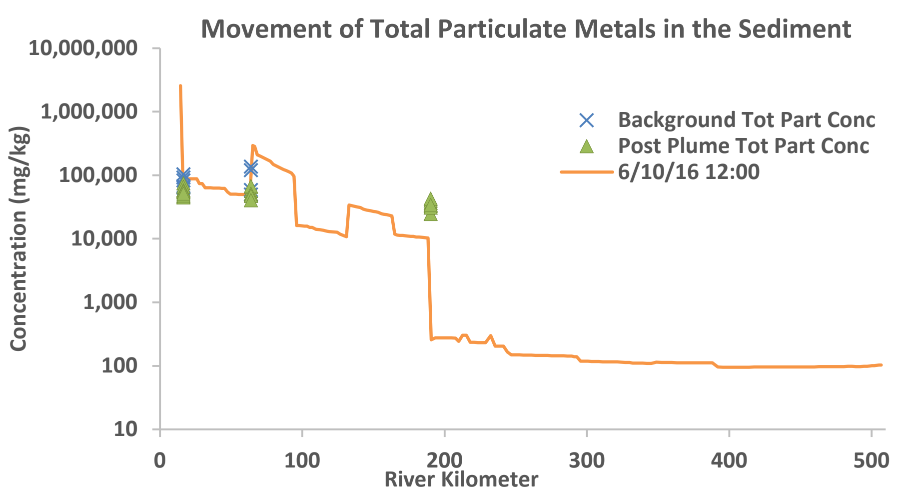
All concentrations < 1 mg/L

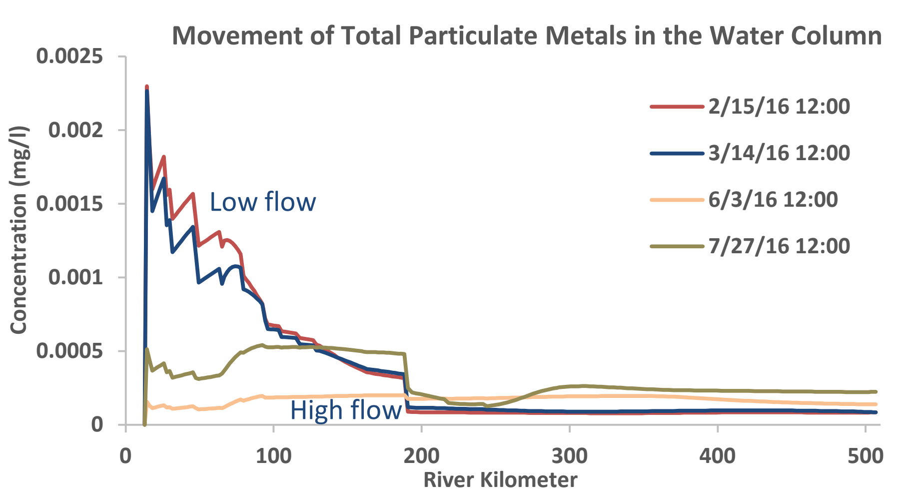
Concentrations lower at high flows

Very small changes in concentrations

Long-term Effects (Snowmelt Scenario)

- Using the developed metals concentrations in the sediments, we ran WASP using flow from 2011 to simulate 2016.
- Simulated low, middle, and high flows, including the snow melt period.
- Sediment concentrations changed negligibly over the length of the simulation
- Water column concentrations were highest during low flow periods and nearest the GKM.
- Highest concentrations during low flow period all < 3 µg/L
- Matches patterns with empirical analysis based on observed data

