WQ in the San Juan River Basin

A Synthesis of WIIN monitoring, projects, and other background information

Session 1: The relationship between water, sediment and metals

Purpose of San Juan Watershed Program Webinar Series

- Meet the objectives of the WIIN Act
  - Conduct collaborative water quality and sediment monitoring
  - Communicate information about the condition of the watershed to the public through a Clean Water Act lens

This Webinar Series does not address:

- The Superfund process for the Bonita Peak Mining District NPL Site, including but not limited to any potential response actions, additional investigations, scoping of contamination, or delineations of the Site
- Clean Water Act Sections 303(d) and 305(b) water quality assessment decisions
- Recommendations to states and tribes regarding water quality standards

Watershed-wide Monitoring Study Questions

- **Throughout the watershed, what is the extent of waters supporting state and tribal designated uses for aquatic life, fish consumption, agriculture, recreation, and drinking water (e.g., current condition)?**
- **How does the quality of water and sediment change over time, relative to metals loading?**
- **How does the quality of water and sediment vary as a function of hydrologic regimes?**
- **Can we use the monitoring and assessment data to predict and/or anticipate impacts to human and aquatic health, particularly with respect to agricultural crop and livestock watering safety?**
    - Can we identify and quantify metals contributions from different anthropogenic and natural sources and furthermore, what are the transport processes and the ultimate fate of metals?
- **Are buried metals-bearing sediments bioavailable to the overlying water column, benthic macroinvertebrate, and fish and how do environmentally changing conditions in pH, temperature, and dissolved oxygen affect bioavailability?**

WINN Program has sponsored projects to learn more about:

- ❖ Status of water quality conditions
- ❖ Where materials originate
- ❖ Where materials end up
- ❖ Defining risk
- ❖ Predicting where or when adverse levels occur

Central Themes of This Session

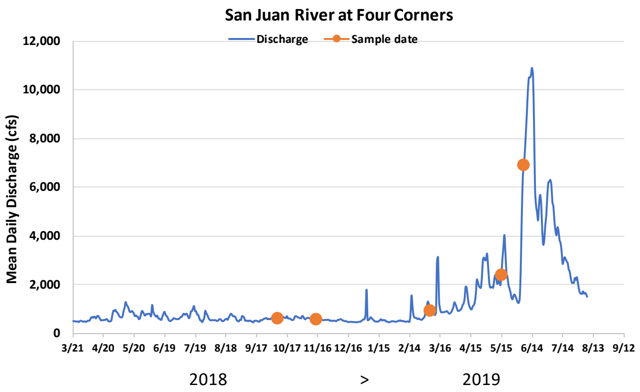
- Do metal concentrations vary with flow?
- Do metal concentrations vary with suspended sediment?
- Are there spatial trends in metals concentrations?
- Are there temporal trends in water quality conditions?
- Can metals concentrations be predicted?
- Can we identify and quantify metals contributions from different anthropogenic and natural sources?

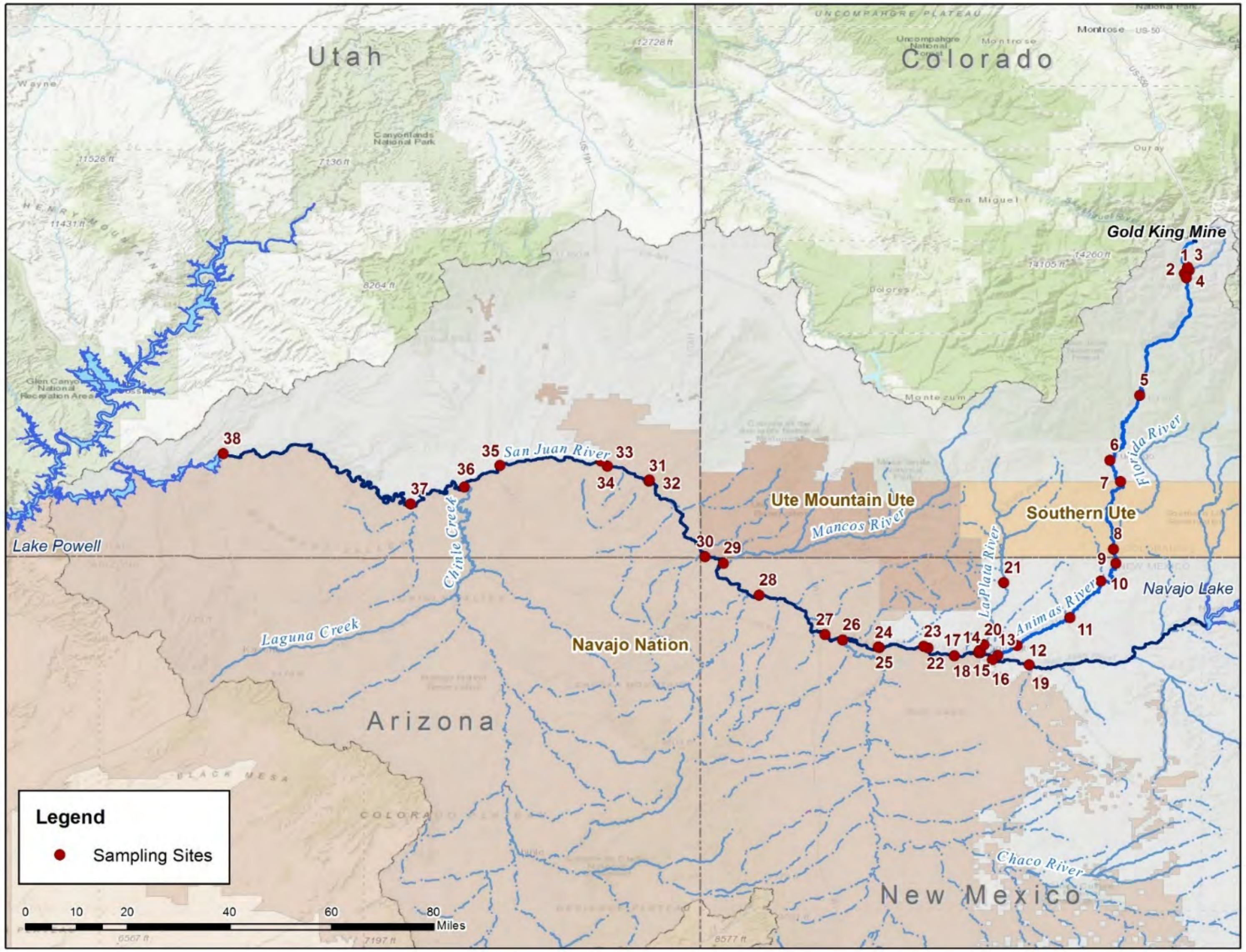
Primary Sources of Information

- DATA (Water, Metals, Sediment)
  - WINN monitoring
  - USGS monitoring gages (historic more than modern)
  - Previous water quality monitoring (extensive, but I will make limited use of)
- Reports/Projects
  - University of Utah Lake Powell and Source ID (Frederick *et al.*) -- "Utah group"
  - USGS Regression work predicting metals from sondes –"USGS regressions"
  - Church 1997 report on metals in sediments as part of USGS Prof Report 1651
- Also useful but not for today's topics:
  - NM groundwater studies on the Lower Animas
  - NM studies of agricultural fields and plant uptake

Water Quality Monitoring Data

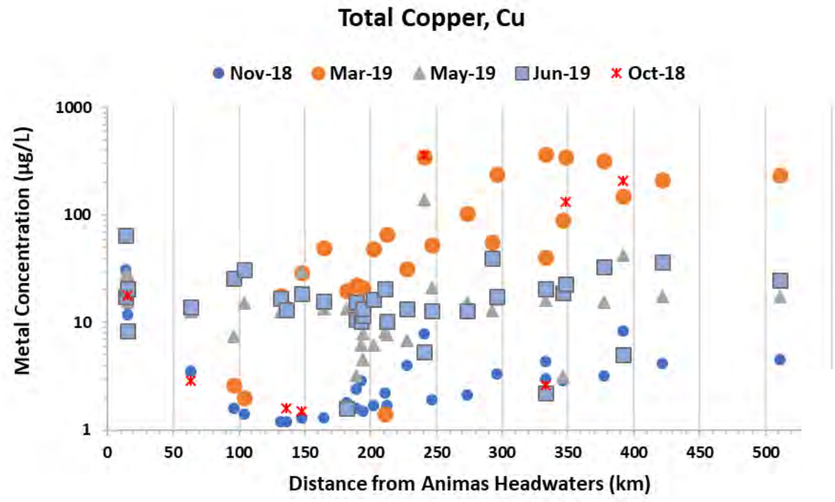
- WIIN funded San Juan Watershed Monitoring 2018-2019
- 39 sampling locations
- 5 sampling campaigns
    - Fall 2018 through Snowmelt 2019
    - Sampled a variety of flow conditions
- 329 individual samples
    - Metals
    - Nutrients
    - Physical parameters incl. sediment



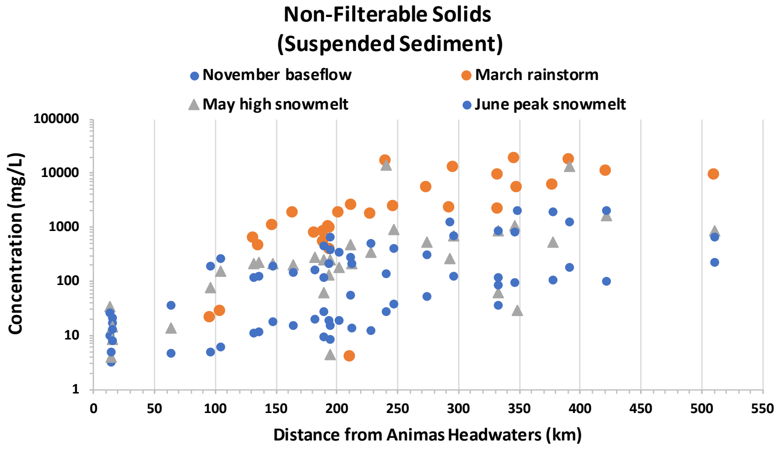


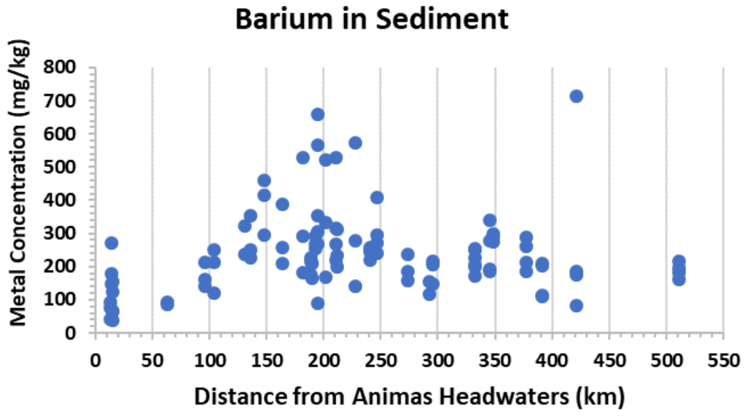
WINN Monitoring Data

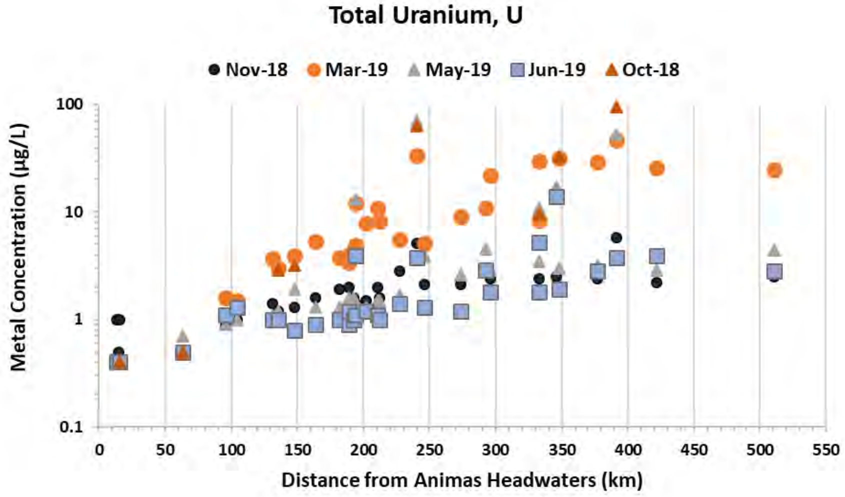
- 5 sampling dates
  - Baseflow (Nov 2018)
  - Storm event (Mar 2019)
  - Mid Snowmelt (May 2019)
  - Peak snowmelt (June 2019)
  - Mixed (Oct 2018)



All the metals + Uranium and Strontium

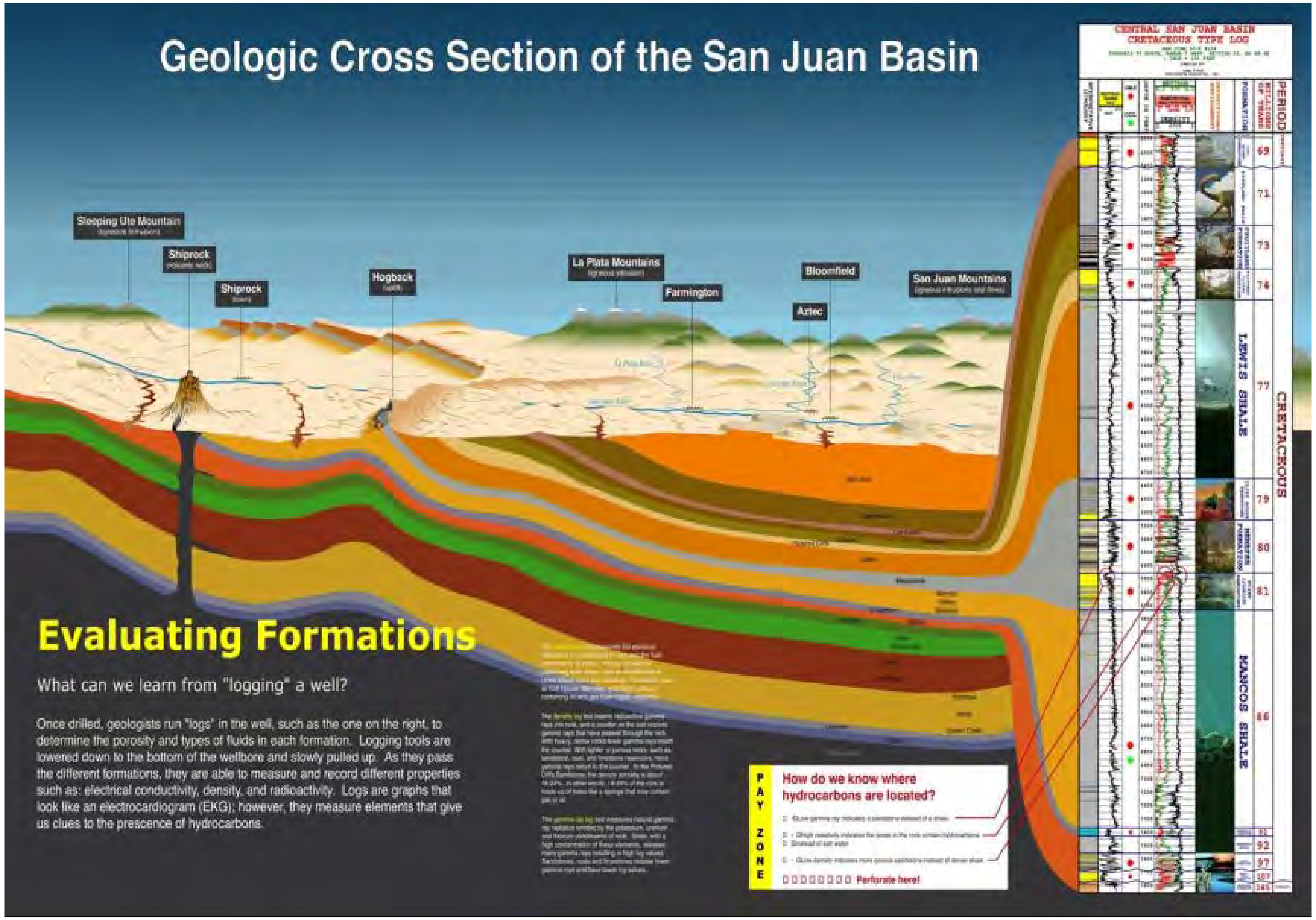






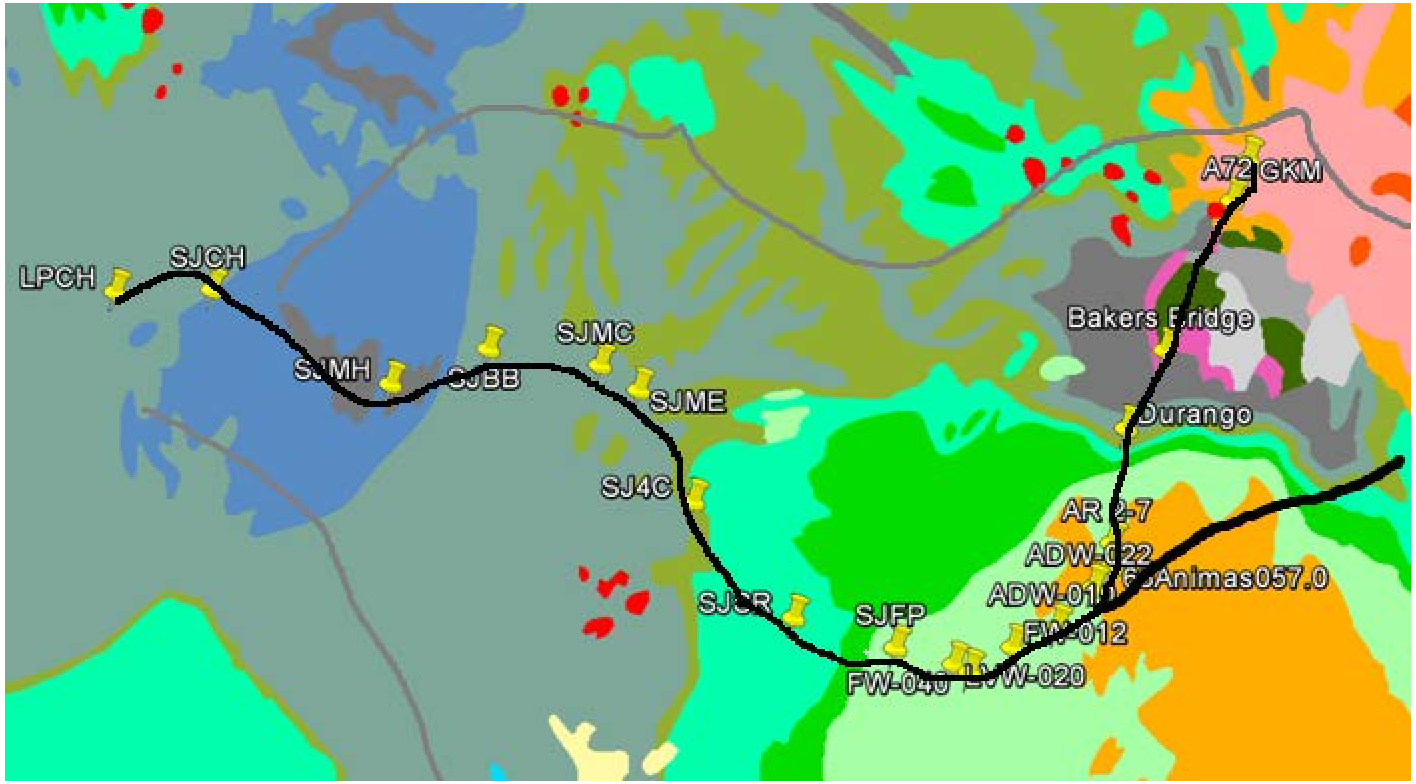
Physical parameters:

- **Nutrients**
- **DOC**
- **Sediment**
- **Others**



Geology Controls the Availability of Sediments and Metals

A general surficial geology map of much of the San Juan Basin



Dull orange and red = Volcanic intrusives: high in some metals

Dull pink = Felsic Volcanic intrusives: high in some metals

Bright greens = Various aged finer grained sedimentary shales

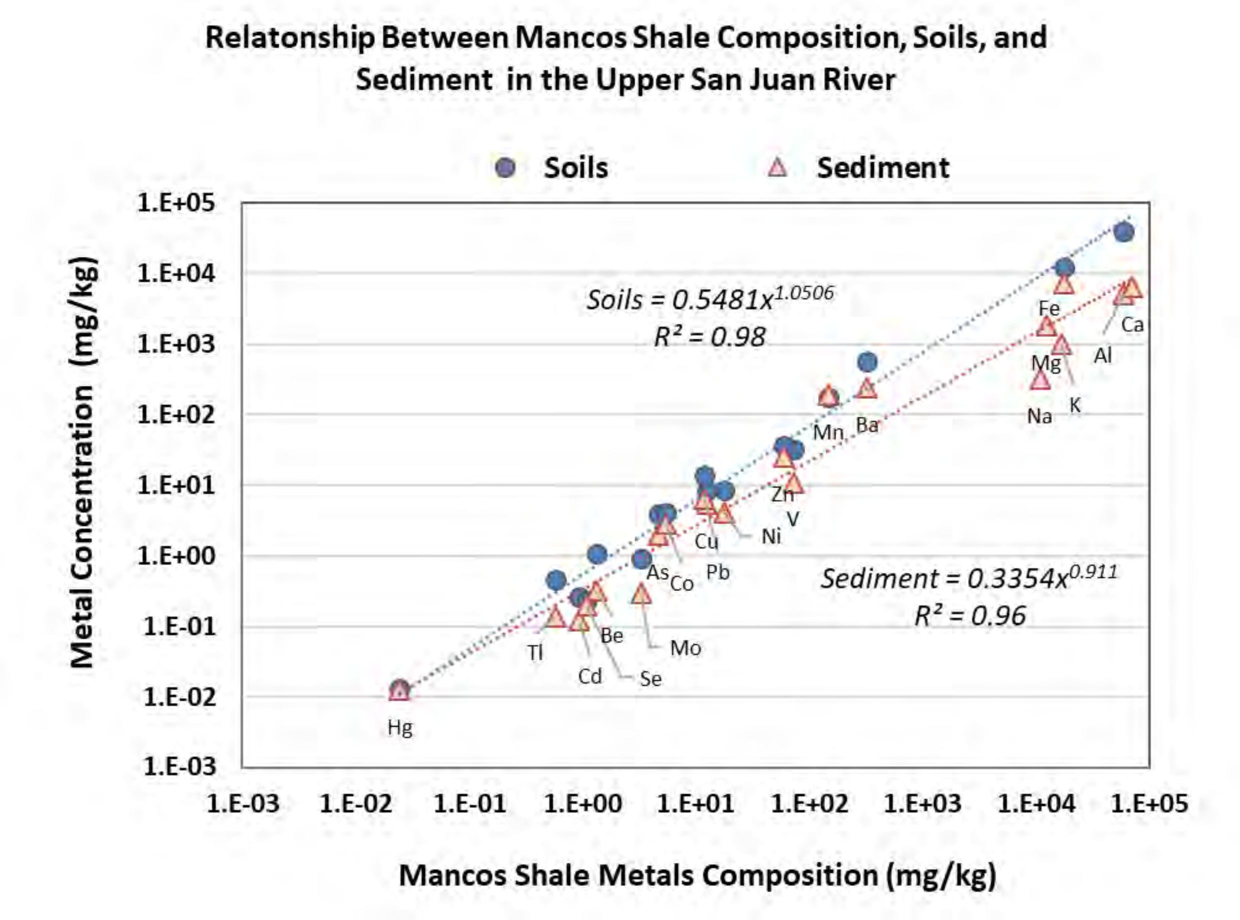
Dark gray and blue = Various aged mostly sandstones

Each of these geologic groups has a characteristic lithology:

- particle characteristics
- mineralogy and metals content

Volcanic intrusives in the northern tributaries: very high in some metals

Sedimentary rocks of all types in the rest of the basin: relatively low in the same metals

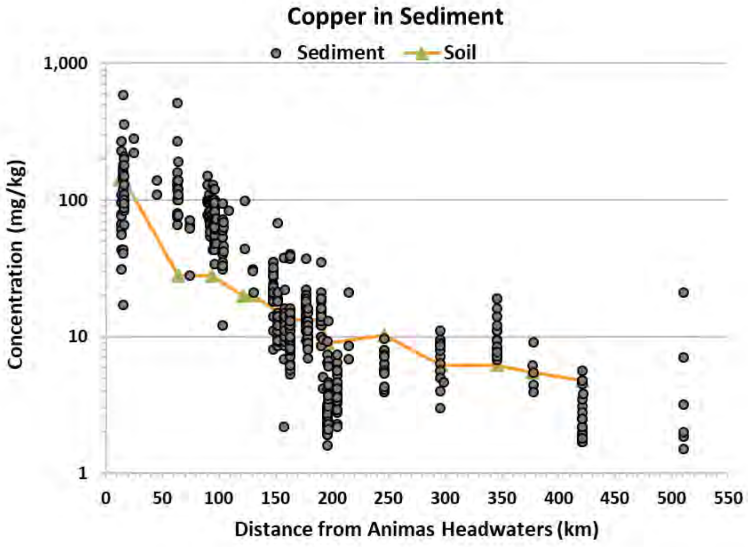


Metals Content of the Mancos Shale

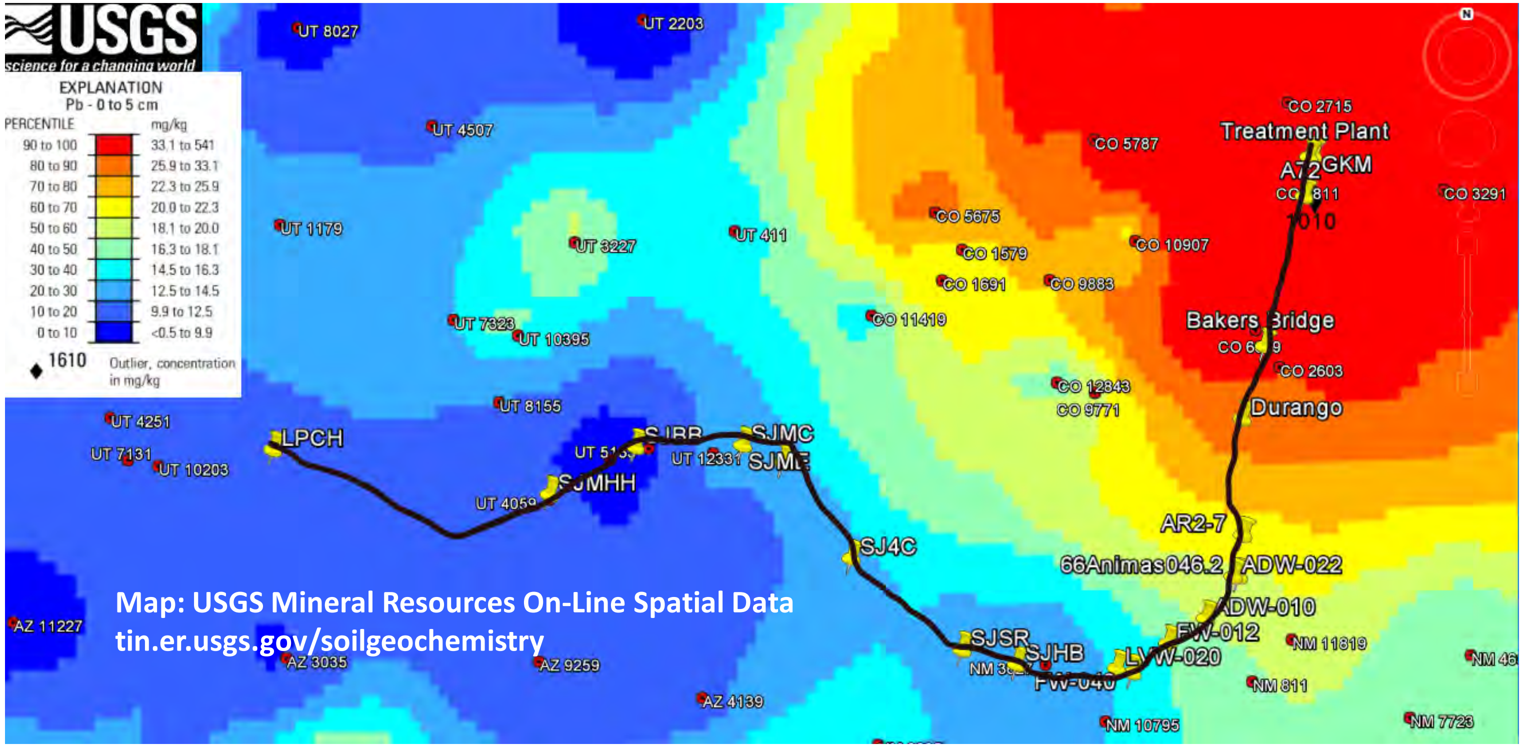
- **The Mancos shale is relatively richer in Barium, Manganese, Zinc for example**
- **The soils and sediment in the river mirror the geologic substrate**

The river mixes metals the sediments and water at a more general scale that is reflected in USGS soils metals "heat" maps

- **Metals in sediment and water tend to mirror this map**
- **It is a good starting point for expectations of what to expect in water quality monitoring**



USGS Soil Chemistry Map--**Lead**



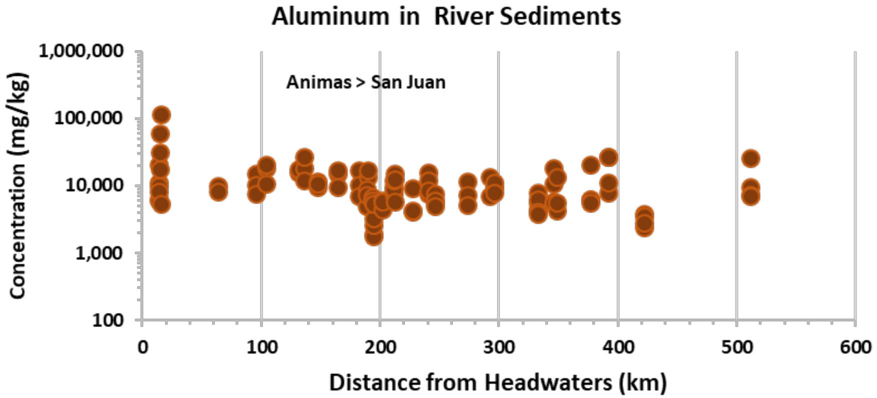
The Enrichment Ratio (ER)—
a very useful and easy to obtain a geologic tracer

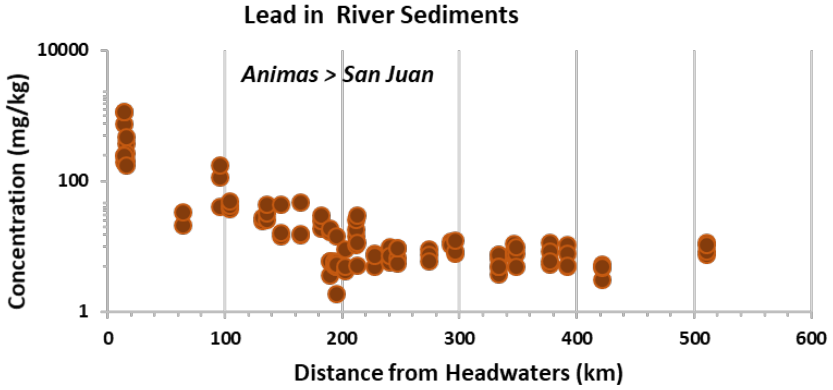
- The characteristic metals composition of the geologic types may assist “tracing” them within the basin or identifying exogenous sources
- Aluminum and iron make up a significant portion of most rocks
- Trace metals can be expressed relative to one of these dominant elements

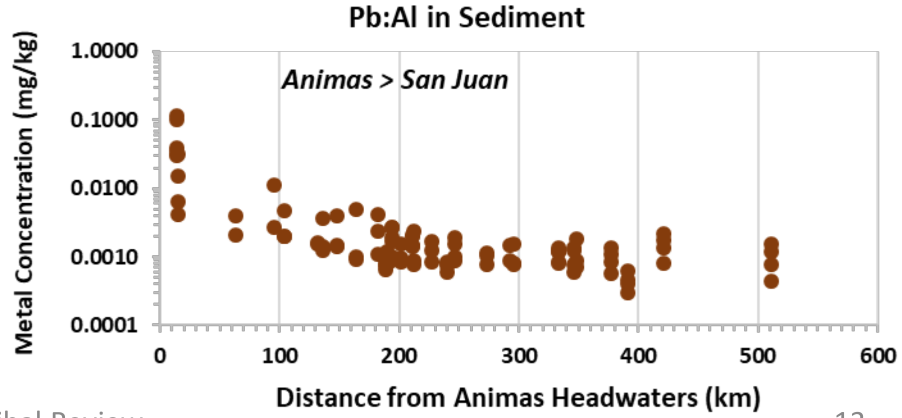
$$\textbf{\textit{Enrichment Ratio}} = \frac{[\textbf{\textit{Trace Metal}}]}{[\,\textbf{\textit{Aluminum}}]}$$

- If the trace metal is present in significantly greater proportion than commonly present in the geology in that area, there must be an additional source

