2016

Environmental Conditions of the Animas and San Juan Watersheds

with Emphasis on Gold King Mine and Other Mine Waste Issues

May 17-18, 2016

Henderson Fine Arts Center, San Juan College, Farmington, NM

Co-sponsored by

Tuesday, May 17 Morning Session

8:30 a.m.	**WELCOMING REMARKS** NM WRRI Director Sam Fernald Mayor Tommy Roberts, City of Farmington
8:45	**CONGRESSIONAL STATEMENTS** Senator Tom Udall Senator Martin Heinrich Congressman Ben R. Lujan State Representative Paul C. Bandy
9:05	*New Mexico's Response to the Gold King Mine Spill* Ryan Flynn, Trais Kliphuis, Dennis McQuillan, and Allison Majure, NM Environment Department Presentation to be given by Dennis McQuillan (Abstract 5)
9:25	*Emergency Response* Kim Carpenter, San Juan County
9:45	*Geologic Setting and History of Mining in the Animas River Watershed, Southern Colorado* Virginia T. McLemore, NM Bureau of Geology and Mineral Resources (Abstract 33)
10:00	*1989 – Memories from the Sunnyside Mine* Evelyn Bingham, AECOM (Abstract 1)
10:20	**BREAK AND POSTER SESSION**
11:00	*Water Quality of the Upper Animas River, Before, During, and After the Gold King Mine Release* Robert Runkel, Katherine Walton-Day, and Daniel J. Cain, U.S. Geological Survey (Abstract 15)
11:30	*The Gold King Spill – How Did We Get Here?* Peter Butler, Animas River Stakeholders Group (Abstract 32)
12:00	**LUNCHEON** *'on behalf of water' – Diné art as an Act of Healing Navajo After the Gold King Mine Disaster* Venaya Yazzie, Navajo/Hopi (Abstract 36)

Tuesday, May 17 Afternoon Session

	THE GENIE IS OUT OF THE BOTTLE – WHAT NOW?
1:30 p.m.	*Everyone Wants a Walk Away: Long-Term Mine Closure in the Silverton Caldera* Briana Greer, President, Solid Solution Geosciences, LLC (Abstract 6)
1:50	*Utah's Response to the Gold King Mine Release and Long-Term Monitoring and Assessment Plan* Erica Gaddis, Utah Department of Environmental Quality (Abstract 29)
2:10	*Total and Dissolved Surface Water Metals – Post-Gold King Mine Spill Trends in the Animas and San Juan Rivers* Diane Agnew, Bruce Yurdin, and Dennis McQuillan, NMED (Abstract 19)
2:30	*Clay Contributions to the Gold King Mine Spill* Antonio Lara, Emilio Rivera, Raul Rivera, Tiffany Fowler, and Jeremy Jones, NMSU (Abstract 8)
2:50	*Rapid Assessment of Soil Metal Concentrations Along the Animas River, New Mexico* Kevin Lombard, April Ulery, and Brandon Francis, NMSU; David C. Weindorf, Bogdan Duda, and Carla Millares, Texas Tech University (Abstract 9)
3:10	**BREAK**

3:30 *Geological Processes Affecting the Chemistry, Mineralogy, and Acid Potential on Particle Size Fractions: Examples from Waste Rock Piles in New Mexico, USA*
Virginia T. McLemore, NM Bureau of Geology and Mineral Resources (Abstract 12)

3:50 *Examination of Sediment Microbial Communities in the Animas River Watershed Following the Gold King Mine Spill*
Patrick McLee, Sumant Avasarala, Lucia Rodriguez-Freire, Jose Cerrato, and Andrew Schuler, UNM (Abstract 18)

4:10 *Before the River Turned Orange: Bacteria and Nutrient Pollution in the Animas and San Juan Rivers*
Melissa May, San Juan Soil & Water Conservation District (Abstract 28)

4:30 *Assessment of the Fish Community in the Animas River After the Gold King Mine Spill*
Jim N. White, Colorado Parks and Wildlife (Abstract 16)

4:50 p.m. **ADJOURN**

Wednesday, May 18 Morning Session

ARE YOU SURE IT'S SAFE?

8:30 a.m. *Hydrogeology and Ground Water Quality at the United Nuclear Corporation Uranium Mill, Church Rock, New Mexico*
E.C. Dixon, Tsali Associates (Abstract 2)

8:50 *Stories from the Field: Biomonitoring in San Juan County, NM – October 2015*
Alexander Coyle, NM Department of Health, Barbara Malczewska-Toth, Heidi Krapfl (Abstract 20)

9:10 *Summary of Various Environmental Characterization Efforts in the San Mateo Creek Area, Grants Mining District, New Mexico*
E.C. Dixon, Tsali Associates (Abstract 4)

9:30 *Animas River Environmental Contamination from the Durango Mill Site*
Norman R. Norvelle (Abstract 14)

9:50 *Animas River Groundwater Level Monitoring After the Gold King Mine Mine-Water Release of 2015*
Ethan Mamer, Stacy Timmons, and Cathryn Pokorny, NM Bureau of Geology and Mineral Resources at NM Tech (Abstract 11)

10:10 **BREAK**

10:30 *Investigation of Metal Persistence in Sediments of the Animas River Watershed After the Gold King Mine Spill*
Lucia Rodriguez-Freire, Sumant Avasarala, Abdul-Mehdi, Joseph Hoover, Kateryna Artyushkova, Eric Peterson, Laura Crossey, Adrian Brearley, and Jose M. Cerrato, UNM; Diane Agnew, NMED; Drew Latta, University of Iowa (Abstract 17)

10:50 *Initial Assessment of the Gold King Mine Spill: The Role of Sediment Transport and Groundwater-Surface Water Interactions*
Jesus Gomez-Velez, Daniel Cadol, and Andrew Luhmann, NM Tech (Abstract 7)

11:10 *Monitoring the Animas River Alluvial Aquifer Groundwater Chemistry After the Gold King Mine 2015 Mine-Water Release*
Stacy Timmons, Ethan Mamer, and Cathryn Pokorny, NM Bureau of Geology and Mineral Resources at NM Tech (Abstract 24)

11:30 *What Are the Effects of the Gold King Mine Spill on San Juan County, NM Agricultural Irrigation Ditches and Farms?*
Kevin A. Lombard, April Ulery, Barbara Hunter, and Sam Fullen, NMSU (Abstract 10)

11:50 *Turbidity as an Indicator of Heavy-Metal in the Animas and San Juan Rivers*
Dennis McQuillan and Diane Agnew, NMED; David Sypher and Paul Montoia, City of Farmington Public Works Department; Monica Peterson, CH2M Hill (Abstract 21)

12:10 p.m. **LUNCHEON**

The Samarco Mine Tailings Dam Failure, November 2015: Effects and Observations
Katherine Walton-Day, Kate Campbell, Bradley Van Gosen, and Kris Verdin, USGS
Presentation to be given by Katherine Walton-Day (Abstract 31)

Wednesday, May 18 Afternoon Session

AND WHAT'S THE PLAN TO FIX THIS MESS?

1:30 p.m. *Hydrogeology and Ground Water Quality in the Vicinity of the Bluewater Disposal Site, Grants Mining District, New Mexico*
E.C. Dixon, Tsali Associates (Abstract 3)

1:50 *Ion Imprinted Polymers for Remediation by Selective Sequestration and Sensing of Hazardous Metal Ions*
George M. Murray and Thomas E. Ward, TechSource Inc. (Abstract 22)

2:10 *Solar and Ocean Based Hydrologic Forecasts for the Animas River Leading to the End of 2022*
Michael Wallace, Michael Wallace and Associates (Abstract 25)

2:30 *Remediation of the Terrero Mine and El Molino Mill, San Miguel County, New Mexico*
Dennis McQuillan, NMED; Virginia McLemore, NM Bureau of Geology and Mineral Resources; Paul Robinson, Southwest Research and Information Center (Abstract 13)

3:00 *Tó'Łítso, the Water is Yellow: Investigating Short Term Exposure and Risk Perception of Navajo Communities to the Gold King Mine Spill*
Karletta Chief, Paloma Beamer, Nathan Lothrop, Nicolette Teufel-Shone, University of Arizona; Jani Ingram and Manley Begay, Northern Arizona University; Rebecca Clausen, Fort Lewis College; Janene Yazzie, To' Bee Nihi Dziil; Mae-Gilene Begay, Navajo CHR (Abstract 38)

3:20 **BREAK**

3:35 PANEL: *WHERE DO WE GO FROM HERE?*
Moderated by Virginia T. McLemore, NM Bureau of Geology and Mineral Resources

Steve Austin, Navajo Nation EPA
Kim Carpenter, San Juan County
Karletta Chief, Department of Soil, Water and Environmental Science, University of Arizona
Rich Dembowski, Gold King Mine Citizens' Advisory Committee
Bonnie Hopkins-Byers, New Mexico State University, San Juan County
Dennis McQuillan, New Mexico Environment Department

5:00 p.m. **ADJOURN**

Conference Planning Committee

Diane Agnew, NM Environment Department
Laura Crossey, University of New Mexico
Sam Fernald, NM WRRI
Fernando Herrera, NM WRRI
Jesus Gomez-Velez, NM Tech
Trais Kliphuis, NM Environment Department
Kevin Lombard, New Mexico State University, Farmington
Melissa May, San Juan Soil & Water Conservation Dist.
Virginia McLemore, NM Bureau of Geology and Mineral Resources
Dennis McQuillan, NM Environment Department
Paul Montoia, City of Farmington
Catherine Ortega Klett, NM WRRI
Jesslyn Ratliff, NM WRRI
Blane Sanchez, NM WRRI
Jamie Shockey, San Juan Generating Station, PNM
Andy Shuler, University of New Mexico
Stacy Timmons, NM Bureau of Geology and Mineral Resources at NM Tech
Butch Tongate, NM Environment Department
Thomas Turner, University of New Mexico

2016 Conference Photos

2016 Panel Discussion Executive Summary: Where Do We Go from Here?

Panel discussion Wednesday, May 18, 2016 3:35 pm

Moderator: Virginia T. McLemore, NM Bureau of Geology and Mineral Resources

Panel participants:
Karletta Chief, Department of Soil, Water and Environmental Science, University of Arizona

Bonnie Hopkins-Byers, New Mexico State University, San Juan County

Kim Carpenter, San Juan County

Rich Dembowski, Chairman, Gold King Mine Citizens' Advisory Committee

Dennis McQuillan, New Mexico Environment Department

Steve Austin, Navajo Nation EPA

Editor's Note: The following represents a transcription of panelist remarks made at the conference. Remarks were edited for publication by the editor. Some panelists did not review this version of their presentation and the editor is responsible for any errors.

