2017 Poster Abstracts

The Lower Animas Watershed Based Plan: Pollutant sources andopportunities for remediation on the Animas in New Mexico

Melissa May
San Juan Soil & Water Conservation District

Contact: Melissa May, San Juan Soil & Water Conservation District, 1427 W. Aztec Blvd.,Ste. 1, Aztec, NM 87410, melissa.may@sanjuanswcd.com, 505-334-3090 x5

Abstract 4

The Lower Animas Watershed Based Plan (LAWBP) focuses on the segment of the Animas River in New Mexico that flows south from the Colorado state line and reaches its southern terminus at the confluence with the San Juan River at Farmington, NM. The Lower Animas was listed on the State of New Mexico's impaired waters list in 2002, and since 2010 has exceeded water quality criteria for phosphorus, nutrients/ eutrophication, E. coli bacteria, turbidity, and temperature.

The objective of the LAWBP was to combine water quality trends with land use data and the practical experience of local stakeholders to make informed decisions on how best to improve water quality on the Animas River. This plan utilizes two new data collection efforts initiated by the San Juan Watershed Group in 2013 and 2014: Microbial Source Tracking (MST) and 2014 Lower Animas Targeted Sampling. The MST study provided information regarding the sources of bacteria (e.g., human, ruminant, horse, dog, and waterfowl) that are most prevalent in the Animas and San Juan Rivers. The Lower Animas Targeted Sampling determined the nutrient and E. coli contribution of inflows (e.g., arroyos, tailwater ditches, field drains, and return flow from irrigation ditches) along the Animas River during low flow conditions. Data from these two new studies indicate the following:

- Measured concentrations and loads of nitrogen, phosphorus, and E. coli in 2014 often exceeded NM state water quality criteria, and total maximum daily load targets established for the Animas River, which confirms impairment.
- Nutrient and E. coli loads in the Animas River vary seasonally; during summer and fall precipitation events that cause an increase in river flow and turbidity, concentrations of nutrients and E. coli become elevated. High turbidity was correlated with total phosphorus and total nitrogen. This is likely due to stormwater runoff from the adjacent landscape.
- The primary source of nutrient and E. coli loads in the Animas River at low flow cannot be solely explained by inflows. It is possible that inflows do contribute a higher portion of the nutrient and E. coli load during storm events, but this remains an unknown since there is limited data from inflows along the lower Animas River during storm events.
- There is a very consistent source of ruminant bacteria in the Animas River (90% of samples positive), and a less pervasive but consistent source of human bacteria (60% samples positive).

From these recent datasets, we concluded that management measures should not solely focus on reducing pollutant loads from single, discrete inflows, but instead should take a more holistic watershed approach by addressing contributions from different land uses during low flow and especially during storm event conditions. Therefore, we proposed a menu of projects and outreach efforts that address the pollutant

sources, impairments, and threats to watershed health organized based on project types specific to a given land use or pollutant source category:

- Septic, sewer, and wastewater management
- Agricultural best management practices (BMPs)
- Upland restoration and rangeland BMPs
- Urban stormwater projects
- Riparian restoration
- Streambank, wetland, and floodplain restoration
- Irrigation infrastructure improvements

For each of these land use or pollutant source categories, we describe management measures, implementation strategies, implementation schedule, and possible funding sources. We summarize specific project locations, costs, and expected pollutant load reductions. In order to estimate the nutrient and sediment load reduction that can be expected from implementing best management practices for specific projects, we utilized an EPA model called STEPL (Spreadsheet Tool for Estimating Pollutant Loads). As this plan is updated through adaptive management over time, the management measures and implementation strategies should stay relatively the same, while specific project areas and costs will be updated as original projects are completed.

The long-term goal of this plan is to restore the Animas River to an unimpaired condition such that it meets all of its designated uses. This means that bacteria concentrations are reduced to a point where they don't impact recreation, and nutrient concentrations, functioning capacity, and sediments are improved to where they support healthy aquatic life. The effectiveness of this plan will be assessed by interim achievement criteria, progress milestones, and continued water quality monitoring.

Link to EPA accepted Watershed Based Plan: https://www.env.nm.gov/swqb/wps/WBP/Accepted/Lower%20 Animas/LowerAnimasWBP_Aug 2016_FINAL.pdf

Assessing the Correlations Between Automatic Sonde Data and the Total Concentration of Metals in the Animas River, Southwestern Colorado and Northwestern New Mexico

Katrina M. Bryant
Geosciences, Fort Lewis College

Contact: Katrina M. Bryant, Geosciences, Fort Lewis College, katrinakdb@yahoo.com, 505-716-6665

Abstract 10

Historically, the water quality of the Animas River has been affected by acid mine drainage caused by mining activities near its headwaters in a highly-mineralized zone of the San Juan Mountains. Concern regarding water quality was renewed in August 2015, when 3 million gallons of metal laden water spilled into the Animas River from the Gold King Mine. In the months that followed, metal concentrations were monitored downstream by various agencies via sample collection. Additional instrumentation (sondes) that continuously measure pH, turbidity, and specific conductance was installed on the stream gages at Durango (USGS 09361500), Cedar Hill (USGS 09363500), and Aztec (USGS 09364010).

Due to the outlay of time and money associated with sampling and the capability of the sondes in providing continuous real-time measurements, it was contemplated as to whether the sondes could be used to detect when total metal concentrations are high and act as a surrogate when sampling is not feasible To test this rationale, the water sample data that had been collected by the various agencies between April 2016 and November 2016 was compiled along with the measurements from the sondes and the relations between the total concentrations of six metals (aluminum, arsenic, copper, iron, lead, and zinc) and readings from four sondes (discharge, pH, turbidity, and specific conductance) were examined.

Broadly speaking, sonde data yields only weak correlations with metal concentrations. Turbidity yielded the strongest correlation (e.g. R2 of 0.7 with [Al]). This absence of strong correlations can be partially explained by a hysteretic pattern that was observed for total metal concentrations, turbidity, and pH when individual flood pulses were isolated and examined. The total concentration of metals and turbidity are commonly higher on the rising limb of a flood pulse than at the same discharge on the falling limb. However, this pattern reversed downstream for the total concentrations of Cu, As, and Pb as they were higher on the falling limb than the rising limb near the Aztec gage. At each site, pH decreases along the rising limb of each flood pulse that passes a gage but pH returns to the average range once the pulse passes. pH generally increases downstream along the Animas River, accounting for the high total concentrations of Al and Fe in precipitated form. Further, it was observed that there is an inverse relationship between specific conductance and discharge suggesting that dissolved ions are effectively diluted by increased discharge.

These observations are a start to understanding the potential value and limitations of how the sondes can provide real-time monitoring of the metal content in the Animas River.