E.g. higher than expected enrichment ratio

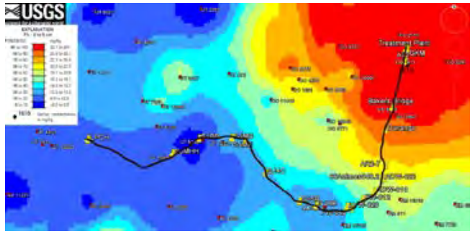


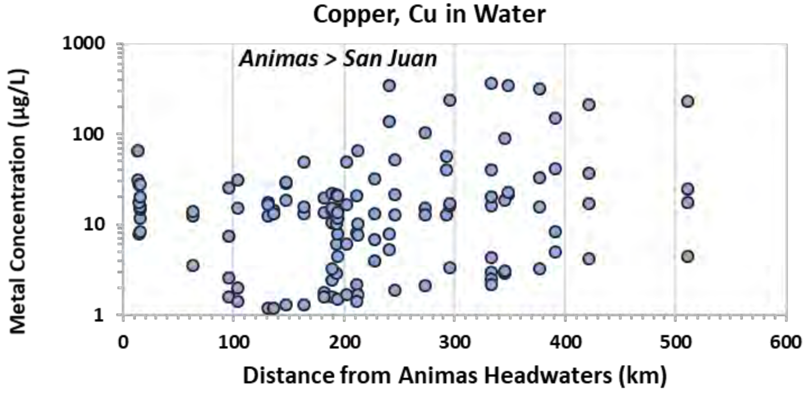


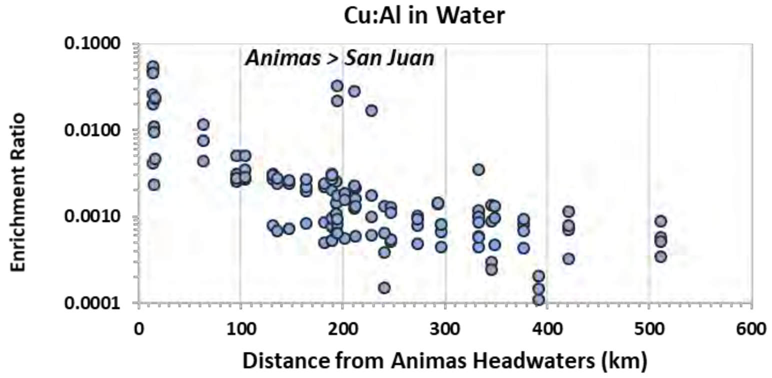


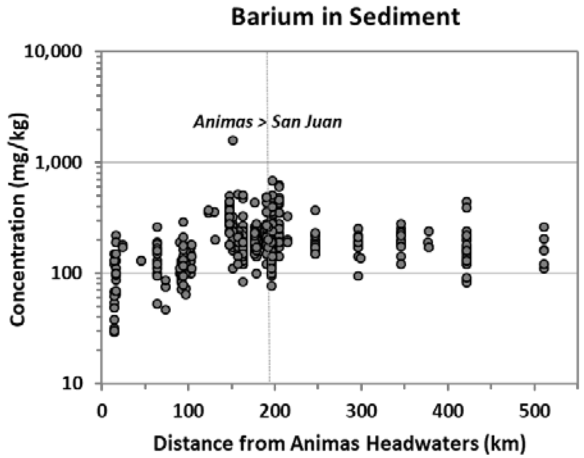
Enrichment Ratio

- **The content of some metals is very high in the headwater volcanic intrusives compared to the sedimentary rocks found in the rest of the watershed (e.g. copper)**
- **Water with high metals content leaves the headwaters with a high enrichment ratio**
- **The river gains flow and mixes with lower metals content waters**
- **Dilution reduces metal concentration and lowers enrichment ratio from signature in headwaters**









Not all metals are high in the volcanic intrusive rocks (e.g. Barium)

In this watershed, the most useful geologic distinction for characterizing metals:

- Volcanic intrusives
  - Northern tributaries
  - Animas, Mancos, LaPlata, McElmo
- Sedimentary
  - Southern and western tributaries
  - Chaco, Chinle, Montezuma, all the rest

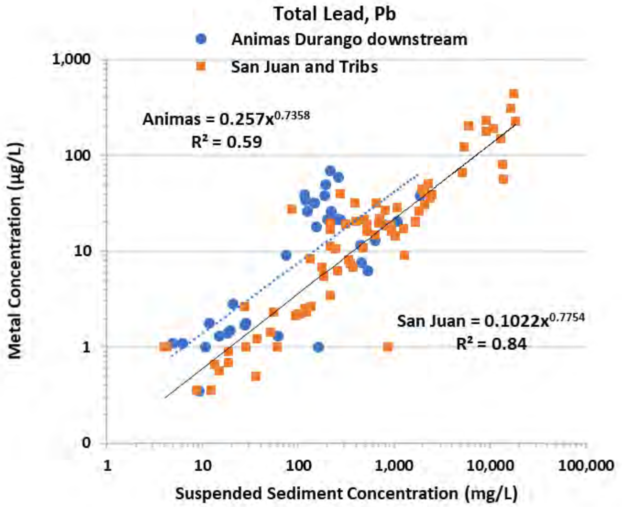
Animas at peak snowmelt

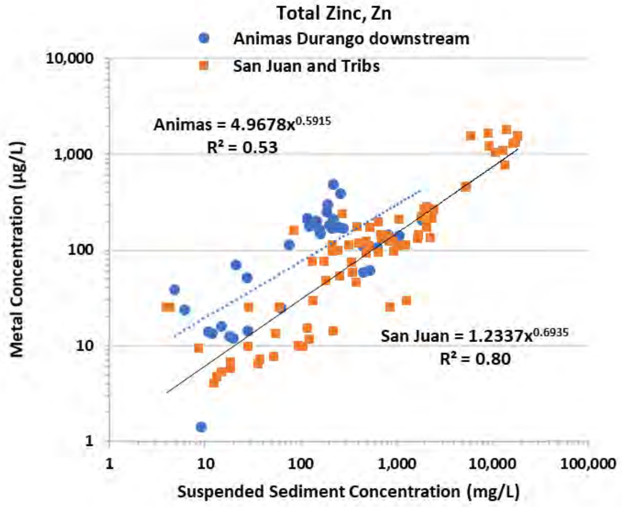
San Juan during high flow

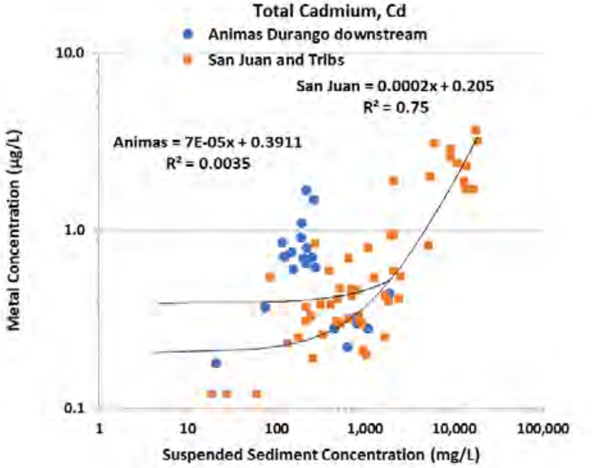
Metals in Relation to Sediment

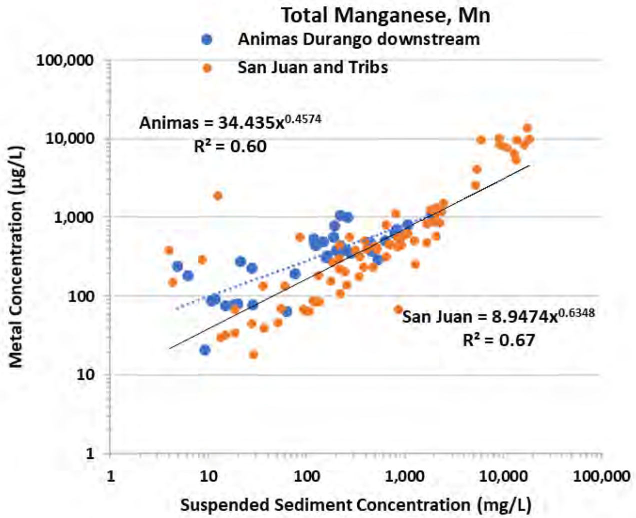
Relationship of Total Metals Concentrations to Sediment

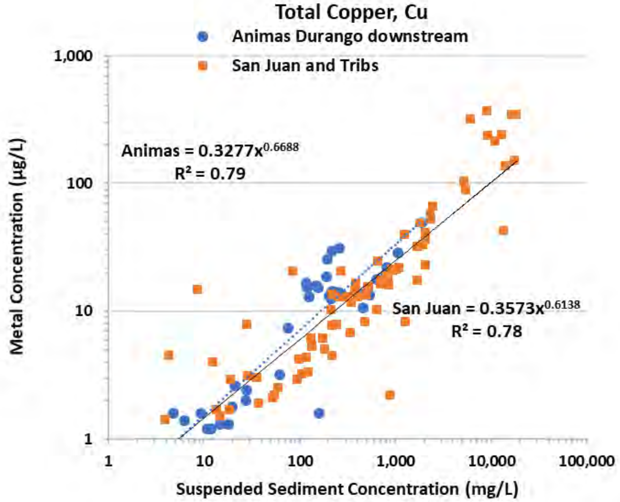
Highly Correlated To Sediment—Different Between lower Animas and San Juan









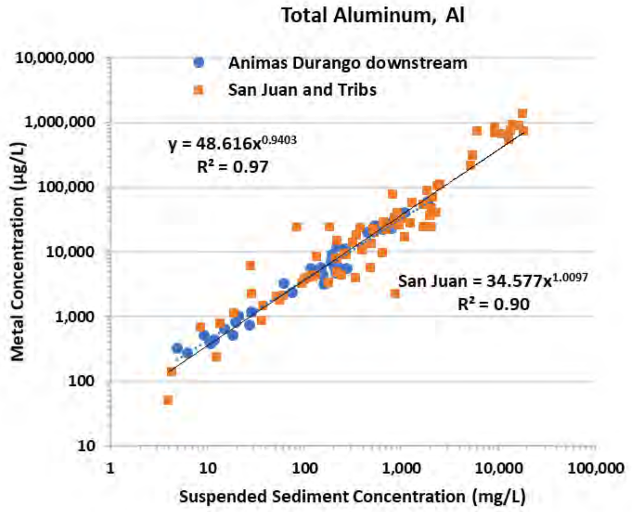


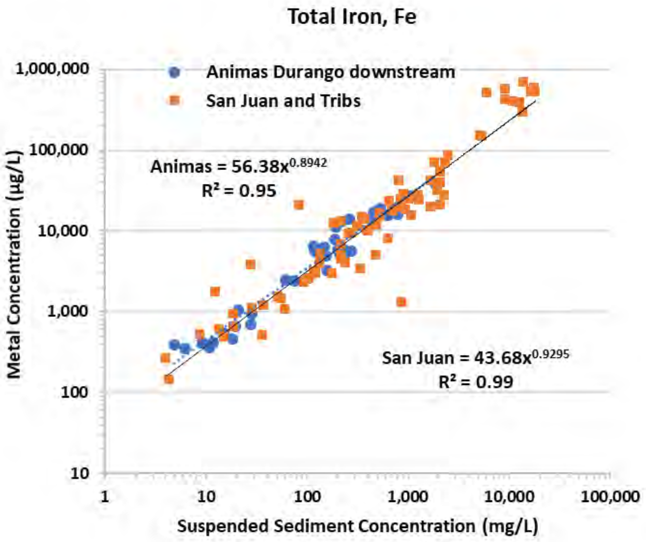
--Upper Animas volcanic intrusives transporting to lower reaches

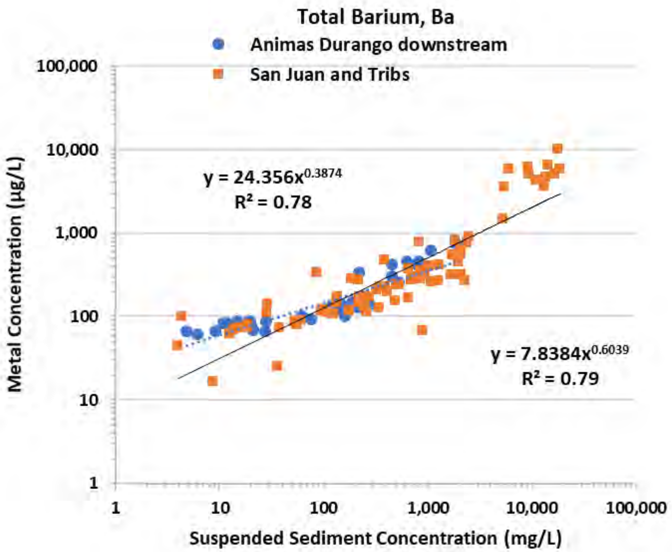
- **Lead, Pb**
- **Zinc, Zn**
- **Manganese, Mn**
- **Copper, Cu (much less so)**
- **Cadmium, Cd (much more so)**

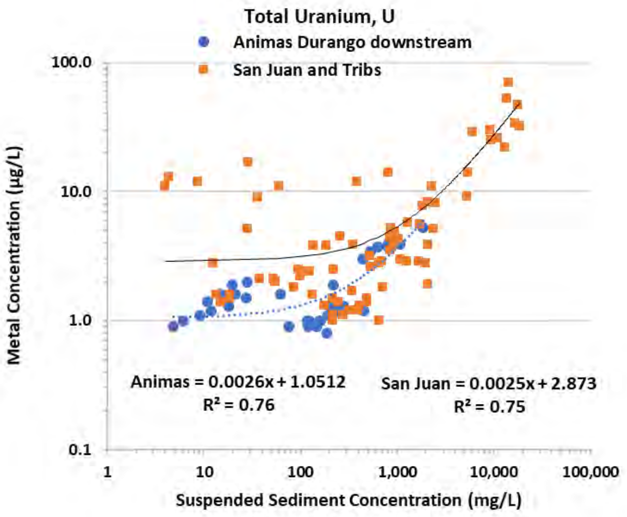
Relationship of Total Metals Concentrations to Sediment

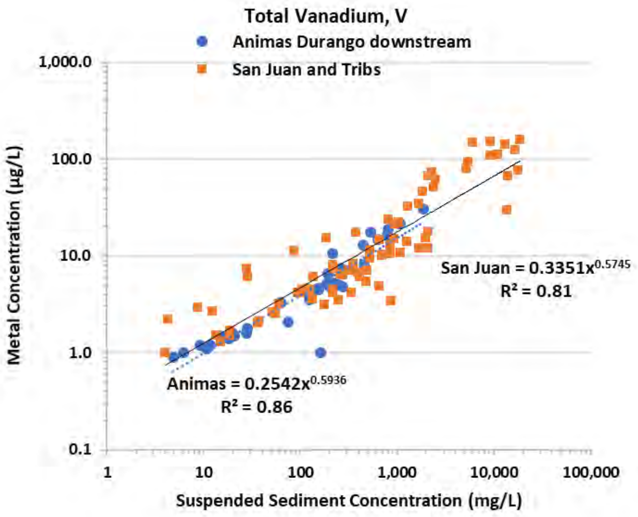
Highly Correlated to Sediment—No Difference between lower Animas and San Juan

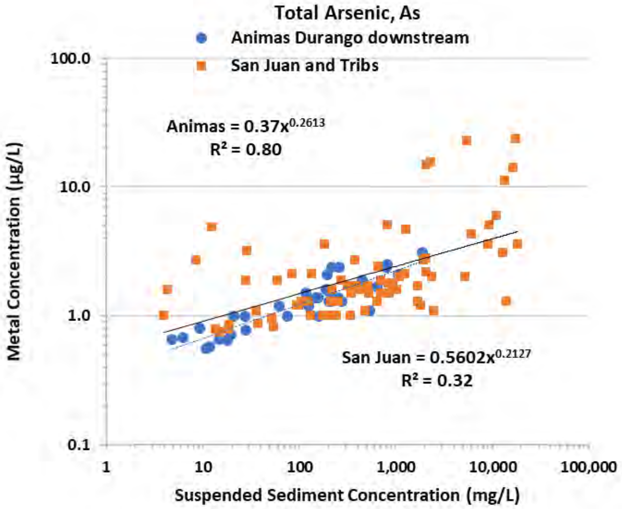






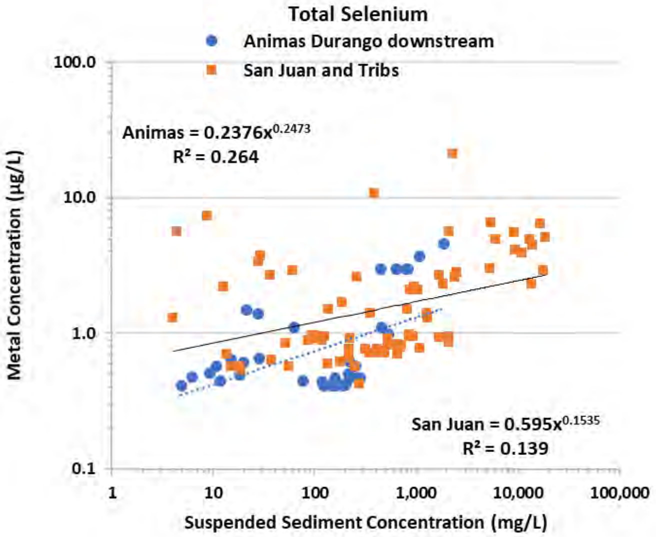


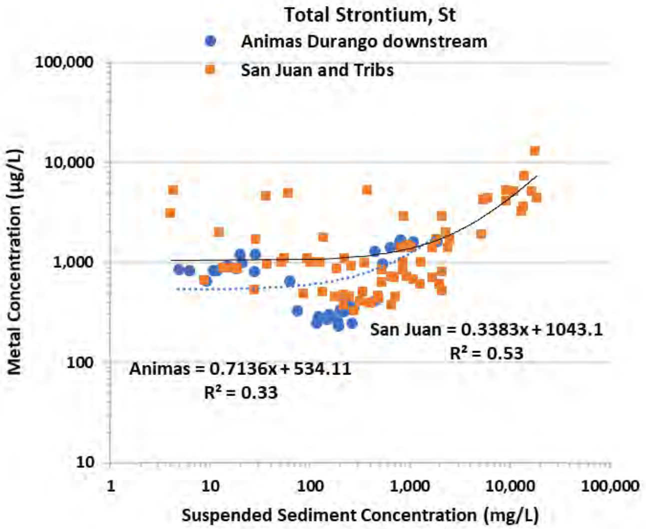




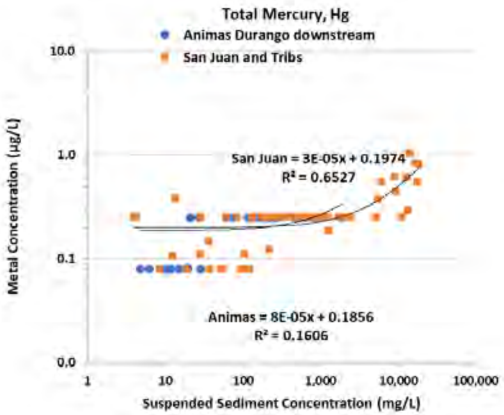
Relationship of Total Metals Concentrations to Sediment

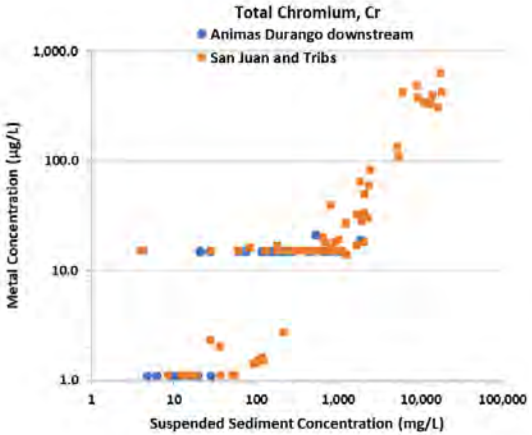
Weakly correlated to sediment—

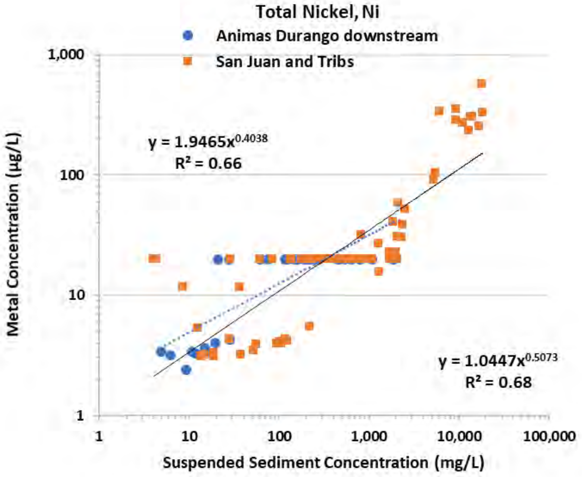




. . . or interpretation hampered by detection limits







Within the San Juan Basin, Total Metals in Water

--Virtually all metals concentrations in water are influenced strongly by the amount of sediment in the water
--Some are significantly enriched within the ore-rich geology of the headwaters of the northern tributaries and can influence downstream waters

These metals are related to sediment only and NOT enriched by ore-rich headwaters

- **Aluminum, Al**
- **Iron, Fe**
- **Arsenic, As**
- **Barium, Ba**
- **Vanadium, V**
- **Selenium, Se**
- **Uranium, U**
- **Strontium, Sr**

These metals are influenced by ore-rich headwaters as well as sediment

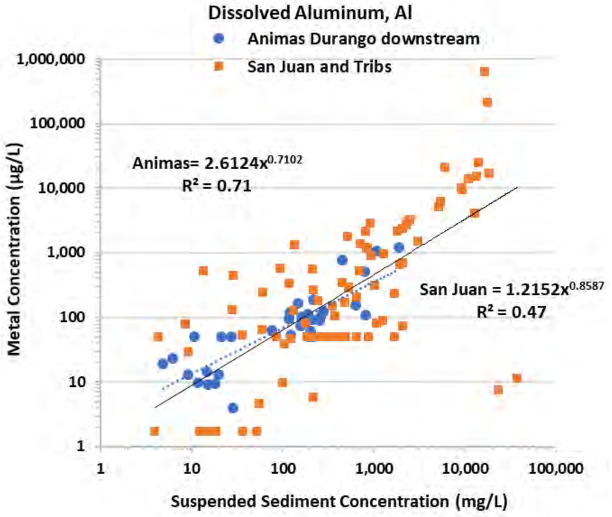
- **Copper, Cu**
- **Lead, Pb**
- **Manganese, Mn**
- **Cadmium, Cd**
- **Zinc, Zn**

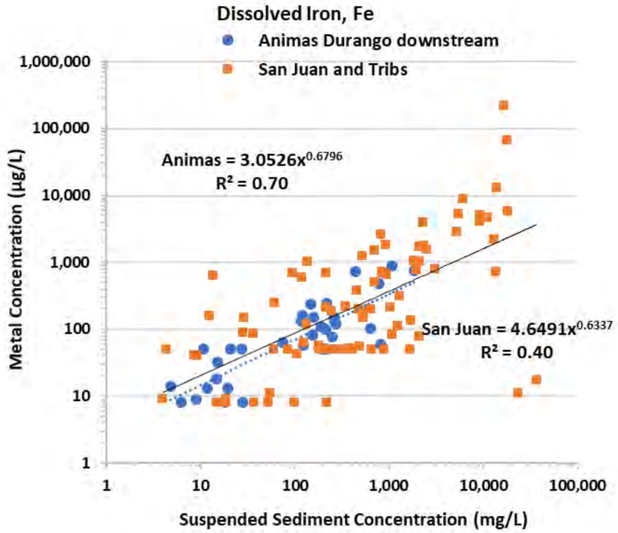
Not enough information to know

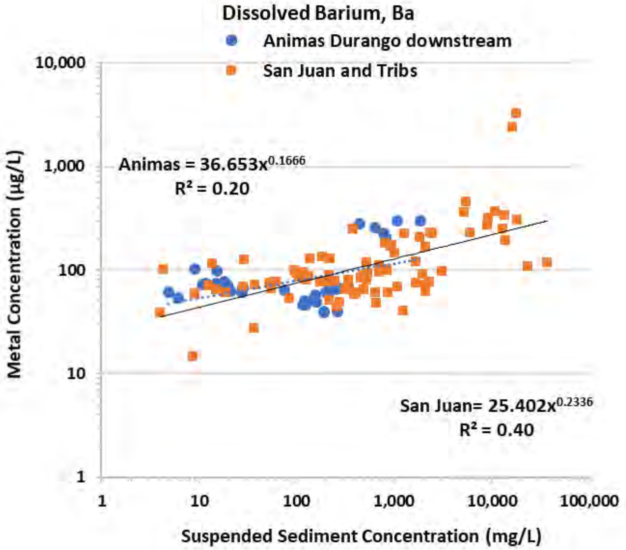
- **Beryllium, Be**
- **Cobalt, Co**
- **Mercury, Hg**
- **Silver, Ag**
- **Molybdenum, Mo**
- **Nickel, Ni**

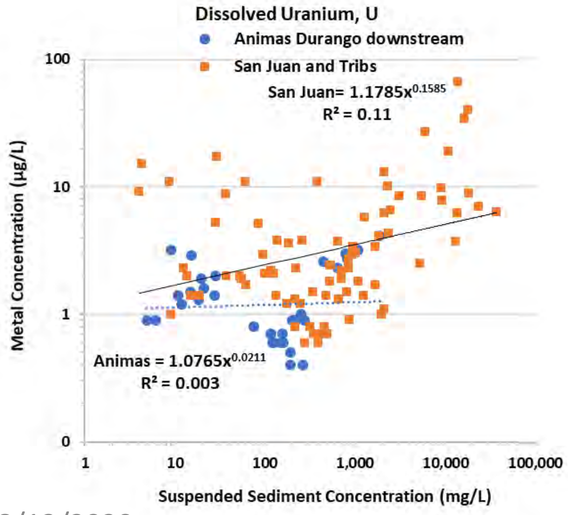
Relationship of Dissolved Metals Concentrations to Sediment

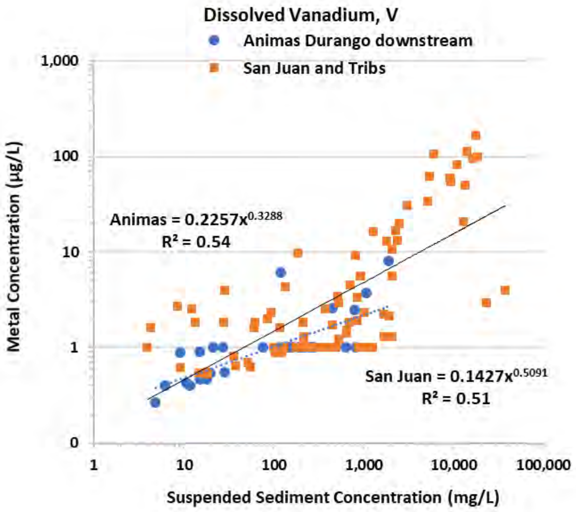
Dissolved metals are also related to sediment, but with much wider variability

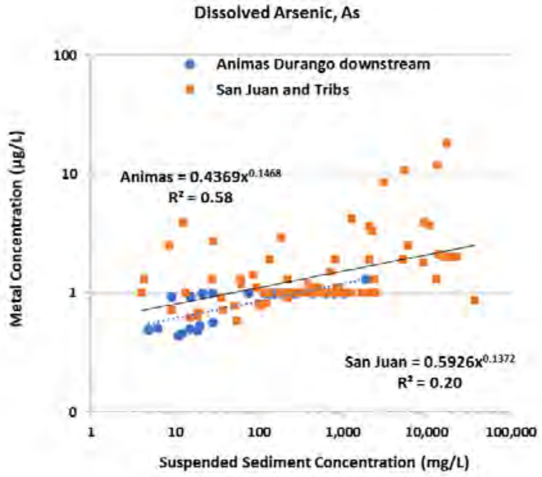






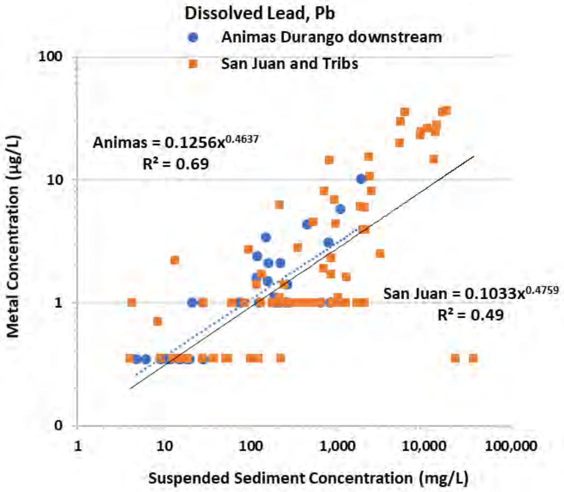


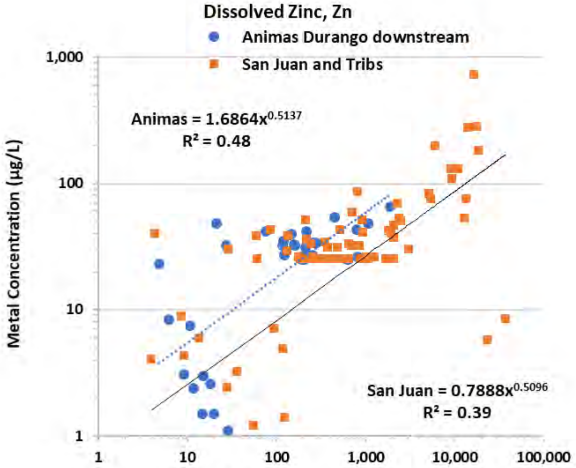


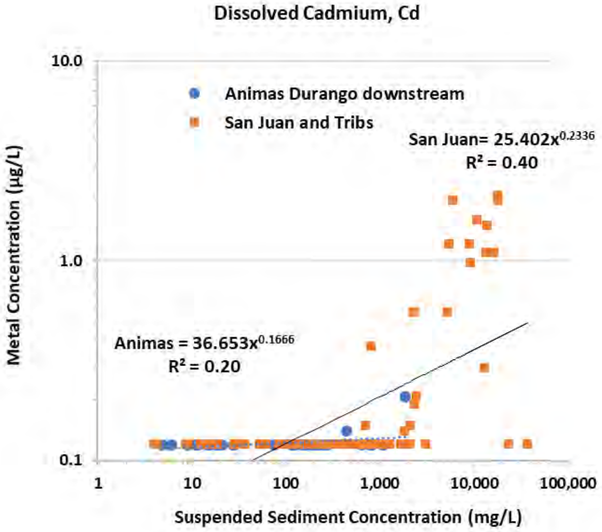


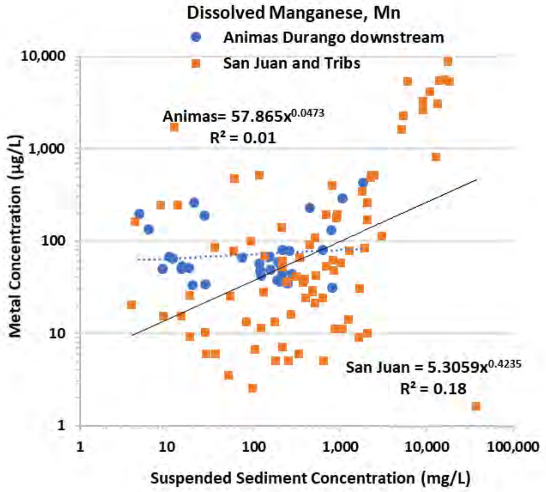
Relationship of Dissolved Metals Concentrations to Sediment

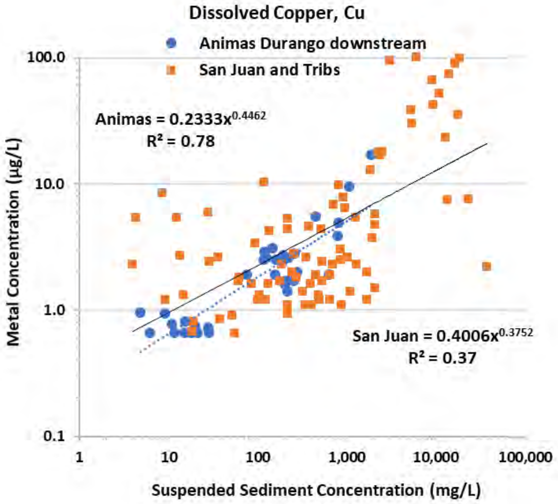
Total metals of this group were notably higher from ore-rich locations—dissolved metals do not show the same distinction