Virginia McLemore: The goal of the panel discussion is to discuss the path forward in terms of science and engineering. We welcome the public to join us in the field to see how we sample and we plan to have another conference next year to follow up.

Steve Austin: Seeing similar issues pre and post-spill. We need to figure out what is naturally occurring and what is going on in the system.

We need to check on local geology, historic mining, power plants, coal mining and/or gas development. We need to figure out what these sources are and try to deal with the problems and figure what screening levels we are using and the concentrations.

What is really safe and for what use? Ag use and livestock use.

We will continue to monitor weekly once our funding gets into place. We want to see what is coming down the river and make sure it is acceptable levels. We need to know how much is from pre-spill and how much is from Gold King.

Kim Carpenter: With what's happening with the chemistry of the river, we want to clean up nitrates. From the aspect of SJC point of view, we have been working the last decade to get more structured systems in place and gravity flow system that would eliminate failing septic systems.

We know there is a potential for it to happen again and we want to look at prevention and backup measure

There is data out there that can help us with a perspective of what's going in regard to the nitrates in the river. We have to address all of this issues and the other factors that contribute to the negative effects.

As far as San Juan County and notification planning, we have had a comprehensive plan in place for a long time. We found ourselves notifying the Navajo Nation. I want to start talking collectively. We need to work on the communication side to have scientific and political approach to protect the future generations.

Karletta Chief: I believe where we could go is better communication of data and research that is going on around the San Juan River upstream and downstream. A concern I hear from the community includes the lack of communicating the data and research going on. This will help them to understand standards and understand where their water comes from. Also, I would like to see watershed partnerships for the Navajo Nation in terms of making people able to do their own monitoring and practice land management of their own land. A fair water testing day to educate people on collecting samples.

Work to build trust in providing information back to the people.

Also, recognize different perspectives and respecting that and valuing it in the sense that indigenous people use water very differently. Examples include: mud baths, spiritual practices, or sediment put on skin as part of prayer. Recognize that daily life for the Navajo people is very different and incorporate that into exposure assessments.

When we did listening sessions, we said very little and just listened to the community members and that will help with healing. It's about healing as a community and being optimistic about the future.

Rich Dembowski: If we are going to be serious about moving forward then we need to understand the pre mining conditions that go back 100's of years, look at how it was then and before/after the Gold King Mine spill. We need to define "normal". In order to achieve that would require a compilation of various engineering standards; health, Ag, sediment, and water quality.

Lurking in the background of the science is an entity. The entity is very poorly defined and over time as additional research comes in to play, the entity will be fed data and will be a constantly changing body of thought.

The mission of the Gold King Mine Citizens' Advisory Committee is to serve as a liaison between the public and government. We want to convey public concerns to the NMED and ensure that they are addressed. I can assure all that every member of the committee is invested in our mission statement. The committee developed and approved our own bylaws (self-govern) and we honor no master other than the public.

Many questions remain: What's the projected cost of monitoring and cleanup? Will NM benefit from Colorado application for superfund status? If not then do we need to apply?

Development and maintenance of trust is part of moving forward. The elephant in the room is the fact that we don't trust the government and that's unfortunate but it is reality. The key element is giving the citizen a reason to trust and have faith in the government. The EPA needs to be accountable and responsive. We need less road blocks and do more than talk. I suggest Heinrich and Udall need to be proactive and act to cause the EPA to be accountable, transparent, and receptive.

Bonne Hopkins: I represent NMSU staff and employees. The big thing is that this emergency is local and there is no one that will be more invested than us here today.

We can see Ag was put at the forefront of this emergency and that's rare. Usually farmers have to fend for themselves. We do have to preserve the legacy of Ag in this state. It is important to tradition, culture, and heritage. We need to focus on maximum contaminant levels and we need to establish levels that are acceptable for us. We want to be able to say according to the max levels and the data we have, it is safe to irrigate. We can't assume that we know all questions and answers. We need to keep an open mind and respect the emotions related to the spill.

We look at livestock as a concern and are watching monitoring levels. Also, we are looking at the ecosystem and we may lose ecosystems if we don't irrigate.

We need a holistic perspective and need to continue working together and focus on future generations and protect Ag legacy.

Dennis McQuillan: It's important to communicate with the public and be honest about the good, bad and the ugly. This conference has done a good job of identifying data gaps. We put together the exposure and risk dashboard. It explains exposure pathways. This whole process is data driven as we take samples and then decide where to go next.

EPA soil numbers have been mentioned and those are not appropriate for recreational standards. The NMED will not stand for that number. We have some gnarly tech issues that need to be addressed but we are going to use good science and subscribe to peer review and collaborate.

Question from the audience: What is the best way for outside researchers to build trust with Navajo communities in order to better communicate scientific results that may impact those communities? For example, bacteria pollution in the San Juan River.

Karletta Chief: Working with Navajo experts, getting support of Navajo community leaders having Navajo consultants, working with Navajo Students and partnering with Navajo scientists to give advice and guidance to the researchers.

Make sure you have approval regarding environmental and human subjects. This takes a lot of time, discussion, and outreach to respond to their questions.

Steve Austin: You have to work with tribal government but you won't gain the trust of the locals if you don't work with the chapter officials. The local people need to be involved in the community meetings. It takes a lot of time to gain trust.

Question from the audience: What was the population of the area studied before 1935 when tailings were being dumped in rivers? Our perceptions and expectations have greatly changed in the intervening years. We have a much larger populations that is more concentrated in large towns and cities whereas before ranchers, farmers, and miners were more dispensed. Before vaccines, antibiotics, and safety regulations. People were more resigned to accidents, illness, and death but today modern technology and machinery has made pollution a much greater problem and modern communications have made awareness of problems greater and more immediate.

How can we resolve these existing problems without blaming "the other" as we are all involved?

Kim Carpenter: Historically when Silverton was at its peak there was quite a bit more people. The area was plagued by disease that wiped out the population in the twenties. There will be evolutions of decline population and evolutions of increased populations. The biggest thing about it who is here, what we need to do better to collaborate throughout the entire corridor

With regard to population: we need to understand the presence of the Navajo Nation in terms of data collection, sharing and then get the minds together and lay down the issues at hand of determining what are the important numbers and what is acceptable?

Rich Dembowski: We need to evaluate how our societies have changes over the last 100 years. The growth of oil and gas which is now bad affect our society from Silverton and downstream. Resource extraction. We will evolve from economic system

We will experience change over the next 100 years that will focus on economies. We will lose people but we will also gain others.

Paul Montoia: Regarding the first question, I think it's all the communities in general. The public does not have a good light of EPA.

What I would like to see is the NMED commit to setting up a meeting with officials from EPA regions 8, 6 and 9 because we hear we're not getting the true story, so if we could pull all those people together for a community discussion that would be beneficial and should be one of the goals that we could set here today.

Question from the audience: Gold King Mine spill has and continues to have national attention. As a concerned San Juan County citizen, what is EPA doing in the following areas:

1. Spill remediation along the entire waterway
2. Time frame to commence and finish remediation

Dennis McQuillan: To respond to Paul's comment, the EPA held three public meetings in CO but we need a meeting for stakeholders in NM and we have asked EPA if they could hold a superfund meeting in Farmington or Aztec and have not receive a response. We are stakeholders down here and we need to make sure we are heard.

Regarding remediation, there are no proposals to go in and remove solids that are in the river bed. There is a data gap when it comes to the 880,000 lbs. of metals and the distribution is not well defined. We have hot spots with high levels of lead and that needs to be mapped and identified that we have discussed. Nobody has cleaned any sediment in the river to-date.

Question from the audience: Why was it not dammed back up as soon as possible? Why allow continual seepage? We have concrete that sets up in the ocean. Why are we not using it? There is a water system created in India that pull clean water out of the air. Why are we not filtering the river?

Dennis McQuillan: EPA did install a water treatment plant on emergency basis.

Rich Dembowski: As an engineer, I write and certify spill plans which are required by the Clean Water Act. Did the EPA have all these plans that they require the rest of us to have? What actions were taken? You're required to have a log under the Clean Water Act, so where is their log? They have refused to disclose any data regarding these things.

Come to my meetings and hear your neighbors talk about EPA coming onto their property without concern for ownership, taking samples, then unwilling to share information with landowners. It is that elephant in the room, folks.

Gilbert Yazzie from Shiprock, NM: It's happened in the past and the grassroots Navajo won't understand the technical info. Technical info needs to be brought down to the level of the people.

Karletta Chief: I rely on Navajo geologists that have been at the forefront of translating technical terms. There is challenges in explaining parts per million (PPM) in Navajo so when I presented samples, I worked with the Navajo geologist to translate my research. They have standardized Navajo medical terms.

Steve Austin: We presented our results in Shiprock and we had a co-worker translate the technical information.

Dennis McQuillan: How to visualize PPM: What if you plant a row with 1000 irises with 1000 rows? That's a million iris's and you pull out one and put in one poison ivy.

Delia Bell from Farmington: I live in northern CO and I am a friend with a representative in CO that could help you if you want me to be in contact with him. Randy Baumgardner CO State Senator. I would be happy to give you his contact info.

Question from the audience: Colorado has been feeling the effects of chronic mine drainage for many years. This blowout is the first time that the effects have been felt so far downstream. It was suggested yesterday that superfund will address chronic loading but is unlikely to address the possibility of future min blowouts. What role should downstream jurisdictions take in advocating for research and/or remediation to prevent future mine blowouts?

Kim Carpenter: There has been significant blowout in the 70's that was devastating to this area. I think it is not effective for everyone to stand aside and hope this doesn't happen again. This will happen again and were talking about drainage that will last more than a couple of weeks. People have to get involved. We need to fight for what we have instead of fighting for what we want. What else is being polluted? People downstream need to get involved. Were also dealing with other issues so I encourage every jurisdiction to get involved and speak up. The Southwest is very difficult and were basically forgotten as a result of not being on the East Coast.

We would not carry the voice we had if there were not others standing beside us. This event was a local emergency that stemmed assistance from other agencies. The county is concerned for our friends.