Quantitative Analysis of the Heavy Metal Content of Environmental Samples by Atomic Emission Spectroscopy

Alexandra A. Dobbs and Callie A. Cole
Fort Lewis College

Contact: Alexandra A. Dobbs, Fort Lewis College, aadobbs@fortlewis.edu, 970-903-2037

Abstract 11

On August 5th, 2015 an accident at the Gold King Mine near Silverton, CO led to the release of over three million gallons of contaminated water into Cement Creek, a tributary of the Animas River. This incident brought the issue of acid mine drainage and heavy metal contamination to the forefront of both the national and international media. Although various city and non-profit entities have studied heavy metal contamination post-incident, few projects have combined analyses of many environmental sample types including soils and plants. Analysis of a variety of environmental samples provides a more thorough picture of if and how heavy metals are accumulating in the Animas watershed system. This study explores the precision and accuracy of the quantitative analysis of several heavy metals in both soil and plant samples by acid digestion (EPA method 3050b) and atomic emission analysis (Microwave Plasma Atomic Emission Spectroscopy, or MP-AES) using two forms of calibration: external standards and standard addition. This method may be applied to samples taken along the Animas River in the future to monitor the quantities of heavy metals in various environmental sample types.

Watershed-Scale Sediment Sampling and Assessment – Lessons from the Field

Diane Agnew
New Mexico Environment Department, 121 Tijeras Avenue NE, Albuquerque, New Mexico 87102, United States

Amy Rosebrough
University of New Mexico, Environmental Sciences Department, Northrop Hall, 221 Yale Blvd NE, Albuquerque, NM 87131

Bruce Yurdin, Dennis McQuillan, and Kristine Pintado
New Mexico Environment Department, 1190 Saint Francis Drive., Santa Fe, New Mexico 87505, United States

Contact Person: Diane Agnew, New Mexico Environment Department, 121 Tijeras Avenue NE, Albuquerque, New Mexico, 87102, diane.agnew@state.nm.us, 505-222-9555

Abstract 12

On August 5, 2015, a United States Environmental Protection Agency (EPA) work crew digging into the Gold King Mine (GKM) adit triggered a blow-out, resulting in a continuous discharge of impounded mine water. The discharge from the adit during the blow-out contained heavy metal laden sediment and water that spilled into Cement Creek, which flows into the Animas River and eventually downstream into New Mexico, where the Animas River joins the San Juan River. In response to the 2015 GKM spill, the New Mexico Environment Department (NMED) developed a Long-Term Monitoring Plan (LTMP) to evaluate short- and long-term impacts to the Animas and San Juan watershed.

River sediment characteristics can be extremely variable, both spatially and temporarily. Additionally, due to the ever-changing flow conditions of rivers, particularly during Monsoon season, it can be challenging to get a watershed-scale snapshot of sediment nature and extent. Understanding and mapping out the nature and extent of contamination from natural geologic sources, historic mining and milling activities in the region, along with heavy metal impacts resulting from the August 5, 2015 GKM spill, required a multi-faceted sampling event that presented unique logistical challenges. To assess the nature and extent of sediment contamination along the Animas and San Juan Rivers, NMED designed a sediment sampling approach to collect field measurements with laboratory confirmatory sampling of sediment along the Animas and San Juan Rivers, approximately 193 kilometers extending from the confluence of Cement Creek and the Animas River in Silverton, Colorado to the San Juan River in Farmington, New Mexico.

An NMED sampling event was scheduled for late-September 2016 during low flow, near baseflow conditions to delineate a baseline for sediment and to ensure the highest rate of access to low-energy depositional areas for sediment. Following the NMED Sampling and Analysis Plan and Quality Assurance Project Plan (NMED, 2016), 101 sediment samples were collected along the Animas and San Juan Rivers. This presentation will highlight the accomplishments and lessons learned from the NMED sediment assessment September 2016 sampling event.

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AML Project: Inventory and Characterization of Inactive/Abandoned Mine (AML) Features in New Mexico

Virginia T. McLemore
New Mexico Bureau of Geology and Mineral Resources

Marcus Silva, John Asafo-Akowuah and Joseph Shakelford
New Mexico Tech

Contact: Virginia T. McLemore, New Mexico Bureau of Geology and Mineral Resources,
801 Leroy Pl., Socorro, New Mexico 87801, virginia.mclemore@nmt.edu, 575-835-5521

Abstract 13 – Both Oral and Poster

New Mexico's mineral wealth is among the richest of any state in the U.S. In 2015, New Mexico ranked 10th in coal production, 2nd in copper production, and 20th in total nonfuel minerals production (McLemore, 2017). Most of the state's production comes from oil, gas, coal, copper, potash, industrial minerals (potash, perlite, cement, zeolites, etc.) and aggregates. Other important commodities include molybdenum, gold, uranium, and silver. However, legacy issues of past mining activities forms negative public perceptions of mining, and inhibits future minerals production in the state. Some legacy mines have the potential to contaminate the environment; the Gold King uncontrolled release into the Animas River is a recent example. At the time the General Mining Law of 1872 was written, there was no recognition of the environmental consequences of discharge of mine and mill wastes or the impact on drinking water, and riparian and aquatic habitats. Miners operating on federal lands had little or no requirement for environmental protection until the 1960s-1970s, although the dumping of mine wastes and mill tailings directly into rivers was halted by an Executive Order in 1935. It is important to recognize that these early miners were not breaking any laws, because there were no laws to break, but legacy issues still exist.

The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) has been examining the environmental effects of mine waste rock piles and tailings throughout New Mexico since the early 1990s (http://geoinfo.nmt.edu/staff/mclemore/projects/environment/home.html). There are tens of thousands of inactive or abandoned mine features in 274 mining districts in New Mexico (McLemore, 2017; including coal, uranium, metals, and industrial minerals districts), however many of them have not been inventoried or prioritized for reclamation. The New Mexico Abandoned Mine Lands (AML) Bureau of the New Mexico Mining and Minerals Division (NMMMD) estimates that there are more than 15,000 abandoned mine features in the state (http://www.emnrd.state.nm.us/MMD/AML/amlmain.html). The New Mexico AML Program has safeguarded over 2,300 mine openings since inception in 1981 in about 250 separate construction projects (some of which were focused on coal gob reclamation and not safeguarding). The U.S. Bureau of Land Management (BLM) recently estimated that more than 10,000 mine features are on BLM lands in New Mexico and only 705 sites have been reclaimed (http://www.blm.gov/wo/st/en/prog/more/ Abandoned_Mine_Lands/abandoned_mine_site.html).

The NMBGMR has collected published and unpublished data on the districts, mines, deposits, occurrences, and mills since it was created in 1927 and is slowly converting historical data into a relational database, the New Mexico Mines Database (McLemore et al., 2005a, b). More than 8,000 mines are recorded in the New Mexico Mines Database and more than 7,000 are inactive or abandoned. These mines often include two or more actual mine features.

Most of these mine features do not pose any physical or environmental hazard and many more, pose only a physical hazard, which is easily but costly to remediate. But a complete inventory of these features is needed. Some of these inactive or abandoned mine features can pose serious health, safety and/or environmental hazards, such as open shafts and adits (some concealed by deterioration or vegetative growth), tunnels and drifts that contain deadly gases, highwalls, encounters with wild animals, radon and metal-laden waters. Other sites have the potential to contaminate surface water, groundwater and air quality. Heavy metals in mine waste piles, tailings and acid mine drainage can potentially impact water quality and human health.