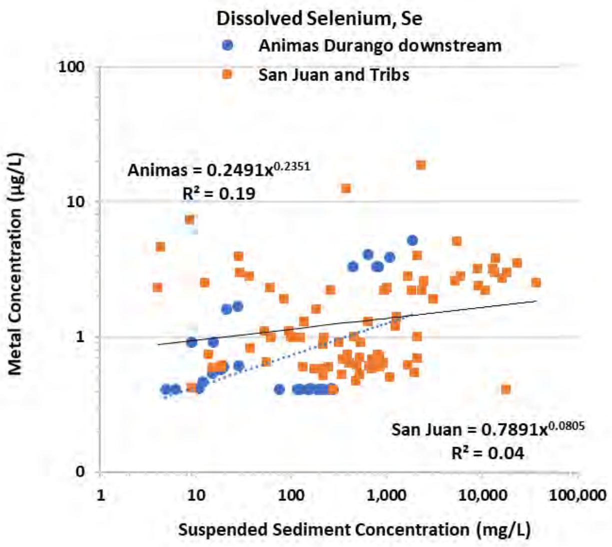


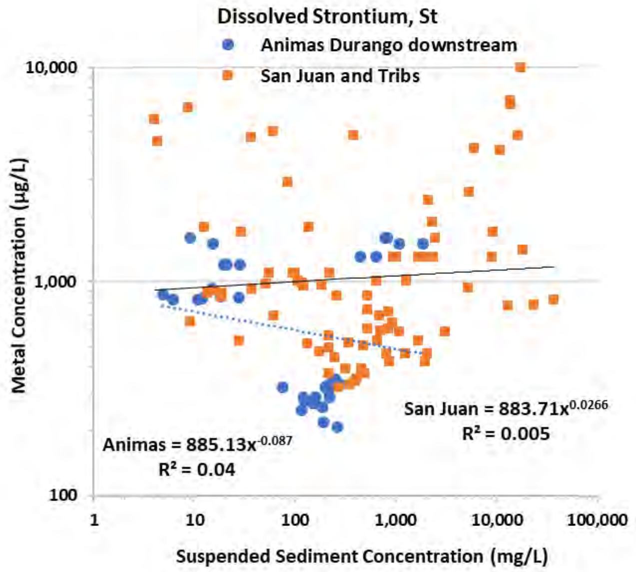




Relationship of Dissolved Metals Concentrations to Sediment

Not strongly related to sediment





Within the San Juan Basin, Dissolved Metals in Water

--The dissolved concentrations of most metals are related to sediment concentration
--The dissolved form of metals does not differentiate between the ore-rich and sedimentary geologies

These metals are related to sediment only and NOT enriched by ore-rich headwaters

- **Aluminum, Al**
- **Iron, Fe**
- **Arsenic, As**
- **Barium, Ba**
- **Vanadium, V**
- **Selenium, Se**
- **Uranium, U**

These metals are not influenced by sediment

- **Strontium, Sr**

These metals are influenced by ore-rich headwaters as well as sediment

- **Manganese, Mn**
- **Copper, Cu**
- **Lead, Pb**
- **Cadmium, Cd**
- **Zinc, Zn**

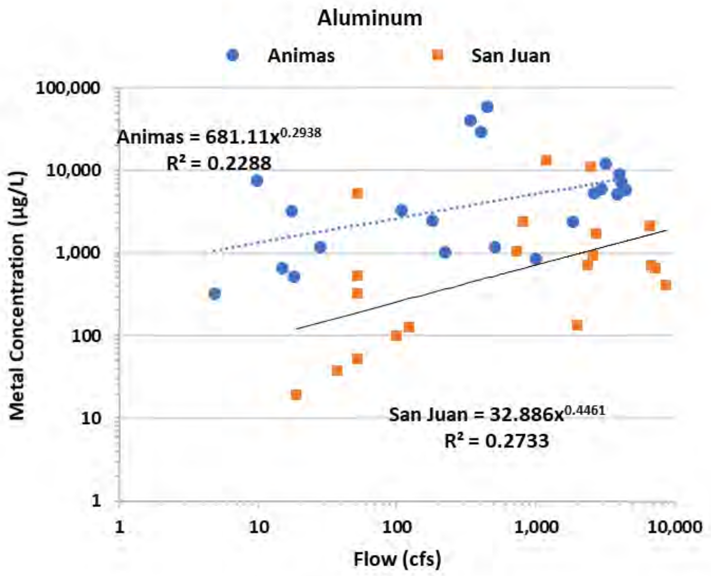
Not enough information to know

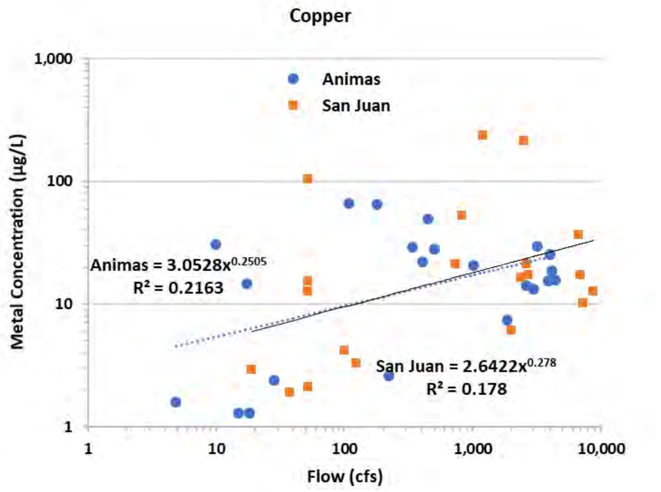
- **Beryllium, Be**
- **Cobalt, Co**
- **Mercury, Hg**
- **Silver, Ag**
- **Molybdenum, Mo**
- **Nickel, Ni**

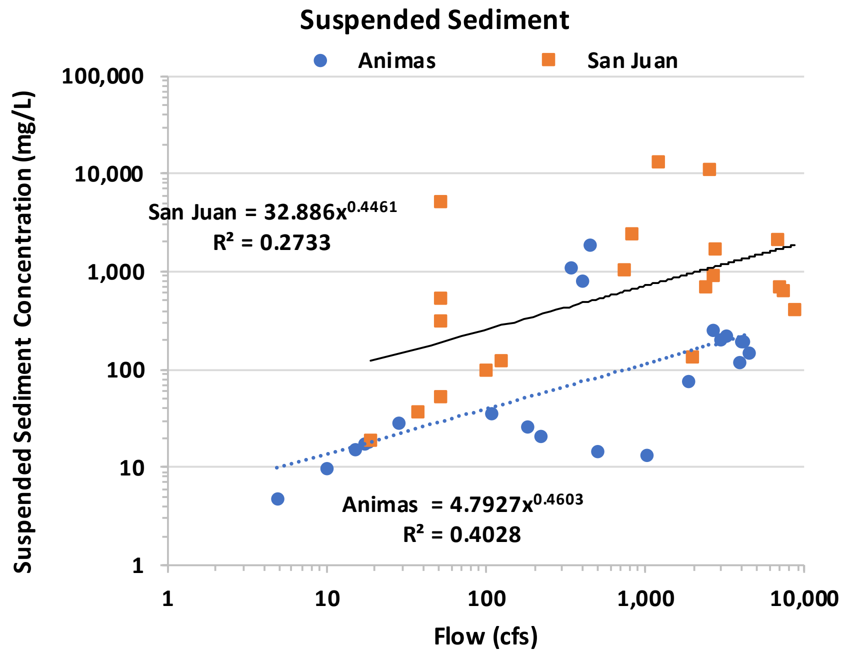
- ***Dissolved metals originate directly in the low pH environment of Animas River headwaters and can be present without sediment (volcanic intrusives)***
- ***Dissolved metals also originate with sediments***

Metal Relationship to Flow

- **There is a general trend of increasing metals with flow, but there is a great deal of scatter and it is not generally strongly predictive by itself**
- **Other factors such as sediment or local water conditions are more direct influence on dissolved metals**



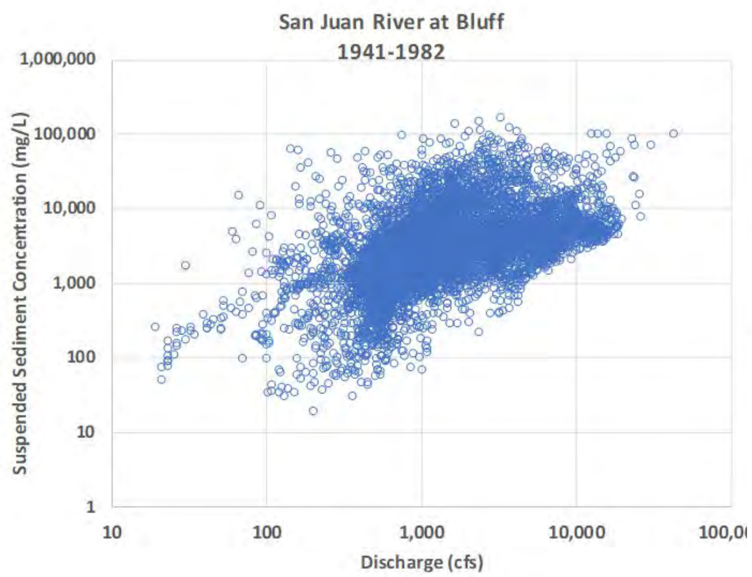




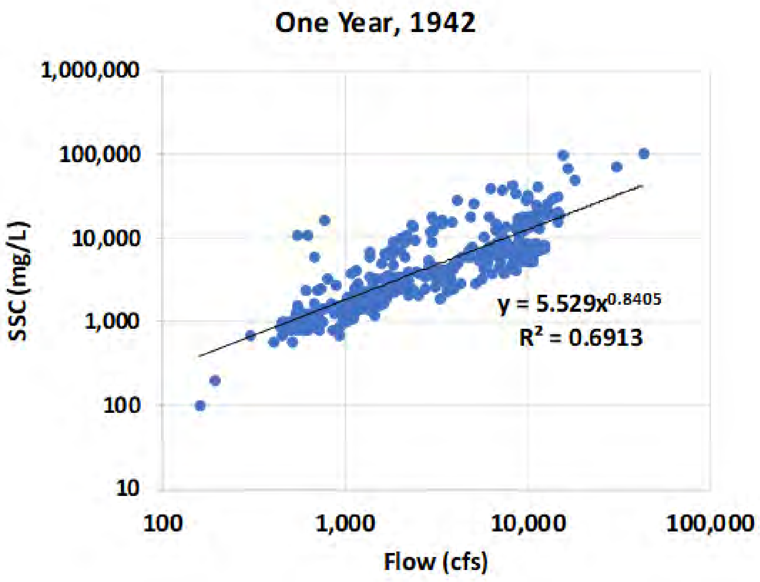
Predicting Metals Concentrations

Sediment is clearly a critical factor in understanding metals concentrations in much of the river system, especially in the sediment geology, but it is notoriously variable. That is especially true in this watershed that has some of the highest sediment loads in the nation at times

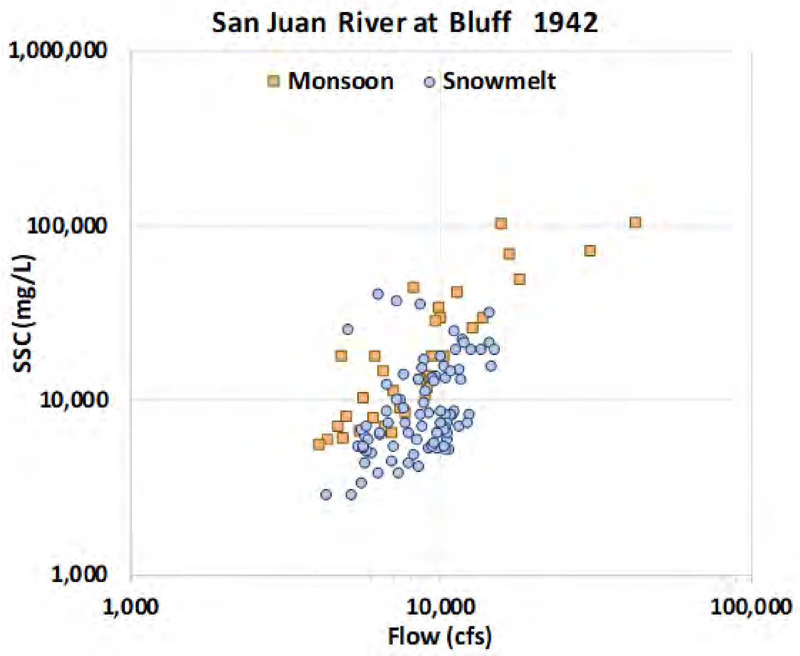
41 year record of suspended sediment



1 year record of suspended sediment



Separating events within that year

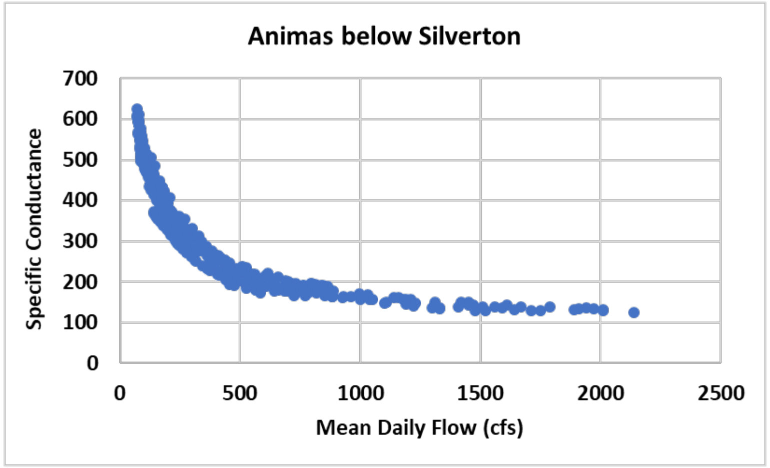


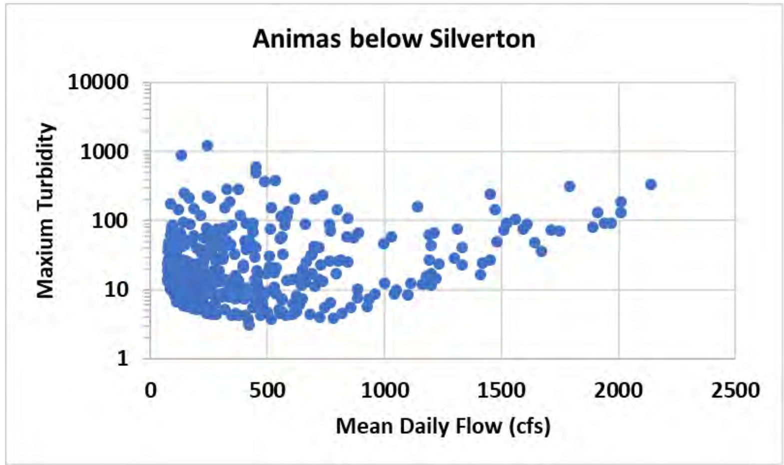
Suspended sediment is highly related to flow, but there is significant variability from event to event --very challenging for building effective predictive relationships

Predicting Metals Concentrations USGS Regression project

USGS regression project used concentration data and physical parameters available at USGS gaging stations (Flow and Sondes) to try to predict metals concentrations

$$\boldsymbol{Metal\ Concentration = f\ (specific\ conductance, turbidity, pH, flow, temp)}$$





USGS (*Mast et al.*) regressions do show that metals respond to sediment, water, and other parameters

. . . But relationships have only moderate predictive success over

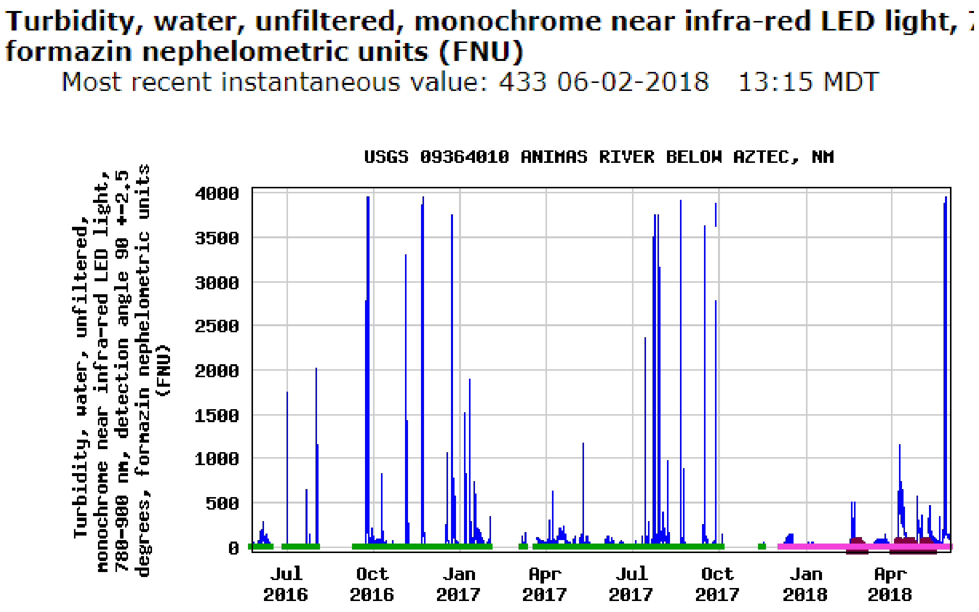
Summary of USGS Regression Models Using Sonde Parameters

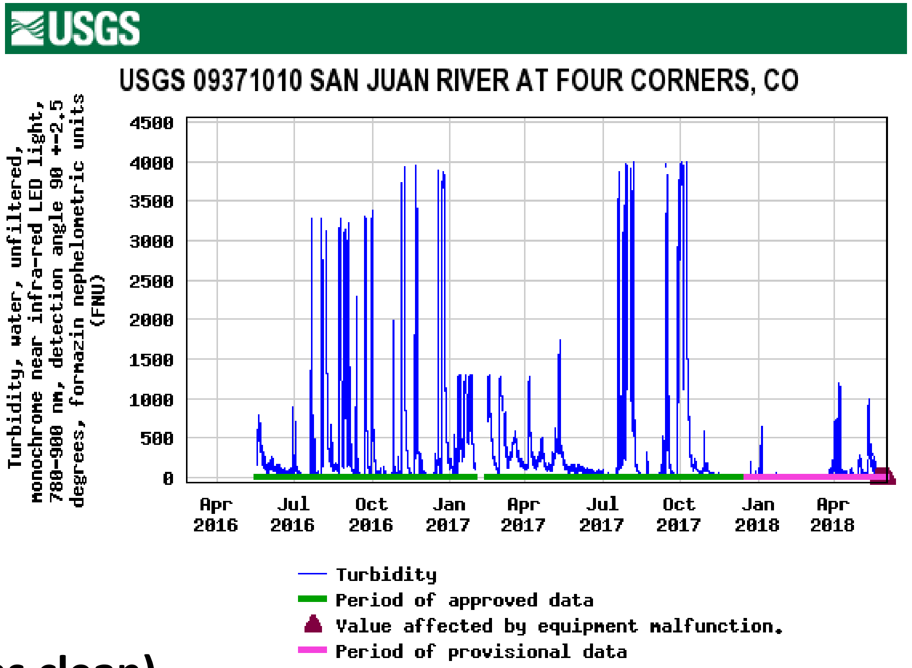
	% of Models	
	Dissolved	**Total**
Statistically Significant Models	35	92
Turbidity	0	80
Flow	32	42
Seasonal Term	88	70
Specific Conductance	72	26
Temperature	28	18
pH	20	20

- Results shown from WINN data generally agree with USGS results:
- Sediment is useful for total metals concentrations
- Dissolved do not predict as well with sediment and need other parameters

	Cement	A72	Durango	Cedar Hill	Aztec	SJ at Farm	Shiprock	4 Corners	Bluff
Aluminum dissolved	0.96	0.55			0.86				0.52
Arsenic dissolved									0.54
Cadmium dissolved	0.77	0.84							
Copper dissolved				0.81	0.56				
Iron dissolved	0.85	0.84	0.62		0.92				
Lead dissolved	0.75		0.69	0.62					
Manganese dissolved	0.98	0.97	0.63						
Zinc dissolved	0.91	0.92		0.59	0.65			0.6	
Aluminum total	0.91	0.8	0.73	0.67	0.84	0.66	0.88	0.7	0.79
Arsenic total		0.6	0.52	0.8	0.77		0.93	0.81	0.75
Cadmium total	0.79	0.83	0.72	0.77	0.63			0.61	0.71
Copper total	0.57		0.75	0.91	0.79	0.66	0.86	0.71	0.78
Iron total	0.68	0.72	0.73	0.82	0.83	0.78	0.87	0.81	0.78
Lead total	0.56	0.76	0.83	0.83	0.78	0.63	0.89	0.71	0.88
Manganese total	0.98	0.89	0.8	0.86	0.7	0.62	0.86	0.81	0.84
Zinc total	0.94	0.39	0.72	0.79	0.65	0.77	0.86	0.77	0.83

Turbidity measured by continuous sondes is also a “messy” surrogate for suspended sediment





- **Equipment issues for real time response (keeping the lens clean)**
- **Machine limits (4000 ftu) really important in this watershed**

Animas

San Juan

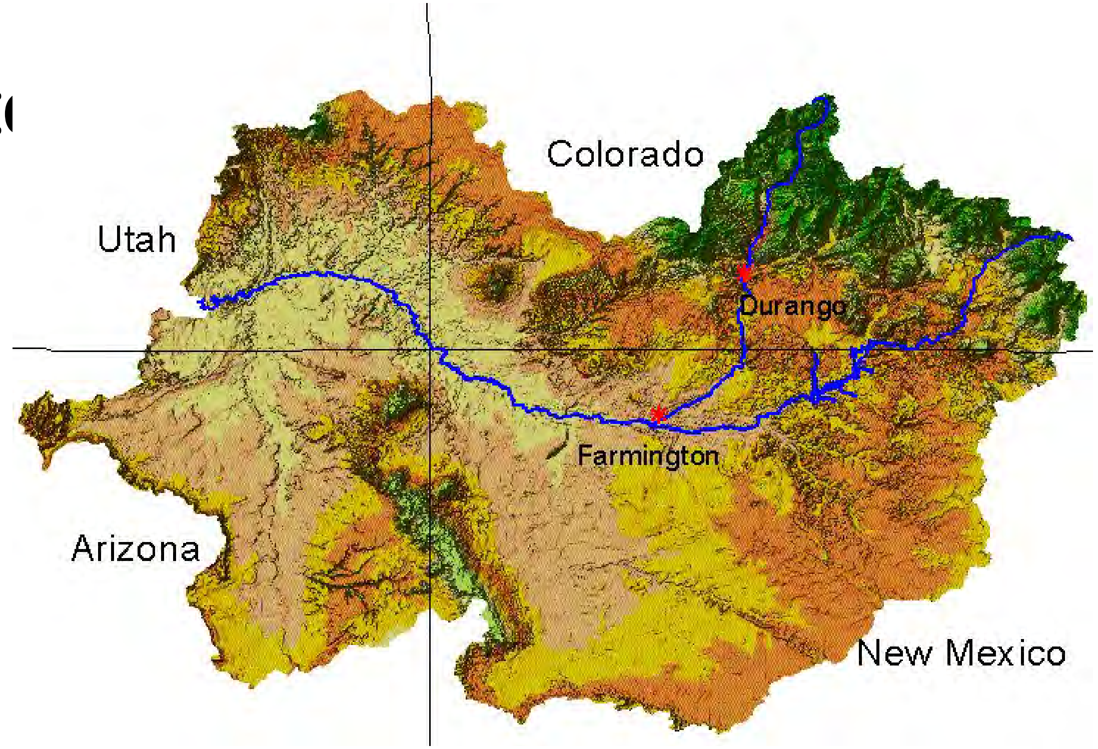
Hydrology

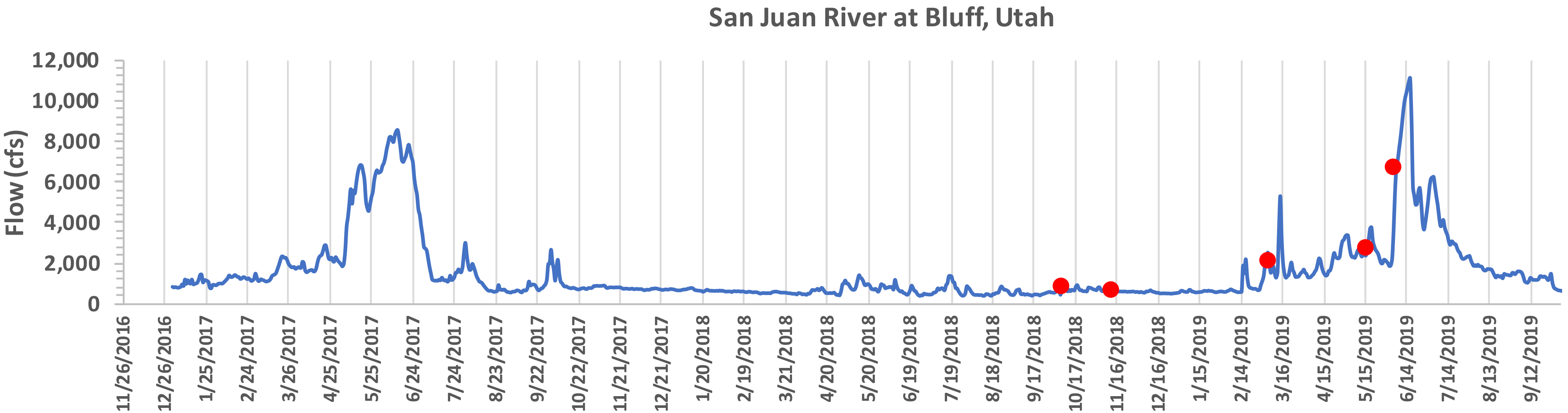
-Flow within the Basin

-Sampling

Water Delivery in the San Juan Wat

- **Overall Pattern**: Snowmelt followed by low summer, fall winter baseflow punctuated by intense southern convective type storms.
- **Snowmelt Dominated**: Montane, northern tributaries. These generate low sediment loads, high metals loads from volcanic intrusives
- **Monsoonal**: Generate large sediment loads from tributaries, usually low to moderate flows





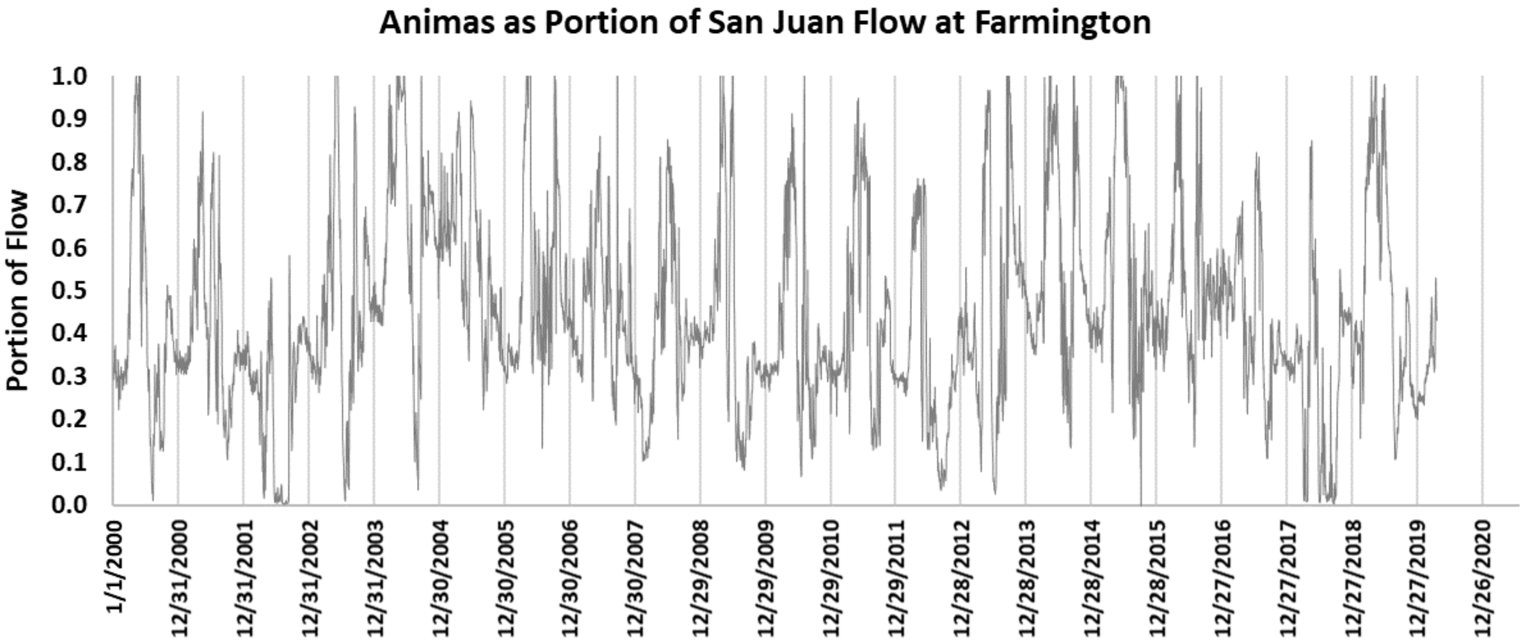
Tributary Basin Areas

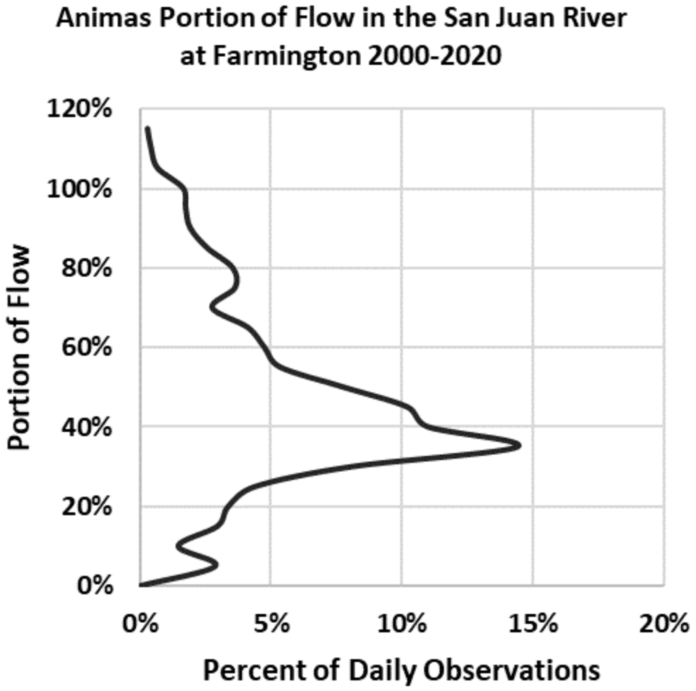
Tributary	Area (mi^2)	% SJ Basin
Upper SJ at Navajo Dam	3,260	9%
Animas	1,360	4%
La Plata	602	2%
Mancos	785	2%
McElmo	705	2%
Chaco	4,353	11%
Chinle	3,725	10%
Washes and Arroyos	23,510	61%

Total Area	38,300

Animas is the largest free-flowing perennial river in the watershed

Animas River is a significant contributor to flow in the San Juan River at Farmington most of the time





As high as almost 100%, as low as almost 0 (realistic range 10-90%)

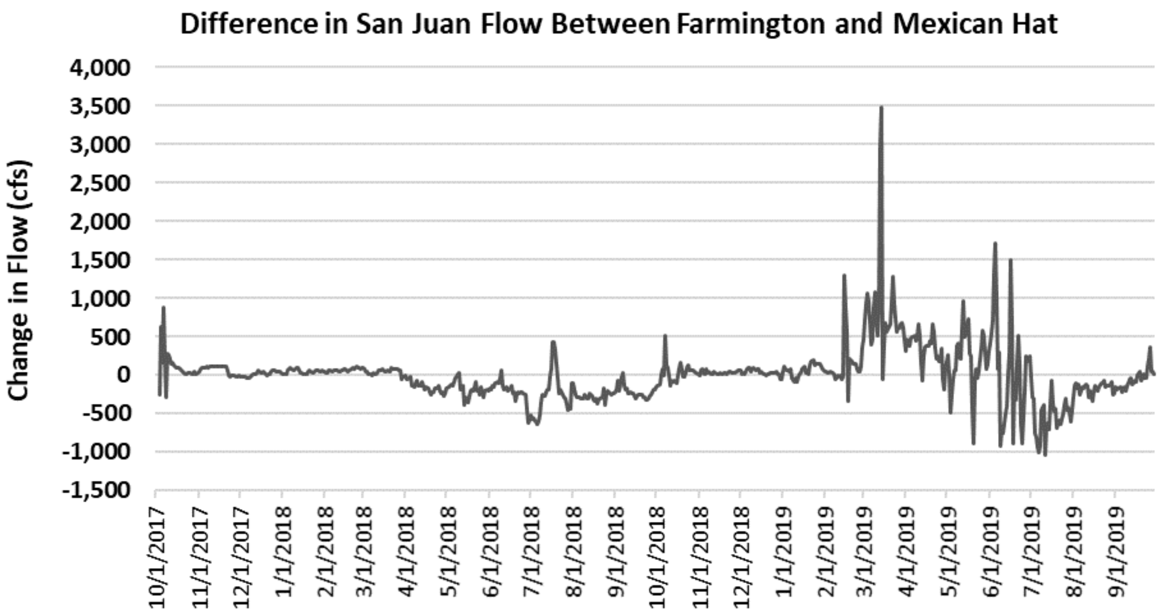
Median = 36%   Mean = 40%

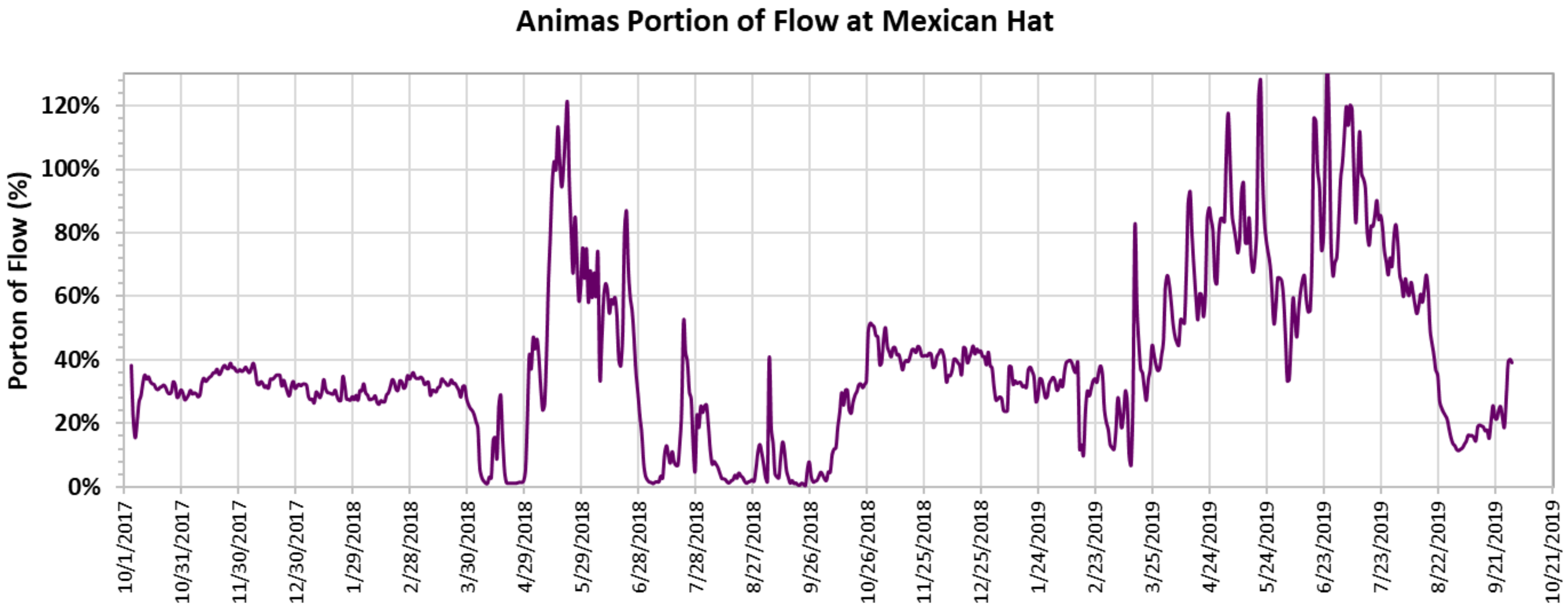
(Uncertainties in knowing flow in Animas immediately upstream of the Animas)