Rich Dembowski: The army spends time planning and rehearsing. I don't believe you can always prevent but you can do everything possible to minimize an event.

You depend on training for a plan when reacting. When someone breached that dike, it was an "awe shucks" situation. The guys there probably were not trained on a spill plan. We are continually cited by the EPA if we don't have our own plans and training. We need to ensure that everyone is aware of what needs to be done when there is another disaster.

Dennis McQuillan: The citizens needs to hold the government accountable. Make sure we are doing the right thing.

Darrell Clark from Farmington, NM: This GK incident is not our first, it has happened in the past. The cumulative effect of all this stuff leaches minerals into our rivers is zilch. There is fish in the river, there is wild life just like there was before. We need quit letting them cause an uproar and listen to them.

Duane (Chili) Yazzie from Shiprock, NM: *Daily Times* reported there is 4.5 million gallons of mine waste coming off the mountains into the rivers on a daily basis. Is this an exaggeration?

Kim Carpenter: I can't confirm that is a correct number but that is occurring. There is theory that the American Tunnel is leaching into the GKM but that has not been confirmed. The big thing is that there have been a number mines that have been leaking.

I have seen mine heads that are seeping and this has been going on for years and years and has gotten worse. This is why EPA was looking at the remediation process; trying to filter out minerals that were released in the sludge. I can't tell you a number but there are a number mines that are seeping.

Dennis McQuillan: The mines have been leaking for a long time. They installed bulk heads to control the seepage to plug up lower levels. It caused groundwater in mountains to rise 1,000 ft. Now there is substantial pressure. Installing the bulk heads was a good thing but now we have additional work to do. We need a holistic solution and look at the entire watershed because some of the issues transcend. We will look at the entire health of the watershed and fix it holistically. It will require a lot of collaboration between jurisdictions

Ronnie Ben with Navajo Nation EPA: We went to the site with Dennis's counterparts and the contractors were there with EPA staff. The contractors wouldn't say anything about sampling, filters, or disposal. There were a lot of unanswered questions. I will continue with experts to do a variety of technical things to look at inspections.

Based on our knowledge to better prepare a lot of these sites and put in some BMP's. In the summer, we would like to return to the site and see how we can assist.

2016 Oral Abstracts

1989 – Memories from the Sunnyside Mine

Evelyn Bingham,
AECOM

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Abstract 1 – Both Oral and Poster

In the late 1980s the Sunnyside Mine was an active underground gold mine operation. As a member of the mine engineering staff from 1987-1991, the author had the opportunity to explore many aspects of the underground and surface expression of the mine. Hired to support the underground survey crew in 1987 and later working as the mine ventilation engineer and water treatment plant operator, the author shares memories of the physical characteristics of the operating mine. The presentation uses publicly available maps and diagrams coupled with personal descriptions of the underground workings, the Lake Emma glory hole on C-Level, lime treatment plants and settling ponds constructed to treat acid mine drainage at the American and Terry Tunnels, tailings effluent water quality adjustment at the Mayflower Mill, and surface water sampling in the upper Animas River Watershed in the years just prior to the mine shutdown. The intention of the presentation will be to give the audience a first-hand account of underground mining in the Gladstone area and associated environmental activities circa 1989 and provide an opportunity to improve understanding of mining and the mine area geography affecting the Upper Animas watershed.

Hydrogeology and Ground Water Quality at the United Nuclear Corporation Uranium Mill, Church Rock, New Mexico

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Abstract 2

The United Nuclear Corporation (UNC) uranium mill is located about 16 miles northeast of Gallup, NM along the southern boundary of the Navajo Indian Reservation. The UNC mill produced uranium (U) concentrate from the Northeast Church Rock (NECR) Mine from 1977 to 1982. The Site is situated on alluvial valley fill, sandstone, and shale of Cretaceous age at the southern margin of the San Juan Basin. From approximately 1969 to 1986, large quantities of ground water were pumped from the nearby NECR and Quivira mines to dewater the underground mine workings (Westwater Canyon Member of the Jurassic age Morrison Formation). Mine water was discharged to the Pipeline Arroyo, and a portion of the mine discharge water infiltrated into the previously dry units of Southwest Alluvium, Zone 1, and Zone 3 of the Upper Gallup Sandstone Formation. Mine discharge water that infiltrated the three previously unsaturated units constitutes the "background water" for the Site. Milling operations produced 1.5 million tons of acidic tailings that were impounded within the Tailings Disposal Area. Acidic seepage from the Tailings Disposal Area migrated downward and mixed with background water creating three discrete areas of tailings seepage-impacted ground water.

The cleanup standards are those prescribed from the Environmental Protection Agency (EPA) 1988 Record of Decision (ROD), the Nuclear Regulatory Commission Source Material License. The remedial system of extraction wells installed in each hydrostratigraphic unit pumped seepage-impacted and background water for evaporation for 20 years or more until the systems were turned-off. The source of artificial recharge ended since mine dewatering ceased in 1986. As seepage from the Tailings Disposal Area drained away, the level of saturated thickness in the three units continues to decrease. The Southwest Alluvium historically exceeded Site standards for total dissolved solids (TDS) and sulfate. Zone 1 exceeds Site standards for some non- hazardous constituents outside the property and some hazardous constituents within the Site boundary. Contaminant concentrations in Zone 3 exceed a number of Site standards for non- hazardous, metal, and radionuclide constituents despite persistent extraction well pumping and injection well operational schemes to chemically and hydraulically capture seepage-impacted water.

Based on the results from EPA's ProUCL statistics, the declining saturated thicknesses, and low extraction well efficiencies, some ground water compliance standards are in need of revision to support a future, updated ROD. In 2012 UNC submitted a technical analysis report to the Nuclear Regulatory Commission (NRC) in support of a request for revised background standards under an amendment to the Source Material License for the Site. In 2015 the NRC issued Amendment 52 that revised the Groundwater Protection Standards for select metals and radionuclide in three hydrostratigraphic units. EPA approved use of the revised background standards in the revitalized and ongoing process to develop a three part Supplemental Site Wide Feasibility Study (SSWFS). The UNC SWSFS Parts I and II have been completed. Part III of the UNC SWSFS is expected to provide more technical analysis to support a revised and updated EPA ROD for the Site.

Hydrogeology and Ground Water Quality in the Vicinity of the Bluewater Disposal Site, Grants Mining District, New Mexico

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Abstract 3

The Bluewater Disposal Site is located in west central New Mexico in Cibola County near the communities of Bluewater and Milan. The Anaconda Copper Company opened the Bluewater uranium mill in 1953 to process ore from the Jackpile mine in Laguna, New Mexico. Initially the mill used a carbonate-leach circuit to process limestone ore from the Todilto limestone, but in 1957 the mill switched to an acid-leach circuit to process Jackpile sandstone that operated through 1982. The mill released carbonate and acidic mill raffinate water to the subsurface that impacted ground water quality. As many as 18 regional wells completed in the San Andres limestone-Glorieta Sandstone (SAG) aquifer were once used to monitor ground water for contamination from the mill. The Site was remediated under the U.S. Nuclear Regulatory Commission (NRC) operational license, and then it was transferred to the Department of Energy (DOE) for Legacy Management in 1997 under Title II of the Uranium Mill Tailings Radiation Control Act. Prior to transfer to DOE, NRC amended the operational license to include alternate concentration limits (ACLs) for the alluvial and SAG aquifers. In 2011 the ACL for uranium in the alluvial aquifer at the Site was exceeded at the Point of Compliance (POC) well. DOE installed four new alluvial monitoring wells in 2011-2012 to acquire more ground water quality data, and understand the increasing concentrations for select constituents in some alluvial monitoring wells.

After Site transfer to DOE in 1997 four on site monitoring wells in the SAG aquifer were sampled periodically for a limited amount of ground water quality data. Comprehensive ground water sampling of SAG wells on and around the Site in 2008 by the New Mexico Environment Department (NMED) indicated spatial geochemical variations in water chemistry and isotopic composition possibly related to contamination from the mill. NMED review of the four onsite SAG monitoring well logs in 2009 raised concerns about construction and representative sampling. DOE evaluation of the four SAG wells in 2011 via well logs, field testing, and water quality data revealed two wells were so corroded that representative sampling was compromised and the wells needed rehabilitation or replacement. In order to more fully comprehend the complex SAG hydrogeology and close data gaps, DOE installed six additional, new SAG wells at the Site in 2012. A comprehensive Site status assessment was conducted in order to develop a more reliable groundwater conceptual model that describes aquifers associated with the Site and the potential for mill-related contamination exposure to down gradient ground water users. Oxidized ground water migrating from the Bluewater site in the SAG aquifer flows in the east- southeast direction in a karst-like system with hydraulic properties that vary with location. Available ground water data suggest that Bluewater-derived contamination particularly uranium does not adversely affect any private wells used for drinking water. Ground water quality data from the current SAG monitoring well network on site indicates that contaminant concentrations continue to decline in accordance with historical trends. DOE monitors off site well locations for evidence of contamination, and plans to conduct more investigation and additional well installation where necessary to ensure the ground water supply for the local communities is not at risk to water quality degradation.

Summary of Various Environmental Characterization Efforts in the San Mateo Creek Area, Grants Mining District, New Mexico

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Abstract 4

The Grants Mining District (GMD) in Cibola and McKinley counties of New Mexico was the focus of extensive uranium mining from 1950 to the early 1980s. The San Mateo Creek (SMC) basin of the GMD encompasses approximately 321 square miles including the Ambrosia Lake area where there are 96 documented former producing mines and four mills, some of which have documented contaminant releases. In 2008-2009 the New Mexico Environment Department (NMED) performed a Site Investigation (SI) of approximately 60 ground water sites to characterize the impacts of legacy uranium mining-milling activities on the SMC regional ground water system. In 2010 NMED performed a Phase 2 SI of four more ground water sites in Ambrosia Lake and reconnaissance site visits to four mines including the Johnny M Mine. In 2009 the U.S. Environmental Protection Agency (EPA) performed aerial radiological surveys of the Grants and Cebolletta Land Grant Areas. EPA performed two more separate aerial radiological surveys in 2011 encompassing approximately 22,000 acres of the Ambrosia Lake area that included two mill sites and 27 legacy uranium mines, and 20 square miles of the Poison Canyon area. In 2011-2012 EPA conducted documented release sampling of 10 mine sites in Ambrosia Lake that included gamma radiological surveys and soil-sediment sampling for metals and radionuclide analysis. Environmental characterization data indicates that a number of mine sites will require remediation of surface soils to minimize the risk of radioactive release and exposure. From 2010 to 2015, the EPA's Removal Program assessed over 900 structures and properties for gamma and elemental uranium concentration. Soil radiation levels at 128 of the 900 sites were above action levels and were cleaned up. Relocation of a resident was required near the Johnny M Mine due to elevated surface radioactivity levels.