Many state and federal agencies and mining companies have mitigated many of the physical safety hazards by closing some of these mine features, but very few of these reclamation efforts have examined the long-term environmental effects. There is still potential for environmental effects long after remediation of the physical hazards, as found in several areas in New Mexico (for example Terrero, Jackpile and Questa mines). Some of these observations only come from detailed geochemical and electron microprobe studies that are not part of a remediation effort.

The NMBGMR in cooperation with the Mineral Engineering Department at New Mexico Tech and the AML program is conducting research on legacy mine features in New Mexico. The objective of our research is to develop a better procedure to inventory and characterize legacy, inactive or abandoned mine features in New Mexico. This project will inventory, characterize, and prioritize for remediation the mine features in three mining districts in New Mexico: the Jicarilla Mountains district in Lincoln County and the North Magdalena and Rosedale districts in Socorro County for the New Mexico AML Program. Additional mining districts in Socorro County are being examined as well. The project involves field examination of the mines features and collecting data on the mine features (Bureau of Land Management, 2014). Samples are collected to determine total whole rock geochemistry, mineralogical, physical, and engineering properties, acid-base accounting, hydrologic conditions, particle size analyses, soil classification, shear strength testing for stability analysis, and prioritization for remediation, including hazard ranking. Not only will samples be collected for geochemical and geotechnical characterization, but the mine features will be mapped, evaluated for future mineral-resource potential, and evaluated for slope stability.

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An Overview of the Gold King Mine Release and its Transport and Fate in the Animas and San Juan Rivers

K. Sullivan, M. Cyterski, C. Knightes, J. Washington, S. Kraemer, L. Prieto
National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, GA

Brian Avant
Oak Ridge Institute for Science and Education

Contact: K. Sullivan, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, GA, sullivan.kate@epa.gov, 706-355-8100

Abstract 17 – Both Oral and Poster

On August 5, 2015, a large acidic mine pool trapped behind a collapsed mine structure and rock debris in the Gold King Mine (GKM) was accidently breached releasing approximately 11.3 million liters (3 million gallons) of low pH (~3) metal contaminated mine drainage into a small tributary in the headwaters of the Animas River in southwestern Colorado. The release introduced approximately 490,000 kg of dissolved and particulate metals over a 12-hour period into the Animas River at Silverton, CO, located 13 km downstream from the mine. The mine effluent contained 2,900 kg of dissolved metals. Most of the released metals were eroded from the old waste pile outside the mine entrance and within Cement Creek by the rushing water. The release introduced large quantities of particulate aluminum, iron, manganese, lead, copper, arsenic and zinc to the Animas River, of which 15,000 kg was in dissolved form.

The release traveled as a coherent plume of metals through 550 kilometers (342 miles) of the Animas and San Juan Rivers over an 8- day period before ultimately reaching Lake Powell in Utah. As part of emergency response measures, EPA, States, Tribes and non- governmental organizations initiated extensive monitoring of water and sediments, collecting over 1,400 water quality and 800 sediment samples the rivers from August 2015 to November 2016. These data were extensively analyzed and augmented with modeling to quantify the source, transport, and fate of metals released from the Gold King Mine. Metal mass estimates were based on empirical reconstruction of water samples and flow measured at USGS gages, supported by a process-based water quality model (Water Quality Analysis Simulation Program --WASP) that simulated the contaminant transport as the plume flowed through the rivers.

When the acidic plume entered the larger and more alkaline Animas River at Silverton, CO, both dissolved and colloidal/particulate metals concentrations declined rapidly, as chemical reactions and hydraulic processes diluted, transformed and deposited material. Only 5% of the metal mass released from Gold King Mine arrived at Lake Powell with the plume. Most of the entrained particulates and the iron and aluminum oxides that formed within the plume were deposited in the river bed and along channel margins, primiarly in the upper reaches of the Animas River between Silverton (16.4 km from source) and Durango, Colorado (100 km) (Figure 1). This material remained in place until it was mobilized during snowmelt in 2016. Another 6% of the release mass (49,000 kg) was deposited in the lower Animas and San Juan Rivers during the plume. These deposits were remobilized and delivered to Lake Powell during a monsoonal storm that occurred on August 27, 2015, 20 days after the release event. Bed sediment samples confirmed that deposits had been removed by the storm.

Snowmelt mobilized the large mass of Gold King release deposits in the Upper Animas River starting in early April 2016 when increasing streamflow exceeded the levels observed during the GKM release. During this

period, water samples collected throughout the Animas and San Juan Rivers matched the metal composition of Gold King deposits transporting 433,000 kg that could be attributed to the GKM release. The sum of estimated Gold King Mine release mass delivered to Lake Powell in the three events was 506,000 kg (Fig. 2). The cumulative sum was very close to the initial estimate of 490,000 kg released to the Animas River.

Movement of the GKM release mass through the San Juan River in each of the three stages was accompanied by significant amounts of sediment that also naturally contain the same metals as the Gold King release, but in different mineral form and abundance. The elemental composition of metals in sediment was similar to that of the Mancos Shale that produce them. The Gold King release mass delivered to Lake Powell in the three events was mixed with 15,000,000 kg of sediment associated metals (Fig. 2B).

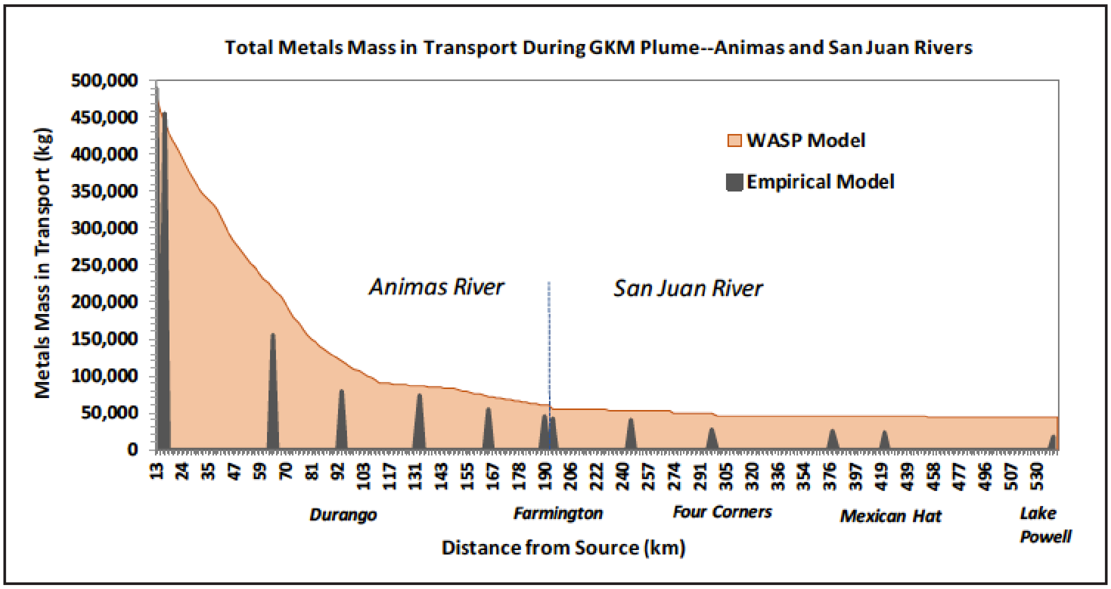


Figure 1. The total metals mass transported at locations in the Animas and San Juan Rivers during the Gold King Mine (GKM) plume, as simulated by the Water Quality Analysis Simulation Program (WASP) and empirical analysis of water sample data.