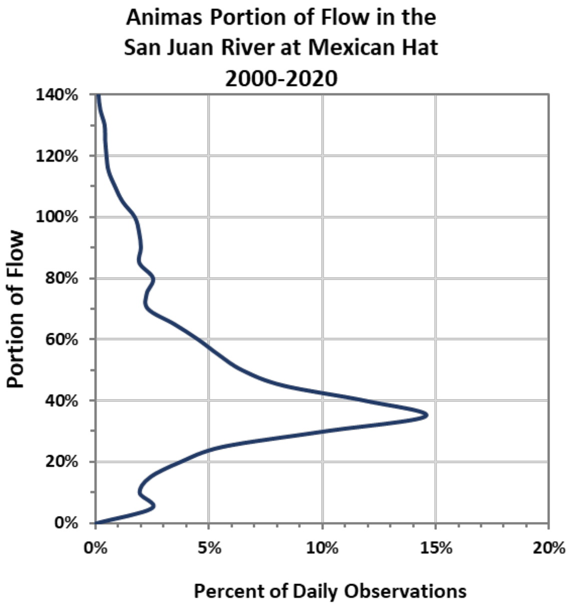
Flow in the San Juan River at Mexican Hat is generally about the same as it is in Farmington

- Gains during monsoonal events in lower tributaries
- Gain during snowmelt from northern tributaries
- Loses during summer season

The Animas River also contributes a significant portion of the San Juan flow at Mexican Hat

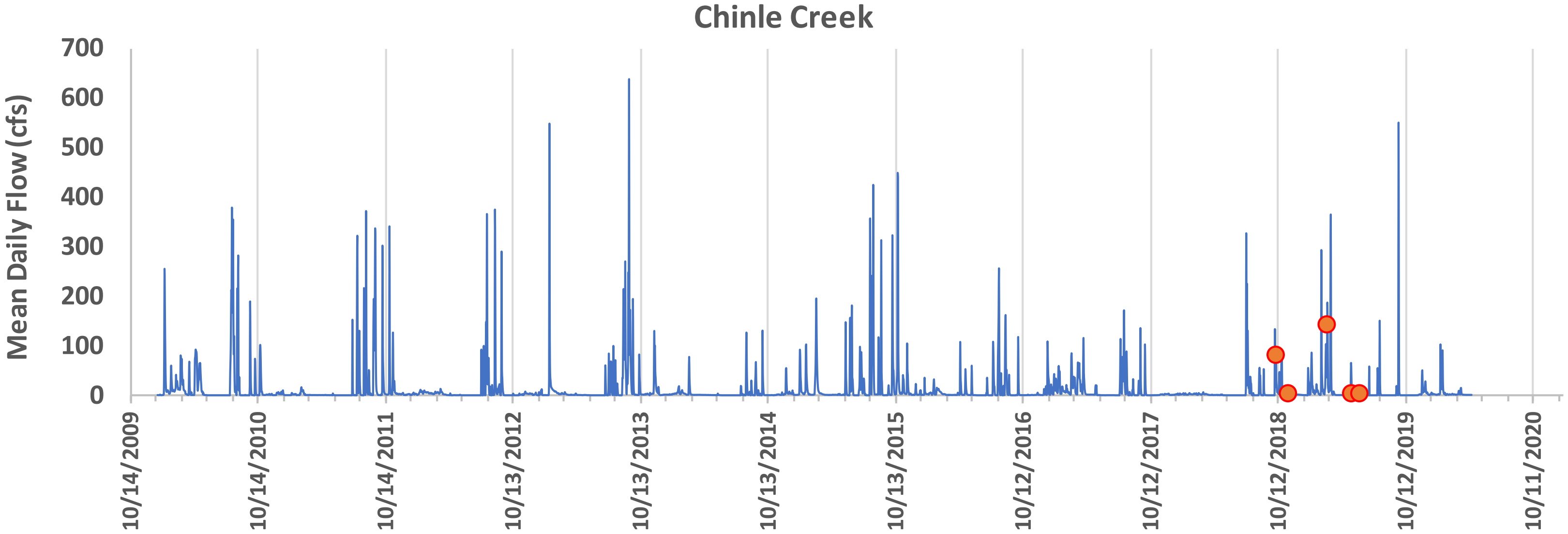




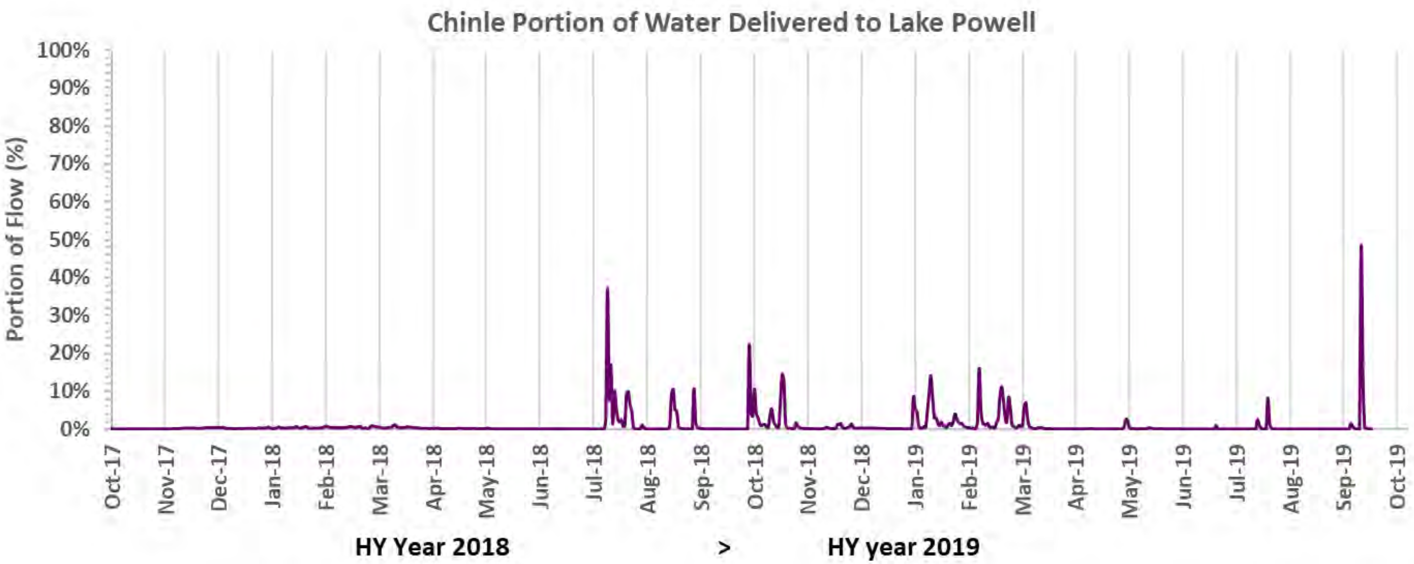


Chinle Creek – a southern tributary

Flow greater than 10 cfs occurs 14% of time



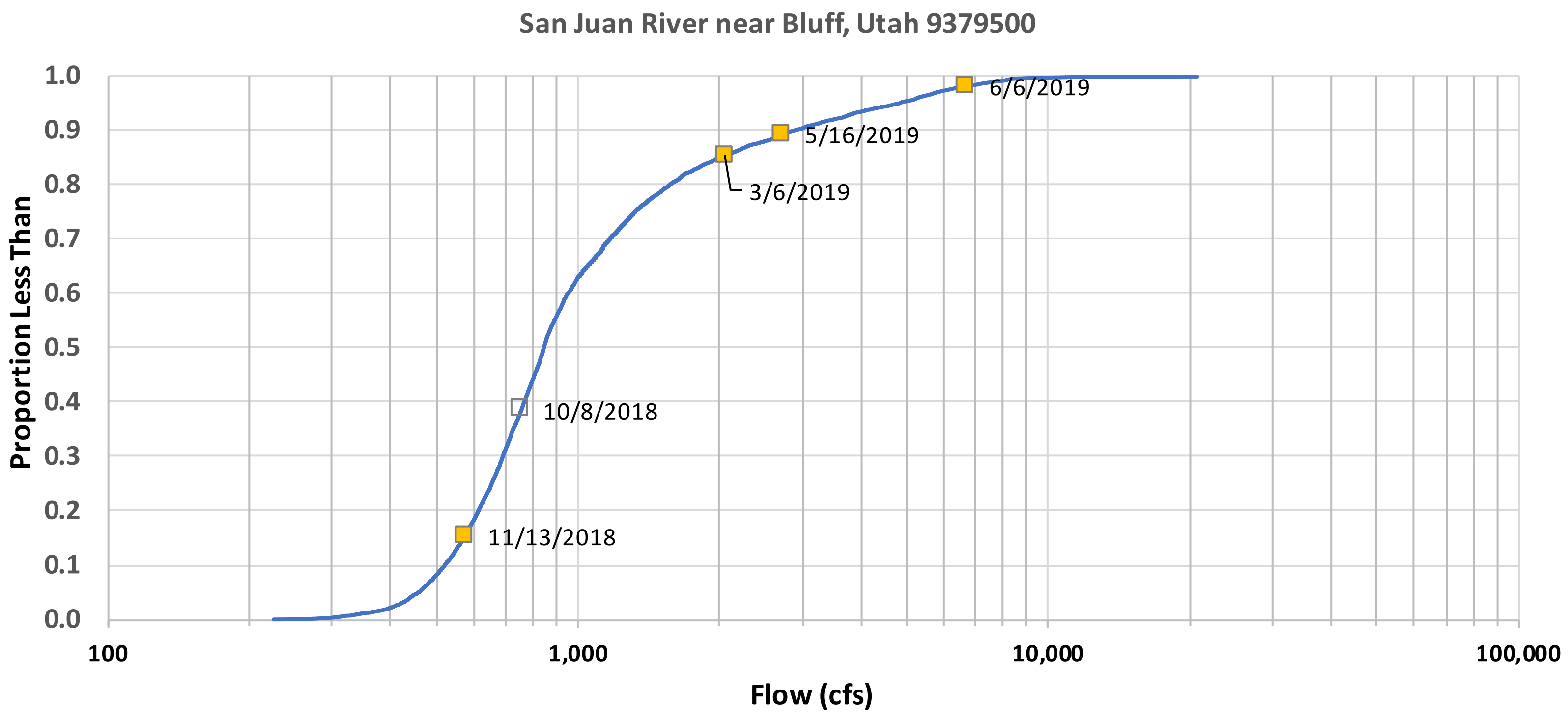
Chaco River



Characterizing Flow—Flow Duration Curve allowed comparison between stations with different flows

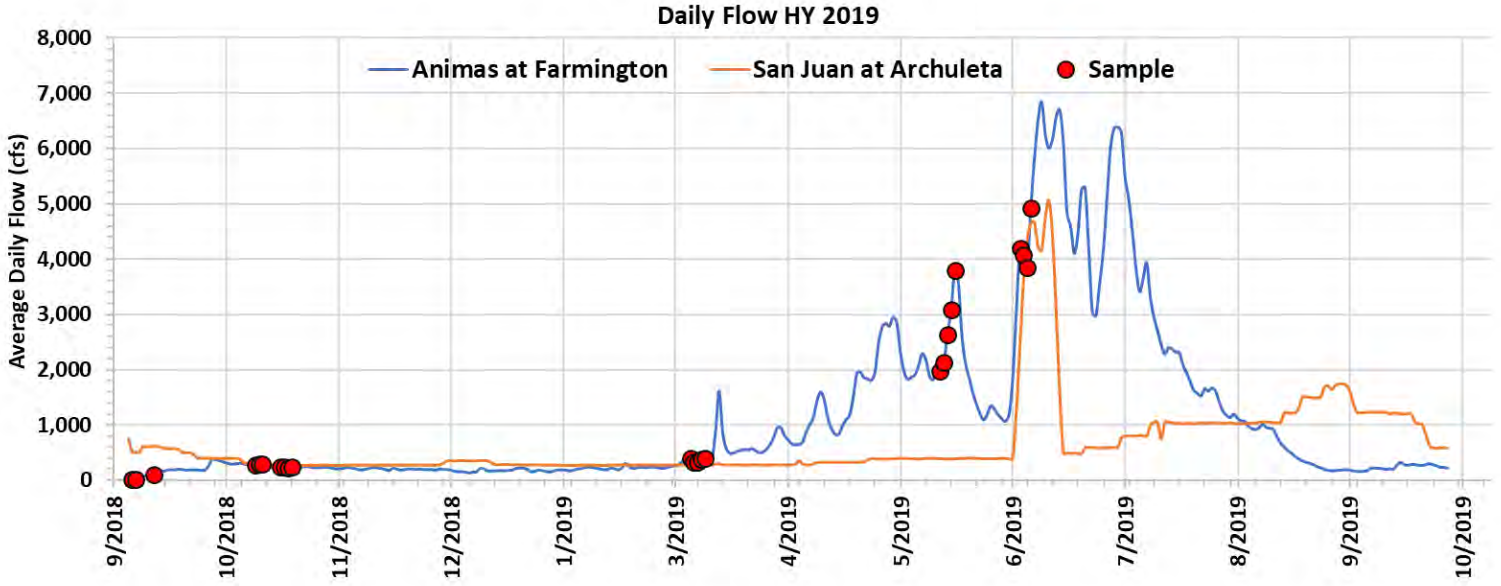
- Obtained 20 years of record at each hydrology station
- Ordered from lowest to highest
- Computed probability of each flow level as flow duration

(Proportion of flow less than)

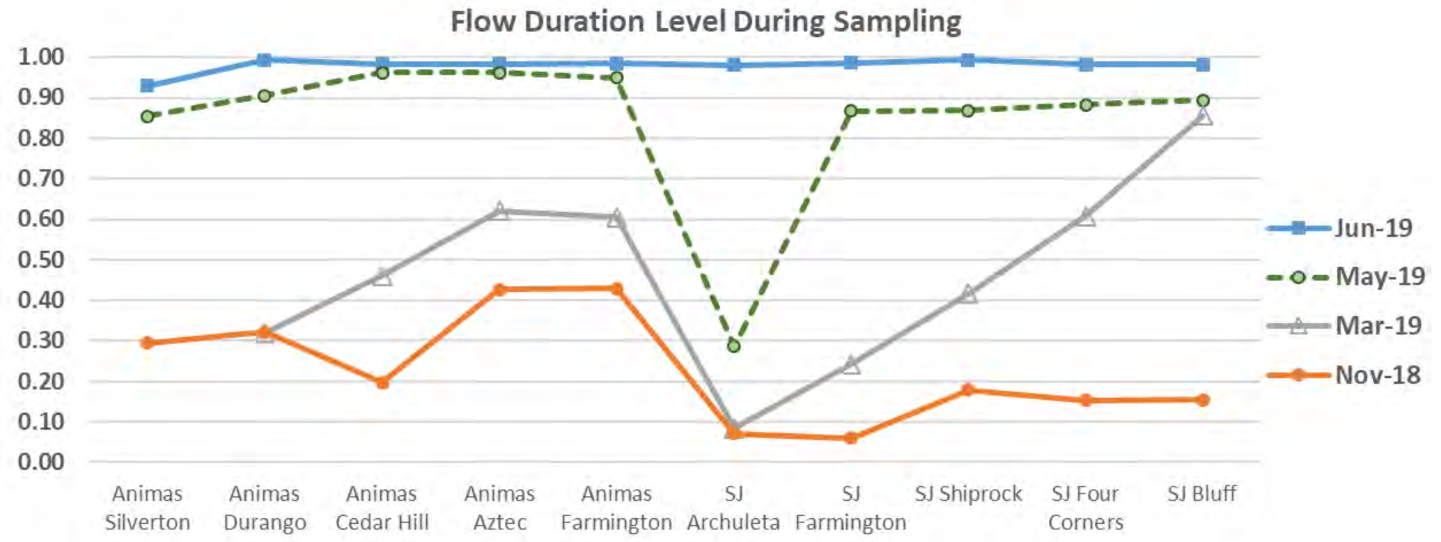


Stream Flow During Sampling

Sampling	Flow Regime	Animas Portion of Flow at Farmington
Nov-18	Baseflow	48%
Mar-19	Mixed Baseflow/Rainfall	12%
May-19	Snowmelt	97%
Jun-19	Snowmelt	61%



March sampling occurred during a rainfall event in the southern tributaries

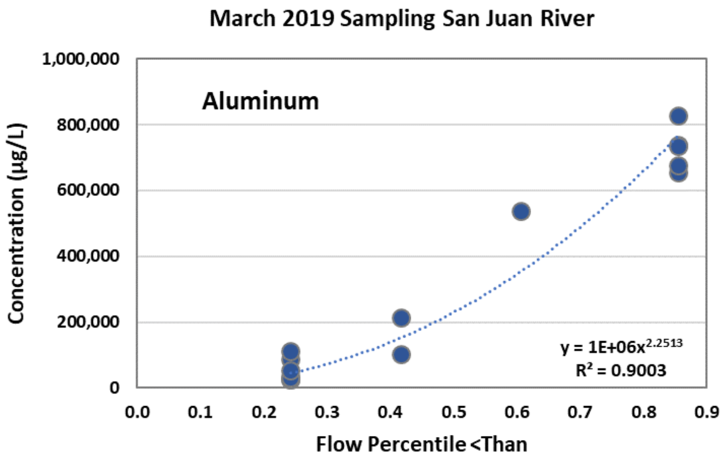


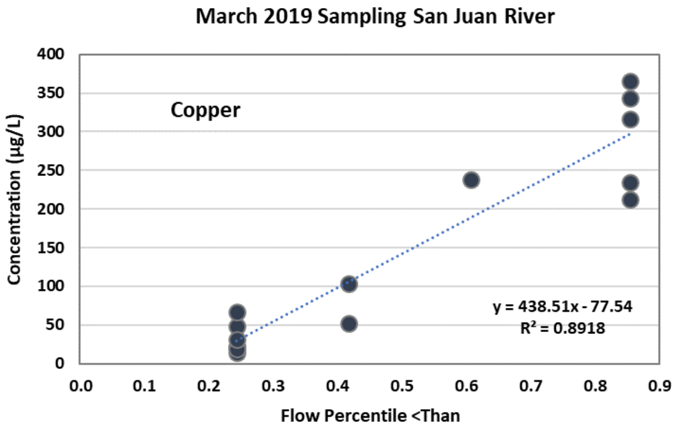
The March sampling gave a good glimpse of the effects of a rainstorm on the San Juan

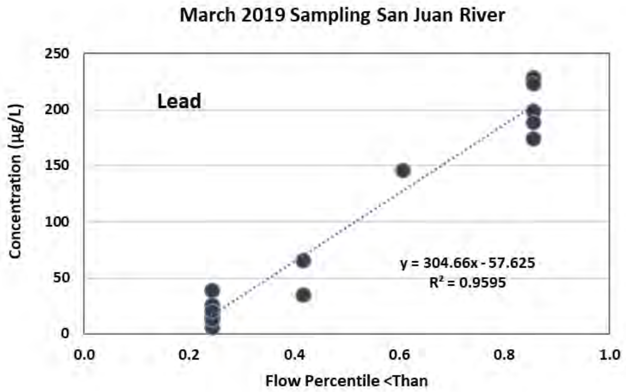
Summary of Flow Percentile (<Than) during sampling as indicated by nearest gage

	Oct-18	Nov-18	Mar-19	May-19	Jun-19
Animas Silverton	0.44	0.14		0.85	0.93
Animas Durango	0.02	0.32	0.32	0.84	0.99
Animas Cedar Hill	0.01	0.20	0.46	0.96	0.98
Animas Aztec		0.43	0.62	0.96	0.98
Animas Farmington		0.43	0.60	0.95	0.98
SJ Archuleta		0.07	0.08	0.29	0.98
SJ Farmington		0.06	0.24	0.87	0.99
SJ Shiprock		0.18	0.42	0.87	0.99
SJ Four Corners		0.15	0.61	0.88	0.98
SJ Bluff	0.39	0.15	0.86	0.89	0.98
Chinle Creek	0.96	0.29	0.98	0.36	0.20
LaPlata River		0.11	0.45	0.36	0.99
Mancos River			0.76	0.91	0.98

The March sampling captured a significant rainfall event in the lower San Juan while the rest of the watershed was low to moderate flow.







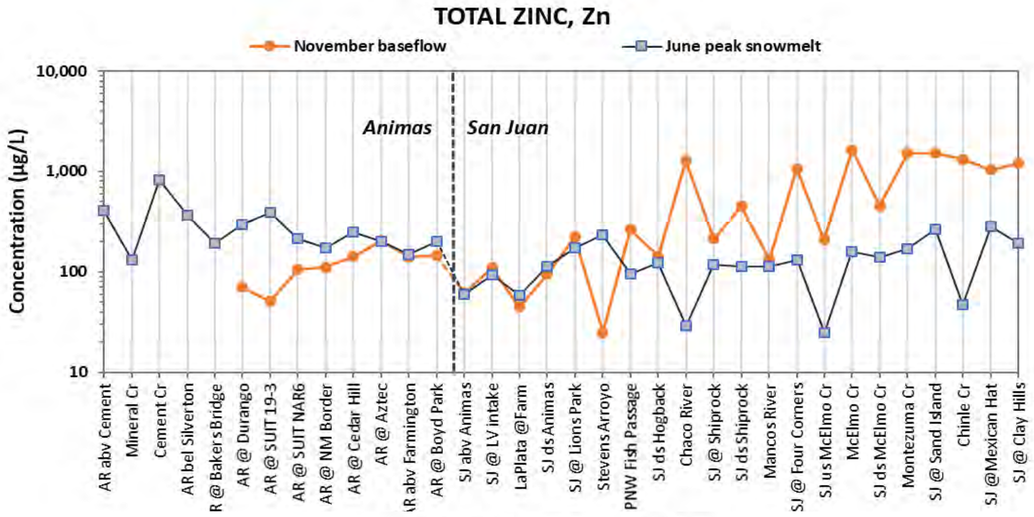
Summary of Hydrology

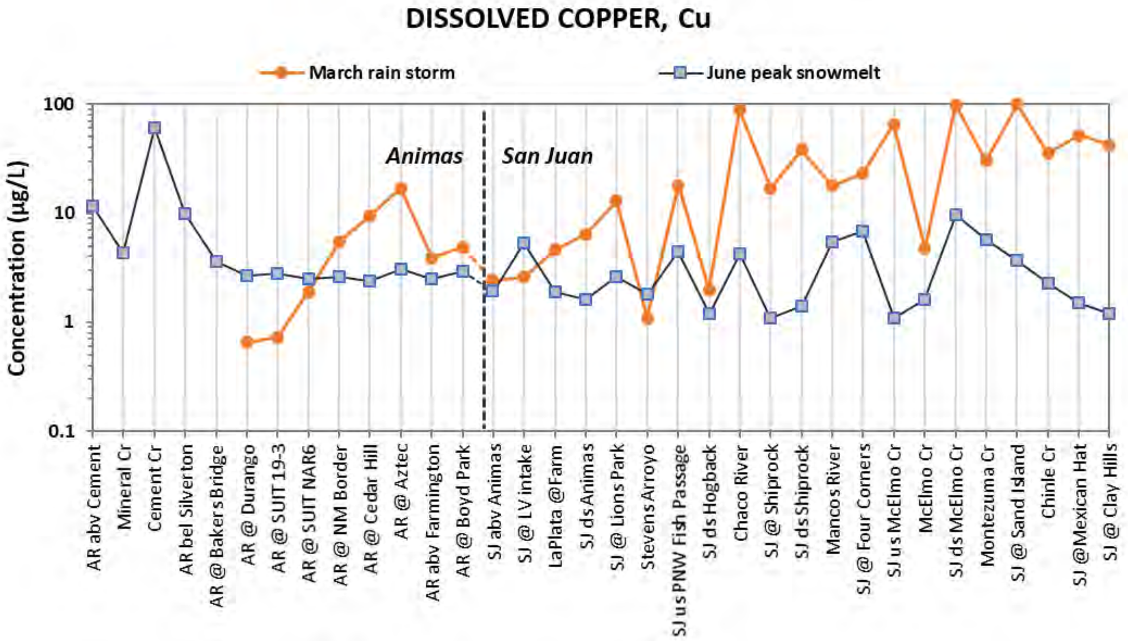
- Useful categorization of flow
  - Baseflow: 61% of time
  - Snowmelt: 25% of time
  - Rainfall (Monsoonal): 14% (?) of time
- The Animas supplies a substantial portion of the flow in the San Juan River for much of the year, averaging 40% and approaching 95% at times
- Rain storms ("Monsoonal") in the southern tributaries can sporadically substantially increase flow in the San Juan, but usually storms have a more moderate effect
- Flow from other tributaries (Mancos, LaPlata, McElmo) are too small relative to Animas to influence much

Analysis of WINN Data

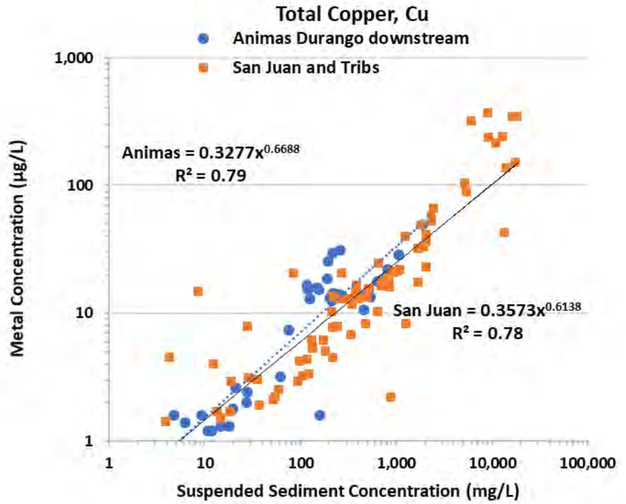
Patterns and Relationships Within the Watershed

What does this mean in WINN data?





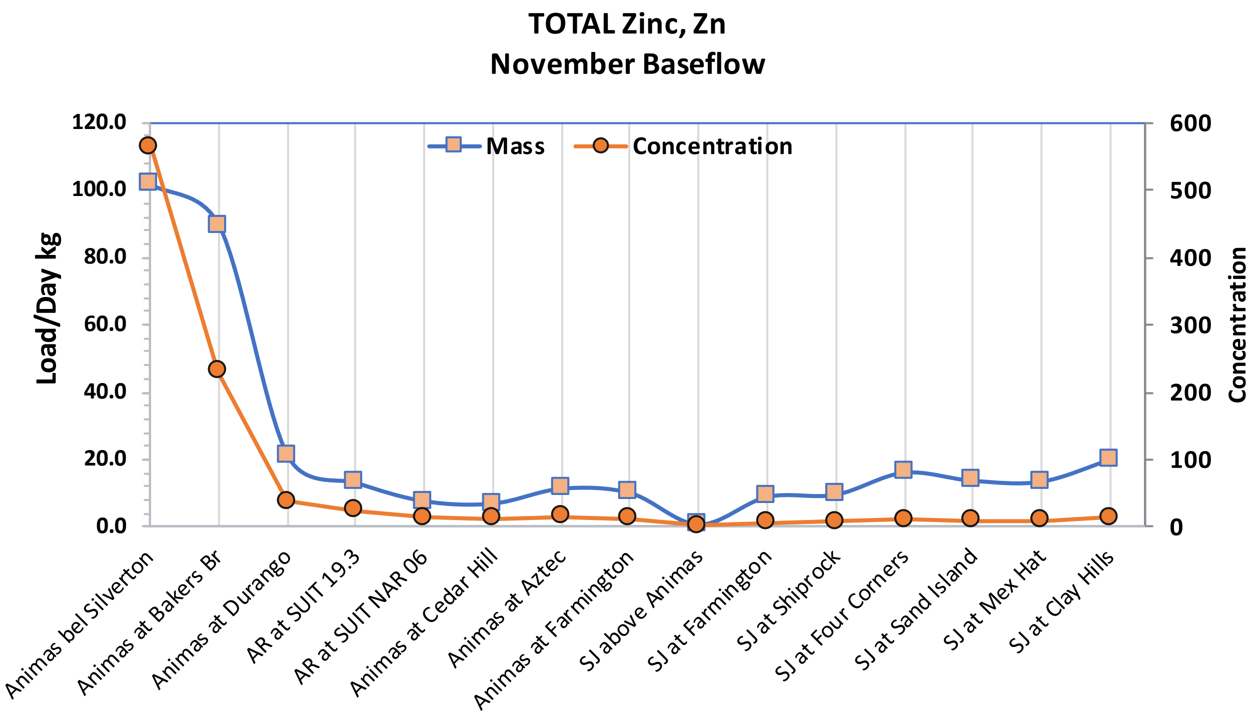
- **The Animas headwaters can be a significant source of metals downstream at times, but it is not the only source**
- **During rainstorms, total metals can exceed anything seen from the volcanic intrusive northern tributaries**
  - **Increase with sediment**
  - **Consistent with suspended sediment/metal relationships**



Transport of metals mass within the San Juan Basin

Upstream/downstream and tributary connections

Tracking Mass in the San Juan River using WINN data



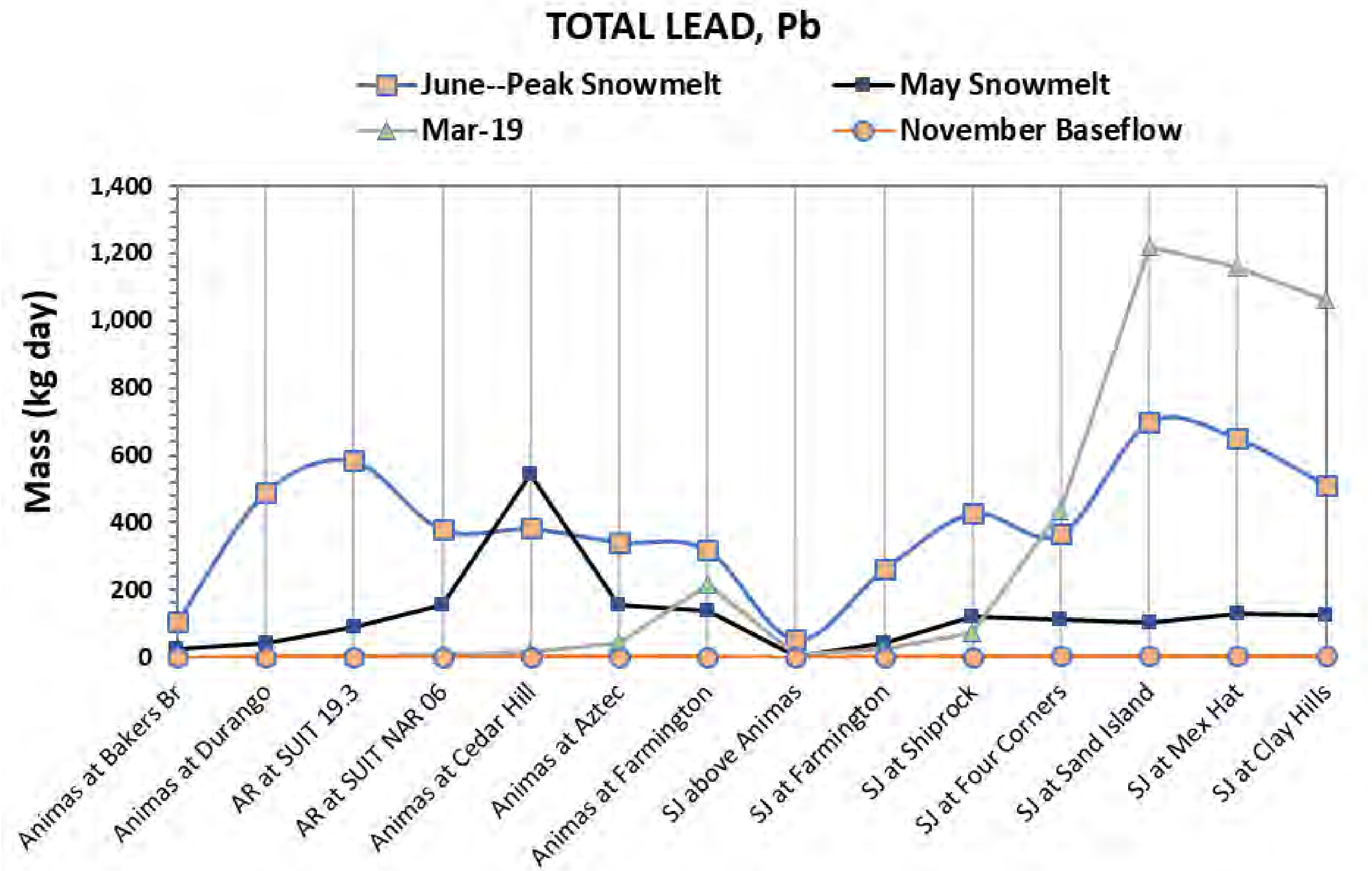
- Concentration is important for evaluating water quality, but it is not useful for determining sources
- Translate to mass: h
- ow much is in the system

