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

Water Quality Since the Release Event

August 2015 to November 2016

Gold King Team
National Exposure Research Lab/ORD

January 3, 2017

Fate of the Gold King Mine released metals

- **Approximately 500,000 kg estimated to have been delivered from mine to Animas River at Silverton**
  - 1% from within mine
  - 99% from waste pile outside
- **90% of mass deposited in the Animas River**
  (most between Silverton and Durango CO)
- **5% deposited in the San Juan River**
  (distributed over 250 km)
- **5% to Lake Powell**

Gold King Effects Continued After the Plume Passed

CURRENT QUESTIONS:

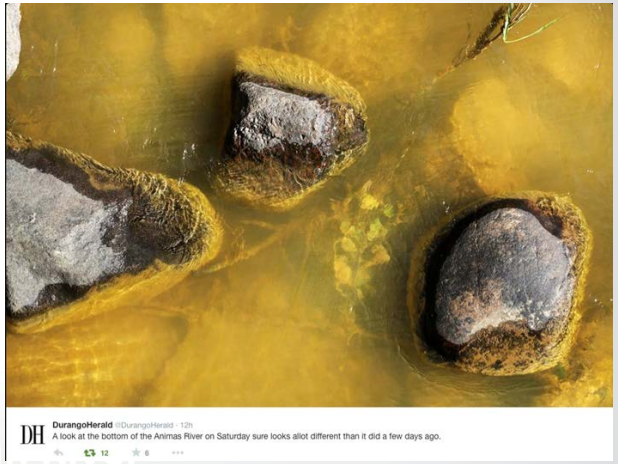
- **What were the Gold King effects on water quality after the event?**
- **Has water quality returned to pre-event conditions?**
- **Was there be a second wave of contamination during 2016 snowmelt when high flows could mobilize deposits?**
- **Can we recognize the Gold King influence given the pre-existing contamination from historic mining?**

What Was Left Behind

Sludge-like material

Colloids (Paint-like)

Deposits along channel margins



Key Findings—Gold King Release Post Event

- ORD produced hydrologic and geochemical evaluations of the Gold Kin release during and for a year following the release
- Post event water quality response from August to October 2015 varied location
  - Animas in Colorado returned to background
  - Animas in New Mexico and San Juan River had some elevated metals above expected
- 2016 snowmelt had elevated metals throughout the system—partly from Gold King, partly from historic mining impacts
  - Model results and analyses indicate GKM metals now out of rivers
  - 2016 samples after snowmelt at pre-event levels at all locations
  - We have a "fingerprint" unique to identify metals of the Gold King release
- There were some water quality exceedances before, during the plume and post event varying by location and state or tribe, some due to Gold King
- ORD findings will help inform EPA monitoring and reporting

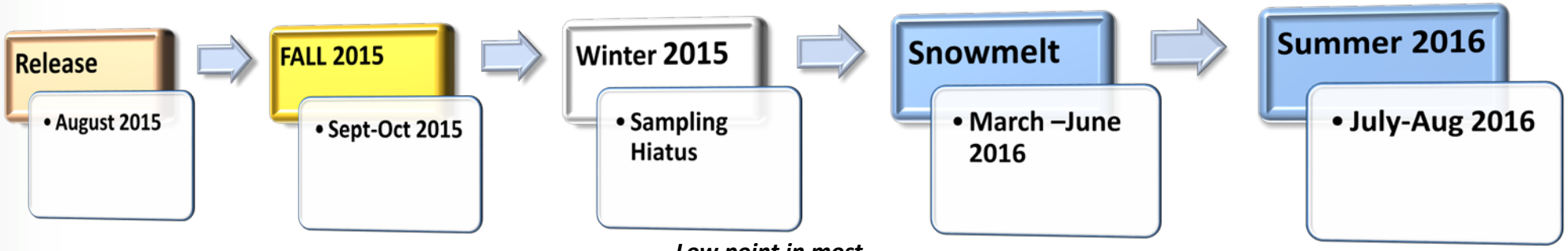
Animas at Bakers Bridge (above) and popular swimming beach north of Durango (right)

August 2016

Both areas experienced high settling rates during plume

Synopsis of Post-Event Trends

Gold King release effects on water quality depended on where and when



Mass analysis and water quality suggests Gold King release out of river system

- Deposition of materials through entire 550 km river
- WQ returned towards background within days
- Adjustments to water chemistry into August (1-3 weeks)

- Post event water quality varied by location
- Some water quality criteria exceedances
- Extensive monitoring reveals chronic water quality exceedances not related to Gold King

Low point in most metals going into winter

- Expect elevated metals in upper Animas due to past contamination
- Metals elevated during snowmelt throughout the system
- Some evidence of additional metals due to Gold King
- Metals in sediment and water back to low concentrations by end of snowmelt

August – November 2016 Water and sediment concentrations are the same or lower than Fall 2015

Water and Sediments Monitored Since the Release

POST GOLD KING MONITORING

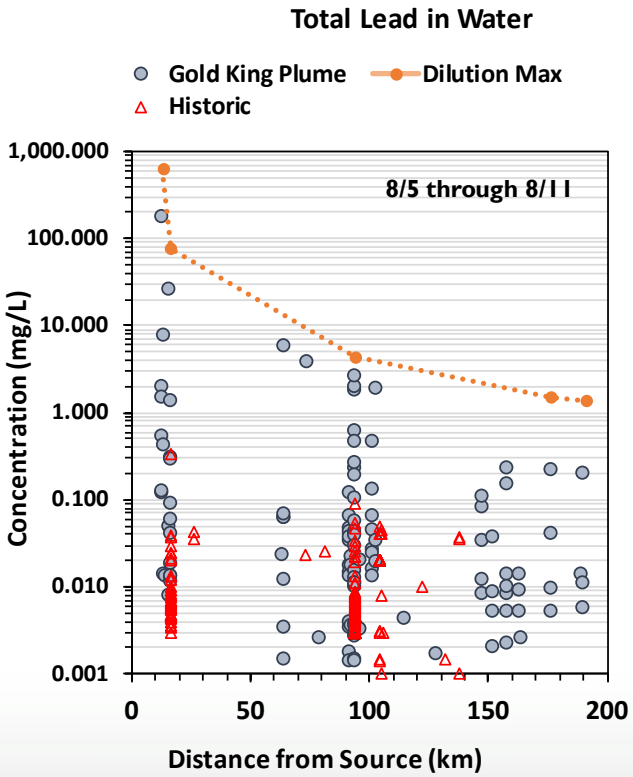
- 1,400 total and dissolved water samples through 8/27/2016
- 820 sediment samples through 9/1/2016
- 294 sites with 1 or more samples