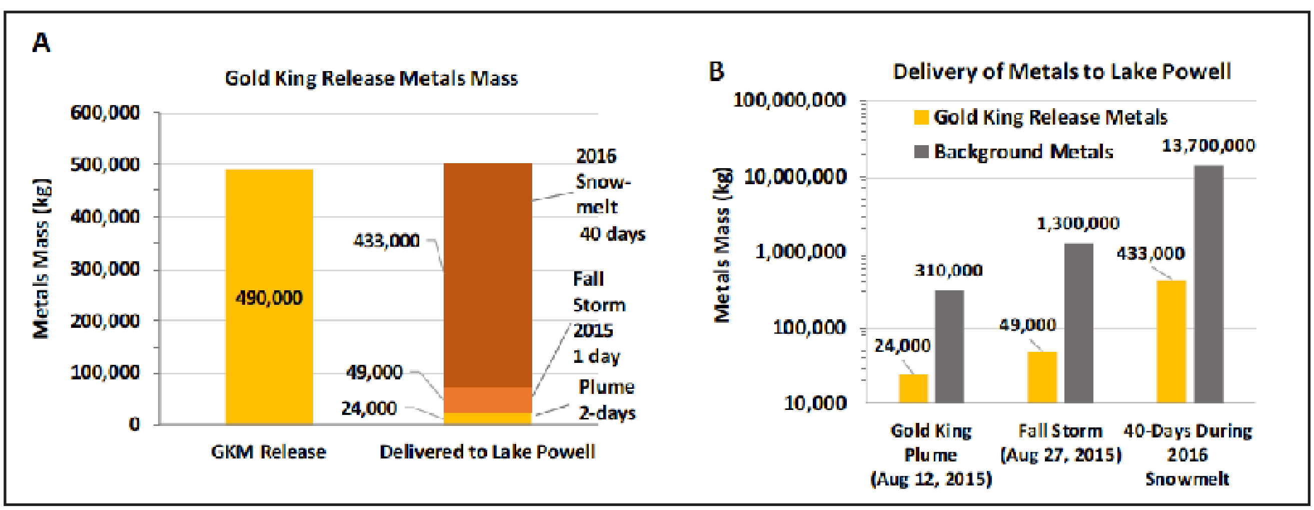


Figure 2. Summary of delivery of Gold King Mine (GKM) released metals mass to Lake Powell (kg) in three events: A) Estimated release mass and timing of delivery to Lake Powell; B) Mass of GKM compared to background metals in each event.

Illustration of a Fingerprinting Method to Isolate Gold King Release Metals from Background Concentrations in the San Juan River

K. Sullivan, M. Cyterski, C. Knightes, J. Washington, S. Kraemer, L. Prieto
U.S. Environmental Protection Agency, Office of Research and Development, Athens, GA.

Contact: K. Sullivan, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, GA, sullivan.kate@epa.gov, 706-355-8100

Abstract 18 – Both Oral and Poster

Detecting the Gold King Mine metals as the release plume passed was difficult once it entered the San Juan River on August 8, 2015. Plume metals concentrations were relatively low after 200 km of travel and deposition in the Animas River while background concentrations of the same metals were high due to high sediment load in the San Juan River. A metal fingerprinting technique was used to isolate metals in the Gold King release from background using the measured concentrations of the 23 TAL metals (Metal/Cynaide Target Analyte List) available with most water samples. The method associates the concentration of trace metals to that of aluminum or iron as representative of the dominant metals in the geologic substrate. Metal concentrations can be plotted together, as in Figure 1A, or the ratio can be computed for each sample for use as a value, such as plotted in time in Figure 1B. The correlation technique allowed maximum use of typically available water sample data to isolate Gold King metals as contaminants within the varying background concentrations associated with the natural sediments of the San Juan River.

The rationale for the approach was that aluminum and iron are abundant crustal elements and exist in relatively-consistent proportions in the rocks, soil, and sediments that weather from them.Because aluminum and iron are abundant metals, their concentrations in water should be proportionate to the sediment mass and readily measurable. In turn, the trace metals should be present in proportion to aluminum or iron. Higher concentrations of all the metals would be expected when sediment loads are higher and samples collected over a range of flows should routinely reflect the range of sediment in the water.

Figure 1A provides an example of the correlation ratio of lead to aluminum concentrations in samples collected from the San Juan River. Data include historic samples and those collected during and after the Gold King release including during several large fall storms. Concentrations vary over 3 orders of magnitude and demonstrate a consistent relationship between lead and aluminum. All of the trace metals show a strong relationship of this kind, except for selenium. For some metals, such as vanadium, the relationship explains up to 95% of the variability among samples in the San Juan River. In addition, the relative abundance of trace metals in the Mancos shale explains as much as 80% of the variability of the trace metals in water.

The technique was effective in identifying the GKM release metals within background concentrations during the plume and in post-event samples from the San Juan River. For example, the correlation technique indicated that some trace metals sampled at the times thought to coincide with passage of the Gold King plume were elevated relative to expected given the concentration of aluminum, such as illustrated for lead in Figure 1. Metals that were notably elevated in the San Juan River during the Gold King plume included lead and to a lesser extent zinc. After the plume passed, ratios fell back into their normal pattern. Other metals were comparable to background metals during the GKM plume, and concentrations did not differ from their basic concentration relationship. Although metals concentrations were much higher during the fall storms (highest values in Figure 1A) there was no indication that lead concentrations were elevated above expected after August 10 2015 (Figure 1B) suggesting no GKM influence.