In 2009-2010 the U.S. Geological Survey (USGS) examined the geologic framework, regional aquifer properties, and spring, creek, and seep properties of the upper SMC basin near Mount Taylor. Beginning in 2013, in collaboration with the USGS and NMED, EPA designed and initiated a phased ground water investigation for the SMC basin alluvial aquifer background water quality. Investigation fieldwork consisting of seismic surveys and exploratory borehole drilling for alluvial ground water began in 2014 and was completed in 2015. Despite an extensive amount of drilling, conditions representing background alluvial ground water were largely nonexistent, and only five boreholes were completed as monitoring wells. In 2014 Roca Honda Resources, LLC (RHR) submitted a revised permit application for a new mine for its proposed Roca Honda uranium mine in the upper part of Ambrosia Lake that included a Baseline Data Report (BDR). The RHR BDR includes the results of extensive environmental investigations for the period 2006-2012 that focused on sampling and investigation of soil, surface water, and ground water systems at the proposed site and regional area. This paper will present a brief summary of the various environmental characterization efforts primarily in the SMC-Ambrosia Lake area, and highlight some of the interesting results of legacy uranium impact investigations through 2015.

New Mexico's Response to the Gold King Mine-Water Spill

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Abstract 5

On August 5, 2015, a U.S. 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. EPA reported that more than 3 million gallons of acidic mine water containing sediment, heavy metals, and other chemicals spilled into Cement Creek, which flows into the Animas River and into New Mexico where it joins the San Juan River before flowing into the Navajo Nation and Utah.

On August 6, 2015, the N.M. Environment Department (NMED) was notified of the spill by the Southern Ute Tribe. NMED advised public water systems to stop taking water from the river, and provided notice of the spill to public sewer systems, the Navajo Nation, Arizona and Utah. NMED and the N.M. Office of the State Engineer (OSE) advised irrigation ditch users to close river diversions. Some irrigation ditches did not have head gates, and could not be closed. NMED also mobilized a technical team to begin monitoring the impacts of the spill.

On the morning of August 7, 2015, the NMED Secretary and the N.M. State Engineer arrived on site and began coordinating response actions with the San Juan County Emergency Operations Center to ensure that public health and safety were protected. The first NMED technical team also arrived on site, installed multi-parameter sondes in the Animas and San Juan Rivers, and began collecting water samples for laboratory analyses of metals and general chemistry. NMED issued additional precautions for private domestic wells and livestock watering. The N.M. Department of Game and Fish (NMDGF) advised anglers not to eat fish caught in watershed. NMED also authorized up to $500,000 in expenditures from the N.M. Hazardous Waste Emergency Fund, and created a dedicated webpage for spill information.

GKM contamination in the Animas River entered the State of New Mexico on August 8, 2015. During the weekend of August 8-9, NMED, OSE, San Juan County and NMDGF continued to coordinate emergency response actions, along with N.M. Department of Health (NMDOH), N.M. Department of Agriculture (NMDA), San Juan Soil and Water Conservation District, and N.M. Department of Homeland Security and Emergency Management (DHSEM). Governor Susana Martinez declared an emergency and authorized an additional $750,000 in expenditures.

By Monday, August 10, 2015, NMED had 25+ staff on site, along with staff of the other state and local agencies. NMED set up a mobile laboratory at the San Juan County Fairgrounds to provide free tests of private domestic wells using field instruments. During the week, well users were encouraged to bring water samples to the mobile lab. NMED tested 580 water samples for specific conductance, temperature, pH, nitrate, iron, manganese and fluoride. Field teams consisting of NMED and EPA personnel were created to sample private domestic wells, located within 500 feet of the Animas River, for more rigorous analysis by a certified laboratory. Wells were self-identified by homeowners and also were selected by the sampling teams who knocked on doors in the field to fill in data gaps. The field teams sampled 144 wells for analysis by an EPA contract lab for metals and general chemistry. To date, field and laboratory test results show no evidence of impacts from the GKM spill to any private domestic wells located in N.M. NMED was in daily contact with

public water system operators to share information and provide consultation and assistance. Public drinking water storage was calculated and water sharing efforts were initiated among the systems while river intakes remained closed. NMED and the water systems conducted extensive testing of treated drinking water. No public water system customers received contaminated drinking water or lost water service.

On August 14, 2015, after careful consideration of all available data, the New Mexico executive agencies, EPA and San Juan County agreed to lift the precautionary advisories that had been issued the week before. All irrigation ditches were flushed with river water for 12 hours, without irrigation diversions, to wash spill sediment back into Animas River. Drinking water system intakes on the Animas River were not opened until after the irrigation ditches had been flushed.

NMED staff testing well water.

Governor Martinez appointed a GKM Long Term Impact Team (Team) led by NMED with membership from other executive and local agencies including the City of Farmington. The Team recruited top science and engineering experts from New Mexico State University, the New Mexico Water Resources Research Institute, New Mexico Tech, the New Mexico Bureau of Geology and Mineral Resources, and the University of New Mexico. The Team developed a conceptual site model, identified data gaps and potential human exposure pathways for GKM contaminants, and drafted a monitoring plan that was released to the public for a 30-day comment period. NMED also seated a Citizen Advisory Committee to provide stakeholder input on the monitoring plan as it is dynamic and subject to data-driven modifications.

While funding does not presently exist to fully implement the Long-Term Monitoring Plan, selected elements of the plan are being conducted on a priority basis to fill data gaps directly related to protection of public health. Defining hydraulic relationships between the river, irrigation canals and aquifer was identified by the Team as a top priority needed to protect well users. The N.M. Bureau of Geology conducted water-level surveys and additional well sampling in August 2015 and January 2016. Both surveys show that, on a regional scale, the Animas River is gaining from groundwater inflow. This finding supports a generally low risk of water well contamination, but pumping wells may still be able to draw water from the river or from irrigation ditches. The next water-level survey is scheduled to occur during spring runoff which may alter aquifer-river hydraulics from what was observed in August and January. Monitoring by the City of Farmington has correlated elevated turbidity levels with elevated levels of heavy metals in the river. Farmington and NMED also have installed sondes in the Animas and San Juan Rivers to measure turbidity and other parameters. The sonde data will be communicated to water users to help inform decisions on the use of river water as a source of potable, irrigation and livestock water during periods of elevated turbidity.

Numerous staff from NMED and other New Mexico agencies are gratefully acknowledged for working long hours, often in difficult heat or weather conditions, to provide a comprehensive, holistic and exemplary response to an emergency situation. Additional information is on the NMED's GKM spill website, www.NMEDRiverWaterSafety.org

Everyone Wants a Walk Away: Long-Term Mine Closure in the Silverton Caldera

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Abstract 6

When considering mine closure, miners and regulators alike want a walkaway solution. In the Upper Animas Mining District, the combination of high snowfall, expansive mining, and hydraulic connectivity between individual mines creates substantial challenges to walkaway long-term closure. Most mines in the district consist of underground workings. Bulkheading underground mine adits and ventilation shafts has been the preferred closure alternative for underground mines in the Upper Animas Mining District for many years. Bulkheads have numerous benefits, including: reducing flow, limiting the acid generating oxidation pyrite, and reducing the likelihood of unintended releases from the bulkheaded opening. However, even with bulkheads, instream water quality standards are difficult to meet without treatment. Bulkhead maintenance and instream water quality targets create substantial challenges to walk away closures in the Upper Animas Mining District.

Despite the benefits of bulkheads, they are not always a walkaway solution to mine closure. The bulkheading of the Sunnyside Mine in the 1990's and early 2000's substantially reduced metal loads to the Animas River for a number of years, until the bath tub behind the bulkheads filled. The snow melt derived water found other ways out of the mountain, including other near- by mines such as the Mogul, the Red and Bonita, and the Gold King. The end result has been beneficial, but not a walk away solution from a mining district perspective. Monitoring of the mine pools and bulk head pressures would be beneficial to a district wide understanding of the effects of the bulkheading.

The long-term structural integrity of the bulkheads themselves also requires monitoring, as even the best designed and built bulkhead has the potential for failure as rock and bulkhead weather under the influence of acidic mine water. The Kohler Mine, located at the head waters of Mineral Creek, was bulkheaded in 2003. The bulkhead holds back more than 600 feet of head. But, the bulkhead continues to leak metalliferous and low pH water. Bubbling at the bulkhead is suggestive of concrete weathering under the acidic conditions. The Kohler suggests there may be long term repair and replacement efforts associated with bulkheads.

In addition to the walkaway challenges above, water that continues to flow (although often from a different opening) rarely meets in-stream water quality standards for the protection of aquatic life. Additional treatment is likely necessary to meet water quality standards, and even passive systems need occasional maintenance.

Both regulators and miners want a walkaway solution that will meet water quality guidelines, however, in an alpine, heavily mined environment, a true walk away solution may be difficult to achieve. Combining multiple current technologies, including bulkheads and passive treatment, may not yield a walk away solution. New technologies and understandings needed for true walkaway solutions in the Upper Animas Mining District.

Initial Assessment of the Gold King Mine Spill: The Role of Sediment Transport and Groundwater-Surface Water Interactions

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Abstract 7

Groundwater and surface water are continuously exchanged along river corridors. This exchange process modulates the transport, accumulation, and release of heavy metals from acute and chronic contaminant inputs. At the same time, sediment redistribution along the river serves as a vector for heavy metals, resulting in both a source and a sink of contaminants for the exchange zones. To explore the role of both sediment transport and groundwater-surface water interactions, two synoptic field campaigns were conducted shortly after the Gold King Mine spill. This work summarizes our preliminary findings. The general pattern of contamination showed exponential decreases in deposition of visible oxides on the streambed and banks downstream of the contaminant source in Cement Creek. Dissolved and total metal loads in the water, however, showed more complex patterns downstream. Redox state was particularly important in controlling dissolved and total concentrations in pore water (groundwater) samples. Dissolved surface water metal concentrations showed highest values near Silverton and decreasing downstream, with a few exceptions at individual downstream sites, probably associated with flood remobilization. Total surface water metal concentrations were strongly affected by flooding events, resulting in high concentrations downstream of Aztec, NM. These initial results highlight the importance of a consistent monitoring scheme that accounts for the exchange processes and sediment transport along the river corridor and the role of dynamic forcing due to weather variability.