HISTORIC DATA

- Hundreds of water samples
- 30-50 sediment samples

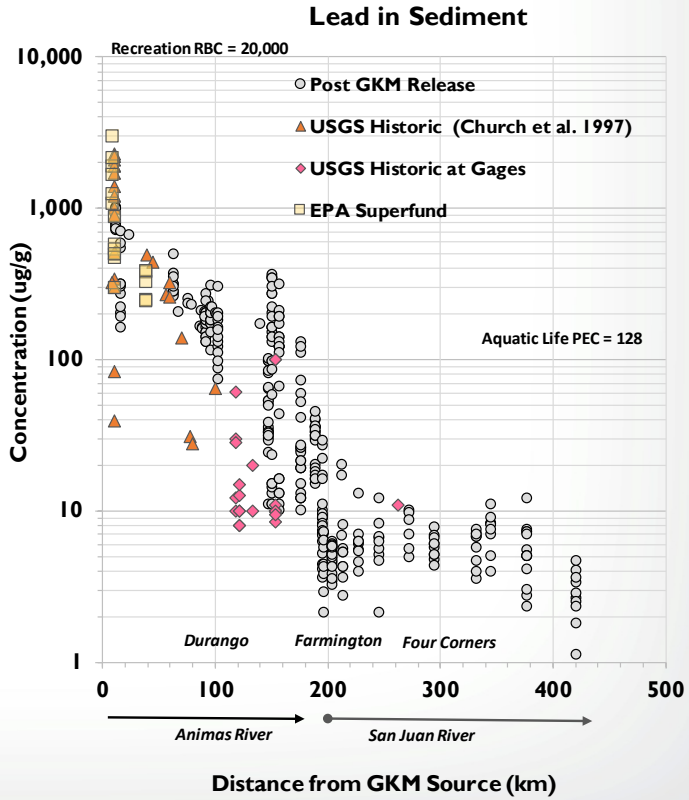
WATER:

--Concentrations decreased in water and sediment moving down river from the Gold King during plume



Sediment:

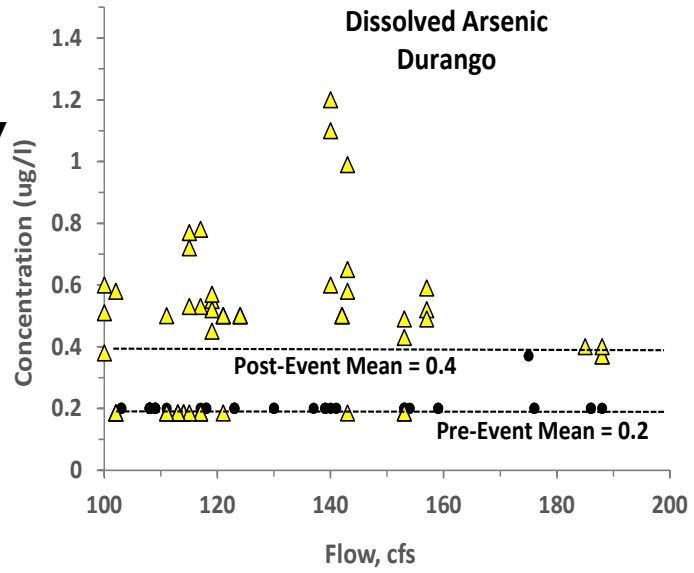
- Deposited metals reflect historic contamination
- No statistical change from historic



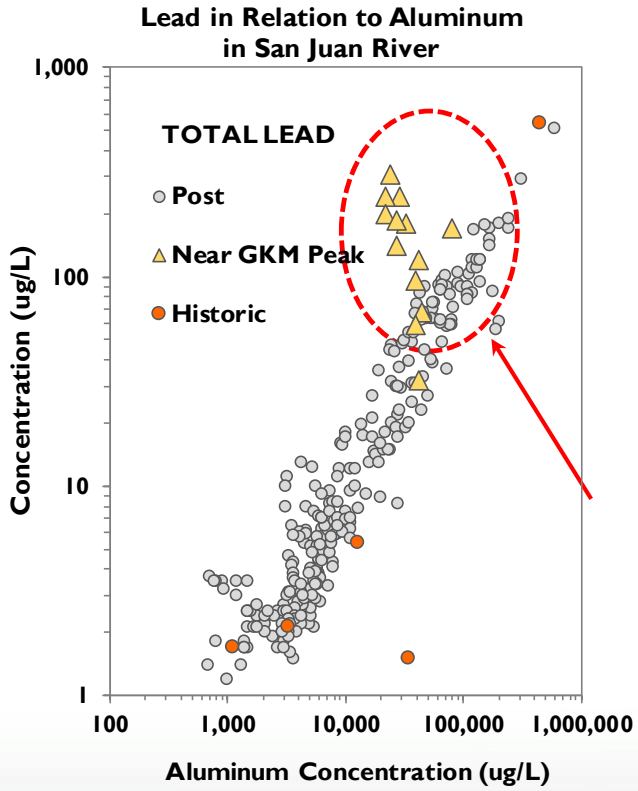
Methods Rationale

- Limited to locations where pre-event data existed
- Comparisons with pre-event limited by available historic data
- Significantly reduced number of post-event monitoring samples that could be used

Statistical comparisons between pre- and post-event samples



Correlation analysis between trace metals and aluminum or iron



- Relationship between trace metals and Aluminum or Iron is an indicator of expected background levels in sediments and water
- Used in project as a sensitive signature of the of Gold King metals
- Maximizes use of available data
- Even a limited amount of historic data is useful

Lead high for amount of background aluminum as Gold King plume passed through

Metals Concentration Trajectories Depended on Location

Animas River in Colorado
(RK 0 to 150):

- returned to pre-event levels in the weeks after the release
- stayed there through the winter

Immediate: Aug 5 to Aug 19
Later : after Aug 19

Aluminum and Iron oxides were a major component of deposited precipitates

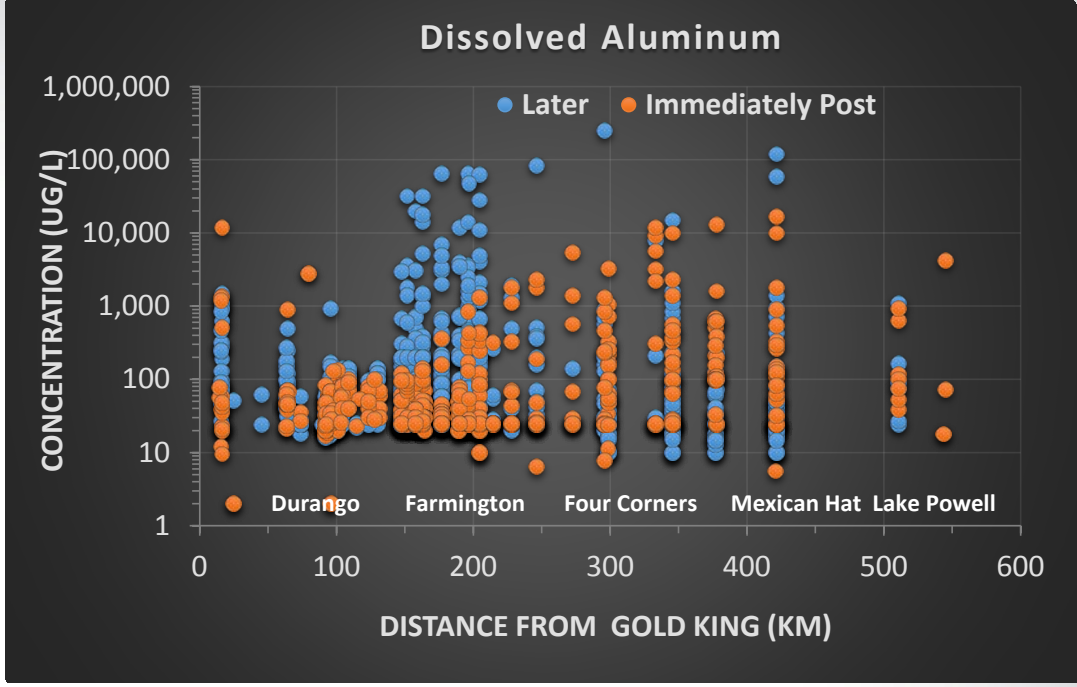
Animas River in New Mexico
(RK 150 to 192):