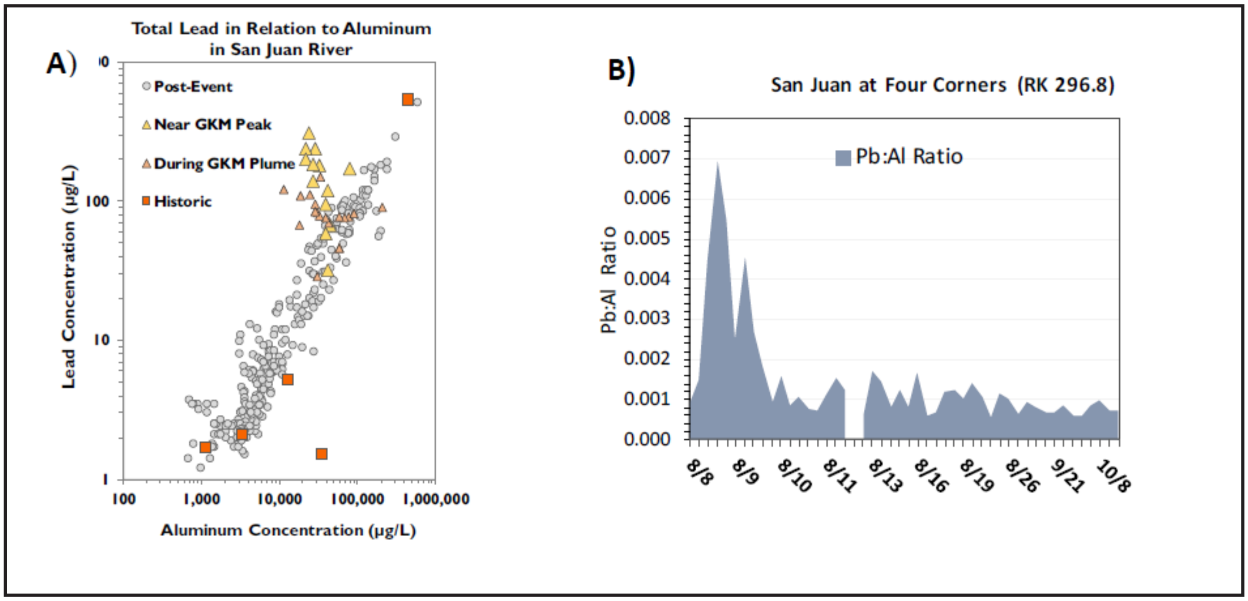


Figure 1. Examples of comparison of trace metals to aluminum concentration. A) all samples collected from the San Juan River identified by time periods relevant to GKM analysis; B) Ratio of lead to aluminum concentrations for samples collected from the San Juan River at Four Corners plotted in temporal sequence from the GKM plume August to October 2015.

The San Juan River received far more Gold King metals mass (433,000 kg) during the 2016 snowmelt period than it did during the actual release in August 2015 (24,000 kg). The correlation method indicated that the concentrations of a many metals were elevated above their expected relationships during April at all locations in the San Juan River, suggesting that GKM deposits were mobile. Metal concentrations were low but while relatively elevated the mass of metals transported was similar to the estimated mass of GKM deposits in the Animas River. Relationships returned to expected levels for the remainder of the snowmelt period.

The relationship of metals concentrations to background sediments in the San Juan River and the application and utility of the technique for isolating metal sources including the Gold King release metals in the San Juan River is discussed, and the potential for using the technique to identify other metals contaminant sources in this watershed is explored.

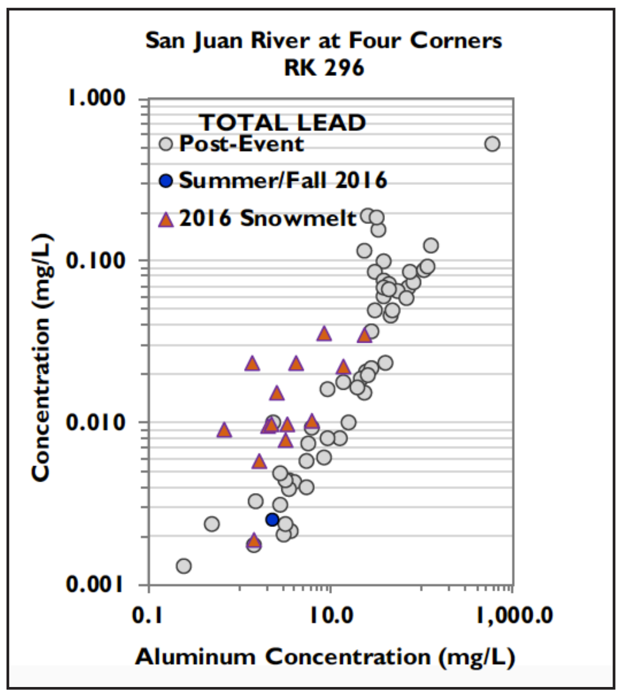


Figure 2. Total water concentration of lead in relation to aluminum during and after the Gold King Release in the San Juan River at Four Corners, emphasizing samples collected during the 2016 snowmelt period.

Characteristics of Metals Concentrations in the Animas and San Juan Rivers During Passage of the Gold King Mine Release Plume

K. Sullivan, M. Cyterski, C. Knightes, J. Washington, S. Kraemer, L. Prieto
U.S. Environmental Protection Agency, Office of Research and Development, Athens GA

Brian Avant
Oak Ridge Institute for Science and Education

Contact: K. Sullivan, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, GA, sullivan.kate@epa.gov, 706-355-8100

Abstract 19 – Both Oral and Poster

The accidental release of 11.3 million liters (~ 3,000,000 gallons) of acidic mine water from the Gold King Mine (GKM) in southwestern Colorado on August 5, 2015, created high concentrations of dissolved and particulate metals into the Animas River over about a 12-hour period. The release traveled as a coherent plume through 550 km (342 miles) of the Animas and San Juan Rivers over an 8-day period before ultimately reaching Lake Powell, Utah. Extensive monitoring of water and sediments by EPA, States, Tribes and others was augmented by water quality modeling to characterize the release.

The release initiated in Cement Creek, a headwater tributary of the Animas River 13km upstream of Silverton, CO. Reconstructed metal concentrations from samples collected within the mine after the release suggest that the acidic mine effluent (pH 2.9) contained approximately 700 mg/L of dissolved metals dominated by iron, aluminum, manganese, copper and zinc with small concentrations of lead, arsenic, and cadmium (virtually no mercury). This concentration of metals was significantly augmented as the low pH effluent eroded the mine waste pile outside the GKM entrance and reworked sediments as it flowed through Cement Creek. By the time the plume reached the Animas River, the peak concentration of total metals was estimated at be approximately 41,000 mg/L (excluding major cations Ca, K, Mg, Na), of which 90% was particulate and 10% was dissolved. Concentrations of several metals such as lead and arsenic increased dramatically. Lead was the signature metal that allowed tracking the release within the naturally occurring concentrations and variability of metals within the river system.

The concentrated core of the plume carried most of the metal mass past most locations in approximately a 12 to 14-hour period that remained remarkably consistent without significant dispersion. Although many water samples were collected as the plume traveled over the lengthy distance, the short duration of the plume's core explains why sampling of peak concentrations was so difficult despite intensive monitoring efforts. When the acidic plume entered the larger and more alkaline Animas River, both dissolved and colloidal/particulate metals concentrations declined rapidly as chemical reactions and hydraulic processes diluted, transformed, and deposited material. Metals concentrations were reduced to 13% of original strength by the time the plume traveled 5 kmthrough the upper Animas where multiple headwater tributaries converge. Dilution reduced concentrations to less than 1% as the plume reached Durango 95 km downstream of the GKM.