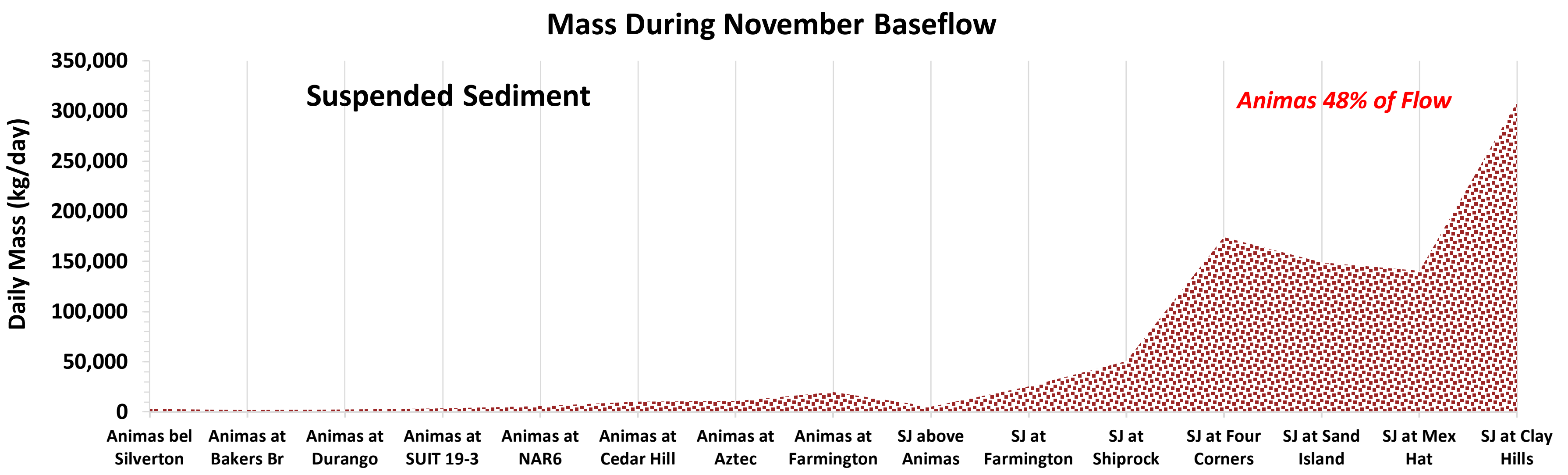
Concentration (mg/L) x Flow Volume (L)=Weight (mg/sec)

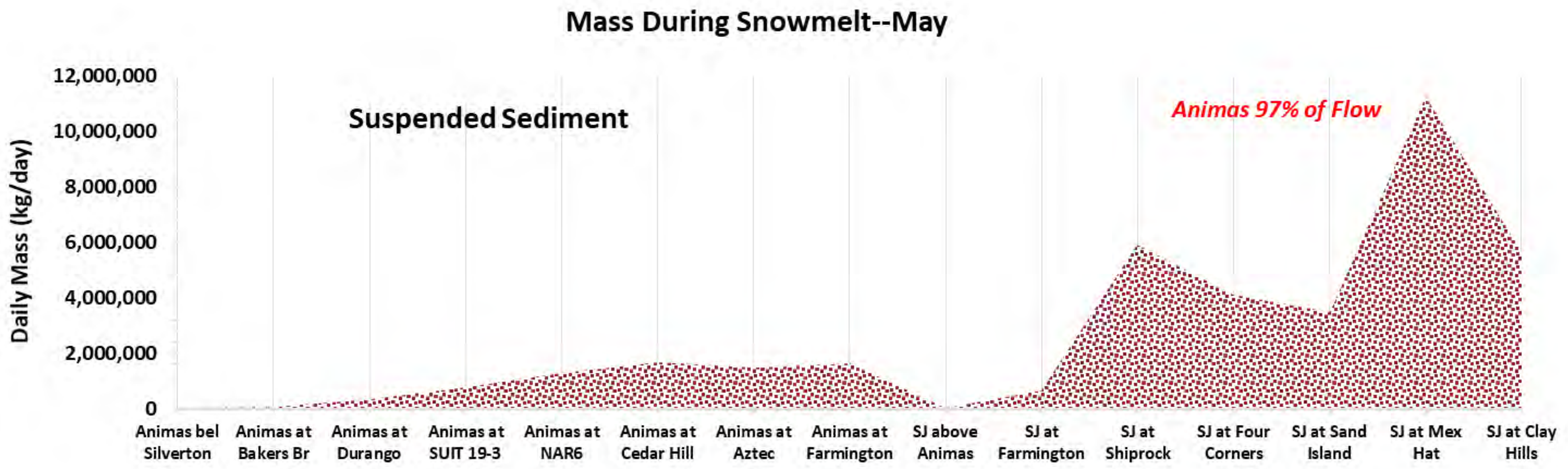
Report in kg/day

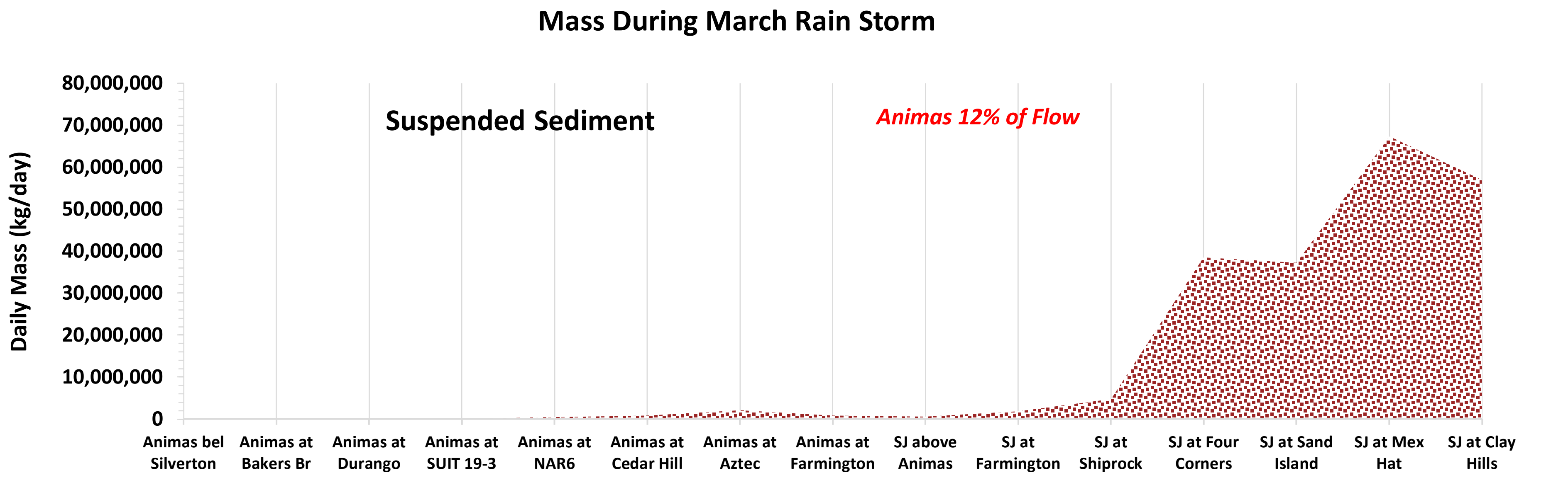
- Reproduces concentration generally
- Allows material to be tracked in general through the watershed, identifying points of increase (new sources) or decrease (deposition)
- Uniquely possible with this kind of dataset where data is collected at more or less the same time throughout

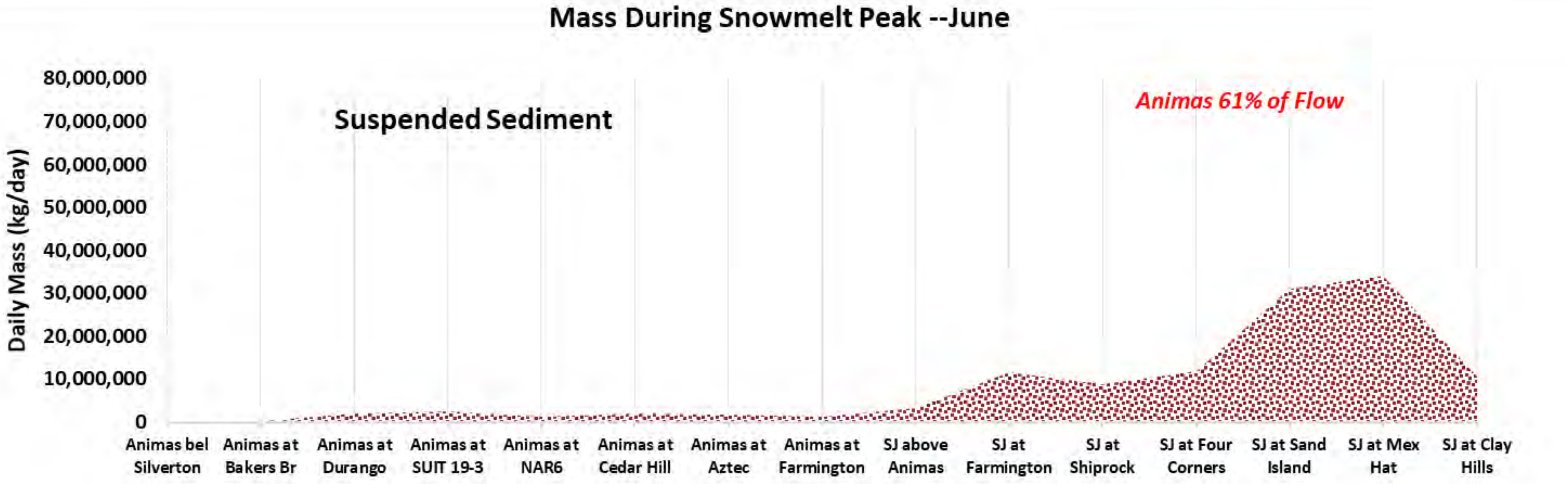
Patterns vary within the river between samplings reflecting flow conditions

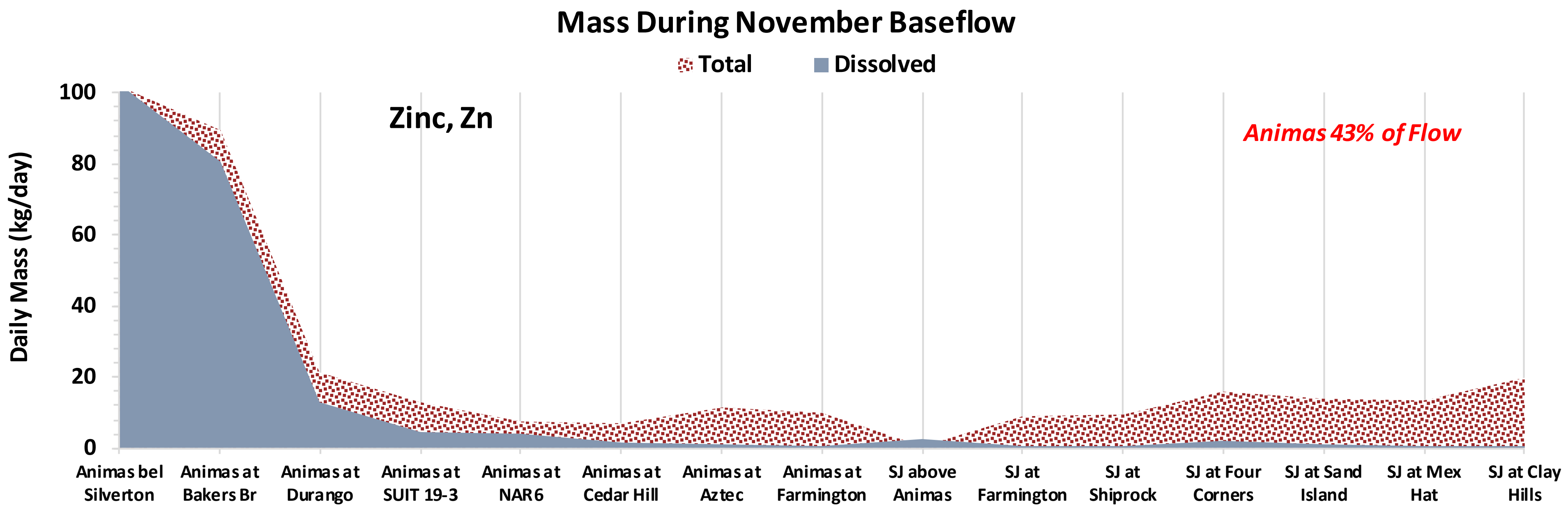


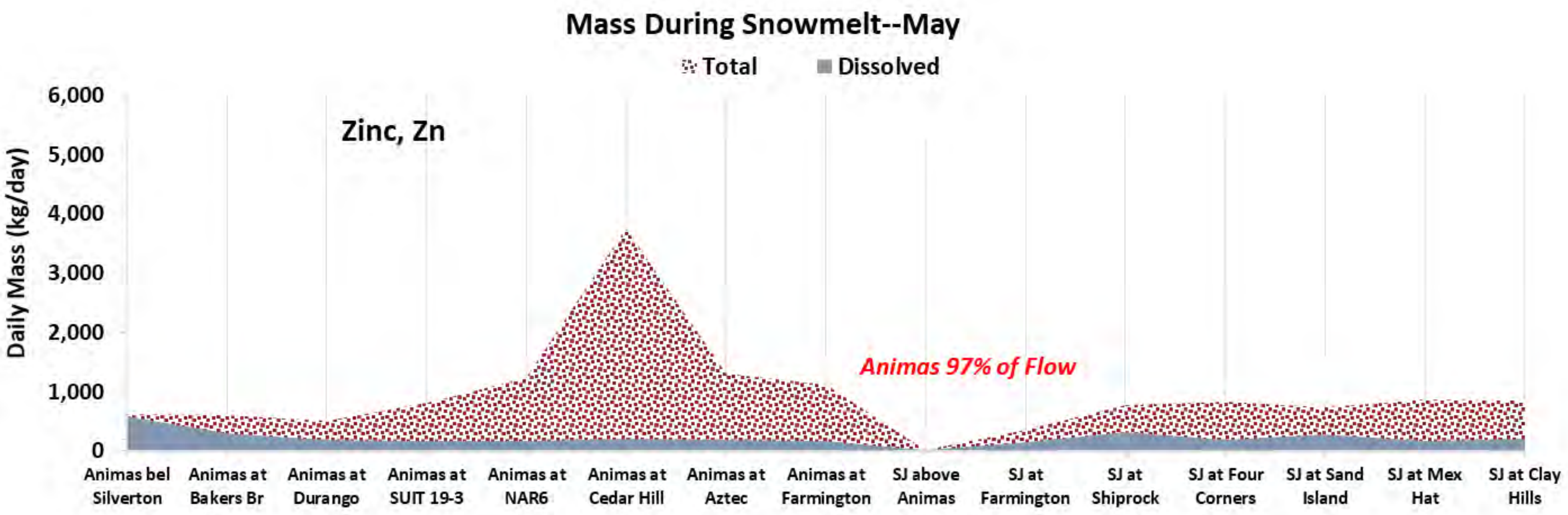

Mass During November Baseflow
Suspended Sediment
Animas 48% of Flow
Daily Mass (kg/day)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

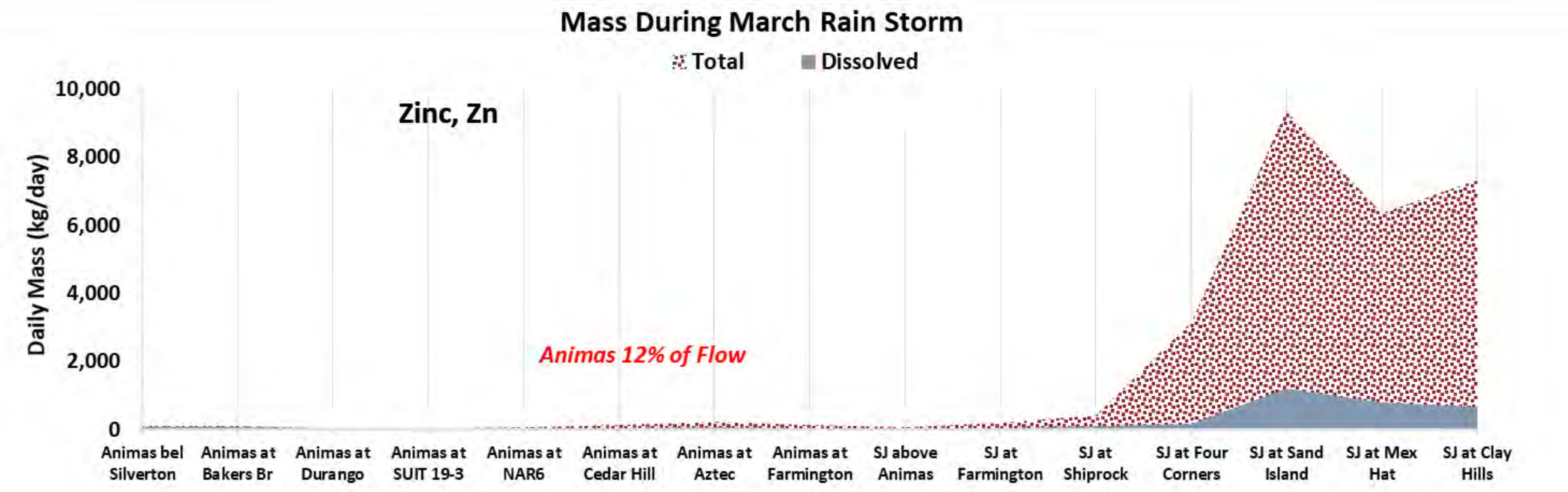

Mass During Snowmelt--May
Suspended Sediment
Animas 97% of Flow
Daily Mass (kg/day)
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills


Mass During March Rain Storm
Suspended Sediment
Animas 12% of Flow
Daily Mass (kg/day)
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

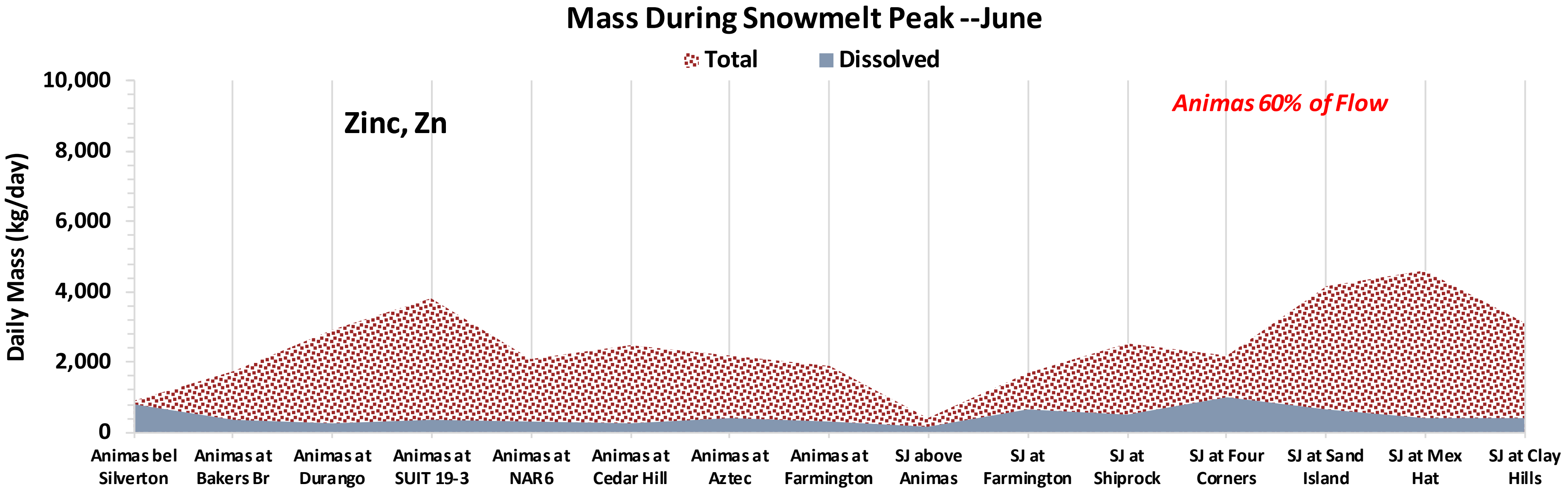

Mass During Snowmelt Peak --June
Suspended Sediment
Animas 61% of Flow
Daily Mass (kg/day)
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills


Mass During November Baseflow
Total
Dissolved
Daily Mass (kg/day)
100
80
60
40
20
0
Zinc, Zn
Animas 43% of Flow
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills


Mass During Snowmelt--May
Total
Dissolved
Daily Mass (kg/day)
6,000
5,000
4,000
3,000
2,000
1,000
0
Zinc, Zn
Animas 97% of Flow
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

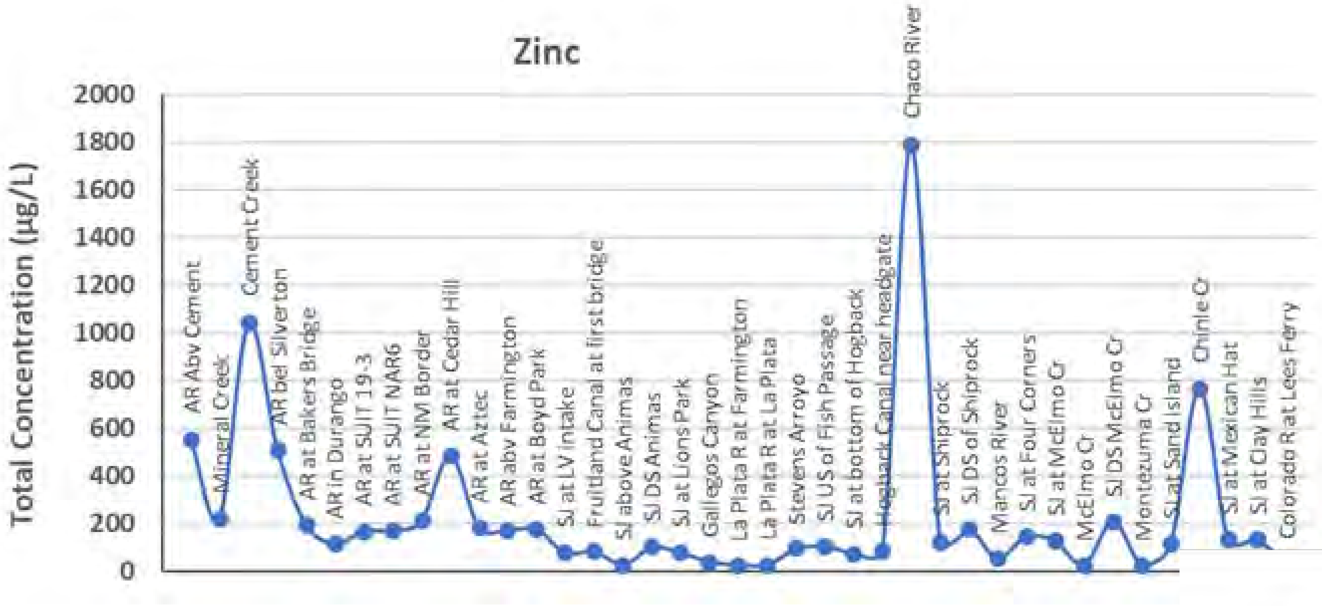


Mass During March Rain Storm
Total
Dissolved
Daily Mass (kg/day)
10,000
8,000
6,000
4,000
2,000
0
Zinc, Zn
Animas 12% of Flow
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills



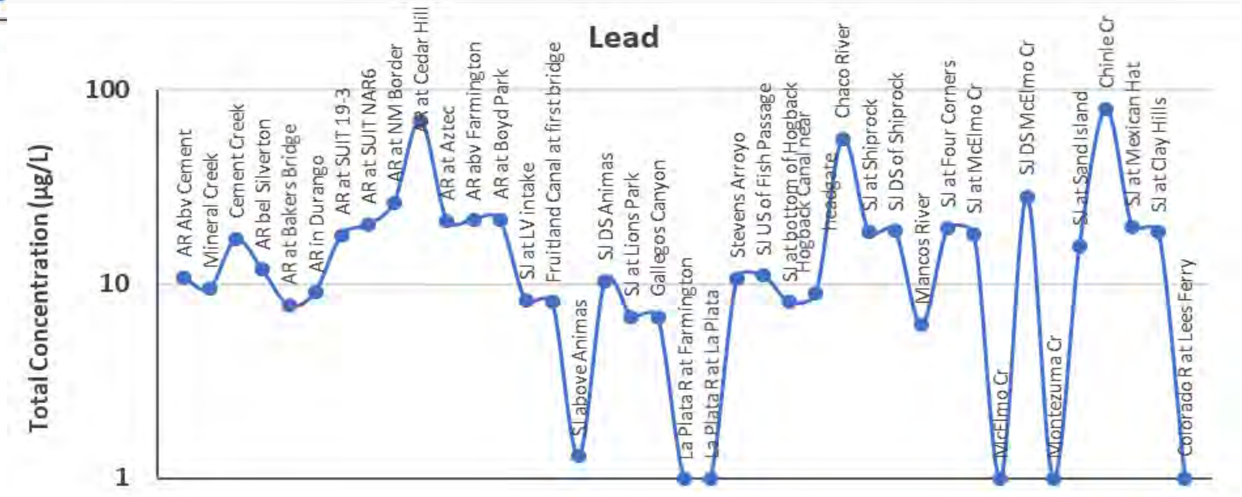
Mass During Snowmelt Peak --June
Total
Dissolved
Daily Mass (kg/day)
10,000
8,000
6,000
4,000
2,000
0
Zinc, Zn
Animas 60% of Flow
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

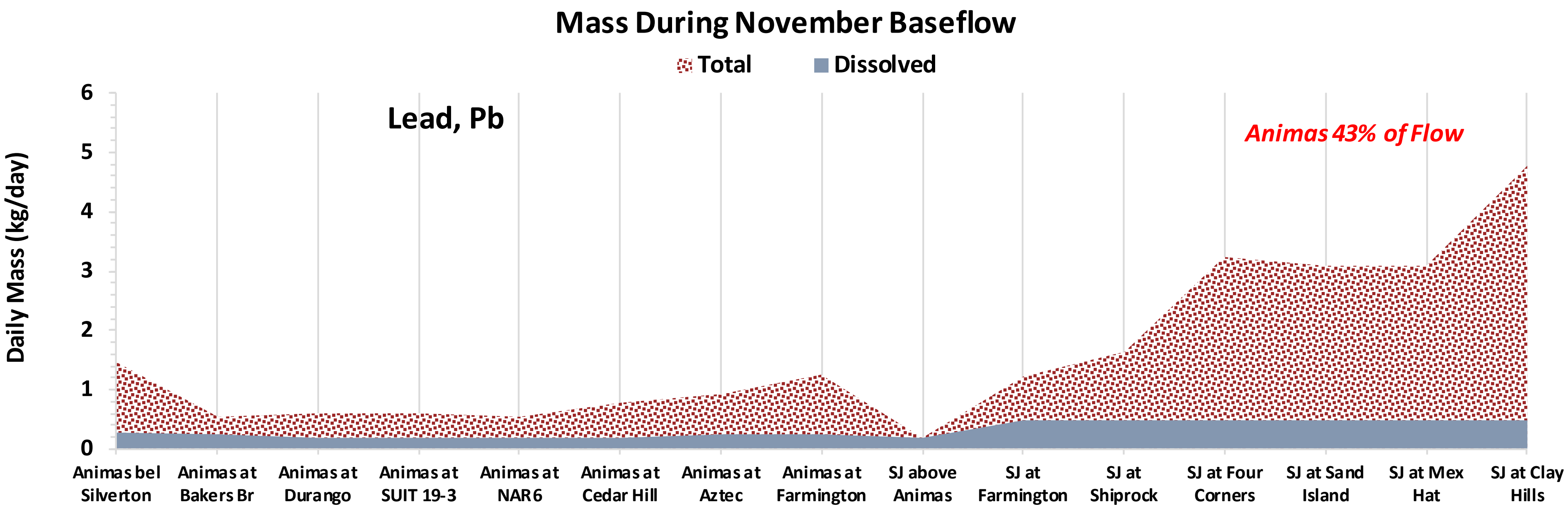
Locally elevated sources (tributaries, other) are evident in the metals concentrations –May 2019



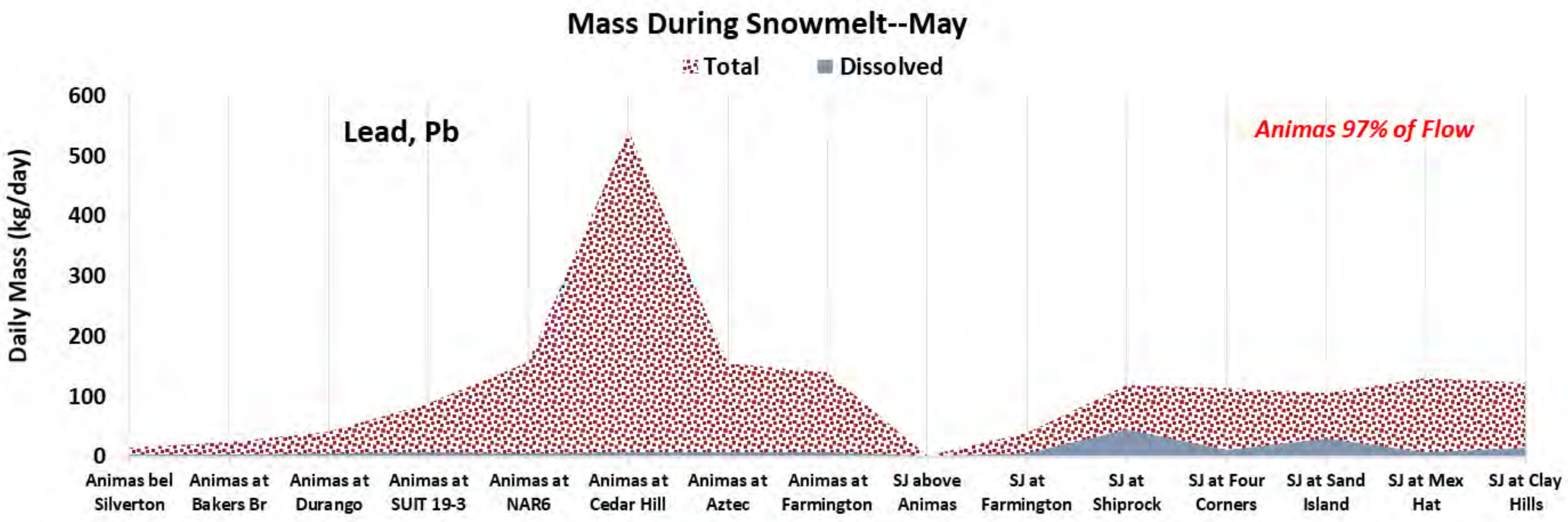
These often don’t move the river much, although they can