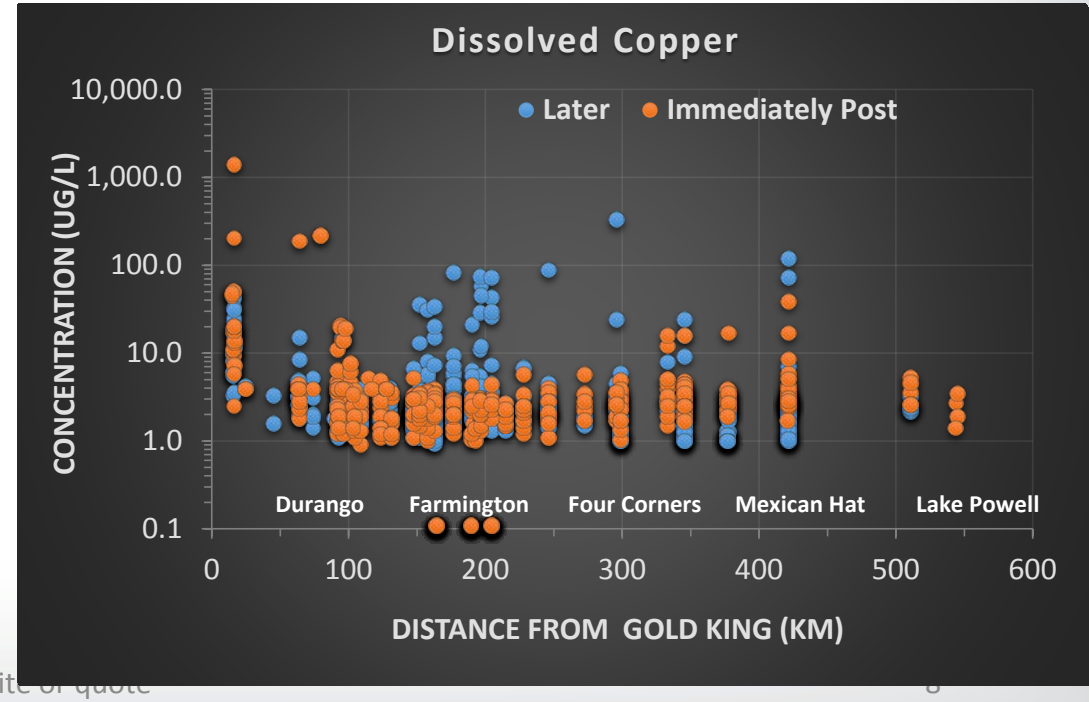
- Initially returned to lower levels (15 days)
- Most dissolved metals increased after Aug 27 storm

San Juan River
(Rk 193 to 540)

- Increased Aluminum and Iron in Animas carried into San Juan

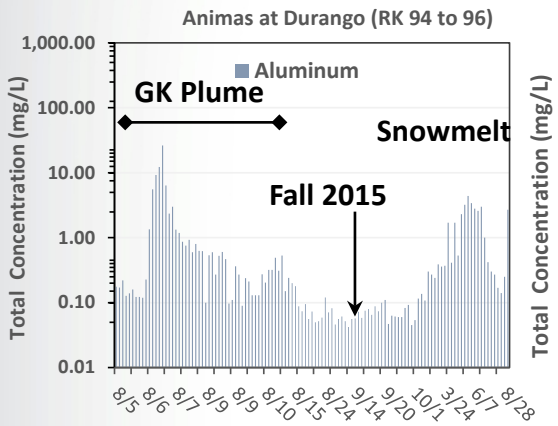
Gold King deposits influenced water chemistry over an extended period Aug 27-October 30+



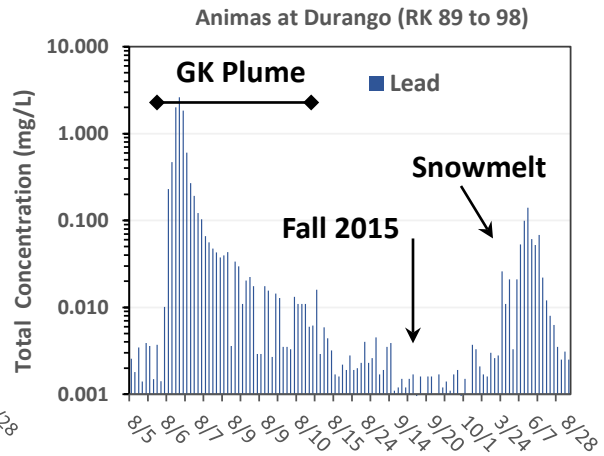


Middle Animas -- Colorado Post Event

Total Aluminum



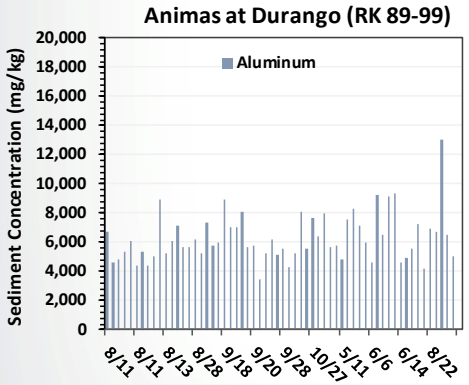
Total Lead

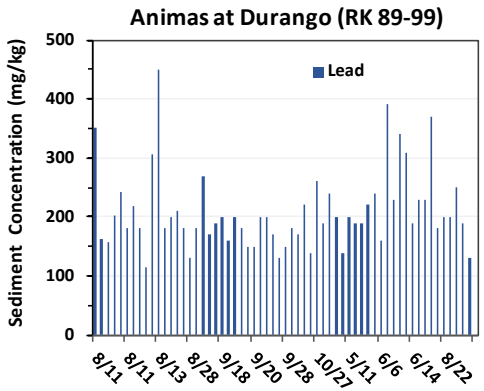


Animas at Durango CO

WATER

- **Water concentrations receded over 2 – 3 week period after the plume**
- **Trace metals very low during Fall 2015 (lower than historic)**
- **Metals increased and declined with flow during snowmelt**
- **Concentrations back to low levels in August 2016**





SEDIMENT

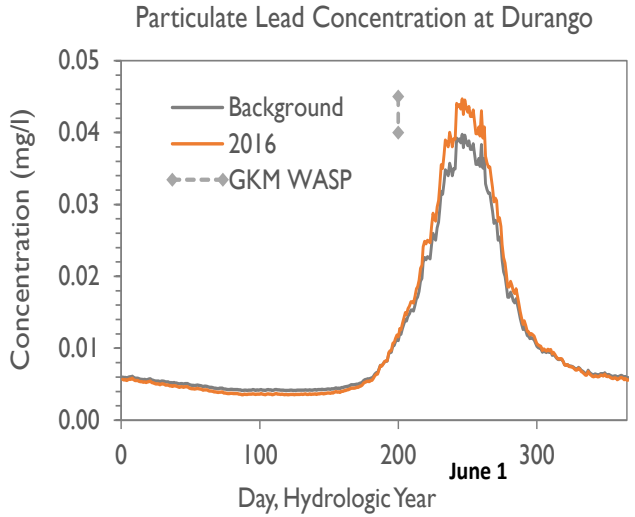
Event to August 2016

- **Background sediment metals are high due primarily to legacy mining**
- **Sediment metals concentrations variable but relatively unchanged during Fall months and snowmelt**
- **Aluminum in the recent deposits "active"**