Clay Contributions to the Gold King Mine Spill

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Abstract 8

Our present research efforts are directed at uranium abatement for polluted water, specifically now on the Navajo Nation. Because of the immense landscape in that region, our solution is to develop a purification system that is simple and cost effective to operate in individual homes. Our work continues to be driven by the consequences of careless uranium mining practices. These include abandoned mines and the largest nuclear spill in the US which occurred in Church Rock, NM thirty seven years ago. There is a correlation between the Gold King Mine and the Church Rock incidents as both were a breach in an earthen dam. We are still dealing with the Church Rock spill.

Due to similarities in the Animas River contamination and our uranium abatement efforts, we took an interest in addressing this most recent situation. We travelled to the Animas River six days after the spill occurred to sample in Farmington, NM and Silverton, CO. The Silverton sampling took place on Cement Creek, approximately 500 feet before it enters the Animas River. The Farmington samples were acquired in Farmington proper near Boyd Park. In both cases, 55-gallon plastic barrels were filled and capped to eliminate head space losses.

Yellow Sediment sample collected from Animas River in Silverton Photo: Emilio Rivera

We investigate metal sorption onto clay substrates in aqueous solutions to abate these toxic pollutants. In every experimental trial, abatement has occurred. In our efforts to address NM problems, we have recently concentrated on lead and uranium. Moreover, these and other studies indicate that most metal ions should be bound to our clay and thus removed from the water.

Should there be leakage into aquifers on which people depend for potable water, we have a solution. While clay makes prevention possible, our technology is at the forefront of remediation efforts. Because this spill has already occurred, remediation is our focus, regardless of the metal or pollutant.

Our strengths and knowledge in sorption onto clays are directly applicable to shine light on facets of the Gold King Mine spill. Clay is the fundamental constituent of river and lake sediment. Lake sediment should be a major concern given the natural settling of pollutants. Moreover, the binding of metals onto clays at ppb levels is indicative of preferential and strong interactions. Thus, sediment is the primary agent for metal containment. Our concern was substantiated when the sediment was 'scooped up' by our team on the shore of the river directly below the spill. We propose that sediment monitoring be priority for long-term plans. The picture to the right is bright yellow mud from the river at Silverton.

Our preliminary results indicate several trends. First, we attempted a quantitative analysis of the river water to subsequently assess sorption with our clay sorbent. Standard addition was the only permissible method

given the complex matrix of the river water. As an example of the complexity, when lead was added to produce a 100 ppm solution with river water, a suspension resulted, and this remained true from pH 2 – 12; this was due to unknown ions and elevated levels of lead thus prohibiting ICP analysis.

The river water in the barrels was further analyzed because it had stratified. Initially the water was a tinted homogeneous phase. Now there is a distinct yellow precipitate that has concentrated at the bottom of the barrel. The solution is now pH 3.4, lending further evidence that we are dealing with an extremely complex matrix. Changing conditions will continue to alter many chemical parameters. This needs attention.

In our analysis of the river water, we encountered difficulties with the standard addition method due to the complex matrix issue. We measured the concentration levels for certain metals in the water from the upper portions of the barrels: mercury (>100 ppb); cadmium (> 100 ppb); uranium (~10 ppb). It must be noted that the volatility of mercury makes it difficult to ascertain its original concentration. We included uranium in our analysis because it is of particular interest to our research. We abate uranium with clay sorbents, and for the river water we see a trend that uranium is abated. For mercury we can qualitatively deduce that abatement occurred. Additional studies are ongoing to statistically ascertain abatement efficacy.

Our clays are deliberately designed in a robust pellet form. They can be easily packaged and safely transported which make them an ideal candidate to help individuals in dire circumstances. In the event that contaminated water needs conversion to potable water, we can lend our expertise and technology to anyone in need.

On the other end of the spectrum, earthen barriers are effective but are prone to fissures and seepage. The latter is due to clay materials. The same is true for sediments; they are fundamentally clay, and our clays sorb heavy metals efficiently. We face similar issues in the laboratory. Our continued studies with uranium, and specifically clay, will allow us to elucidate information on this particular spill.

Rapid Assessment of Soil Metal Concentrations Along the Animas River, New Mexico

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Abstract 9 – Both Oral and Poster

On August 5th, 2015 an inadvertent breech of a mine shaft holding metal laden waters in Colorado was spilled into the Animas River and ultimately into the San Juan River confluence in Farmington, NM and beyond into the Navajo Nation. Farming communities draw irrigation water from the Animas and San Juan Rivers, raising concerns that metal-laden water in the river was spread across farm fields as irrigation water. As the pollutant plume moved down the river, a reddish sludge was deposited in the river sediment and along the riverbanks. Initially, the water containing the plume was cloudy as the sludge was suspended in the water. However, after several weeks, the initial plume ran its course downstream and the water running down the Colorado portion of the Animas River near Durango appeared quite clear in September 2015; so clear in fact that the coating of the orange sludge on the bottom of the river and adjacent banks was readily apparent. The concern now is the remaining sludge in the river will slowly be carried downstream as irrigation ditches are once again activated for the 2016 growing season.

In an effort to rapidly respond to the threat to soil health in the farm fields of the area, the Natural Resources Conservation Service (NRCS), New Mexico State University (NMSU), and Texas Tech University (TTU) partnered to use state of the art portable X-ray fluorescence spectrometry (PRXF) for rapid, on-site analysis of soil elemental composition. PXRF spectrometry is a novel, yet widely accepted means of rapid elemental assessment in soils and sediments. Reference methods for the technique have been developed both by the NRCS (Soil Survey Staff, 2014) and Environmental Protection Agency (US-EPA, 2007) (Method 6200) and NRCS referenced methods for use in soils and sediments. The operational theory, optimized uses, limitations and applications are summarized by Weindorf et al. (2014).

Materials and Methods

On-site rapid PRXF field scans were undertaken Sept. 1-3, 2015 using a Delta Premium (DP-6000) PXRF featuring a Rh X-ray tube operated at 10-40 keV with elemental quantification accomplished via integrated ultra-high resolution (<165 eV) silicon drift detector. Multiple types of land were evaluated including: irrigated lands (water taken from the Animas River), non- irrigated lands (Control), and riverbank sediment. The location of each soil scan was georeferenced with GPS. Scanning was conducted in a proprietary software configuration known as Geochem Mode which offers elemental quantification of the following elements: V, Cr, Fe, Co, Ni, Cu, Zn, W, Hg, As, Se, Pb, Bi, Rb, U, Sr, Y, Zr, Th, Mo, Ag, Cd, Sn, Sb, Ti, Mn, Mg, Al, Si, P, S, Cl, K, and Ca. Geochem mode consists of two beams; each was set to scan for 30 sec, such that one complete sample scan took 60 sec. PXRF performance was assessed via scanning of two NIST certified soil standards.

Results and Discussion

Notably, the riverbank sediment was observed to be a mix of natural alluvial sediment and Gold King Mine sludge; the two of which had substantively different elemental signatures. In total, 140 samples were scanned in three days. Summary results are provided in Table 1.

Table 1. Elemental concentration ranges and averages for soils and sediments scanned with PXRF in the Animas River Valley in Colorado and New Mexico. All units are in mg kg-1.

n	Location	Al Avg	Al Range	Fe Avg	Fe Range	Cu Avg	Cu Range	Zn Avg	Zn Range	As Avg	As Range	Pb Avg	Pb Range
29	Control	64087	25413-83540	28987	9047-50892	33	ND-94	117	25-330	7	ND-13	53	12-230
67	Irrigated	53541	7281-80325	28514	4430-48232	36	11-100	175	39-819	7	ND-13	67	5-271
35	Riverbank	37749	4218-80108	38302	5818-293194	77	ND-220	365	19-1068	11	ND-38	153	10-487
9	Riverbank-Sludge	21018	8730-38781	48355	38292-75959	137	90-176	474	277-1174	40	ND-54	637	509-859
140													

Generally, the properties of the river sludge sent down the Animas River had Pb levels of ~600-800 mg kg-1; and higher levels of Fe, Cu, and Zn. Notably, the residential screening limit for Pb in soils is 400 mg kg-1 (Brevik, 2013). These sludge materials were found both in New Mexico and Colorado, both on the stream banks and underwater. Irrigated lands along the Animas River tended to have slightly higher levels of metals than non-irrigated “control” areas, although these were below agricultural loading rates notably for Pb. Nevertheless, it is essential we monitor these areas over time as more sludge sediment washes down the river and potentially spreads out via irrigation. It is unclear whether contaminated sludge will move down into New Mexico over time in response to hydrologic pulses (snow melt, flash floods, etc). The level of metals found in sludge along the Animas River warrant careful observation and extensive spatial and temporal sampling are recommended such that the levels of metals in soils of the Animas

River Valley will be more thoroughly understood in an effort to protect and optimize soil health. If areas of accumulation are noted, phytoremediation or other remediation strategies should be undertaken to ensure that the metal laden soils do not pose a risk for metal bioaccumulation in plants or feedstocks used by humans or animals.

This technology will be put to use in two phases of the project: 1) initial, rapid, on-site assessment of metal levels in soils of the Animas River Valley, and 2) long term monitoring whereby temporal accumulations of metals can be studied and documented as irrigation with river water once again resumes.

Acknowledgements:

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What are the Effects of the Gold King Mine Spill on San Juan County, NM Agricultural Irrigation Ditches and Farms?

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Abstract 10 – Both Oral and Poster

Livestock production in San Juan County, NM is an 18-million-dollar industry with over 700 producers owning livestock (NMSU San Juan County Cooperative Extension). Alfalfa and other forage hays dominate much of the irrigated agricultural landscape. There are commercial apple orchards and grape vineyards in addition to farms that grow high value specialty horticultural crops including vegetables, herbs and cut flowers. Irrigation ditches that divert water from the Animas/San Juan rivers consist of intake points directly from the Animas River which are regulated by the New Mexico (NM) Office of the State Engineers and Federal Government (on the Navajo Nation) and operated by community ditch cooperatives and farm boards. The irrigation season typically begins around late April and ends late October, at which point the main ditch intakes are closed for the winter.