They will show up in the analysis of water quality relative to benchmarks

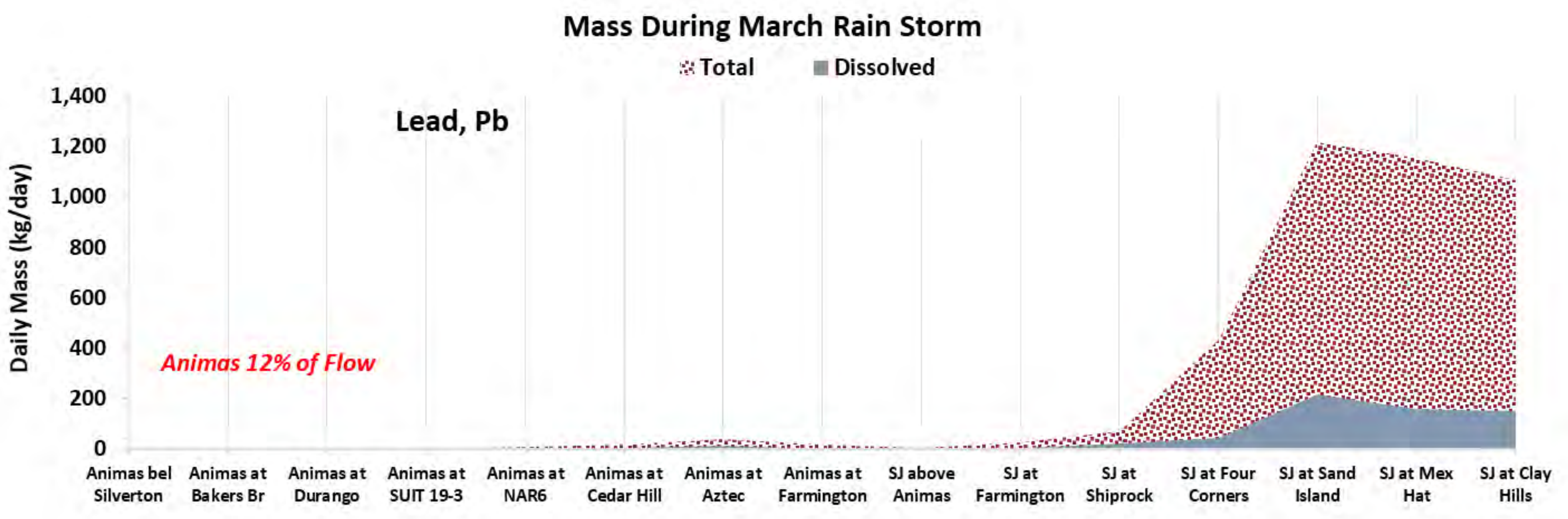




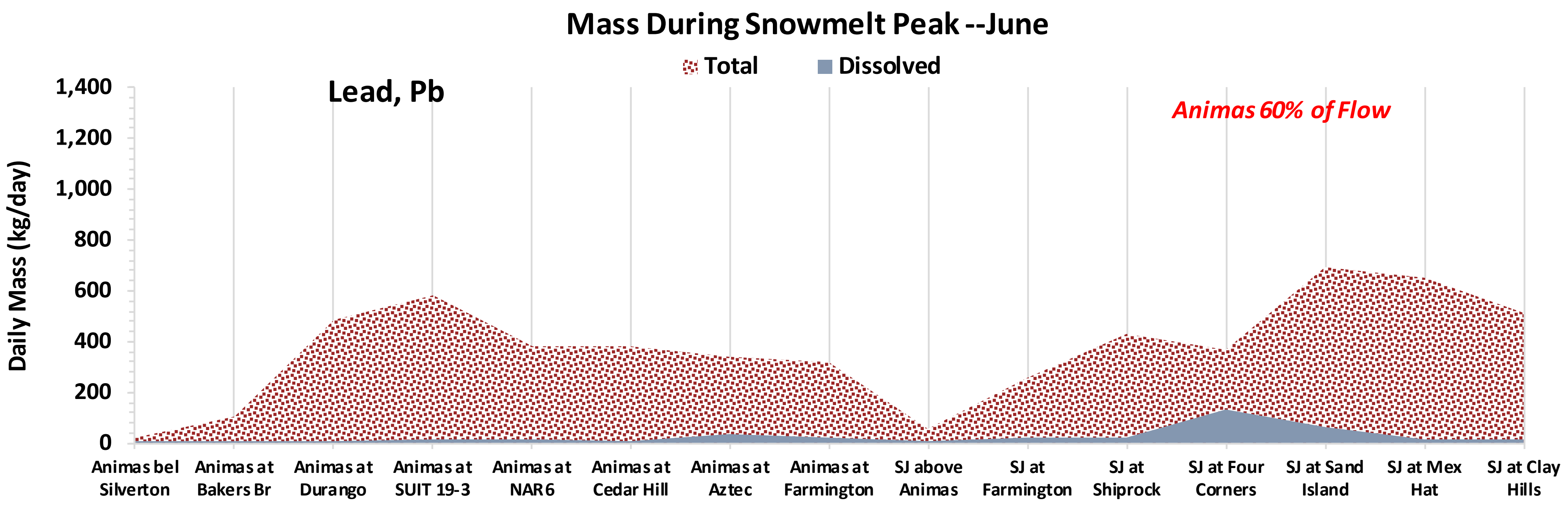
Mass During November Baseflow
Total
Dissolved
Daily Mass (kg/day)
Lead, Pb
Animas 43% of Flow
0
1
2
3
4
5
6
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills



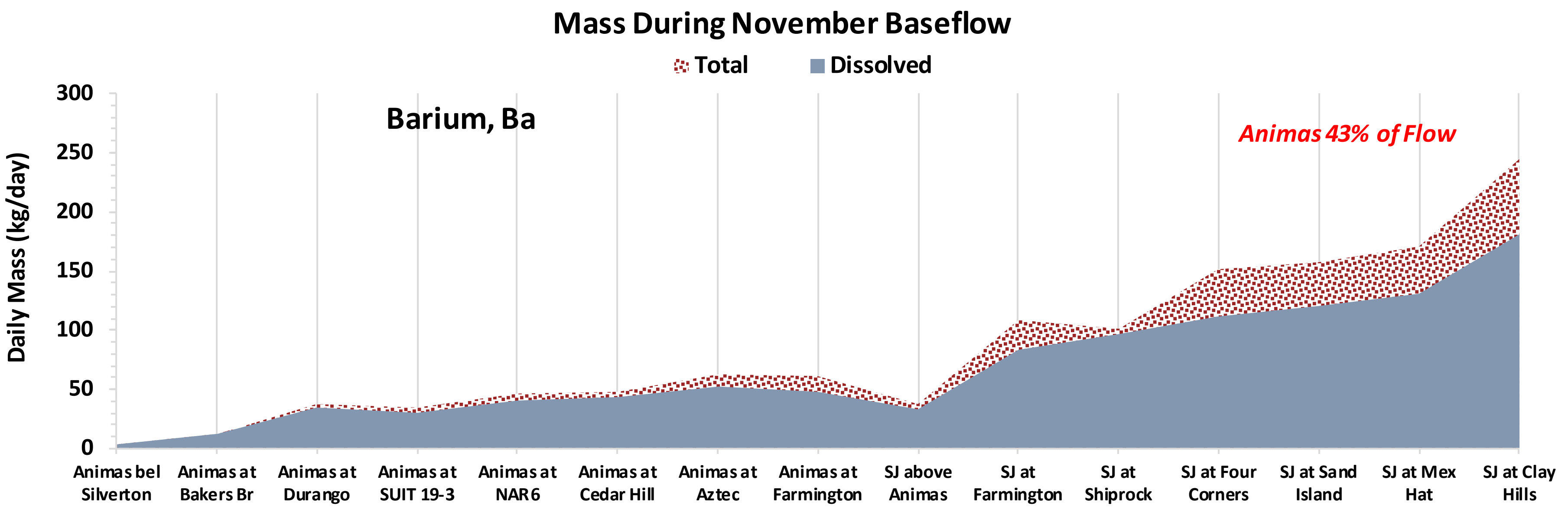
Mass During Snowmelt--May
Total
Dissolved
Daily Mass (kg/day)
Lead, Pb
Animas 97% of Flow
0
100
200
300
400
500
600
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills



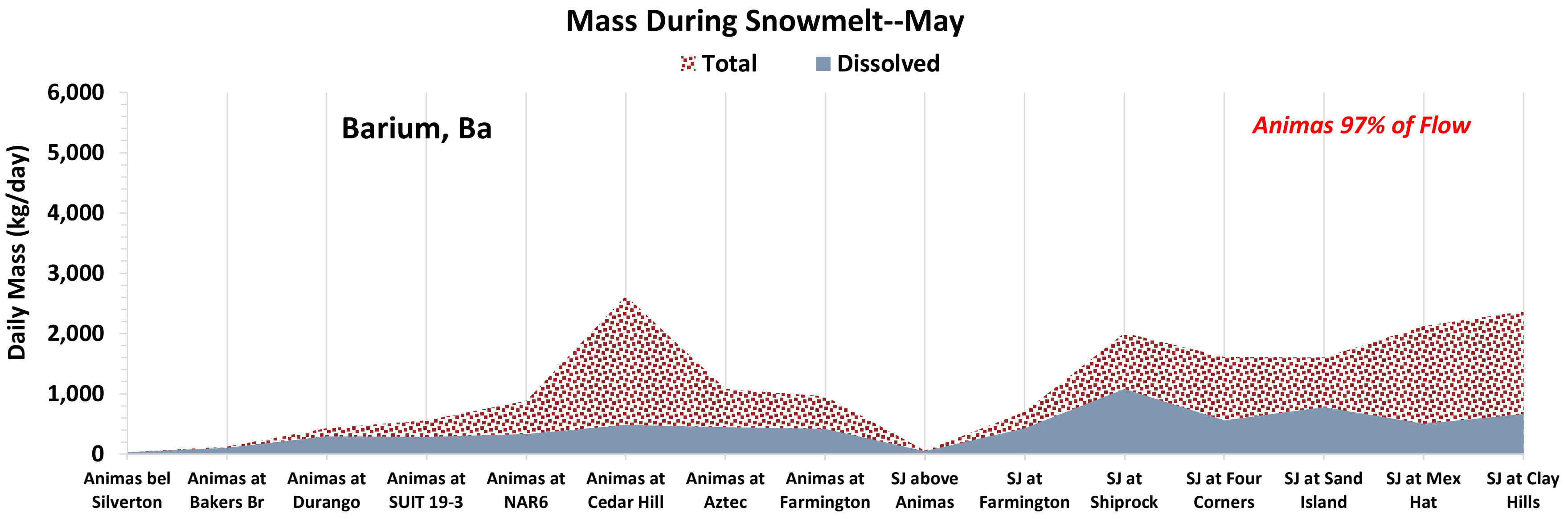
Mass During March Rain Storm
Total
Dissolved
Lead, Pb
Daily Mass (kg/day)
1,400
1,200
1,000
800
600
400
200
0
Animas 12% of Flow
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

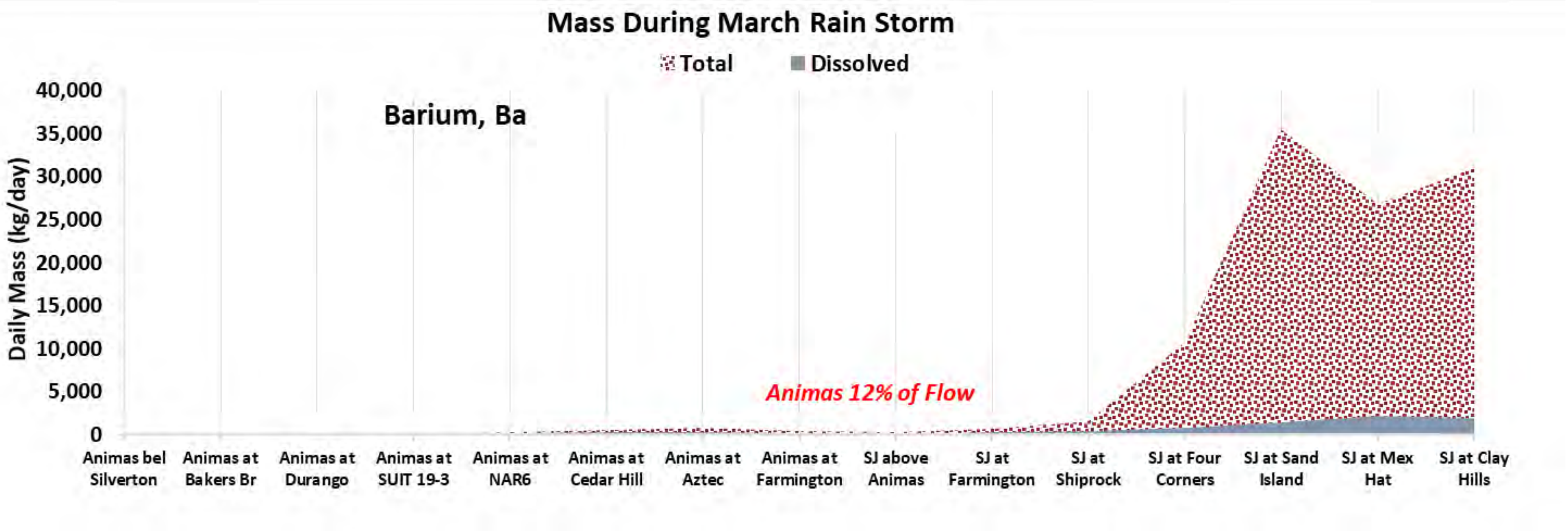


Mass During Snowmelt Peak --June
Total
Dissolved
Lead, Pb
Animas 60% of Flow
Daily Mass (kg/day)
1,400
1,200
1,000
800
600
400
200
0
Animas bel Silverton
Animas at Bakers Br
Animas at Durango
Animas at SUIT 19-3
Animas at NAR6
Animas at Cedar Hill
Animas at Aztec
Animas at Farmington
SJ above Animas
SJ at Farmington
SJ at Shiprock
SJ at Four Corners
SJ at Sand Island
SJ at Mex Hat
SJ at Clay Hills

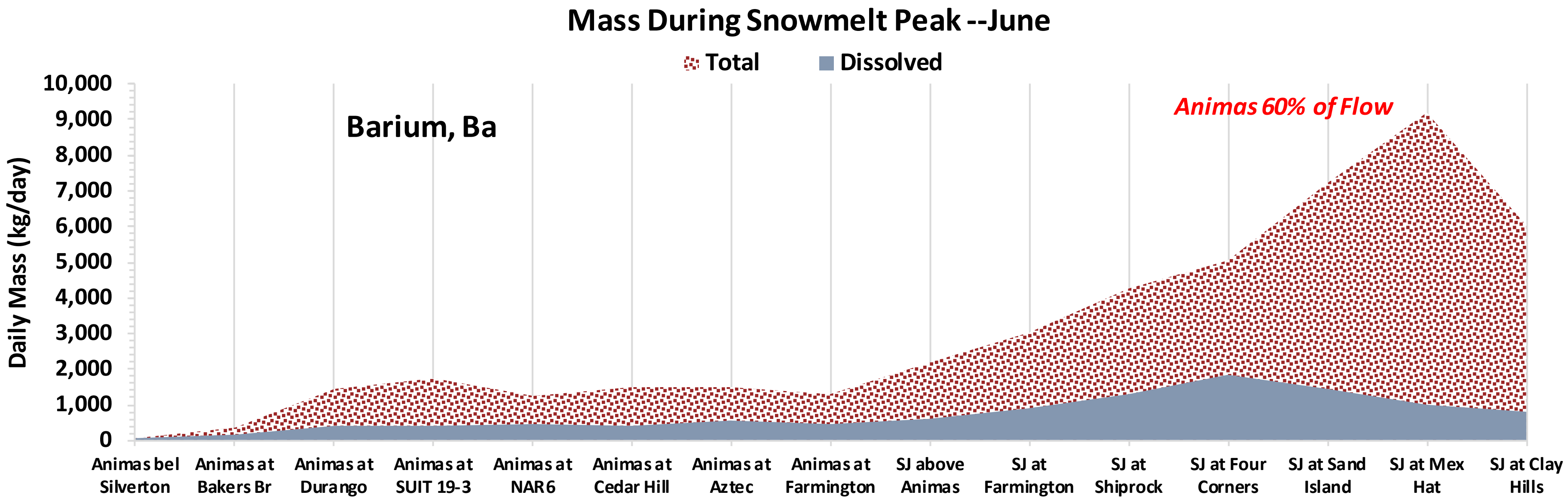


This metal responds to sediment only



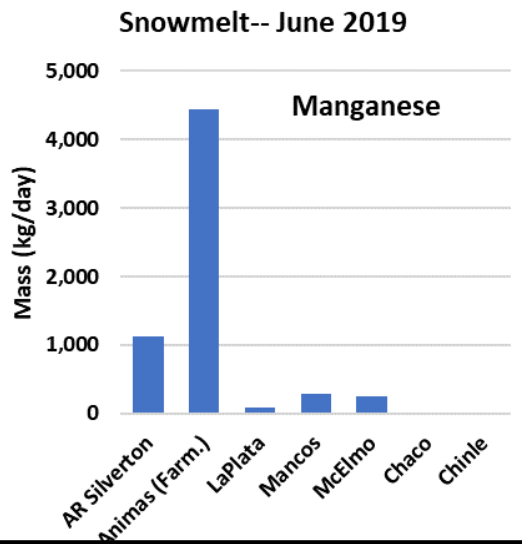


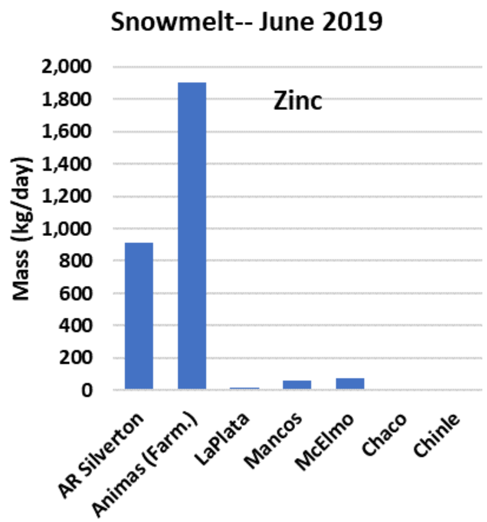
This metal responds to sediment only

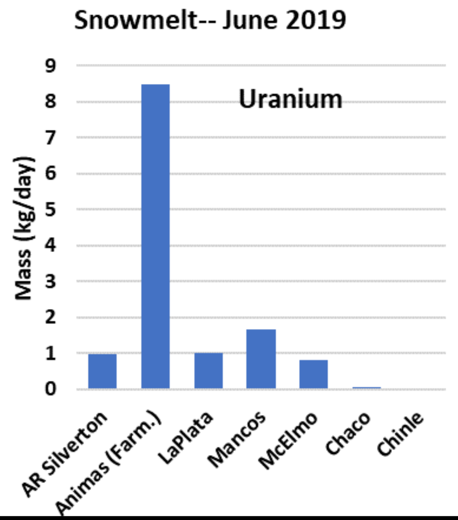


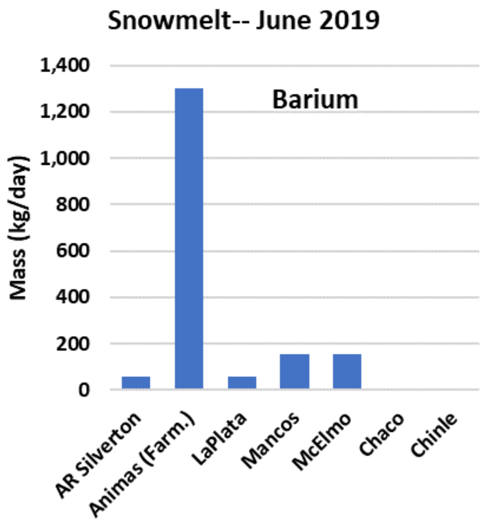
Role of Tributaries—Generally flow is too small to contribute significantly

Peak Snowmelt – June 2019

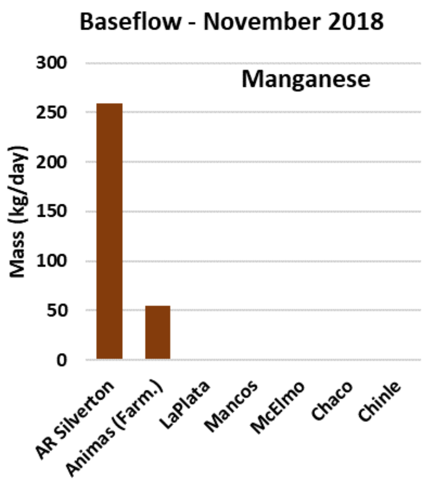


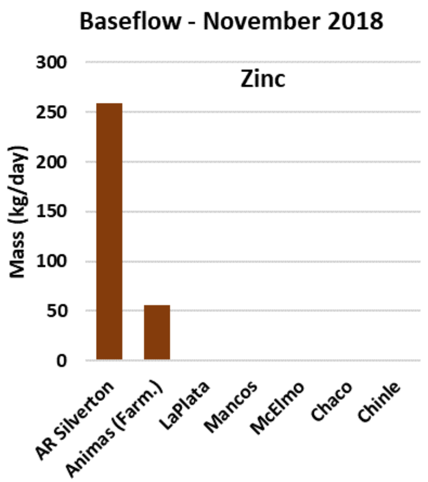


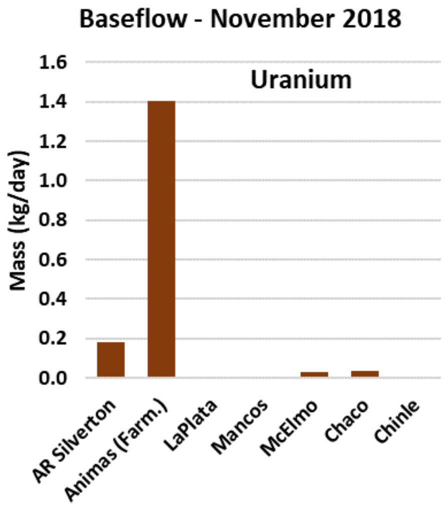


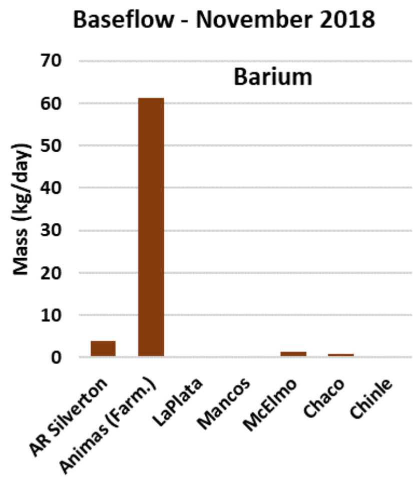


Baseflow – November 2018







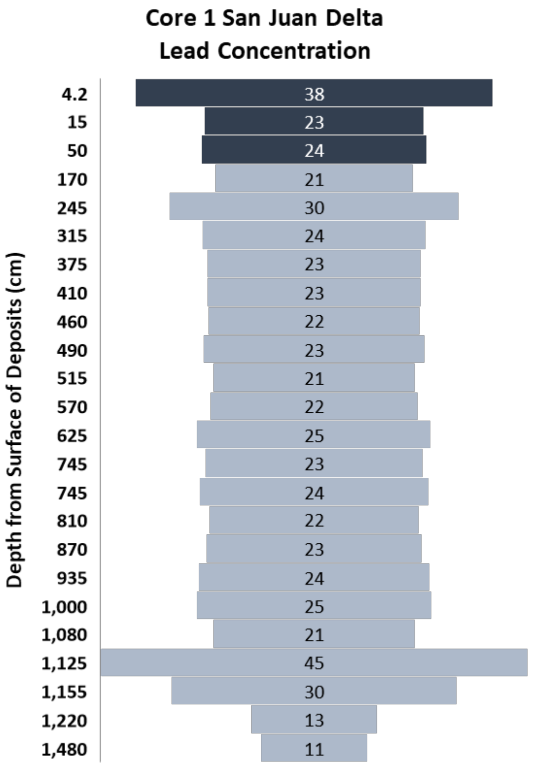


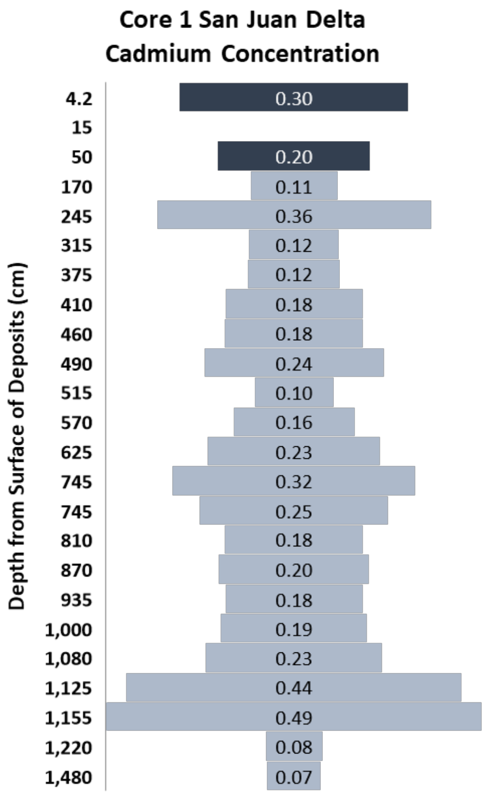
Cores from the lake bed near the head of the reservoir in 2010 tell the story of deposition from the watershed

Lake Powell Source Area Study

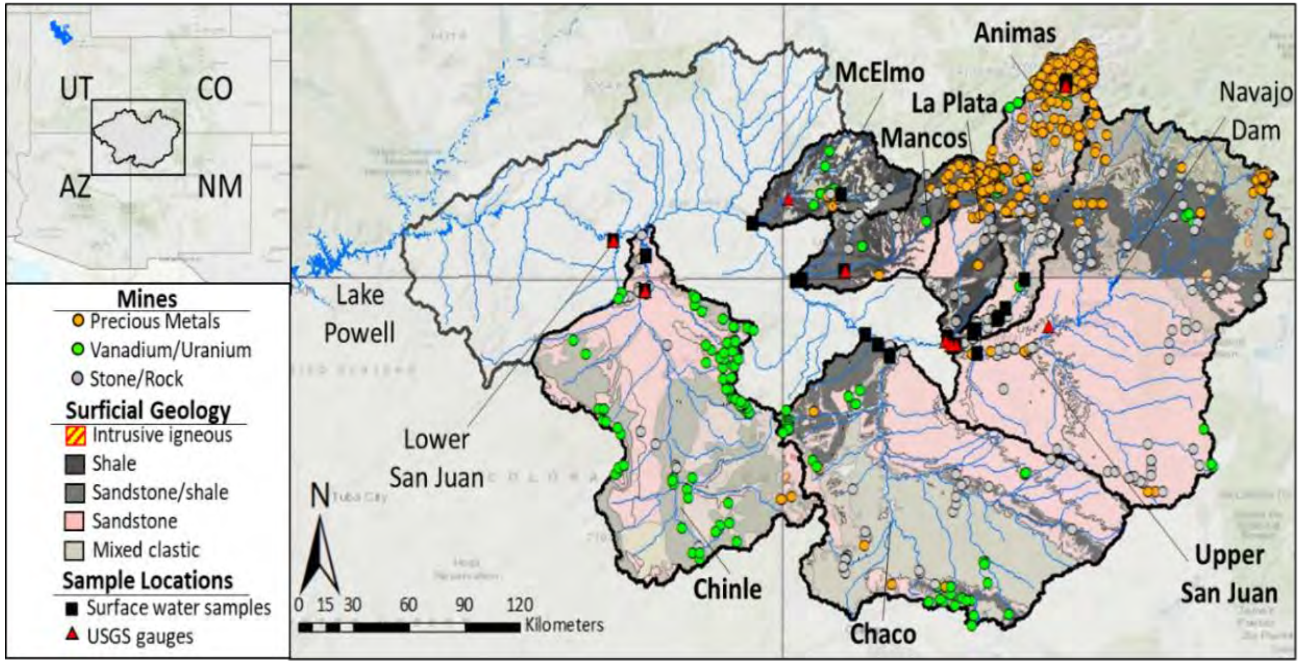
A study conducted by the University of Utah to assess the source of metals from the San Juan watershed deposited in the mouth of Lake Powell

The University of Utah project was designed to assess the source of metals delivered to Lake Powell from the San Juan by the San Juan River and its tributaries





Cores from the lake



From Frederick et al. 2018

Used metals data available from the rivers and tributaries to assess metal loads (similar to what was just showed)

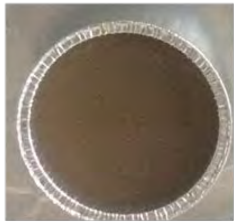
Source attribution used a combination of characteristics

Sediment Characteristics

Upper San Juan River

La Plata River

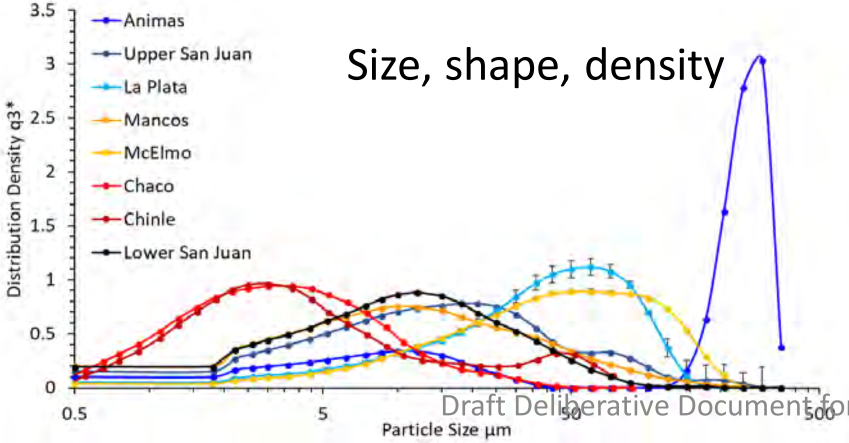
Mancos River



McElmo Creek

Chinle Creek

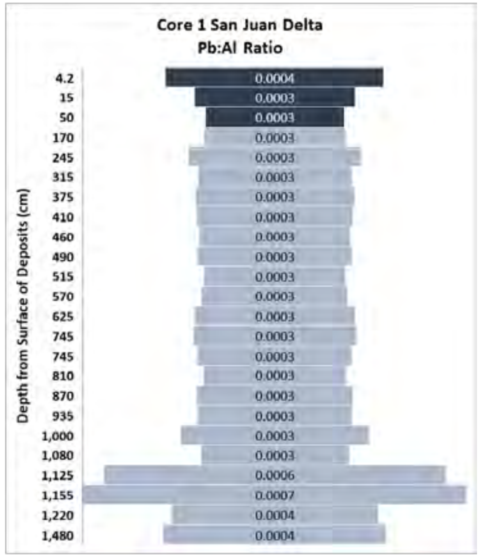
Lower San Juan River



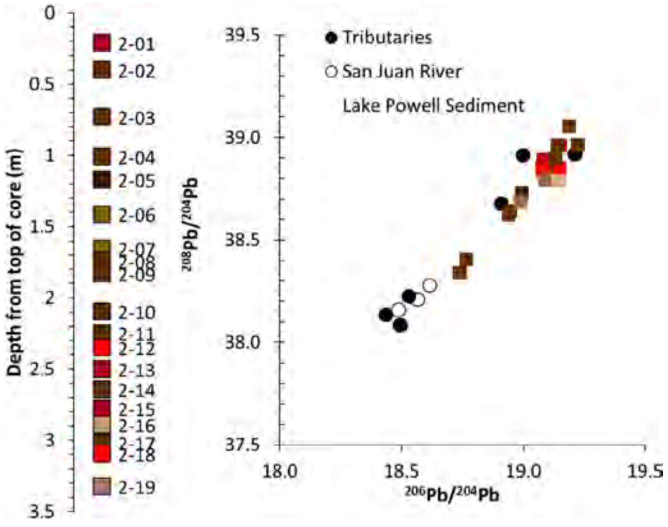
Size, shape, density

Metal Tracer Characteristics

Enrichment Ratios



Lead Isotopes

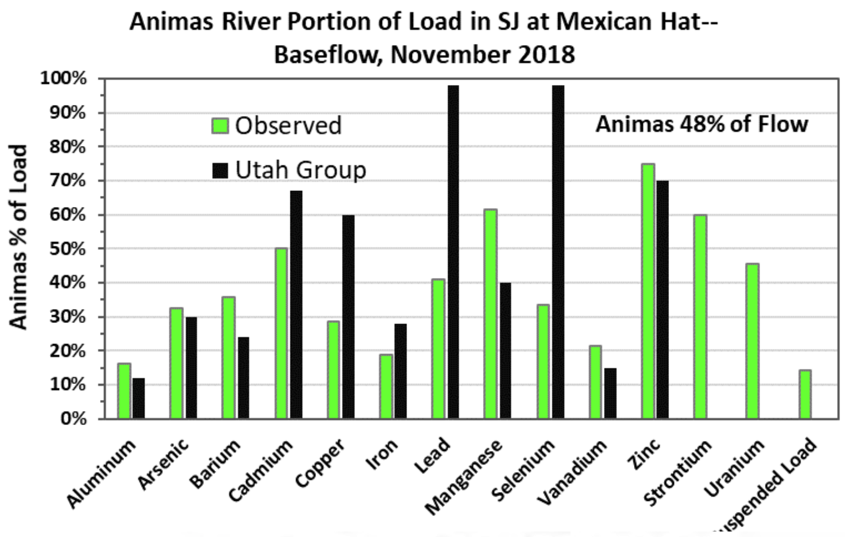


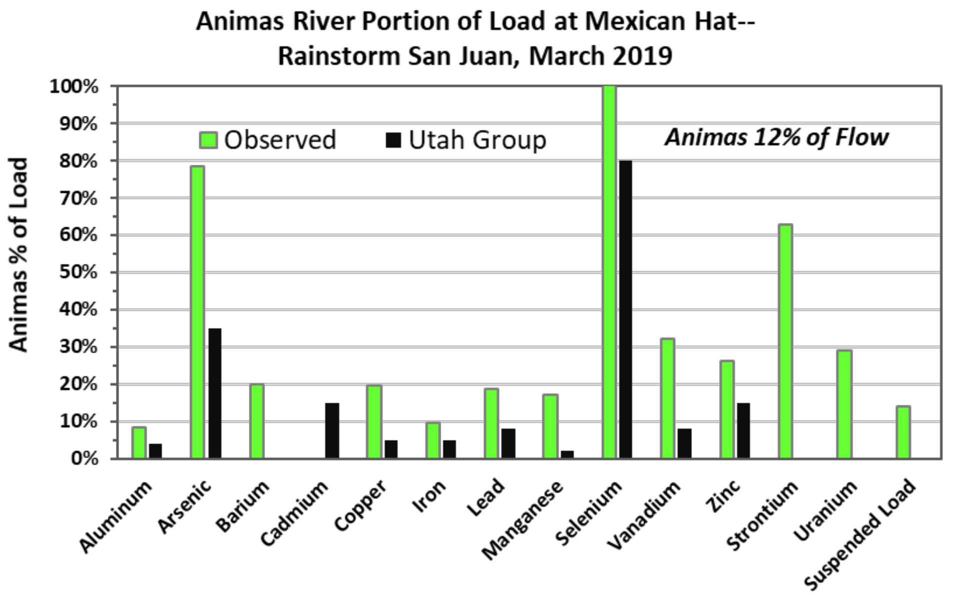
Key Results of the University if Utah Study