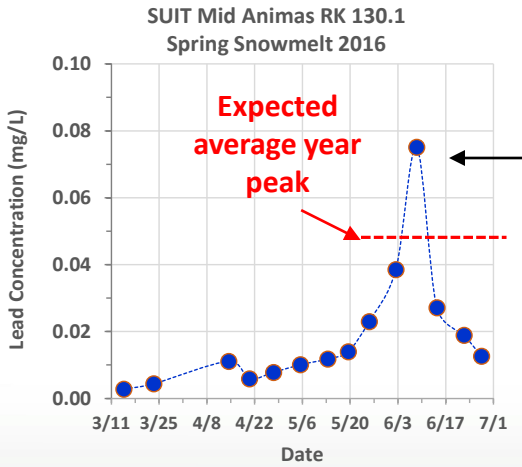
Plots include every sample within 10 km of Animas in the city of Durango plotted sequentially in time– PLOTS COMPRESS TIME

Snowmelt-Colorado

- **We expected increased metals concentrations during snowmelt based on historic observations**
  - **Concentration increase was not large**
  - **Volume of water carries a lot of mass**
- **Metals concentrations appeared to increase a small amount early in snowmelt due to Gold King relative to expected**
- **Concentrations returned to low levels by end of snowmelt**



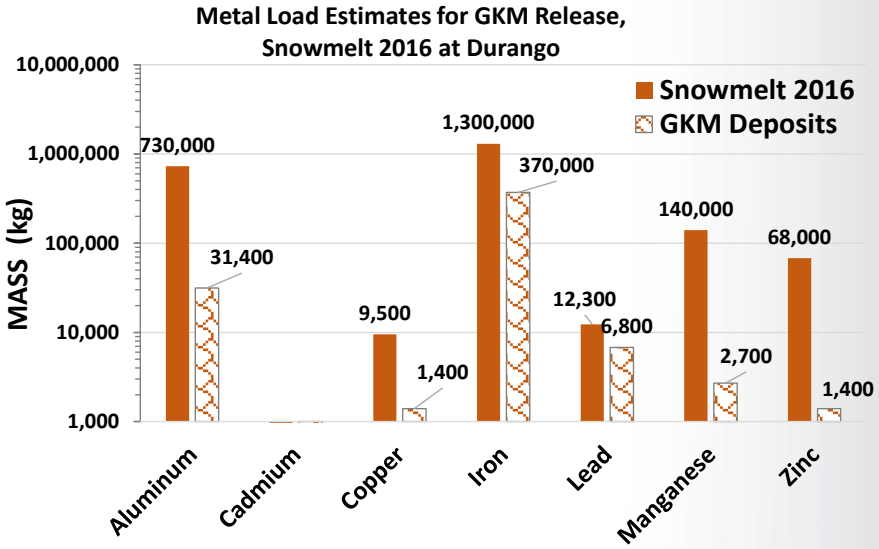
Predicted concentration based on historic data



Observed 2016

Some increase due to Gold King, some due to high snowmelt peak

Total metal mass transported through 2 months of snowmelt



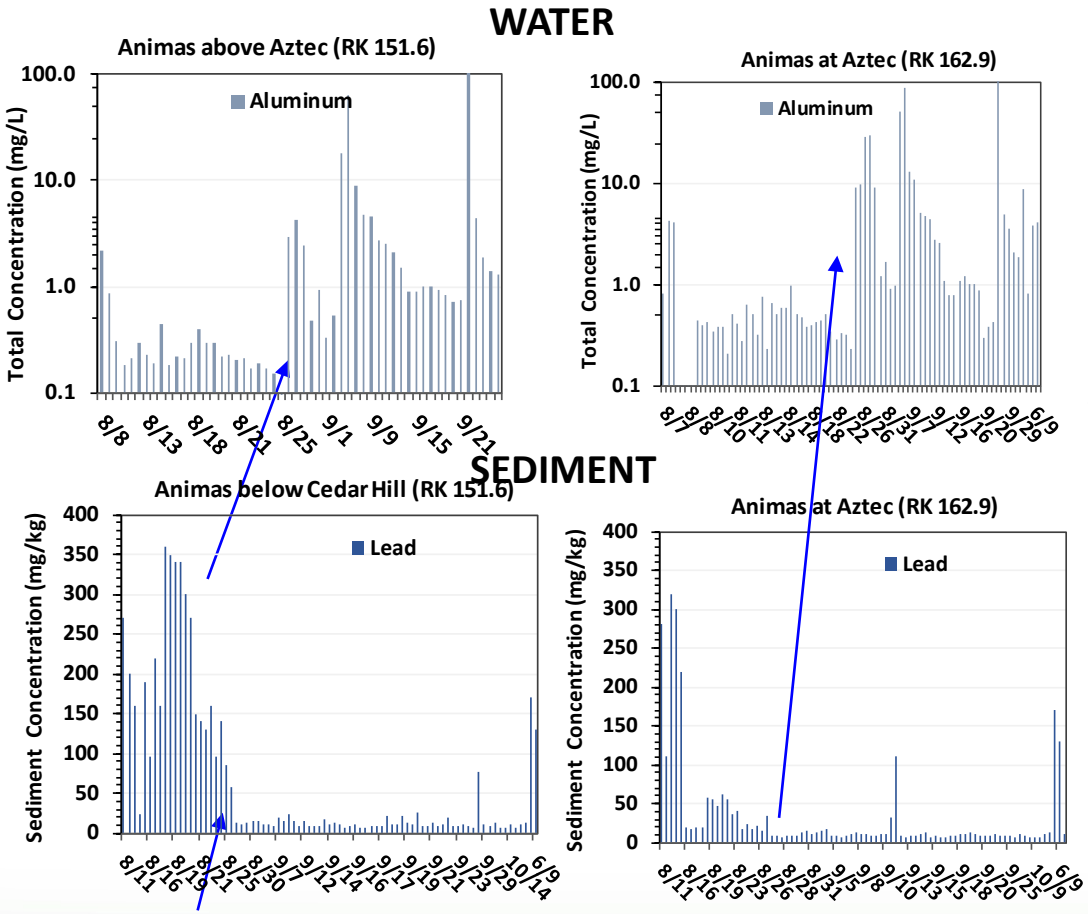
More than enough to account for all of Gold King deposited mass

Lower Animas Post Event

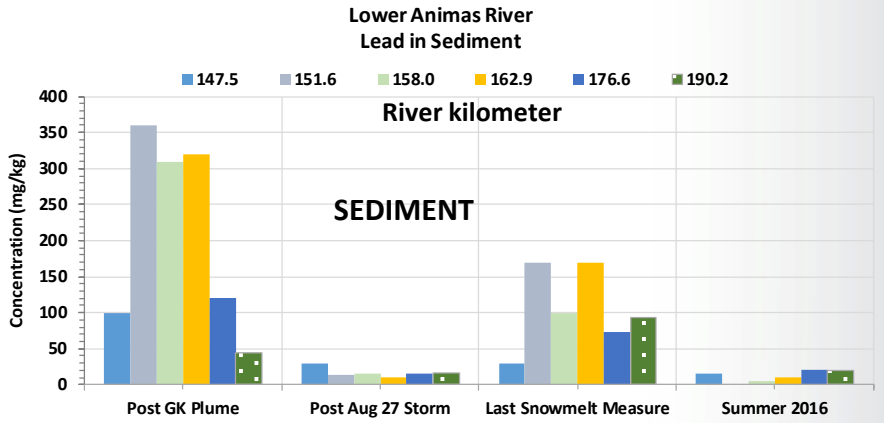
Animas between Durango and Farmington NM RK 132-190

- Lead (and other metals) accumulated in sediment in lower Animas during and after Gold King plume
- Large storm 3 weeks after release cleans deposits from river
- Metals in water then increased
- Carried into San Juan
- Important for water quality
- Snowmelt concentrations in SJ increased—does this happen every year?