Typical furrow irrigated system in San Juan County, NM.

In August 2015, three million gallons of heavy metal contaminated water were accidentally released from the Gold King Mine (GKM) into the Animas River (EPA 2015; https://www.youtube.com/watch?v=ZBlR05tDCbI). Orange colored sediment laden with heavy metals including Pb, As, and Mn was evident along the river one month after the spill. Significant amounts of river sediments accumulate in irrigation ditches, smaller laterals, and gated irrigation areas during the growing season and constitute a potential threat to agricultural lands.

As a precaution against contaminating irrigation ditches, ditch cooperatives in NM and the Navajo Nation closed main diversion points into the 20 or so irrigation canals about 48 hours before the mine spill plume arrived in NM (San Juan Agricultural Water-Users Association 2015). The majority of irrigation ditches reopened after the EPA declared the river "safe" and irrigation resumed. The Navajo Nation made the difficult decision to open some ditches, while leaving others closed. In Northwest NM, some irrigators on and

off the Navajo Nation ceased irrigating crops for the 2015 growing season, just at the time most crops were maturing for harvest.

The GKM spill is hitting the region just as there is a resurgent interest in local food production among both Anglo and Indo-Hispano cultures. Contamination of the Animas and San Juan Rivers following the Gold King Mine blow-out raises a number of questions by farmers and ranchers in San Juan County who are still anxious about the safety of the water and soil. Because the ditches were dry for about 10 days during the closure of the river, this gave our team the unique opportunity to establish base-line measures of irrigation ditch sediment in dry irrigation ditches for future long-term monitoring of the river/irrigation ditch/agricultural field interface and potential contamination threats to agricultural lands.

One of the objectives of our response to the mine spill centered on the following questions:

- What was in the ditch sediment before the spill?
- What is in the ditch sediment after the spill?

Methods, Procedures and Facilities: Thirteen irrigation ditches in San Juan County from the Colorado border to Farmington, NM were sampled August 11-August 14, during the ban on irrigating crops. We sampled only non-contaminated sediments. Where possible, sample transects were made downstream of a NM Office of the State Engineer (NMOSE) gage station. These gage stations monitor flow data in real time and may provide clues to ditch sedimentation. The following week, three main ditches on the Navajo Nation were sampled. Permission to sample was obtained by ditch companies, the NMOES, Navajo EPA and Navajo community farm board members. In one main ditch, we pulled transects at six locations from various points along approximately 15 miles (24 km). Sample sites were recorded with GPS. Through repeated measures, we resampled the same irrigation ditch locations during the winter 2015-2016, once the main intakes were closed for the winter. Because ditch sedimentation during the irrigation season can vary, at each sample point, we attempted to auger to 18-24 inches (46-70 cm) deep in three separate core pulls (6-8 inches long per core). Total metals from soil was measured following USEPA method 3051A (USEPA, 1998) using inductively coupled plasma optical emission spectrometry (ICP-OES) analysis. Baseline samples are now analyzed and we are beginning to analyze time 2 ditch sediment samples.

Our goal is to help restore consumer confidence and grower trust in the region by continuing to sample ditches and fields to ascertain if soil contaminant concentrations are below or similar to pre-August 2015 levels. These evaluations are critical to reassure growers and consumers in the region that the products grown on soils in the Animas and San Juan River Watersheds are safe.

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Animas River Groundwater Level Monitoring after the Gold King Mine Mine-Water Release of 2015

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Abstract 11

Following the August 5, 2015 bulkhead breach of the Gold King Mine, roughly 3 million gallons of mine waste water and tailings were introduced to a tributary of the Animas River, turning the waters a vivid orange. While the river has since returned to its normal color, there is concern that the toxic metals left on the streambed may begin to seep into the shallow alluvial aquifers and impact the groundwater in the surrounding area. In August 2015, in collaboration with other agencies (USGS, NM OSE, and NMED), groundwater level measurements were collected at over 100 locations along the Animas River. Using the network of wells established in 2015, we developed a groundwater level monitoring program in the Animas River valley utilizing private domestic wells. The purpose of this project is to evaluate seasonal changes to the hydraulic conditions along the NM reach of the Animas River. Future sampling campaigns will help us understand the seasonal fluctuations of the water table and if it will affect the groundwater/ surface water interaction in the area.

Continuously recording pressure transducers were installed in two wells in early September 2015 to collect water level and temperature data every 12 hours. From a continuous record of groundwater level we can see brief fluctuations in water levels that help us understand what factors have an influence on the water table in the area. These records of water level change were plotted alongside a precipitation record from Aztec, an Animas River flow gauge, and a record of flow in an irrigation ditch south of Aztec, NM (Figure 1). The hydrographs show a pronounced connection with the ditches and river. Short spikes in river stage can be seen in both wells as small rises in their water level record. When the ditches were shut off one of the wells began torapidly decline.

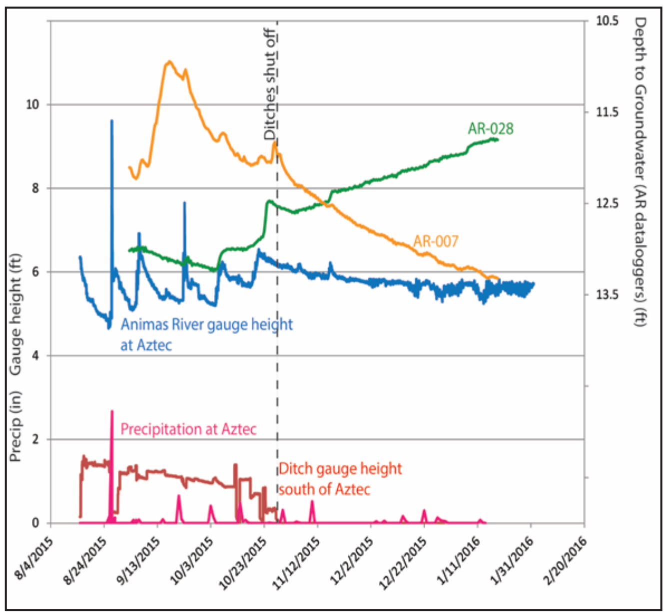

Figure 1. Hydrographs from two wells with continuous data recorders, plotted with potential influences. Well AR-007 is located 4 miles southwest of Aztec, on the east side of the river. Well AR-028 is located just north of Farmington, on the west side of the Animas River

Following our preliminary water level measurements in August 2015, a second round of water level measurements was collected in January 2016. The August water level measurements provided us with a snapshot in time of the flow conditions during the monsoon and irrigation season, when water levels are high. The January sampling represents base flow conditions in the river. Of the 70 wells with repeat water level measurements, the majority of the wells had a decline in water level of 2.1 ft, on average, between August 2015 and January 2016.In general, the wells north of Aztec show more decline than the wells to the south.

In addition to the new water level measurements our analysis has been further supplemented with the release of a LiDAR dataset of the Animas River Valley. LiDAR, in this case, is being used as a high-resolution elevation model of a land surface. The improved spatial resolution of the LiDAR dataset allows us to more accurately approximate the water level elevation based on the higher resolution ground surface elevation. Additionally, this high precision dataset allows us to more accurately represent the changing stage of the Animas River, to better understand how its fluctuations effects the groundwater/surface water interactions.

The higher resolution data has slightly changed our interpretation of the groundwater flow in the valley. In a broad sense, the river is still a gaining system, where groundwater from the surrounding valley flows down gradient toward the river. However, by looking at the water levels in close proximity to the river, we find that the water table gradient is very flat, and even losing in places. With a flat water table, fluctuations in the river stage can turn a slightly gaining reach to a slightly losing reach. The degree to which the river is losing is so slight (less than 1 ft) that it is not detected by coarse resolution, regional water table maps. In areas with dense enough sampling we refined the contouring to 5 ft intervals.

While this does not mean that these wells are in immediate danger of drawing water from the river, it does indicate that there are reaches of the river that are slightly losing. This means that metals that are resting on the streambed have the potential, hydraulically, to move into the groundwater. The water levels indicate that losing reaches are more prevalent during the winter months, when the water table is lowest.

Geological Processes Affecting the Chemistry, Mineralogy, and Acid Potential on Particle Size Fractions: Examples from Waste Rock Piles in New Mexico, USA

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Abstract 12

The NMBGMR has been examining the environmental effects of mine waste rock piles throughout New Mexico since the early 1990s, including the effects of mineralogy, chemistry, and acid potential on particle size fractions. Compositional changes between different size fractions of waste rock piles and other materials were examined in 4 separate areas in New Mexico over the years; including the Pecos (Terrero) mine and Alamitos Canyon (El Molino) mill in San Miguel County, Hillsboro district in Sierra County, Questa molybdenum mine in Taos County, and 6 mining districts in Socorro, Sierra and Otero Counties. These 4 studies examined both man-made waste rock piles and natural materials (stream sediment, debris flows, alteration scars) and included materials of different lithologies and deposit types. None of these areas are currently in production, however, efforts are underway to permit and reopen the Copper Flat copper mine in the Hillsboro district. The Pecos mine and Alamitos Canyon mill have been reclaimed. The Pecos (volcanic massive sulfide deposit) and Questa (porphyry molybdenum) mines are found in the Sangre de Cristo Mountains in northern New Mexico, where elevations range from 2,000 to over 3,600 m and the climate is semi-arid and alpine, with cold snowy winters and moderate warm summers. The Hillsboro (porphyry copper and polymetallic veins) and other 6 mining districts (carbonate-hosted and vein deposits) are in southwestern New Mexico where elevations are lower (1,500 to 2,400 m) and the climate is arid, with moderate winters and hot summers. Monsoons occur during July and August throughout New Mexico.

Detailed petrographic examinations of materials forming the waste rock piles as well as local host rocks provide insights into understanding the geologic, geochemical, pedological and man-influenced processes that can result in the variations in mineralogy and chemistry within different particle size fractions. The size of the original primary igneous minerals during crystallization, often in a fine-grained groundmass, results in minerals of different sizes that are subsequently liberated from the rock fragments. Some of these minerals, such as biotite and hornblende, are more susceptible to weathering and liberation from the host rock than other, more resistant minerals, such as quartz.