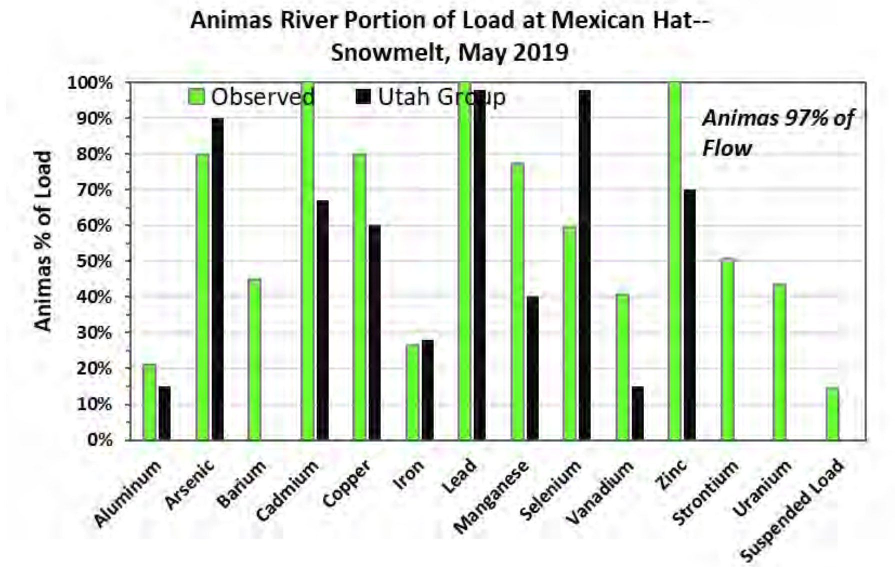
- The lithology of various locations in the watershed can be traced to the Lake Powell sediments using tracer techniques
- Hydrology (climate) determines which portion of the watershed contributes the most metals at any given time
- The Animas River was identified as a significant source of a number of metals during snowmelt

	Northern Tributaries ("Mined") Animas, LaPlata, Mancos, McElmo 9% of Area	**Southern Tributaries ("Unmined")** Chaco, Chinle 21% of Area	**The Rest of the Watershed** Canon Largo, Gallegos, Washes, Arroyos 70% of Area
Snowmelt (25% of the Time)			
Rainfall (14% of the Time)			
Baseflow (61% of the time)			

Apportioning to Hydrology and Tributaries: Compare to U. Utah Report

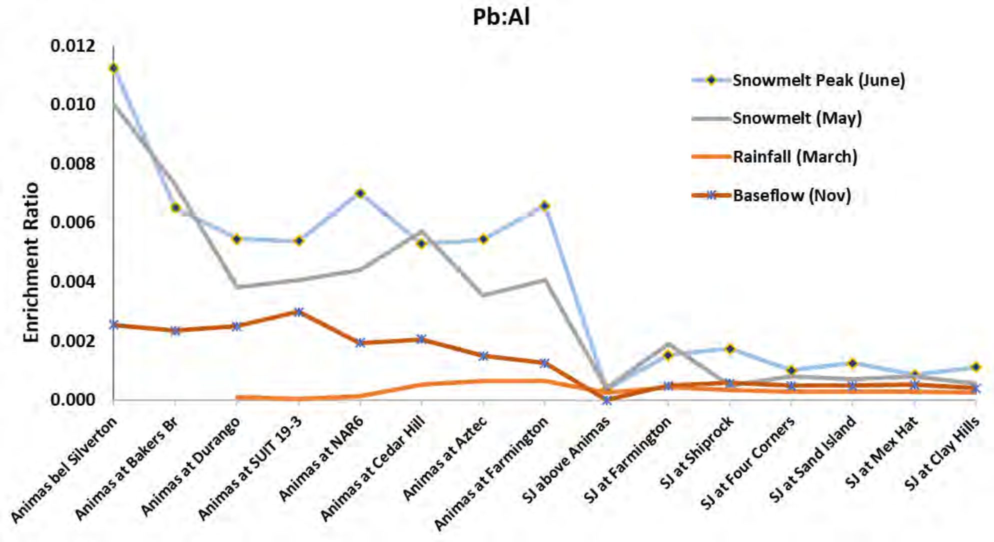


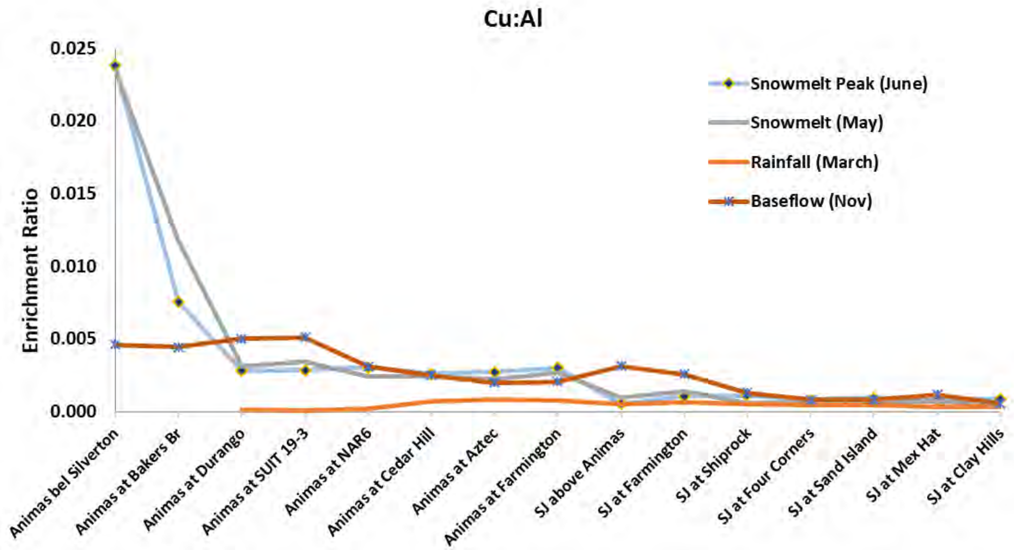


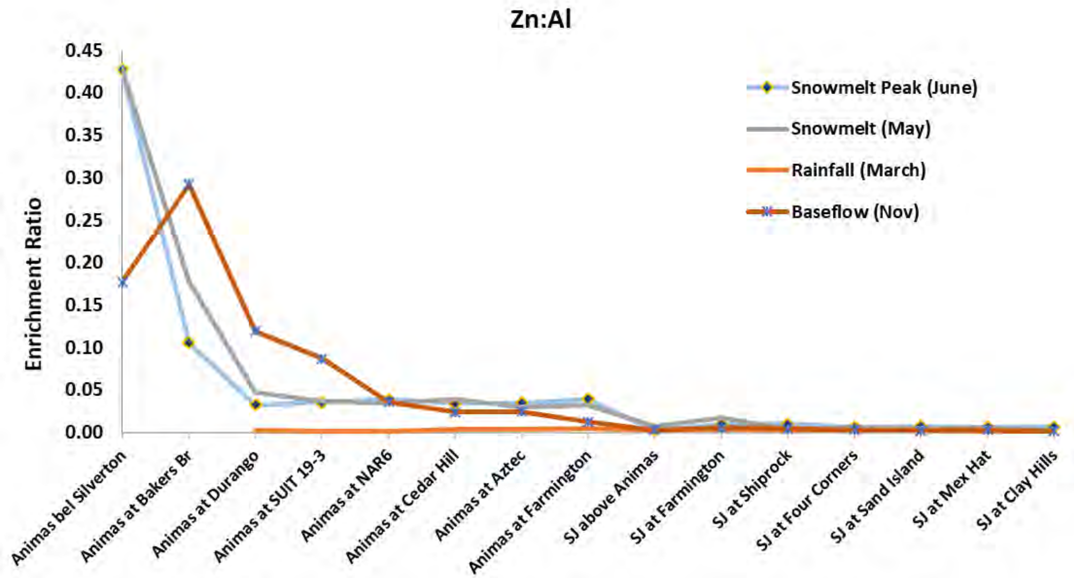


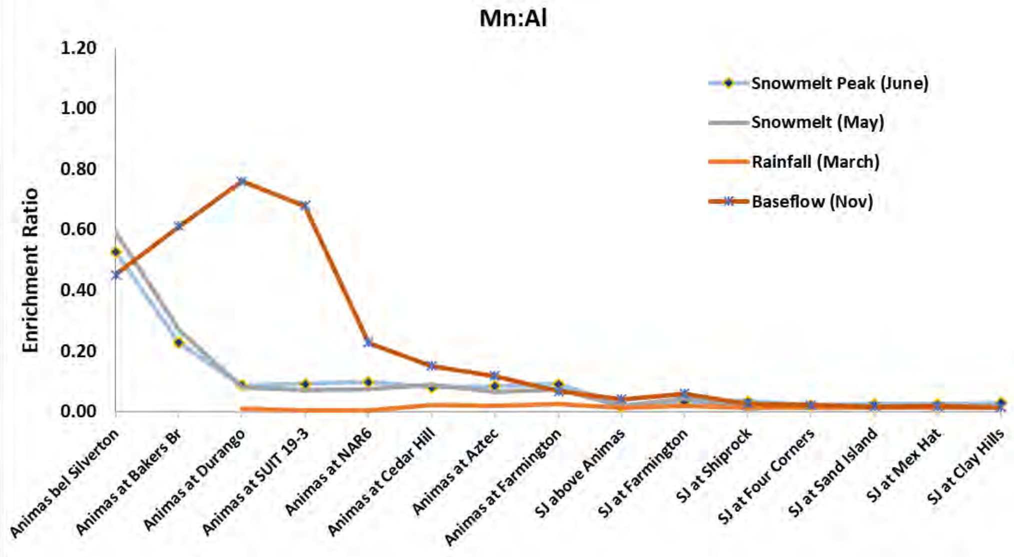
Relative attribution of mass with WINN monitoring data is generally in agreement with University of Utah findings

Enrichment Ratios confirm link of some metals to Animas headwaters volcanic intrusives . . .



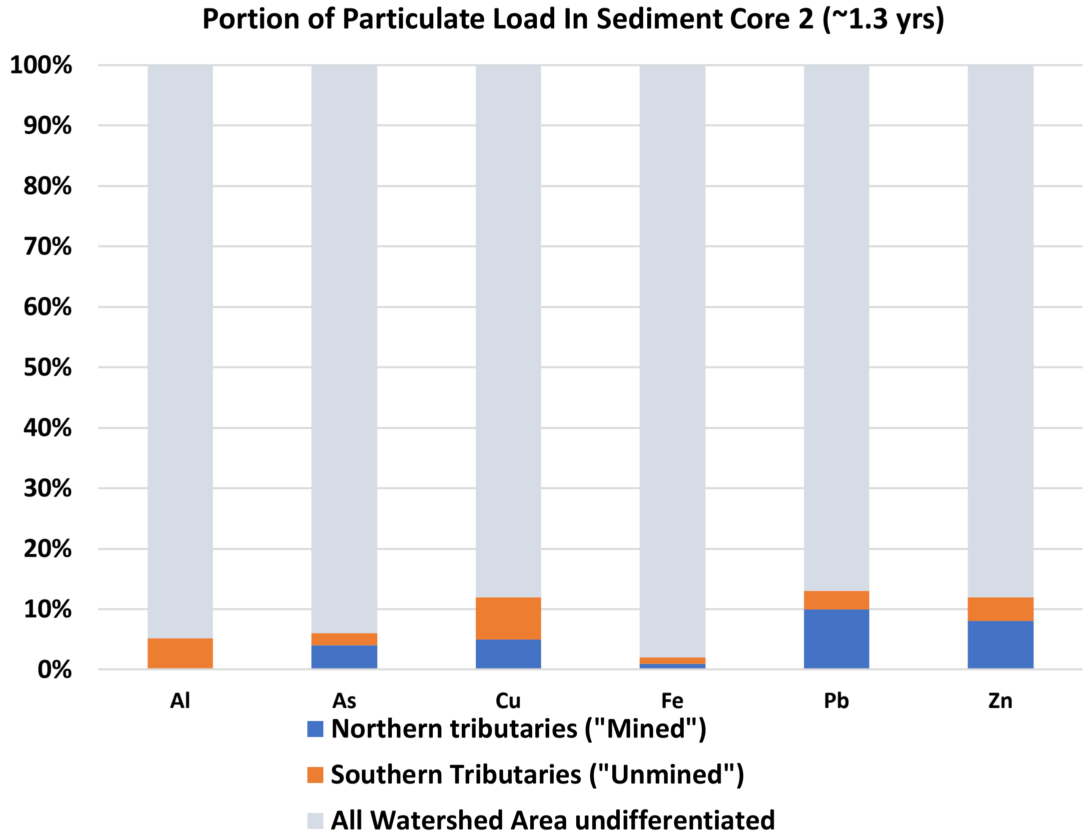






Source of Metals in Lake Powell Sediment Over the Coarse of a Year University of Utah Study

Metals apportioned at the sub-basin level over annual climate cycle show reasonable balance with the mixture of geologies present in the watershed area

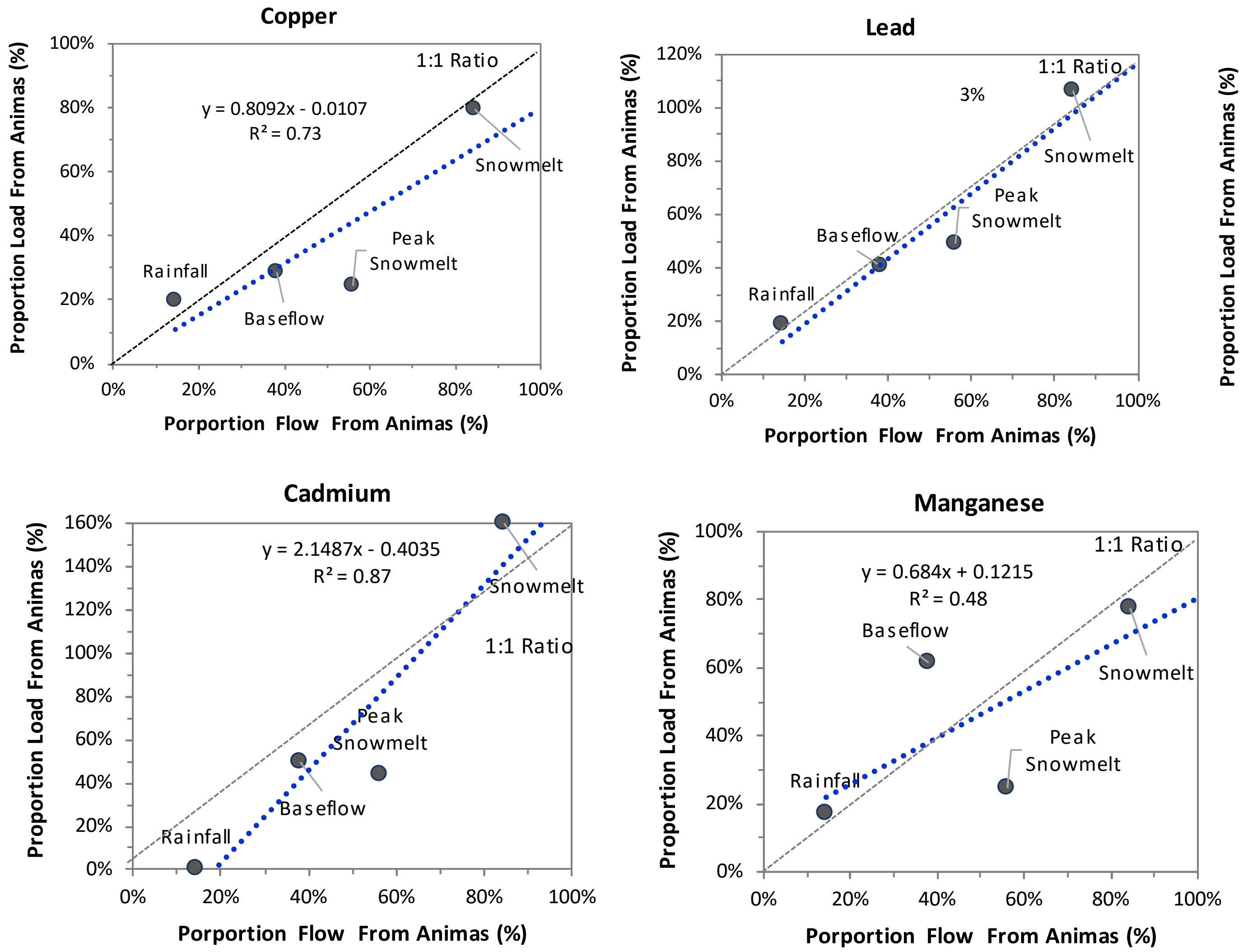


Northern Tributaries 9% Area: Animas, LaPlata, Mancos, McElmo

Southern Tributaries 21% of Area Chaco, Chinle

Rest of Watershed Area: 70%

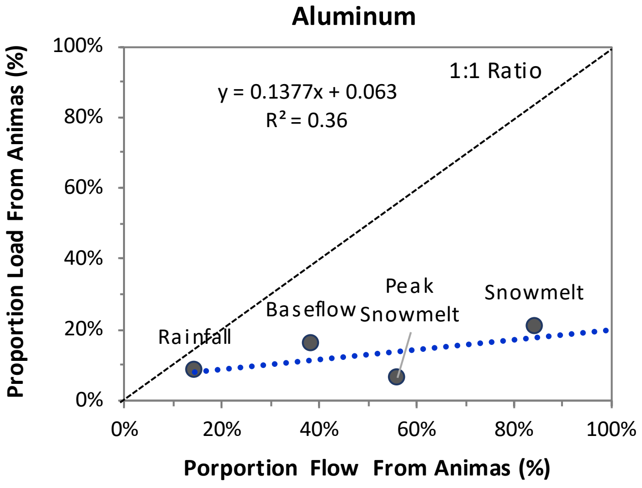
The proportion of flow contributed by the Animas appears to explain . . .

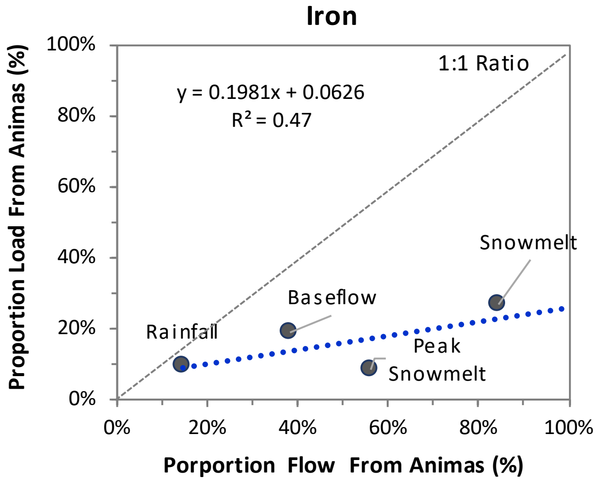


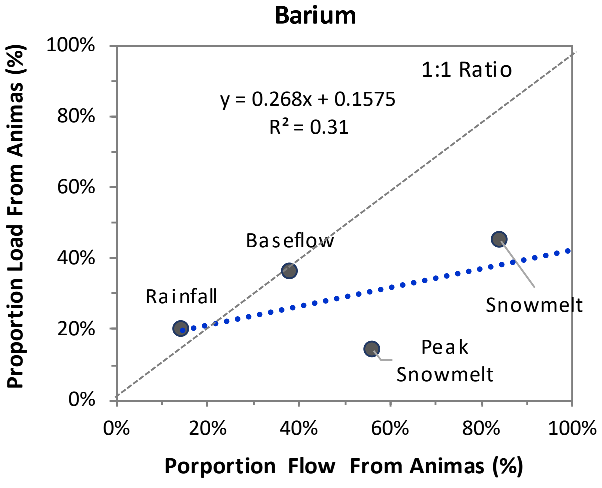
The metals associated with the Animas

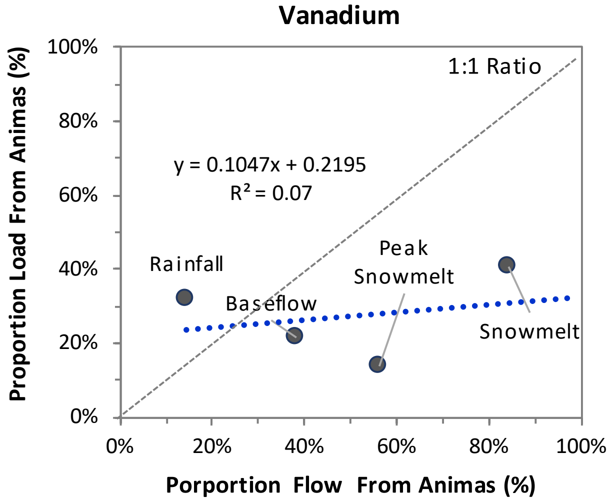
- Copper, Cu
- Lead, Pb
- Zinc, Zn
- Cadmium, Cd
- Manganese, Mn

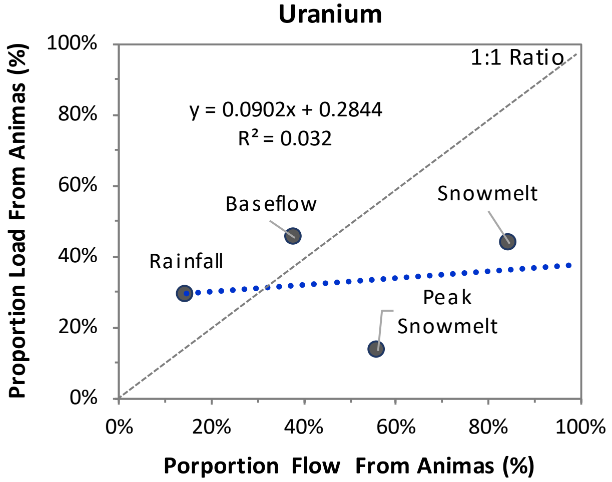
The proportion of water contributed by the Animas does not influence the metals that are strongly correlated to sediment

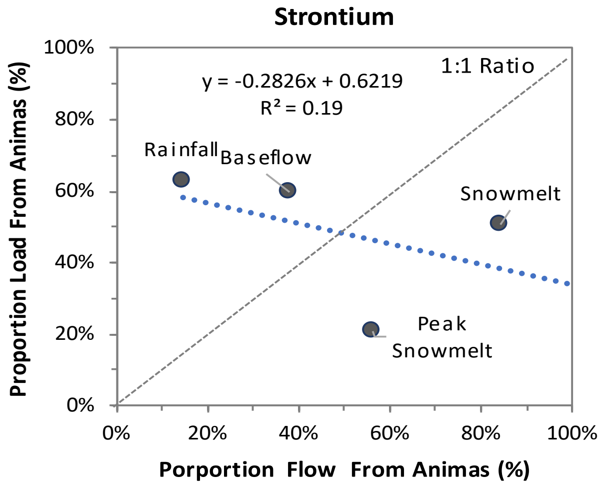












- **Aluminum, Al**
- **Iron, Fe**
- **Arsenic, As**
- **Barium, Ba**
- **Vanadium, V**
- **Selenium, Se**
- **Uranium, U**
- **Strontium, Sr**

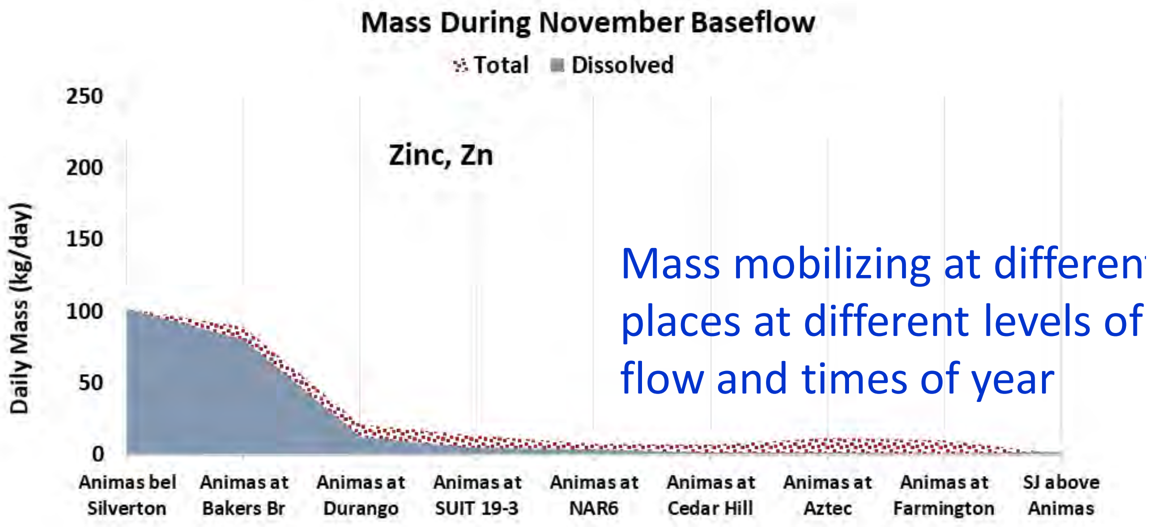
Summary

- The watershed is composed of diverse geologies: metals rich ores in the northern tributaries and sandstone and siltstone sediments in the majority of the land area
- Dissolved and total metals are sourced from geologic types through different mechanisms, varying by metal.
  - Most of the metals are related to sediment throughout the watershed
  - Some of the metals are also associated with the volcanic intrusive ores (Cu, Zn, Cd, Pb, Mn)
- Tracers can help identify dominant sources
- The ore-rich geology typically dominates during snowmelt
- Monsoonal type rain events are short-lived but metals mass carried can be larger than during snowmelt
- The influence of the Animas River on the metals in the San Juan River depends on how much flow it supplies

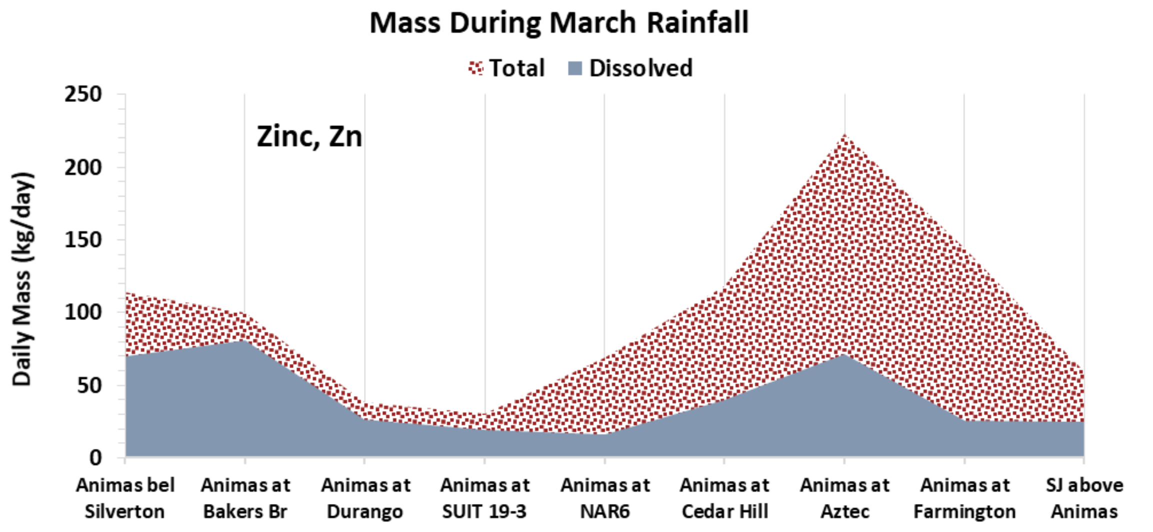
Metals Within the Animas

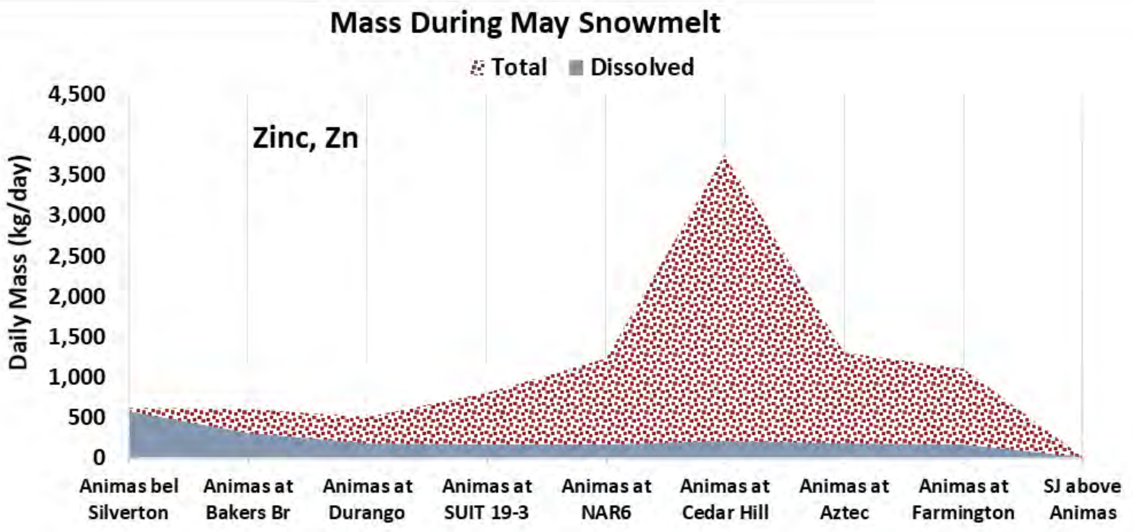
Complex due to mix of geologies and land use

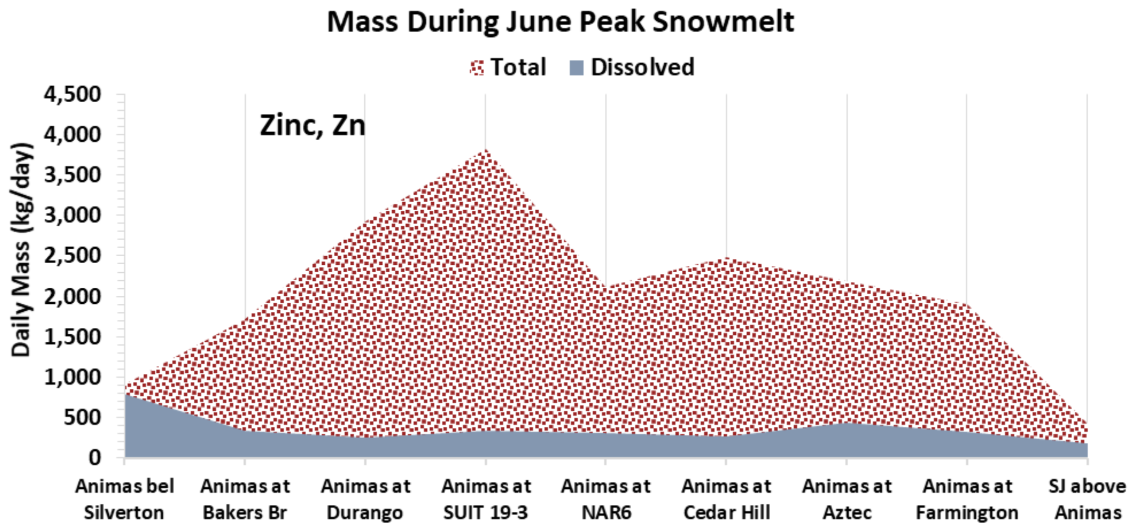
Zinc in the Animas River



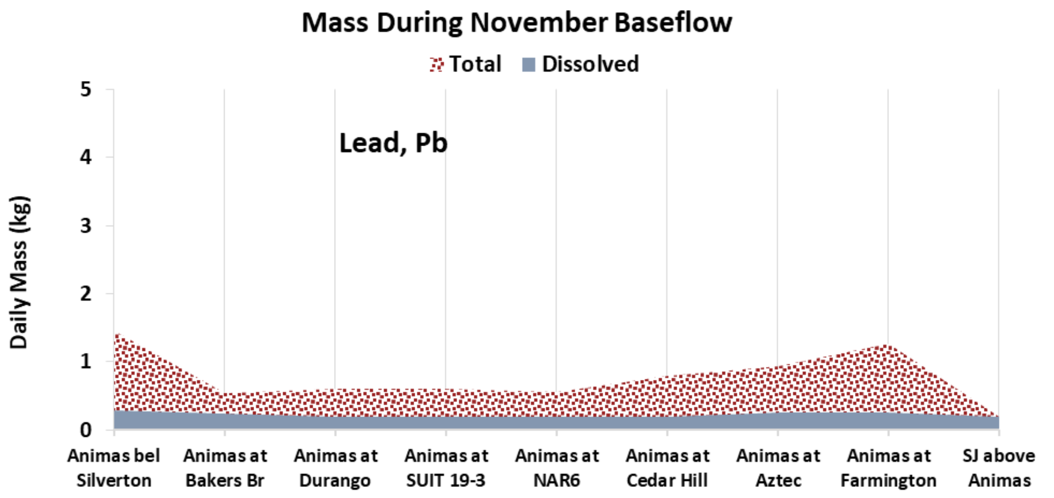
Mass mobilizing at differen[t] places at different levels of flow and times of year