When the plume flowed into the more alkaline waters of the Animas River, geochemical reactions were triggered that produced a vivid yellow color. Increasing pH triggered formation of iron and aluminum oxides and other incipient minerals within the plume that created a mixture of particulate and colloidal materials that scavenged dissolved trace metals into their structures and removed themfrom solution. Data from deployed sondes suggests that the interior of the 12-hour core of the plumewas like a chemical reactor

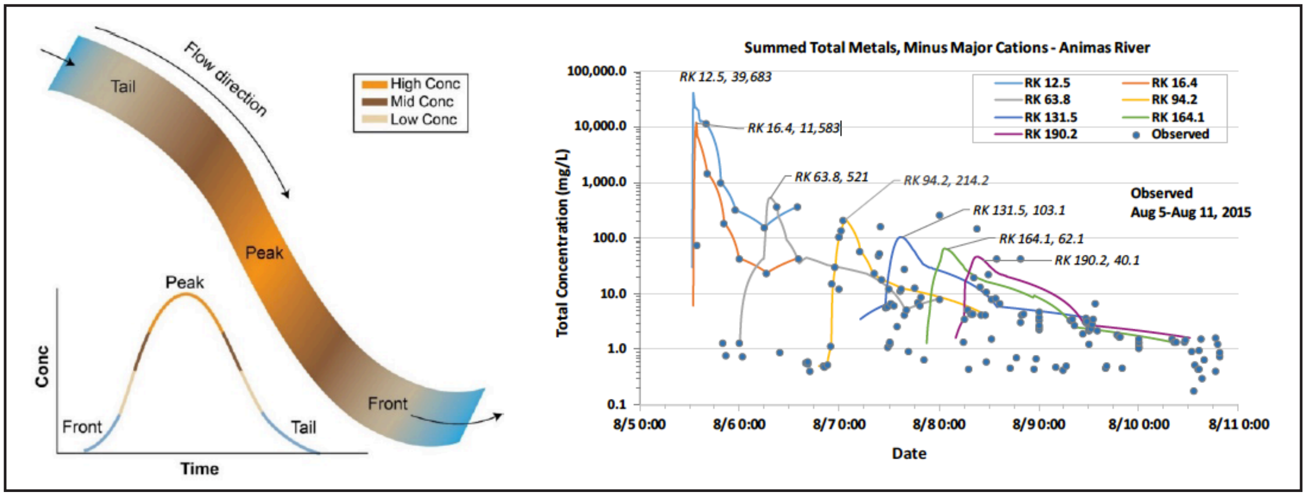


Figure 1. A) Conceptual drawing of what the Gold King plume was; B) Observed total metals concentrations (excluding Ca, K, Mg, Na) and reconstructed plumes in the Animas River.

that was stratified into a series of "fronts." The front of the plume was characterized by dissolved metals, the center by a lower pH interior, and followed by a trail of colloidal/particulate material. This pattern was observed through the length of the Animas River, although most of the chemical reactions appeared to be completed in the first 125 km of the plume'stravel, after which the acidity was largely exhausted. Dissolved metals were at background by 190 km downstream of the GKM.

The particulates and colloids that formed within the GKM plume were deposited throughout the length of affected rivers as the plume moved. Only 5% of the GKM plume mass reached the receiving waters of Lake Powell during the initial release, with 89% left in the Animas River, and 6% was deposited in the San Juan River. Although a large amount of GKM material was deposited in the upper Animas downstream of Silverton, the metal deposits were not different in content or significant in mass relative to metals already in that river bed which has been impacted by a legacy of mining and ongoing acidic mine contamination for over 100 years. GKM metal concentrations inthe sediments of the lower Animas River in New Mexico (river km 145 southward) were much lower but more distinguishable since this area has not been as impacted by previous mining effects. Metal concentrations declined towards pre-release conditions within hours of the plume passing, buta complete return to summer baseline conditions required days to weeks.

States and tribes have adopted water quality criteria that establish concentrations of constituents, including metals, that protect designated beneficial uses from harmful effects. Most of the metals in the GKM release have criteria for one or more beneficial uses that vary by State and Tribal jurisdictions. Despite the unusual metal concentrations, the large number of measured metals and thevariety of beneficial use criteria, there were relatively few exceedances of water quality criteria as the plume passed. However, criteria for several metals were exceeded for a few hours up to the duration of the plume (24 hours). State domestic supply and irrigation criteria for lead and manganese were exceeded in the Animas River. Aquatic acute criteria for aluminum were exceeded for a few hours in the Animas and San Juan Rivers. Tribal criteria for lead in drinking water were exceeded for the duration of the plume in the San Juan River.

Continued Monitoring of the Agricultural Fields Along the Animas After the Gold King Mine Spill

Brandon Francis, Gaurav Jha, April Ulery, and Kevin Lombard
New Mexico State University

David Weindorf
Texas Tech University

Contact: Brandon Francis, New Mexico State University, Ag Science Center at Farmington, NM, bfrancis@nmsu.edu, 970-403-4517

Abstract 23

Purpose of research/big picture significance:

A research team comprised of members from the New Mexico State University Agricultural Science Center (NMSU-ASC) at Farmington, NM and Texas Tech University (TTU; Lubbock, TX) organized in response to the August 5, 2015 Gold King Mine Spill of 2015 to rapidly assess potential heavy metal contamination in the Animas river agricultural environment using portable

X-Ray Florescence Spectroscopy (pXRF). This assessment was started on September 1st and concluded on September 3rd. Over three days approximately 300 field samples were taken and recorded with the pXRF. Data was analyzed and modeled for dissemination to the affected communities along the Animas River Valley and San Juan River Valley in New Mexico, so these communities could make future decisions regarding their agricultural practices. The communities were advised that preliminary results showed that the lead levels released during the event did not exceed Environmental Protection Agency (EPA) agricultural loading limits in New Mexico. In March of 2017, the team began the first year of a three-year study to extensively map three agricultural field sites representative of alfalfa, forage grass, and vegetable crops irrigated with Animas River Water with the objective of monitoring legacy mining impacts and to restore consumer confidence in agricultural products produced in New Mexico.

Main research questions:

Have heavy metals released from the Gold King Mine Spill and legacy mining impacted downstream the agricultural fields irrigated along the San Juan County, New Mexico portion of the Animas River? In the year and half since the event, has water affected the soil through the accumulation of heavy metals and will it continue to accumulate over the course of the study? In which parts of the field at each of the sites do the metals in question appear to accumulate and is there an evident spatial and temporal trend? Do the levels present pose a risk based on EPA standards to the farming practices of the growers along the Animas River?