Every observation at two locations over time



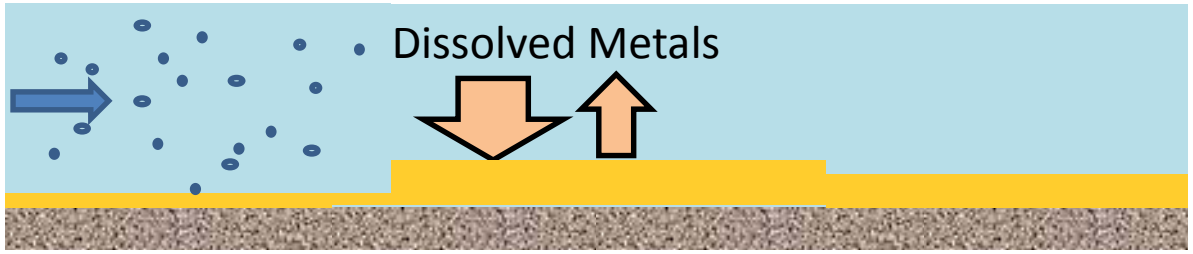
Summary at 6 locations in lower Animas at key times during year



Aug 27 storm sweeps deposits out . . . Not to return until snowmelt

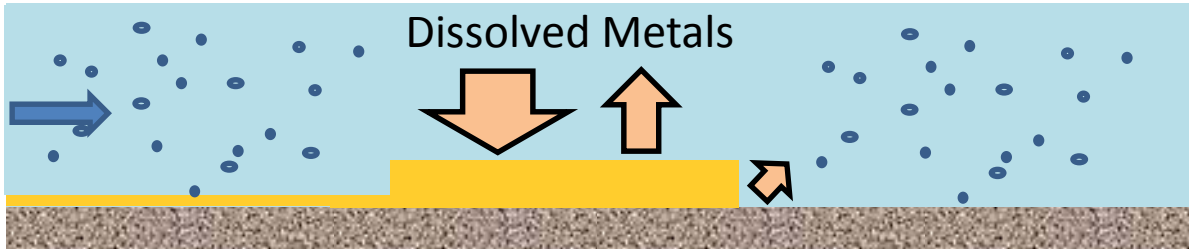
Theory for why metals increased in the lower Animas River during the Fall after the Gold King Release

Post-event Animas River prior to Fall 2015 storms



Dissolved ions exchange between the water and deposited Fe and Al hydroxides
Act like "sponge" for trace metals
Scavenge metals from water

Post-Event Animas River after Fall 2015 storms



Silverton ***km 16.4***

Durango ***94.5***

Farmington ***190.2***

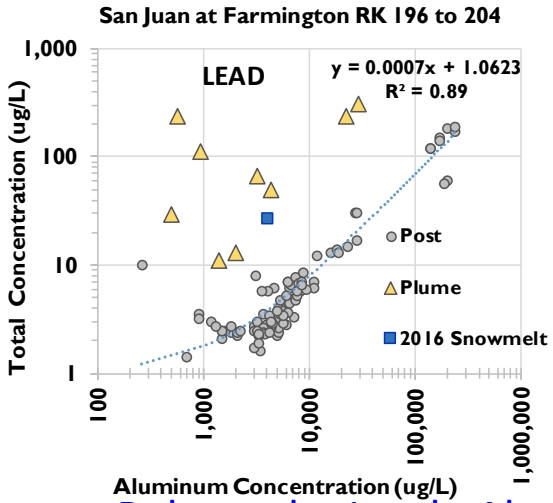
Fall storms removed the sorptive "sponge" of yellowboy from the Animas in New Mexico allowing dissolved metals to remain in the water and travel downstream

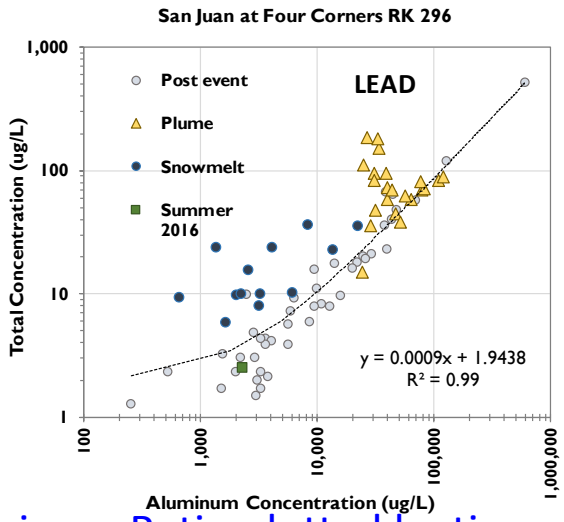
San Juan Post Event Water/Sediment

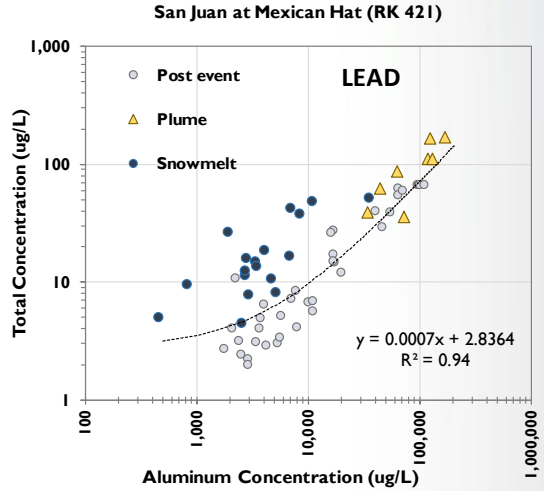
- **Concentrations of metals (lead) in San Juan River**
  - **Influenced by Animas near confluence in Farmington**
  - **Were elevated during plume--undetectable at lower reaches near Mexican Hat**
  - **Also elevated in water and sediment during snowmelt season**
  - **Lead main metal detected**

This correlation technique was powerful for identifying Gold King

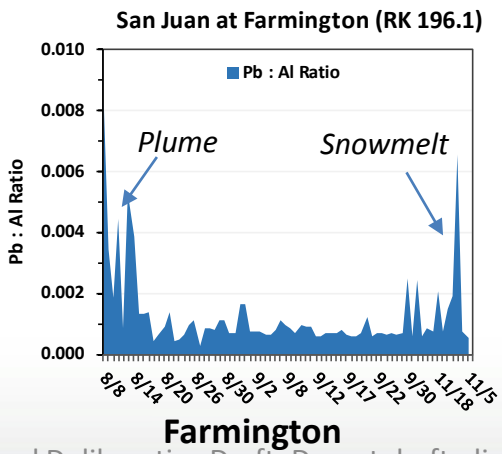
Water Concentration –higher lead detectable during Gold King plume and snowmelt