In general, there are consistent results between the 4 studies. The finer-size fractions are typically the smallest proportion of the sample by weight (generally, <25% in the <2 mm fraction). However, the greatest enrichments of trace elements generally occur in the finer-size portion of the sample.

In the Questa samples, feldspar, quartz, and pyrite are generally higher in the coarser-size fraction. Total clay minerals, gypsum, and jarosite are higher in the finer-size fraction. Paste pH values decrease from the coarser-size fraction to the finer-size fraction, but not all samples show a significant decrease. The coarser-size fractions are less acid generating than finer-size fractions. Na2O and S increase in the coarser-size fraction, whereas SO4 decreases in the coarser- size fraction. Al2O3 shows little change with different size fractions.

Pre-mining hydrothermal alteration and weathering can result in the replacement of larger primary silicate minerals by smaller hydrothermal clay minerals. These replacement clay minerals can remain in the

larger size fractions until liberated during mining and dumping into the rock piles or subsequent physical weathering. Much of the material forming waste rock piles is actually small rock fragments that contain these minerals. In many rock pile samples, the fine-grained soil matrix is weathered, while interiors of rock fragments (even within weathered rock pile material), exhibit little or no signs of weathering.

The finest size fractions (<63 μm) of stream sediments from the Pecos River contained the largest concentrations of metals (Cu, Pb, Zn). Chemical analyses of 6 sediment size-fractions from 6 sites suggested that the metals were predominantly traveling both as suspended and/or absorbed material and as larger minerals or other grains weathered from the waste rock pile and the tailings pile. Statistical analyses of geochemical data indicated that Cu, Pb, and Zn had a high correlation with Fe and Mg, suggesting that these metals were associated with Fe-bearing and ferro-magnesium minerals such as magnetite, pyrite, biotite, pyroxene, etc.

In a study of waste rock piles from different types of deposits in the Hillsboro district in central New Mexico, the <0.25 mm size fraction typically contained the highest Cu, Pb, Zn, and As concentrations. The <0.25 mm size fractions represented <20% of the total sample weight.

Of the 39 samples analyzed from different host rocks and different types of deposits in 6 mining districts in southwestern New Mexico, about half of the samples had the largest concentration of the various elements in the finer-size fractions. For the trace elements, enrichment occurred in the finer-fraction for more than half of the samples in all districts for As, Ba, Co, Cr, Cu, La, Li, Mo, Nd, Sc, and V, with slightly lesser enrichments of Ce, Mn, Ni, Pb, Sr, Y, and Zn.

Collectively, these results are consistent with weathering being more pronounced in the finer-size fraction than the coarser-size fraction. The dissolution of pyrite, calcite, and to a lesser extent some combination of chlorite, illite, feldspars, smectite, and other silicate minerals are the predominant chemical reactions that result in the precipitation of gypsum, jarosite, soluble efflorescent salts, and Fe oxide/hydroxide minerals. These precipitates are mostly in the finer-size fractions, although some authigenic gypsum crystals can be quite large.

No single geologic, geochemical, pedological or man-influenced process is responsible for the differences in composition between particle size fractions. The effects of primary igneous crystallization, pre-mining hydrothermal alteration and weathering, and post-mining blasting, hauling, dumping, and emplacement into the rock pile and subsequent weathering affect the composition of each size fraction. This emphasizes the need to determine not only the composition of the different size fractions, but also perform detailed mineralogy and petrology investigations to understand the processes involved in controlling the compositional differences between size fractions. Although the results are generally consistent, there is some variation between samples and it is recommended that composition of different particle sizes be examined at all environmental sites, especially mine sites.

The importance of understanding the effect of composition on particle size can be used to (1) help plan and assess reclamation procedures, (2) compare trace-element concentrations in mined versus undisturbed areas, (3) determine background concentrations, (4) determine the best size fractions for prediction tests, such as humidity cell or other column tests, and (5) provide background data that can assist with the planning of future mining operations. Benefits to the public include the assessment of changes in environmental parameters of pre-, post-, and abandoned-mined lands, including changes where mining and reclamation activity have improved the quality of those environmental parameters.

Remediation of the Terrero Mine and El Molino Mill, San Miguel County, New Mexico

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Abstract 13

A case study of cooperative efforts between industry, government agencies, and community stakeholders to achieve source control of legacy mining contamination is presented.

The Terrero (or Pecos) mine exploited a volcanogenic massive-sulfide ore body, with at least 50% sulfide minerals, near the confluence of Willow Creek with the Pecos River that was discovered in 1881 and was New Mexico's largest Pb-Zn producer from 1927-1939. The Terrero underground mine produced 2.3 million tons of ore grading 2.9% Pb, 9.2% Zn, 0.4% Cu, 2.4 oz/ton Ag, and 0.08 oz/ton Au worth more than $40 million. Major ore minerals included sphalerite, galena and chalcopyrite in a gangue of quartz, sericite, pyrite, pyrrhotite, chlorite, actinolite, sericite, tourmaline, and minor calcite. Ore was crushed at the mine and transported via aerial tramway 19 km south to El Molino mill, in Alamitos Canyon, which flows through the Village of Pecos before discharging into the Pecos River. "Terrero" is Spanish for mine dump.

Mine waste was piled on slopes surrounding the shaft, deposited into Willow Creek and onto the Pecos River floodplain. Shaft drainage water was released from a log flume near the mouth of Willow Creek. Metal-laden acid drainage with suspended solids flowed into beaver- created wetlands at the confluence of Willow Creek and the Pecos River. Under normal streamflow, solids settling and microbial metal reduction in the beaver wetlands greatly reduced the impact of mine runoff on the Pecos River. During high precipitation events when the Pecos River was at low runoff, the wetlands were unable to detain flows from the mine site and attenuate metals entered the Pecos River. Downstream of the mine site, elevated metals were detected in Pecos River sediment, benthic macroinvertebrates, fish tissue, and in small mammals. The Pecos River and Lisboa Springs Fish Hatchery, 17.7 km downstream of the mine, had a history of fish kills that coincided with high precipitation events when the Pecos River was at moderate to low flows. High levels of Zn and Al are believed to have been at least partly responsible for some of the fish kills.

While mill recoveries were considered good by the standard of the day, process tailings contained as much as 10% Pb, 19% Cu and 6% Zn. Tailings slurry from the mill was discharged directly into Alamitos Canyon, and stored behind two earthen dams, 0.7 and 1.5 km downstream from the mill. Tailings dam failures dispersed tailings downstream in Alamitos Creek and into the Pecos River including portions of the Village of Pecos. After the dam failure, tailings eroded by Alamitos Creek provided an ongoing source of contamination into the Pecos watershed. Surface water contained Cd, Pb, Fe and Mn in excess of standards. Stream sediments contained elevated Fe, Cu, Pb and Zn. Groundwater in alluvial and bedrock aquifer monitoring wells near the tailings contained sulfate, Mn and total dissolved solids in excess of state standards.

The Terrero mine, El Molino mill and tailings site were acquired by the State of New Mexico in 1950 from the successor in interest to the mine owners who retained the mineral rights for all those properties. Up until the 1970s, waste had been removed from the mine and mill sites and used as fill and construction material on Federal and State land for roads, campgrounds, a trailhead, and the state Lisboa Springs fish hatchery.

Early spring rainfall runoff from the Terrero mine in 1991 caused a massive fish kill, more than 90,000 trout died at the hatchery. The fish kill brought attention to the unaddressed contamination from the mine and mill. Concerns about human health led the U.S. Forest Service (USFS) to close forest roads, campgrounds and a trailhead where mine waste had been used as fill. The U.S. Fish and Wildlife Service reported Pb in fish tissue at or near the human consumption criterion and in small mammal tissue above raptor protection criterion. Publicity generated by these 1991 events had a severe impact on the recreational-based economy of the Village of Pecos. Discussions among industry, government agencies and a range of community stakeholders reached a consensus that corrective actions were necessary. However, both AMAX Mining Company, which had retained the mineral rights, and the State of New Mexico that owned the surface, wanted to avoid being designated as "potentially responsible parties" were the site listed on the Superfund National Priorities List, which requires State approval. Local officials and outfitters were concerned about the stigma of a Superfund listing on the recreation- based economy of the Village. The parties were interested in a Superfund level of cleanup without the perceived cost, delay or economic stigma they associated with Superfund listing.

The mining company and state agencies agreed to an Administrative Order on Consent (AOC) containing many provisions parallel to Superfund process to be executed under state authority with Federal oversight. The December 2, 1992 AOC was signed by NMED, the N.M. Natural Resource Damage Trustee, the N.M. Department of Game and Fish, the N.M. Highway and Transportation Department, and AMAX. The AOC included a Cost Sharing Agreement where AMAX was responsible for 80% of the total cost of investigation, remediation and natural resource damages, and the State of N.M. was responsible for 20%. The USFS was not a party to the AOC, but allocated $1.2 million to remove or cap mine waste that had been used as fill at roads and campgrounds. The AOC addressed contamination at the Terrero mine, El Molino mill, campgrounds and recreational use areas, roads, and the Lisboa Springs Hatchery. The AOC included a Remedial Investigation, Applicable or Relevant and Appropriate Requirements (ARARs), Human Health and Ecological Risk Assessment, a Community Relations Plan, a Natural Resource Damage Assessment, Interim Remedial Actions, a Feasibility Study, a Decision Document, Remedial Design, and Remedial Action minimizing Superfund milestones.

During the 1990s and 2000s, mine and mill waste were consolidated and stabilized with vegetated soil covers with the mine waste cover including a geosynthetic liner. Waste used as road fill was chip sealed. Following removal of mine waste, Willow Creek was reconstructed. A vertical metal cutoff barrier installed upgradient of the waste diverted site run-on. Mill tailings were consolidated in place, and Alamitos Creek was reconstructed on top of the tailings using a soil substrate, geosynthetic liner and 18" rip-rap in a channel with a 1,250-year design flow capacity. Subsurface concrete cutoff walls were installed to prevent groundwater flow in Alamitos Creek. Floodplains, wetlands and riparian habitats were restored or replaced and the tailings and mine waste surface revegetated. Mine shafts were capped and water level monitors installed. Corrective actions, monitoring and maintenance are ongoing in 2016.