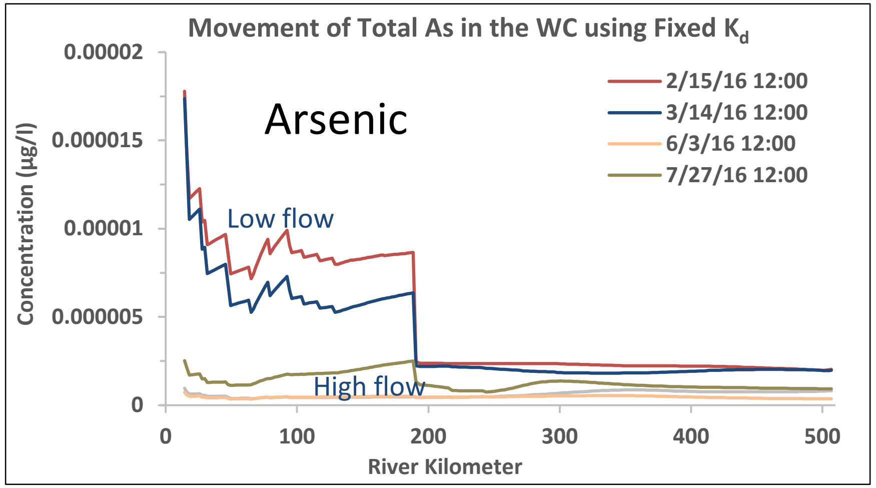


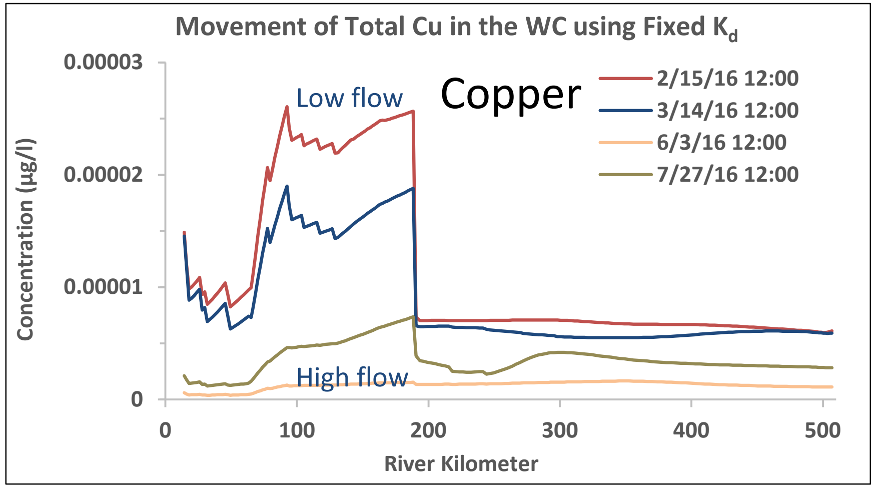


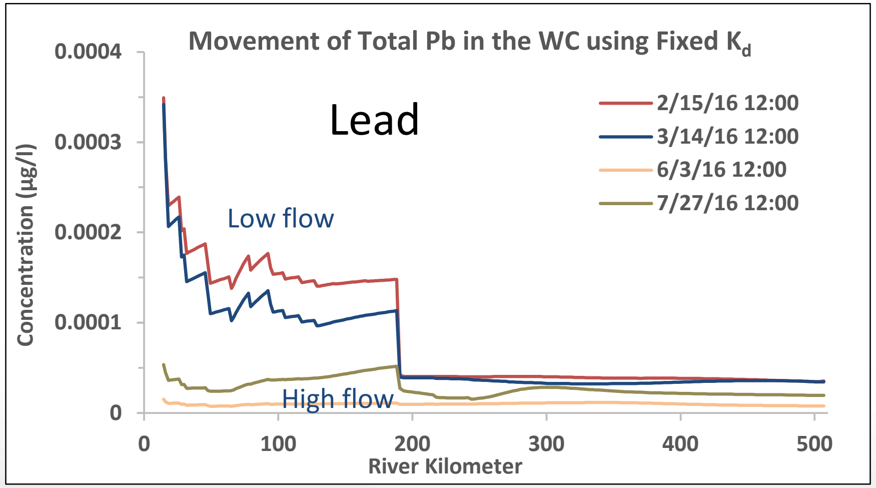
Simulated with 2011 flow data

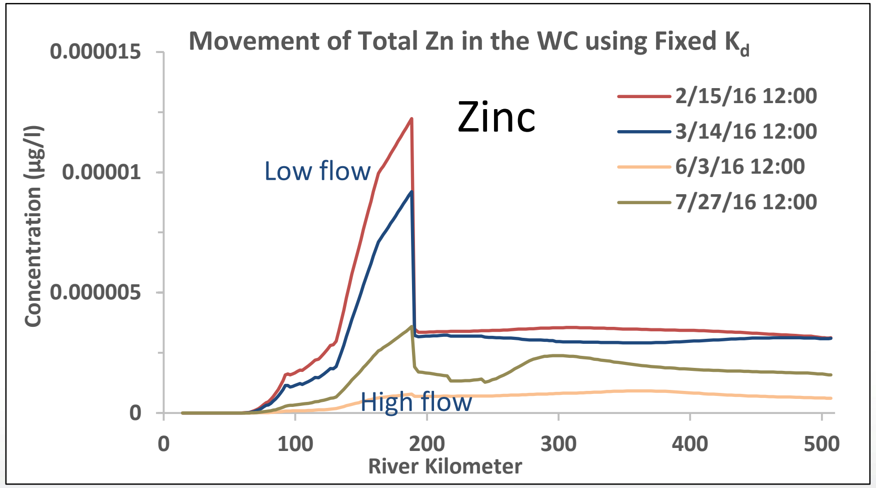
Long-term Effects by Metal

Simulated with 2011 flow data









Results:

Arsenic and Lead highest upstream

Copper highest at Durango

Zinc highest in the lower Animas

Concentrations of all metals were far smaller than .001 ug/l

Summary of Metals In Streambed

- GKM metals mass largely originated in Cement Creek between the mine opening and the Animas River and most deposited throughout the Animas River before joining the San Juan River at Farmington
- Metals mass settled differentially within the Animas River reflecting geomorphology and geochemical reactions
  - Heavier deposition in reaches below Silverton and downstream of Bakers Bridge (traditional areas of sediment deposition indicated by river braiding)
  - Also general deposition along entire course of river declining in downstream direction
  - High pH sorbing metals (zinc) settled farther downstream than low pH sorbing metals (arsenic, lead, copper)
- Pre-existing concentrations of metals in the streambed due to ongoing AMD contamination from headwater mines follow the same pattern observed in the GKM plume
- Despite the large mass of GKM metals deposited, concentrations of metals in the streambed in the months after the release were within the variability of pre-event samples taken at Silverton, Baker's Bridge, and Farmington. This was due to the large pre-existing metal reservoir in stream sediments from ongoing AMD in the Animas headwaters
- The San Juan River received a relatively small mass of GKM metals compared to what was already in transport sorbed to suspended sediments in the San Juan. However, total lead and selenium from the plume was measurably higher.
- Post-event data did not indicate that the GKM plume affected concentrations of metals in the bed of the San Juan River

Summary of Post Event Water Quality

- Metal concentrations in the water declined toward background conditions quickly after the plume passed
- In the 3-month period after the release, there were changes in metal concentrations compared to pre-event conditions
  - Many statistically significant
  - Some metals increased, some decreased, and patterns varied between Silverton, Durango, and Farmington
  - Aluminum and Iron most involved
  - Concentrations remained below water quality criteria
- Could be due to changes in water chemistry, dissolution of precipitates, other?
- USGS studies in the 1990's showed higher metal loads during spring snowmelt
- This study refines that analysis showing annual patterns of metals in relation to streamflow
  - Highest dissolved concentrations during low flow
  - Higher colloidal/particulate concentrations with higher flows
  - Snowmelt carries most of annual load but has relatively low metal concentrations
  - Monitoring should provide additional data to refine relationships between metals and flow to improve loading estimates