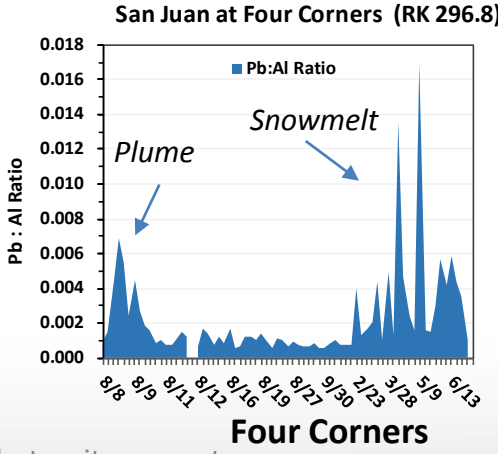


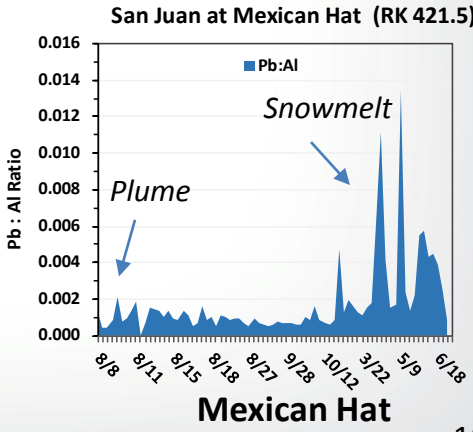




Below: the Lead : Aluminum Ratio plotted by time

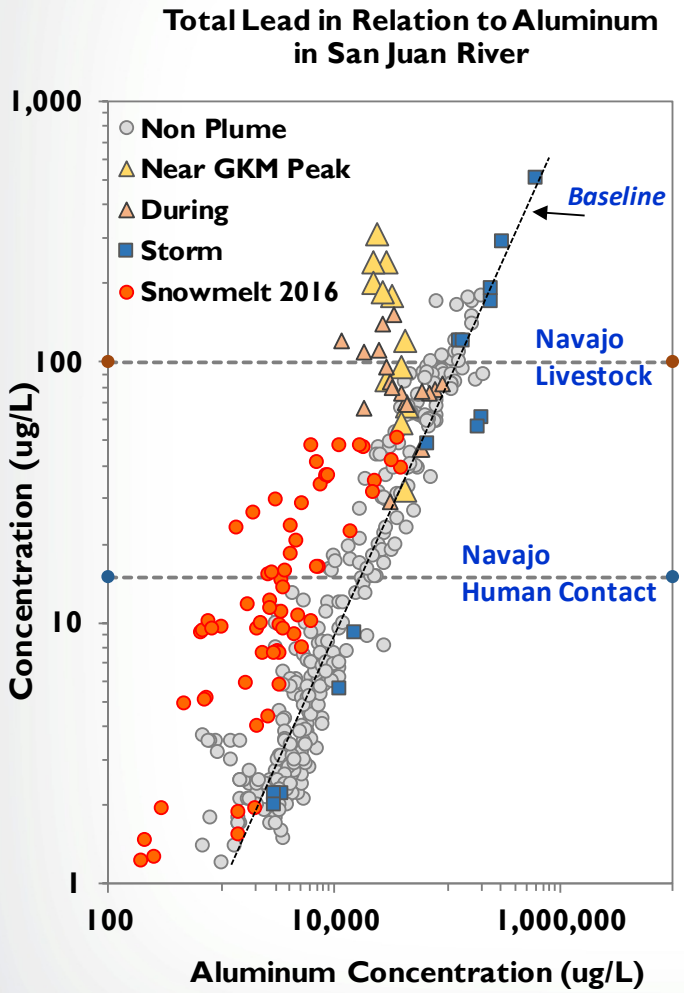






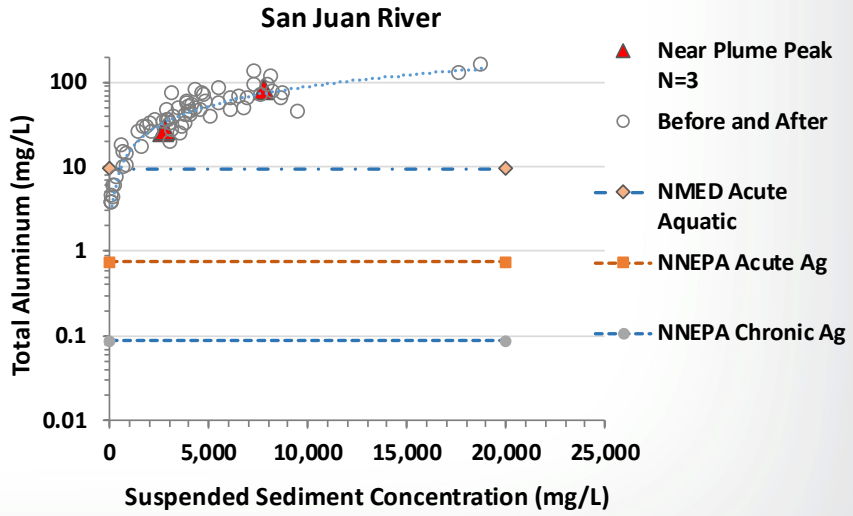
Water Quality Criteria San Juan Out of Alignment with Background Conditions

San Juan at Ship Rock
August 2016



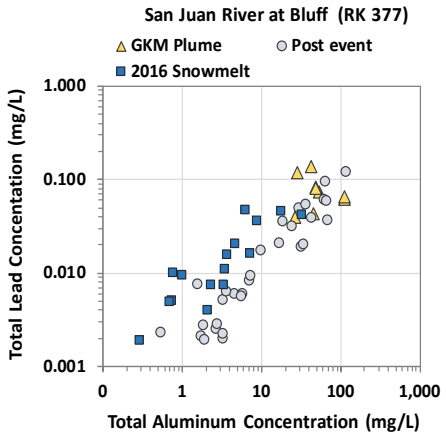
Correlation technique can help with sorting Gold King effects from natural background metals and pre-existing contaminated conditions

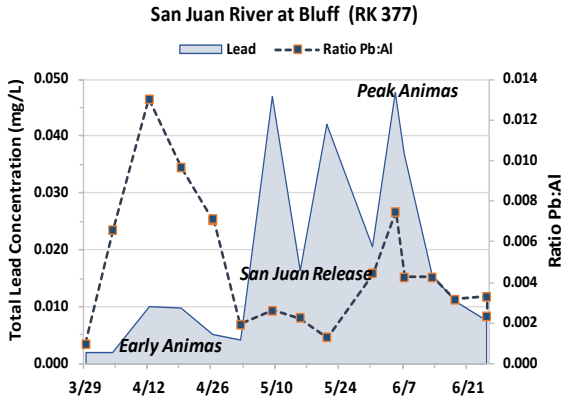
Natural sediment loads in the San Juan ensure that aluminum will almost always exceed some of the New Mexico, Utah and Navajo criteria