Methods/how was the study done:

The fields monitored were sampled in the 2015 rapid assessment study using the pXRF. Six agricultural fields were chosen for long term monitoring beginning March 20176. Five sites are near the Colorado/New Mexico border and one site is located near Farmington, NM. Consent forms were given to land owners for permission to participate in the study. These sites were then mapped using ArcGIS software and sample waypoints randomly chosen using the same software to avoid selection bias. The waypoints were then loaded into a Global Positioning System (GPS) device. For each field, depending on acerage, the waypoints varied from

75 to 100 pXRF sample points/field. At every 10th sample waypoint, soil was auger collected for laboratory analysis of trace metals and soil nutrient status using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The same fields will be resampled with the pXRF mid-way through the growing season (e.g. July) and again at the end of the growing season in October. Monitoring will be repeated for three years to gauge the change over a growing season and subsequent years. The nutrient data will be returned to the growers to inform them of their soil fertility needs. Spatial and temporal variability maps will be made using ArcGIS software to show how the different heavy elements are concentrated in each field.

Preliminary results:

Preliminary results generally show that trace metals tend to be located in the higher portions of the fields where the irrigation is being applied first. In pivot irrigated fields, the trend seems to indicate that the trace metals are more present in the part of the field where the elevation is lower relative to the rest of the field. Heavy metal contaminants are in concentrations below the EPA standards required for agriculture (e.g. < 400 ppm for lead). The levels of all the elements detected by the pXRF during the initial study are also within the limits.

Synthesis/take home message:

Despite the presence of heavy metals in the fields, the levels sampled do not warrant an immediate threat based on initial results. Agricultural operations can proceed but further monitoring is needed to substantiate the findings of the preliminary field results over a longer period of time.

Metal Concentrations in Soil and Sediments after Gold King Mine Spill

Gaurav Jha, April Ulery, Kevin Lombard, Brandon Francis, Barbara Hunter, Hunter Winsor
New Mexico State University

Contact: Gaurav Jha, New Mexico State University - PES, gjha@nmsu.edu, gjha@nmsu.edu, 505-960-7757

Abstract 25 – Both Oral and Poster

Even two years after the August 2015 Gold King Mine Spill, the question “Is it safe to use the water?” is unanswered. The heavy metal contaminated yellow plume of water that flowed into the Animas River is still a concern for public health and agricultural practices. Immediately after the spill, most irrigation ditches were closed for several weeks and contaminated water was excluded from agricultural fields. However, there was disagreement about whether the metals were flushed out of the river or not and if surface water contamination may have spread through the watershed. Our goal is to evaluate the potential impact of the 2015 Gold King Mine Spill discharges and legacy mining/milling wastes on sediment, soil, and crop health. To accomplish this goal, the NMSU team is monitoring the presence of heavy metals in irrigation water diverted from the Animas River, irrigation ditch sediments and irrigated field soils. This presentation will focus on irrigation ditch sediments and agricultural fields.

We are monitoring the total concentration of aluminum, arsenic, calcium, chromium, copper, iron, lead, manganese and zinc in 10 different irrigation ditches fed by the Animas River. Collection sites range from Twin Rocks, near the Colorado-New Mexico border to Indian Village in Shiprock to represent a comprehensive image of agricultural resources and potential impacts. Sediment samples from the dry ditches are collected before and after the irrigated growing season, while water samples are collected at three different times: before the growing season while energizing the ditches (April); mid-growing season (July); and post-growing season (October-November). Soil samples from crop fields were collected before and after the growing season.

Soil and sediment metal concentrations are measured in-situ using portable X-Ray fluorescence (PXRF) and will be compared to samples digested in acid and analyzed by inductively coupled plasma-optical emission spectrometry (ICP-OES) following USEPA methods. The PXRF readings were made under two beams in Soil mode and Geochem mode (for aluminum) for 60 seconds. The concentration of metals in soil will be compared to the residential screening level (RSL) recommended by USEPA (for example lead RSL is 400 ppm, arsenic is 3.5 ppm, etc.).

On examining the concentration of metals in dry irrigation ditches sampled in March 2017, the average value of arsenic (4.8 mg/kg), iron (14,382 mg/kg) and manganese (540.2 mg/kg) were higher than the EPA RSL. However, copper (24.2 mg/kg), lead (43.4), zinc (176.4) and aluminum (5,758 mg/kg)) are below the RSL values. Calcium concentration is in the range of 2,189.5 to 11,219.5 mg/kg and is found as white patches in some areas with higher concentrations. The average value of chromium across the region was 44.8 mg/ kg.

Monitoring and Assessing Surface Coal Mining in Drylands Using Medium Spatial Resolution Satellite Imagery

Robert Sabie, Jr.
New Mexico Water Resources Research Institute

Michaela Buenemann
New Mexico State University

Contact: Robert Sabie, Jr., New Mexico Water Resources Research Institute, rpsabie@nmsu.edu, 575-646-5026

Abstract 28

In the United States, coal is used to produce nearly a quarter of the commercial energy. In the U.S. Southwest, most of this coal is extracted using Surface Coal Mining (SCM) techniques, which has several environmental impacts. To minimize post-mining environmental impacts, the Surface Mining Control and Reclamation Act (SMCRA) requires that mine operators reclaim mine lands upon completion of mining operations. Monitoring is necessary to evaluate both compliance with SMCRA and the relative success of reclamation efforts. Remote sensing can be a useful tool in this context, providing spatially explicit perspectives through time and across space. However, while remote sensing has been used successfully for monitoring SCM reclamation in humid lands for several decades, it is unclear how effective it is for that purpose in drylands like the U.S. Southwest, even though some of the largest disturbances from coal mining occur in these regions. The objective of this research was to address this problem by using remote sensing to monitor spatio-temporal landscape changes and estimate vegetation cover at the La Plata surface coal mine of New Mexico. To meet this objective, three major tasks were performed: 1) supervised classification of pre-mine, mine, and post-mine remediation land cover using Landsat TM and OLI imagery and Maximum Likelihood Classification and Support Vector Machine approaches; 2) land cover change detection using post-classification comparison; and 3) characterization of vegetation cover using the common vegetation indices Difference Vegetation Index, Simple Ratio, Normalized Difference Vegetation Index, and Modified Soil Adjusted Vegetation Index. The results suggest that the methods used in this study are useful for capturing major land cover changes (e.g., shrubland to exposed rock or exposed rock to grassland) in dryland mining environments but not for capturing subtler ones (e.g., shrubland to grassland). Vegetation indices show statistical relationships with vegetation cover and might be useful for locating areas that need additional reclamation efforts, however, they are not effective at quantifying vegetation cover at a level that is useful for determining whether areas have met reclamation success standards.