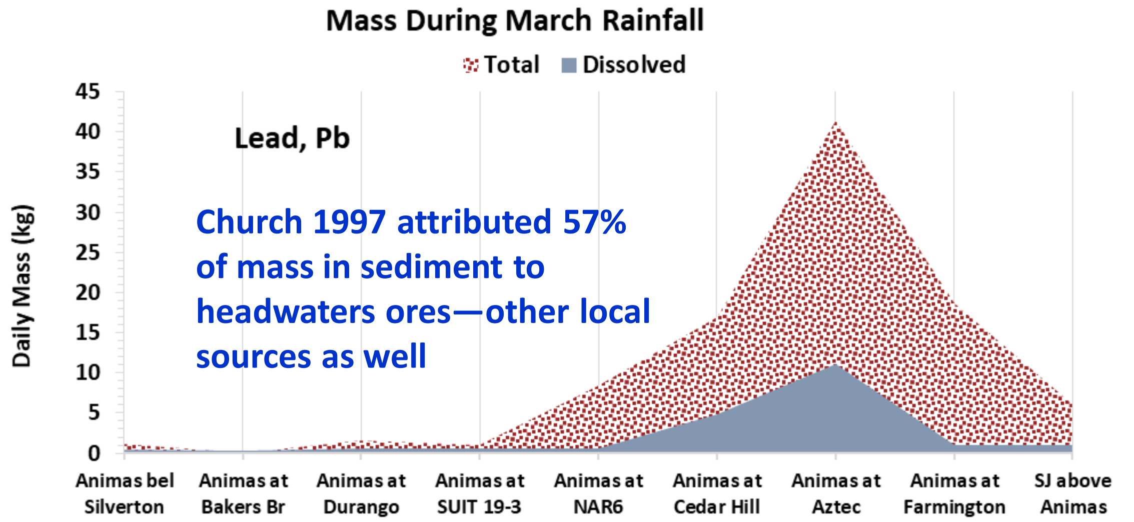




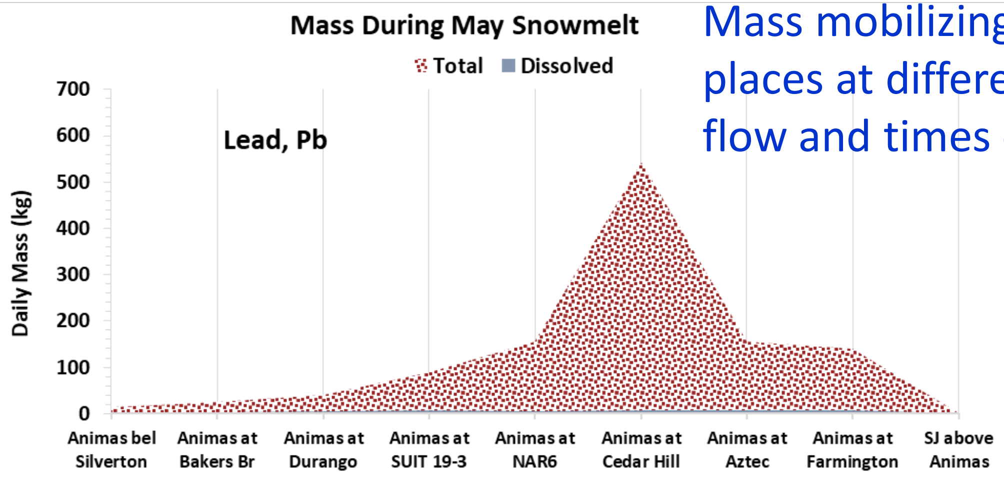


Lead in the Animas River

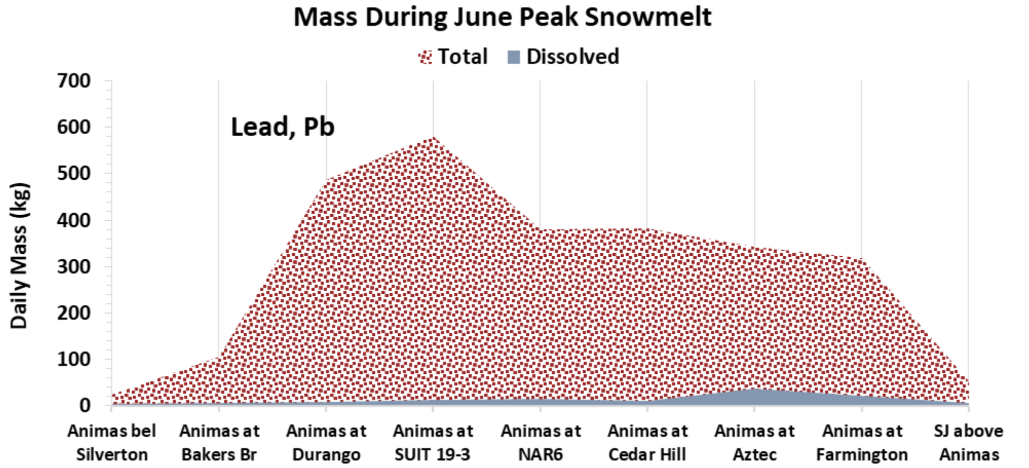




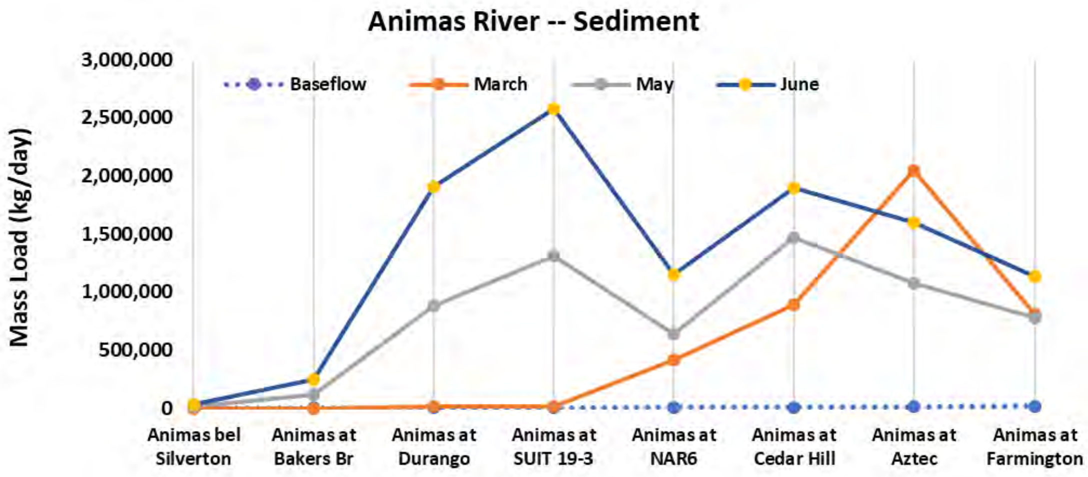
Church 1997 attributed 57% of mass in sediment to headwaters ores—other local sources as well

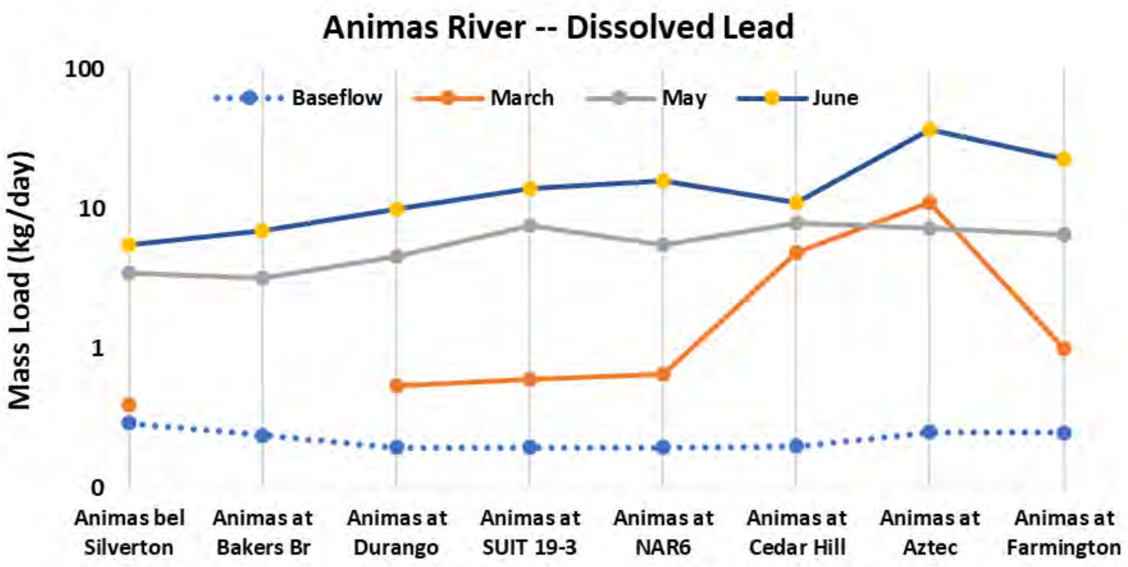


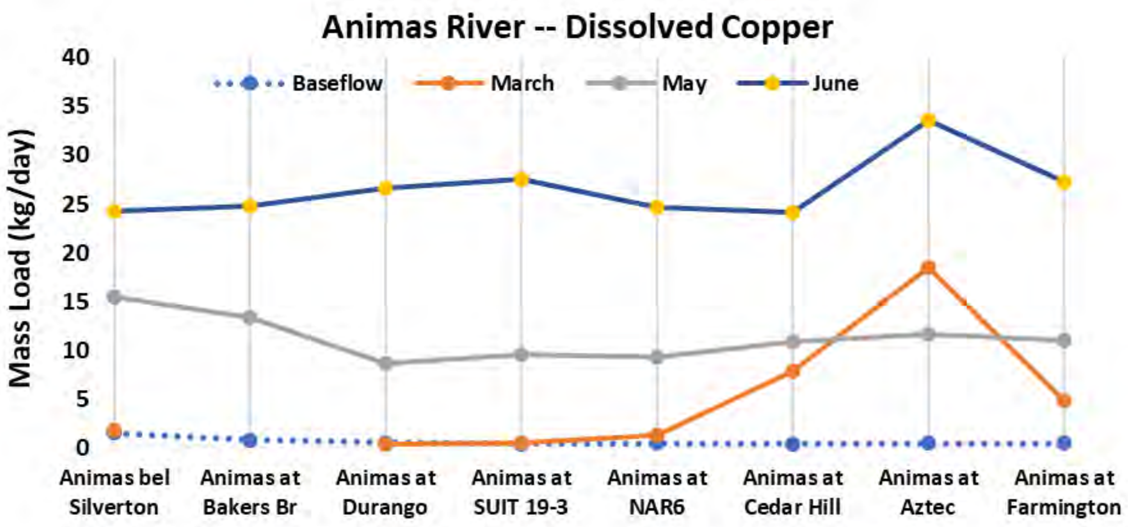
Mass mobilizing at different places at different leve flow and times of year



All Sampling Periods—Animas River

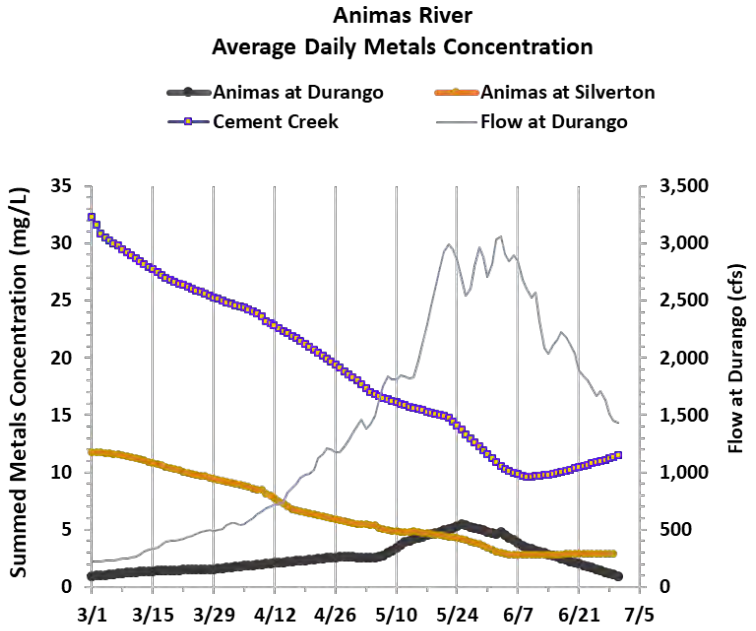






Raises questions about local sources within the middle and lower Animas relative to metals delivery from the Upper Animas
Modern? Lag? Historic?

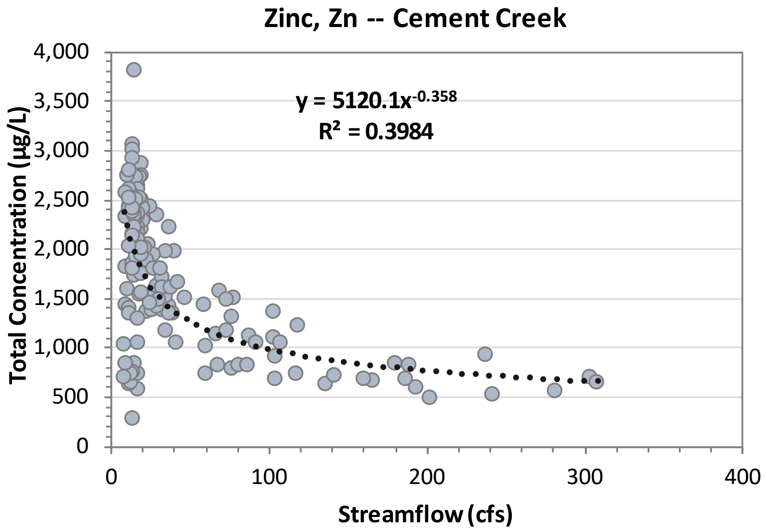
Metals Mass within the Upper Animas

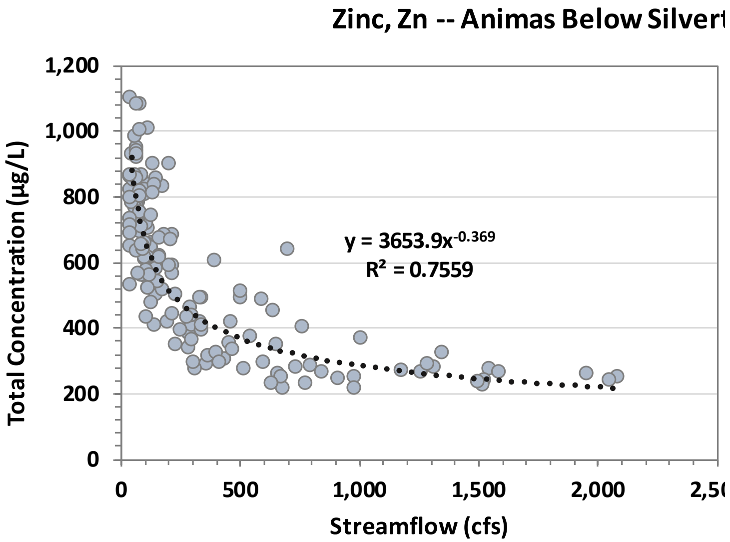


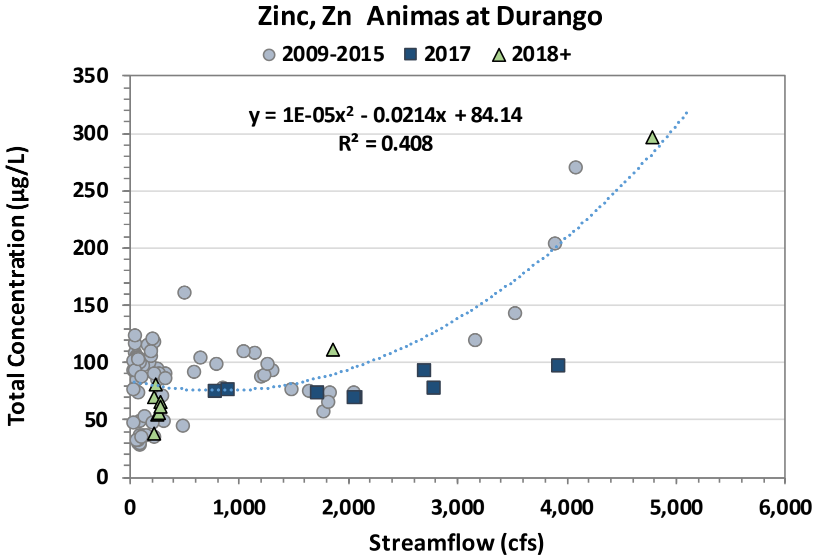
Build models to estimate metals concentrations from flow or other parameters (e.g. LOADEST)

--Estimates only as good as the model

--My preliminary model predicts well at baseflow but misses the largest peaks



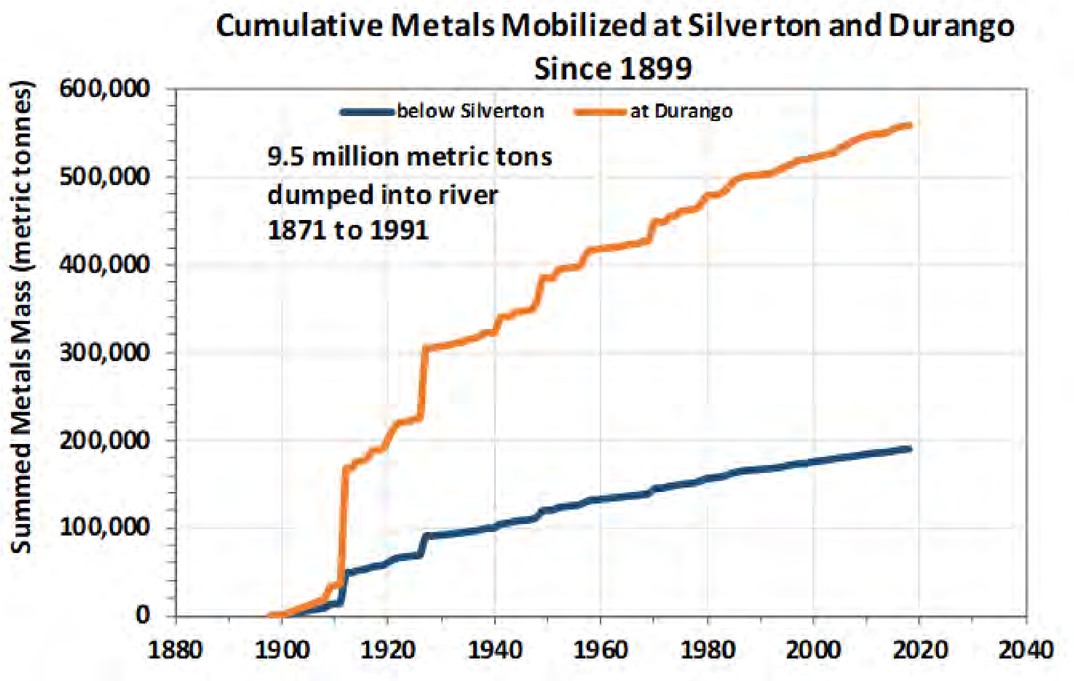




The Animas tends to entrain more metals than produced in the headwaters each year, depending on peak flow

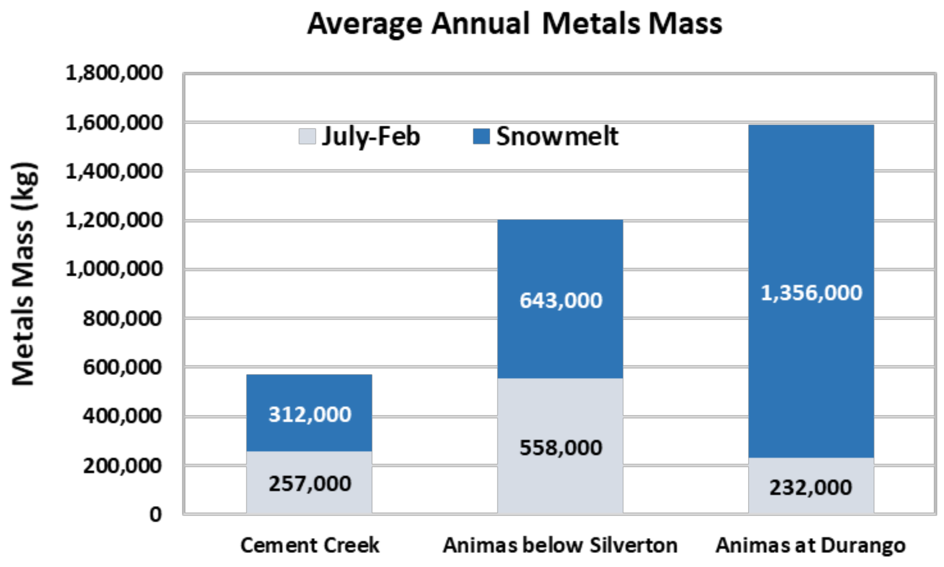
Is this additional mass historically deposited mining waste?

The USGS estimated that 9.5 million metric tons of waste was dumped into or near the river during 100 years of mining operations

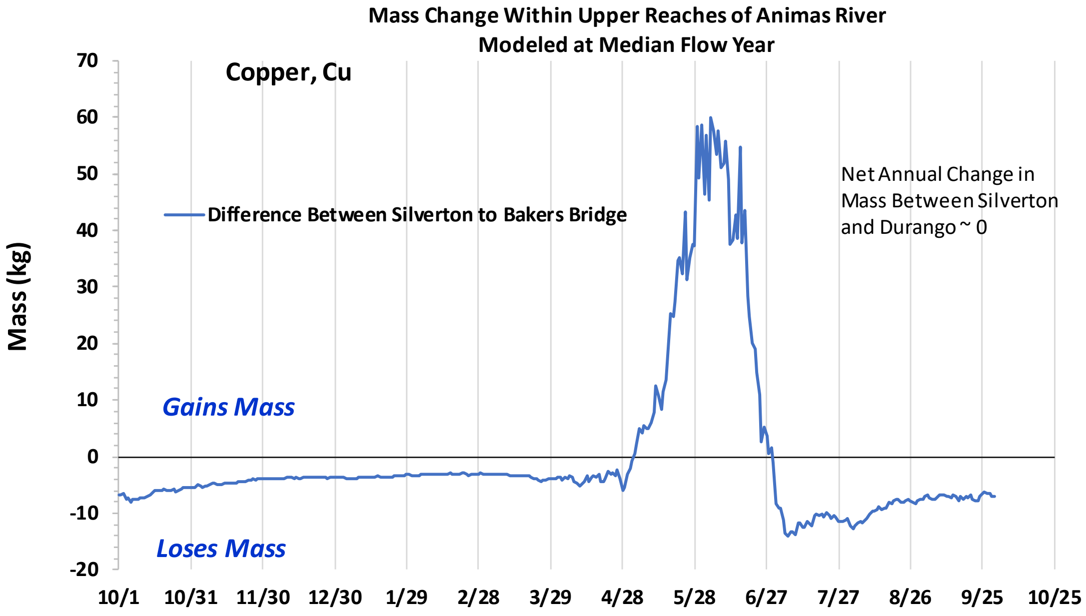


Annual Mass Transfer Within the Headwaters

Annual



Daily



Flow in this estimate is median daily flow

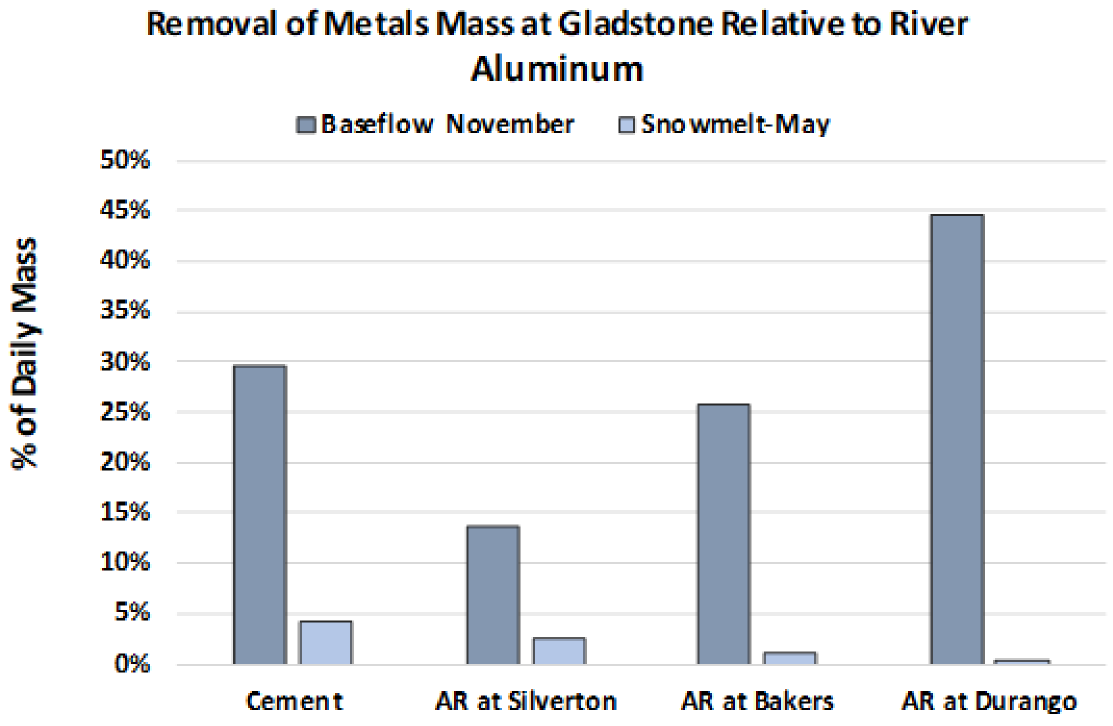
Daily model suggests the mass in the Animas leaving Silverto during baseflow from ~ about March to August

- **is small**
- **generally declines between Bakers Bridge and Durango indicating storage within the reach.**

Metals are re- entrained during higher flows ~ 500-1000 cfs at Durango

Most of the metals generated in the upper Animas are removed past Bakers Bridge during snowmelt

Reduction potential of the Gladstone treatment facility

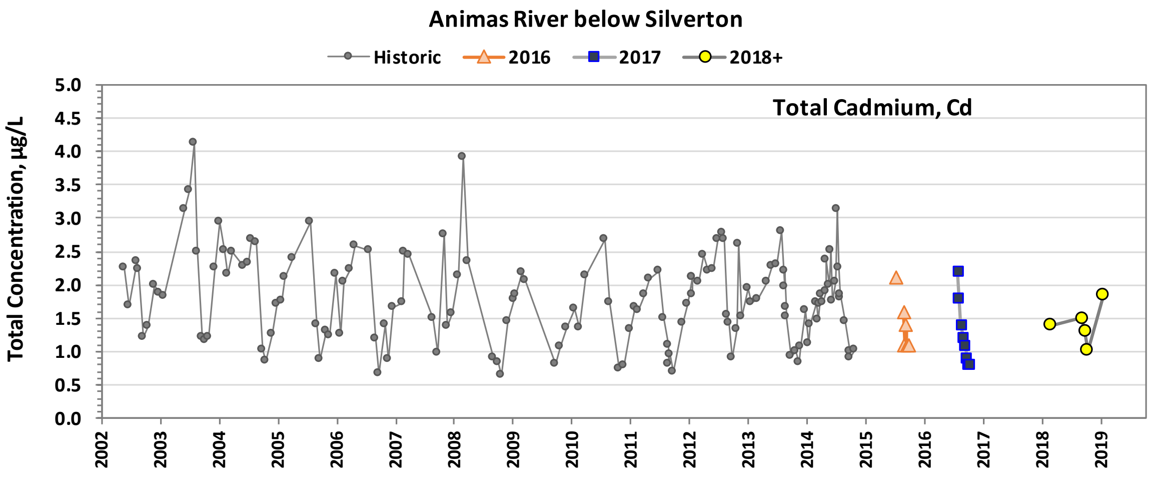


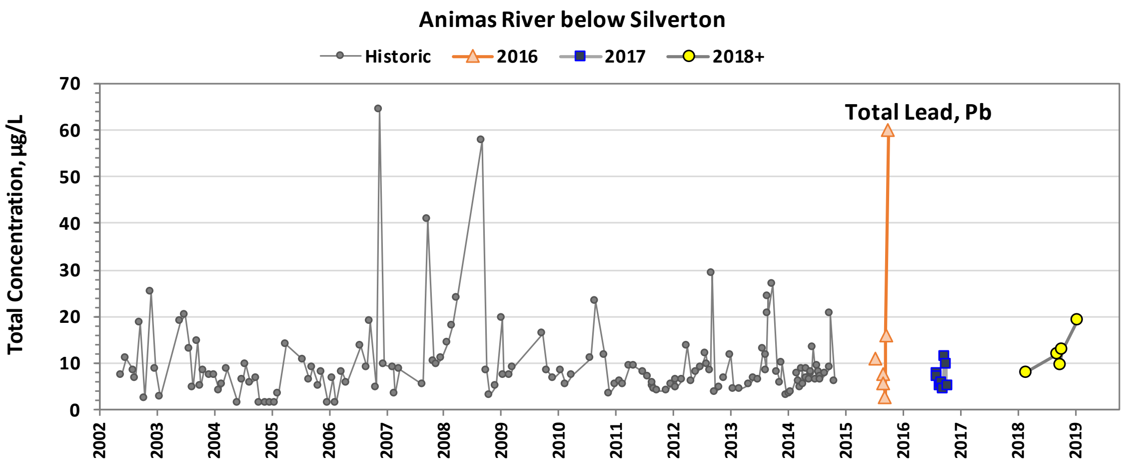
All estimates will be improved with additional modeling project and measurements within the Silverton to Bakers Bridge reach

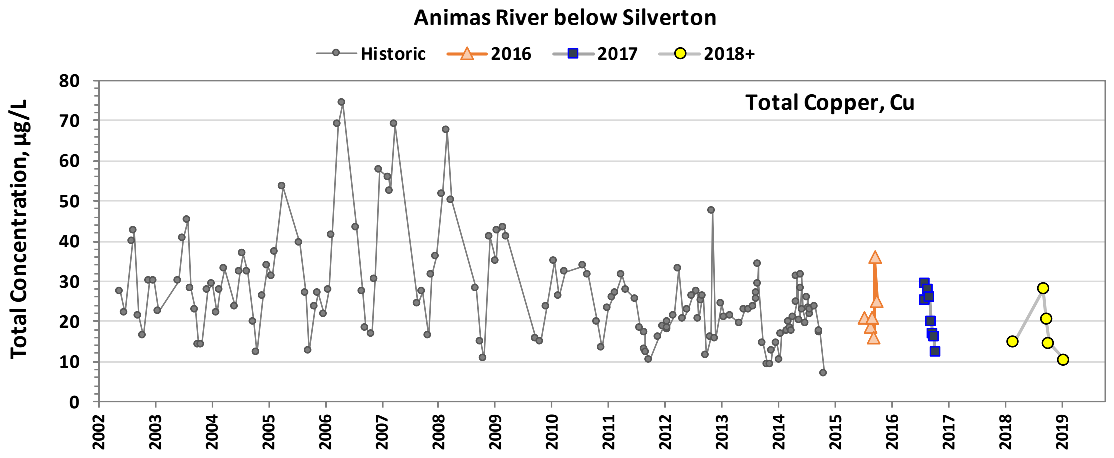
This calculation assumes that any reduction in concentration translates downstream immediately

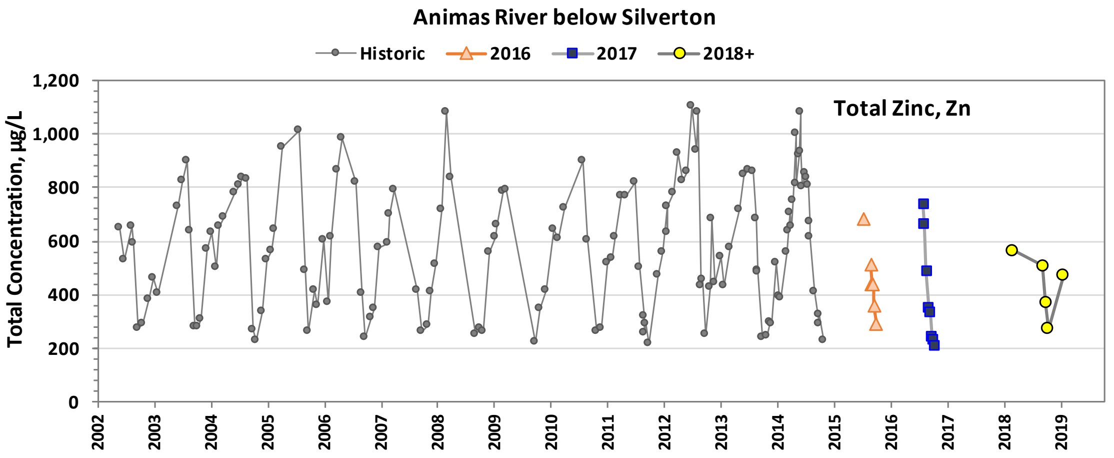
Better understanding of mass transfer from Silverton to Durango on finer timescales would help to define how much benefit may be experienced downstream from the Gladstone treatment facility

Trends in Water Quality in the Animas below Silverton









Assessing Water Quality

FRAMEWORK

	Northern Tributaries ("Mined") Animas, LaPlata, Mancos, McElmo 9% of Area	**Southern Tributaries ("Unmined")** Chaco, Chinle 21% of Area	**The Rest of the Watershed** Canon Largo, Gallegos, Washes, Arroyos 70% of Area
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Rainfall (14% of the Time)			
Baseflow (61% of the time)			