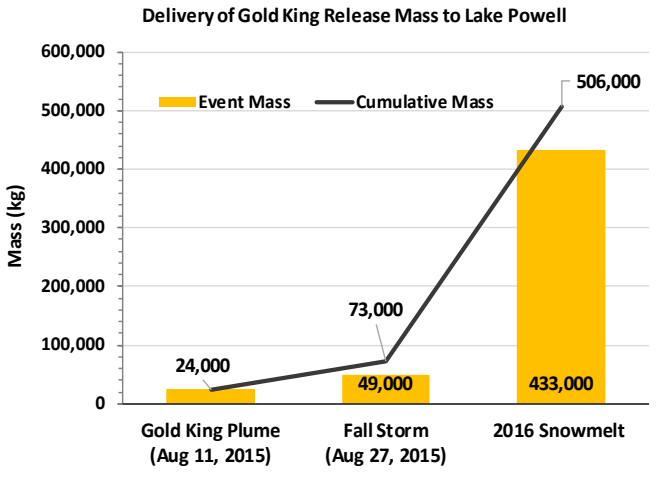
Snowmelt 2016

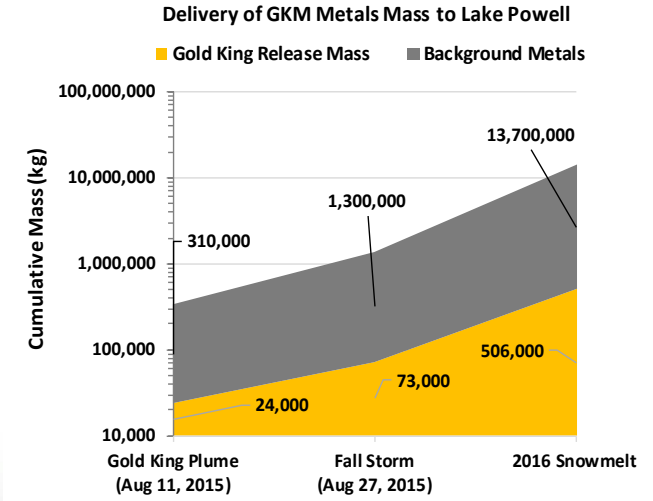
- **Metals elevated throughout Animas and San Juan Rivers—there was a Gold King Release signature during snowmelt**
- **We believe Gold King Deposits mobilized early in the snowmelt season (April)**
- **Estimates of the mass moving through the system were in very reasonable agreement with estimates of what was deposited during the Gold King plume**
- **Appears that Gold King deposits have been mobilized and delivered to Lake Powell**
- **Gold King release delivered with a large mass of sediment**





e.g., Higher than normal levels of lead in April suggested Gold King deposits moving





Has the System Returned to Pre-Event?

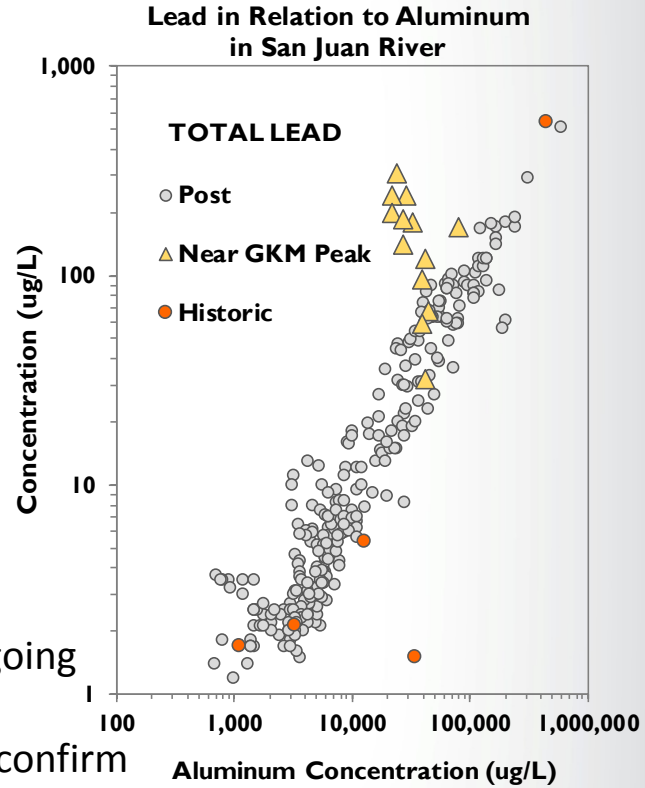
What Did Statistics Confirm About Post-Event Metals—Fall 2015?

Water

- Most metals significantly lower after Gold King in the middle Animas (Colorado)
- Elevated Iron and Aluminum in lower Animas after August storms (New Mexico)
- Elevated Iron and Aluminum in San Juan throughout the period (NM, UT, Navajo)

Sediment

- Despite large deposited mass, no significant increase in river sediments



What Remains to be Established?

Water

- We saw a Gold King signature far down the San Juan during snowmelt
- We expect to see higher sediment mass moved during snowmelt every year in Colorado.). Does ongoing contamination elevate metals every year in the San Juan>
- Can we reliably establish baseline relationships between Aluminum and other metals as evidence to confirm the end of GKM influence in the system?

Are Changes to Water Quality Meaningful?

- **EPA Conceptual Monitoring Plan Implemented 2016**
  - **Proposes to answer this question by comparing observed concentrations to water quality criteria**
  - **To assist OW in doing this for 1st year monitoring results, we have done this screening**
  - **Conducted 188,000 comparisons to a criteria**
- **About the Criteria**
  - **Multiple states and tribes located at different points along the river**
  - **Criteria address both total and dissolved fractions**
  - **Cover a wide range of concentrations depending on beneficial use**