Geostrophic Winds and Related Hydro - Climate Representations Including the Lower Rocky Mountains

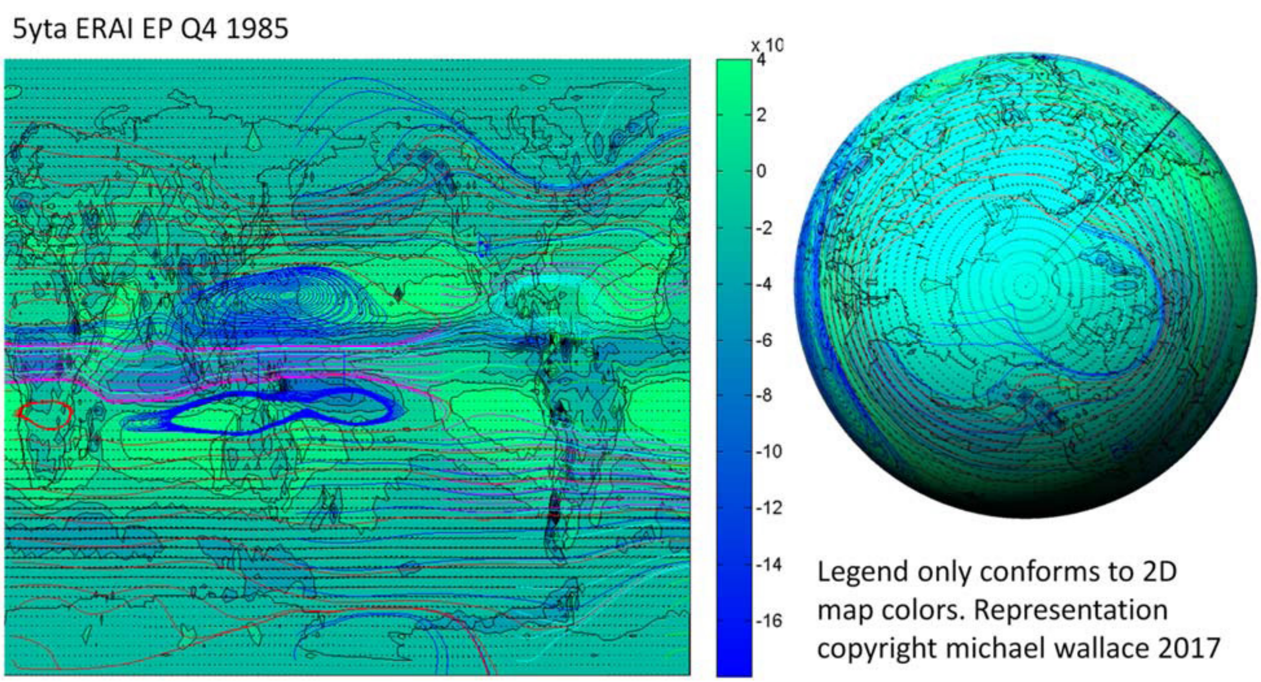
Michael Wallace
The University of New Mexico

Contact: Michael Wallace, Graduate Student, Nanoscience and Microsystems, University of New Mexico, mwa@abeqas.com, 505-401-3785

Abstract 29

The European Reanalysis of satellite data (ERAI)[1] for integrations of key parameters across the entire 100 km thickness of the Earth's atmosphere lend themselves to improved automatic representations of key climate parameters including polar vortexes, jet streams, droughts, the so called Hot Tower, and the Intertropical Convergence Zone (ITCZ). Such full atmospheric thickness data coverages as geopotential height (Z), Evaporation minus Precipitation (EP), and Temperature (T), can be examined for both confirmation of past weather and climate events and related to ongoing work by this author in regression based forecasting of moisture and temperature in the Southern Rocky Mountains.

The poster profiles various aspects and mappings of re-averaged ERAI data along with some comparisons with other related parameters, including solar cycles, the AMO, and the PDO.



[1] http://www.ecmwf.int/en/research/climate-reanalysis/era-interim

Quasi Steady State Sediment Transport and Unsteady Flow Water Quality Modeling in the Animas River

Paulina Lima
PhD student in the Civil Engineer, The University of New Mexico

Contact: Paulina Lima, University of New Mexico, paulinalima@unm.edu

Abstract 31

The simulation of sediment transport and its interaction with iron concentration after the 2015 Gold King Mine waste water spill on August 5th in the Animas River gives insights into the hydrodynamics of the river and the chemical interactions downstream of Silverton. The objectives of this study are to understand the sediment transport in the Animas River and to analyze the iron concentrations from August 4th to September 5th, 2015. A one-dimensional unsteady flow of water quality modelling of iron concentration and quasi-steady sediment transport model using the Hydraulic Engineering Center River Analysis System (HEC-RAS) Version 5.0.3 helps to address the objectives. This software explicitly couples the flow calculations in the cross sections with mobile bed modelling or water quality analysis using common data in the representation of the geometry. The results of this simulation expose that most of the mass bed change in the river was upstream from the stations located between 125 (Tall Silver Resort) and 172 Km (Silverton) from August 5th to 16th as a result of the larger amount of discharge during this period compared to August 17th to September 5th and the large slope in this part of the river. Although the simulation points out that advection-dispersion processes influenced along the river from Silverton to Cedar Hill stations only during 2 days after the spill, the dilution effects downstream of iron concentration were still predominant 13 days later.

Contaminant Element Cycling Through Aquatic Biota Following the Gold King Mine Spill

Benjamin D. Duval
Department of Biology, NM Institute of Mining and Technology
benjamin.duval@nmt.edu

Daniel D. Cadol,
Department of Earth and Environmental Science, NM Institute of Mining and Technology
daniel.cadol@nmt.edu

Contact: Daniel D. Cadol, Department of Earth and Environmental Science, NM Institute of Mining and Technology, Socorro, New Mexico 87801, daniel.cadol@nmt.edu

Abstract 32

Understanding the fate of contaminant elements following the Gold King Mine spill is of considerable interest for human health and for fisheries management. However, physio-chemical differences across the suite of elements released from the spill, and the history of mining-related chemical perturbations in the affected rivers, precludes a single expectation of aquatic biota response to increased contaminant levels. Data from NM Game and Fish suggest that contaminant levels have remained higher in spill-affected parts of the Animas River, evidenced by metal concentrations in Ephemeroptera and two species of sucker relative to non-affected populations of those animals in the San Juan River. An open question is whether internal cycling of contaminants occurs, and if these elements persist in the system longer than would be expected from a pulse event. Do contaminated waters facilitate metal uptake by plants, resulting in sediments with metals bound to organic matter, which can then be consumed by detritivorous invertebrates that in turn are eaten by fish? Are contaminants accumulated or lost during any of these processes? Alternative hypotheses are that contaminant concentrations in higher trophic levels are a consequence of life in a contaminated environment, or related to idiosyncrasies in contaminant uptake and exclusion from biotic tissues, i.e., not related to who is eating whom. We take a systems approach to measure contaminant elements in pools that are likely to interact: sediment/soils, plants, aquatic invertebrates and fish. Work is underway to quantify contaminant pools via ICP-MS from spill affected and non-affected reaches of the Animas and San Juan Rivers in northern New Mexico. Carbon and nitrogen stable isotope values for the same samples will also be determined. These coupled data sets across the breadth of aquatic biotic communities will help resolve whether food quality and trophic position can predict contaminant element movement through these spill-affected food webs.