Surface Water Quality Screening Criteria mg/L

Screening Criteria			Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Potassium	Selenium	Silver	Sodium	Thallium	Vanadium	Zinc
Domestic Water Supply	Domestic Supply	New Mexico		0.0060	0.010	2.0	0.0040	0.0050		0.10		1.30		0.0150			0.0020		0.7		0.050			0.002		10.50
	Domestic Source	Utah			0.010	1.0	0.0040	0.010		0.050				0.0150			0.0020				0.050	0.050				
	Domestic Water Supply	Navajo Nation		0.00560	0.010	1.0	0.0040	0.0050		0.10		1.30		0.0150			0.0020		0.6		0.050	0.0350		0.0020		2.10
	Drinking Water	Ute Mountain Ute	0.2000	0.00560	0.000	1.0		0.0050		0.16		1.00		0.0500			0.0001		0.1		0.050	0.1000				5.00
	Domestic Supply 1-Day	Colorado				1.0		0.0050		0.050				0.050			0.0020					0.10				
Recreation and Human Contact	Primary Human Contact	Navajo Nation		0.370	0.030	98.0	1.870	0.470				9.330		0.0150			0.280		18.7		4.670	4.670		0.0750		280.0
	Secondary Human Contact	Navajo Nation		0.370	0.280	98.0	1.870	0.470				9.330		0.0150			0.280		18.7		4.670	4.670		0.0750		280.0
	Ceremonial, other uses	Ute Mountain Ute	0.2000	0.0056	0.0000	1.0000		0.0050		0.1600		1.0000		0.0500			0.0001		0.1000		0.0500	0.1000				5.0000
	Fish consumption	Ute Mountain Ute		0.056	0.00001			0.084		670.0							0.000		4.6		4.200	110.000				26.0
	Recreational	Utah	621	0.248	0.186	124.2	1.242	0.062		0.4100	7.9310	6.208	851.6	0.9100		31.0	1.242	3.104	17.5		3.104	3.630		0.0250	6.21	217.8
	Recreational	Region 6	170.0	0.0670	0.050	33.0	0.330	0.0830		220.0	0.050	6.70	120.0	0.20		7.80	0.050	0.830	3.30		0.830			0.0020	0.83	50.0
Agriculture	Irrigation	Region 6		5.0				0.010		0.10	1.0	0.20		5.0		0.20			0.20		0.130				0.10	2.0
	Irrigation	New Mexico	5.0		0.10			0.010		0.10	0.050	0.20		5.0				1.0			0.130				0.10	2.0
	Irrigation (short-term)	Utah	20.0		2.0			0.050		1.0	5.0	5.0	20.0	10.0		10.0		0.050	2.0		0.020				1.0	10.0
	Irrigation (long-term)	Utah	5.0		0.10			0.010		0.10	0.050	0.20	5.0	5.0		0.20		0.010	0.20		0.020				0.10	2.0
	Agricultural Uses	Utah			0.10			0.010		0.10		0.20		0.10							0.050					
	Agricultural Supply	Navajo Nation	5.0		2.0			0.050		1.0	0.050	0.20		10.0				1.0			0.020				0.10	10.0
	Agriculture	Ute Mountain Ute			0.1			0.010		0.1		0.20		0.1			0.0100		0.200		0.020					2.0
	Revised Ag Water Supply	Region 9	5.0		2.0			0.050		1.0	0.050	0.20		10.0				1.0			0.020				0.10	10.0
	Agriculture	Colorado			0.10		0.10	0.010		0.10		0.20		0.10		0.20		0.30	0.20		0.020					2.0
Livestock	Livestock	Region 6					0.10	0.050		1.0		0.50		0.10			0.010		1.0		0.250				0.10	25.0
	Livestock updated	Region 9			0.20			0.050		1.0	1.0	0.50		0.10							0.050				0.10	25.0
	Livestock	New Mexico			0.20			0.050		1.0	1.0	0.50		0.10			0.010				0.050				0.10	25.0
	Livestock	Utah	5.0		0.20			0.050	500.0	1.0	1.0	0.50		0.10	250.0		0.010				0.050		1000.0		0.10	25.0
	Livestock Watering	Navajo Nation			0.20			0.050		1.0	1.0	0.50		0.10							0.050				0.10	25.0
	Wildlife Habitat	New Mexico															0.000770				0.005					
Aquatic Life	Acute Ag and Wildlife	Navajo Nation	0.750	0.088	0.340			0.0039				0.0258		0.1361			0.0024		0.8417		0.0330	0.0106		0.70		0.2108
	Acute Warm Water	Ute Mountain Ute	0.050		0.150			0.0039		1.005		0.0258		0.1361			0.0001		0.8417		0.0200	0.0114				0.2108
	Aquatic Acute	Region 6		8.358	0.340			0.00288		0.9720		0.0250		0.130		3.710	0.00140		0.8130		0.020	0.00990				0.290
	Aquatic Acute	Region 9		8.3580			0.340	0.00288		0.9720		0.0250		0.130		3.710	0.1040		0.8130		0.020	0.00990				0.290
	Aquatic Acute	New Mexico	9.5725		0.340			0.003134		0.0160		0.0273		0.145		3.8348	0.0014	7.920	0.884		0.020	0.0117				0.3169
	Warm Water Fish 1-hr	Utah	0.750		0.340			0.004		1.005		0.0258	1.0	0.1361					0.0935		0.01840	10.59717				0.213
	Warm Water Fish 4-day	Utah	0.0870		0.150			0.000		0.1308		0.0162	1.0	0.00531			0.000012		0.093		0.00460					0.213
	Chronic Warm Water	Ute Mountain Ute			0.150			0.000398		0.1308		0.0162		0.00531			0.000012		0.093		0.00500	0.001				0.213
	Aquatic Acute	Colorado	7.9432		0.3400			0.0047		0.0160		0.0240		0.1253		3.6647			0.7879		0.01840	0.00585				0.2800
	Aquatic Chronic	Region 6		3.3480	0.150			0.00072		0.1260	0.050	0.0160		0.0050		2.050	0.00077		0.090		0.0050					0.2190
	Aquatic Chronic	Region 9		3.3480			0.150	0.00072		0.1260		0.0160		0.0050		2.050	0.00077		0.090		0.0050					0.2190
	Chronic Ag and Wildlife	Navajo Nation	0.0870	0.030	0.150			0.0004				0.0162		0.0053			0.000001		0.0935		0.0020			0.150		0.2125
	Aquatic Chronic	New Mexico	3.8351		0.150			0.000777		0.0110		0.0170		0.0056		2.1187	0.00077	1.8950	0.098		0.0050					0.2400
	Aquatic Chronic	Colorado	1.1340		0.150			0.000674		0.0110		0.0151	1.0	0.00488		2.0247	0.00001		0.0875		0.00460	0.0002		0.0150		0.2120

Total **Dissolved**

Challenge for Office of Water

- **How to interpret monitoring data for "importance" of Gold King**

Challenge for ORD

- **Can we identify which of these exceedances belong to Gold King?**

24 metals x 40 criteria : 1400+ samples

WQ Exceedances
During the Interval From August 2015 to August 2016

- There were water quality exceedances during the Gold King plume
- There have been exceedances post-event
  - Infrequent occurrences: domestic water, agricultural, livestock
  - Some occurred during snowmelt 2016
  - Some storm event related
  - Some chronic, not Gold King release related
- Aluminum and lead were involved the most frequently
- Water quality appears to have returned to pre-event levels
  - Most locations and uses within weeks of the GKM release
  - Summer/Fall 2016

Key Findings—Gold King Release Post Event

- **ORD produced hydrologic and geochemical evaluations of the Gold King release during and for a year following the release**
- **Post event water quality response from August to October 2015 varied by location**
  - **Animas in Colorado returned to background soon after event**
  - **Animas in New Mexico and San Juan River had elevated metals above expected, especially in Fall months after storm event**
  - **Chronic exceedances of water quality criteria revealed by monitoring**
- **2016 snowmelt had elevated metals throughout the system—partly from Gold King, partly from historic mining impacts**
  - **Model results and analyses indicate GKM metals now out of rivers**
  - **2016 samples after snowmelt at pre-event levels**
  - **We have a "fingerprint" unique to identify metals of the Gold King release**
- **There were water quality exceedances before, during the plume and post event varying by location and state or tribe, some due to Gold King**

Next Steps:

- **ORD Report will be released 1st week of January**
- **Working with OWOW to handoff findings to assist evaluation of monitoring needs going forward**
- **Publish findings**

Project Team

ORD/NERL

- **Kate Sullivan, Hydrology, project lead**
- **Chris Knightes, WASP lead, water quality**
- **Mike Cyterski, Data analysis, statistics**
- **John Washington, Geochemistry**
- **Steve Kraemer, Groundwater**
- **Brian Avants (EPA ORISE Fellow)**