Since the mid-1990s, no fish kills attributable to the Terrero mine have occurred. By 2000, metal concentrations in Pecos River sediment downstream from the mine had decreased. Exceedances of Water Quality Criteria for Cd, Zn and turbidity in Willow Creek also decreased after restoration. NMED removed turbidity from the list of impairment parameters for Willow Creek in 2004, and removed Cd and Zn from the impairment list in 2012. The recreational economy of the Village of Pecos and the Upper Pecos River remains intact following cleanup.

Animas River Environmental Contamination from the Durango Mill Site

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Abstract 14

The Durango Colorado Mill Site contaminated the Animas River from 1880 to 1990. The Animas River flows south into the San Juan River and onward to the Colorado River's Lake Powell. The Animas River is used as the agricultural and domestic water supply for Aztec, Farmington, and Shiprock, New Mexico. The site was not only a mill, but also a smelter and refinery. This was a processing site for lead from 1881 to 1930, for vanadium from 1942 to 1946 and for uranium from 1949 to 1963. The mine was closed in 1963 after a detailed radiological study was conducted from 1953 to 1960. The site was designated a Superfund Cleanup site and the cleanup occurred from 1986 to 1991.

The presentation will discuss the history, type of processing, and different contaminates for each specific site use; lead, vanadium, and uranium. This will include loss of process solutions, smelter stack gasses, and the various chemicals and metals released into the environment, especially the river. An alarming amount of toxic materials were released.

Due to a greater availability of information more emphasis will be placed on uranium processing. Information will include the release and monitoring of radioactive contaminants that forced the closure and cleanup of the uranium processing site. Also, the presentation will contain information on U.S Public Health Service's (USPHS) human radiation exposure reports and the Atomic Energy Commission's (AEC) first environmental radioactivity monitoring lab, based in Farmington that operated from about 1955 to 1965. A review will be given on measurement units and laboratory instrumentation then and now. The current drinking water standards Maximum Contamination Levels (MCLs) for radioactivity and for various metals will be included.

Water Quality of the Upper Animas River, before, during, and after the Gold King Mine Release

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Abstract 15

The August 2015 Gold King Mine release sent 3 million gallons of acidic, metal-rich water flowing down Cement Creek and the Animas River in southern Colorado, creating an orange plume of contamination that extended into the San Juan River in northern New Mexico. This unfortunate incident has refocused attention on the Silverton Colorado area, where mining activities dating back to the 1800s have adversely affected water quality in the upper Animas River, Cement Creek, and Mineral Creek. This presentation describes instream water quality in the Silverton area before, during, and after the Gold King Mine Release, with emphasis on the predominant sources of contamination, as well as the fate and transport processes that affect metals as they move downstream.

Water quality prior to the release is described using data from an October 2012 synoptic study that provides spatially detailed profiles of streamflow, concentration, and metal load. Results of the 2012 study indicate that concentrations of aluminum, cadmium, and zinc exceeded chronic aquatic life standards over the entire length of the study reach (Cement Creek headwaters to Bakers Bridge on the Animas R. upstream from Durango) (Figure 1A). Spatial profiles of metal load indicate specific source areas for various metals. The Red and Bonita Mine on Cement Creek, for example, accounts for nearly 20% of the zinc loading within the study reach. Further, the North Fork of Cement Creek, which includes drainage from the Gold King Mine, accounts for 40% of the copper load, and Mineral Creek accounts for over 40% of the aluminum load (Figure 1B).

Water-quality samples collected at the mouth of Cement Creek during the second week of the release document increases in aluminum, copper, and other metal loads when compared to historical data from 2009-2014 collected under similar low-flow conditions (Figure 2). Metals transported from the Silverton area are subject to pH-dependent reactions (precipitation and sorption) that transform metals from the dissolved phase to colloidal particles as pH increases. These colloids aggregate and settle to the streambed, which can lead to elevated metal concentrations in the sediment. Bed sediment samples collected at USGS gage 09359020 (Animas River below Silverton, CO) after the release suggest increased concentrations of arsenic, chromium, copper, and vanadium when compared to data collected prior to the release (September 2014) (Figure 3A). Sediment concentrations of cadmium, iron, manganese, nickel, titanium, and zinc were lower following the release (Figure 3B), whereas silver, aluminum, and lead concentrations were relatively unchanged. These results suggest that the effects of the release on overall sediment quality may be minimal, relative to historic conditions. The quantity of contaminated sediments has likely increased, however, and additional monitoring may be needed to assess the effects on aquatic life, irrigation and water-supply infrastructure, and recreational resources.

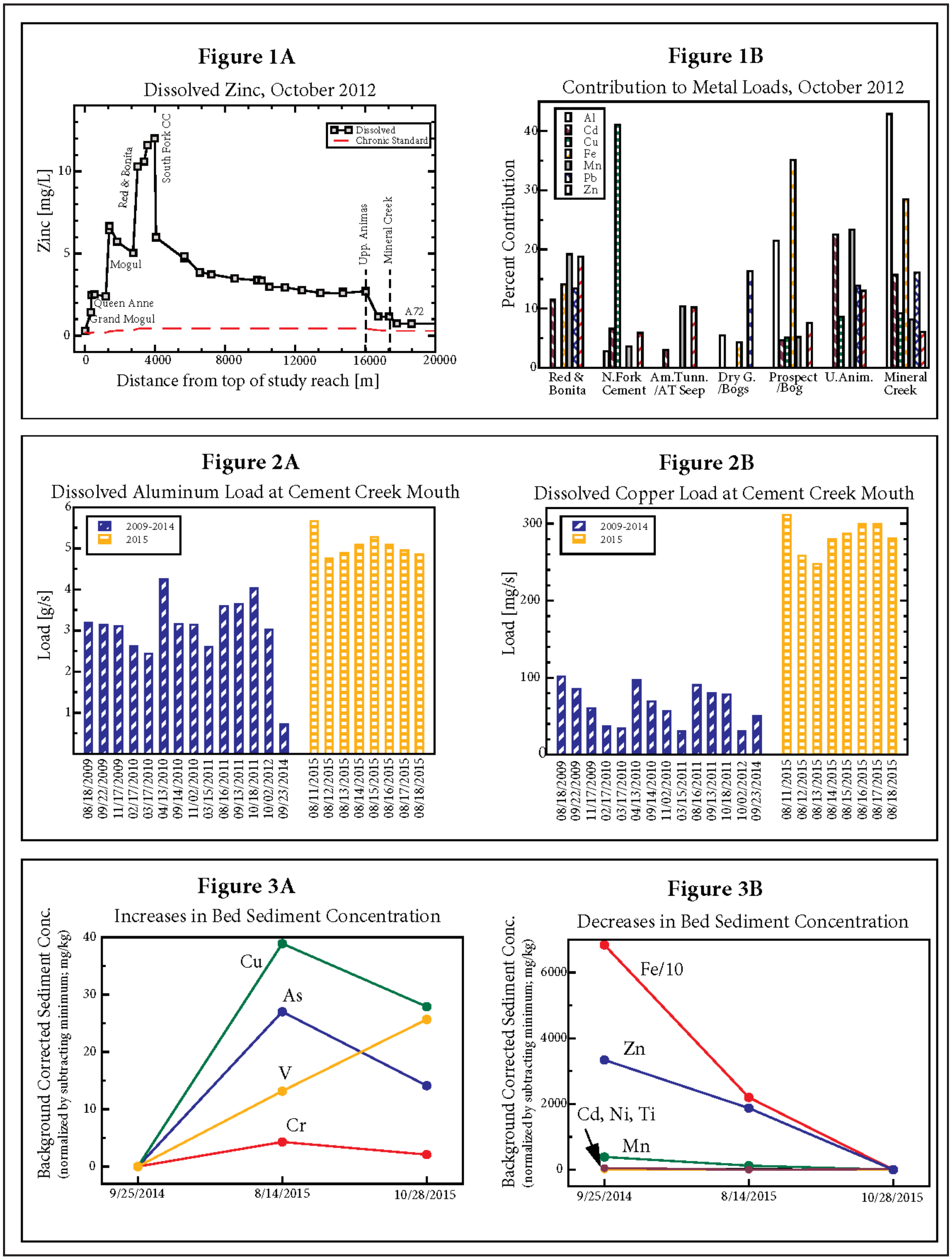
Figure 1A
Dissolved Zinc, October 2012
Zinc [mg/L]
Distance from top of study reach [m]
Dissolved
Chronic Standard
Red & Bonita
South Fork CC
Mogul
Queen Anne
Grand Mogul
Upp. Animas
Mineral Creek
A72
Figure 1B
Contribution to Metal Loads, October 2012
Percent Contribution
Al
Cd
Cu
Fe
Mn
Pb
Zn
Red & Bonita
N.Fork Cement
Am.Tunn. /AT Seep
Dry G. /Bogs
Prospect /Bog
U.Anim.
Mineral Creek
Figure 2A
Dissolved Aluminum Load at Cement Creek Mouth
Load [g/s]
2009-2014
2015
Figure 2B
Dissolved Copper Load at Cement Creek Mouth
Load [mg/s]
2009-2014
2015
Figure 3A
Increases in Bed Sediment Concentration
Background Corrected Sediment Conc.
(normalized by subtracting minimum; mg/kg)
Cu
As
V
Cr
9/25/2014
8/14/2015
10/28/2015
Figure 3B
Decreases in Bed Sediment Concentration
Background Corrected Sediment Conc.
(normalized by subtracting minimum; mg/kg)
Fe/10
Zn
Cd, Ni, Ti
Mn
9/25/2014
8/14/2015
10/28/2015

Assessment of the Fish Community in the Animas River after the Gold King Mine Spill

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Abstract 16

The Gold King Mine (GKM) Spill on August 5th, 2015 highlighted a 100 year old problem in the Animas River: acid mine drainage from the Silverton Caldera region and its effects on the downstream fish communities. Dissolved metals such as zinc, cadmium, copper, lead, and iron can affect fish health, mortality, species composition and distribution. During the peak of the spill Colorado Parks and Wildlife (CPW) monitored the acute effects on the fish community in Durango using 108 fingerling rainbow trout set out in sentinel cages. Post spill, CPW repeated a suite of fish population surveys to assess the possible acute impacts to fishes ranging from south of Durango, Colorado to the headwaters of the Animas river near Silverton. One rainbow trout fingerling died during the 96 hour exposure period during the peak of the spill. The abundance and distribution, species composition, and overall condition of fishes were similar to pre-GKM estimates. A young fish survey conducted in July 2015 and repeated post GKM in early September also suggests no acute impacts to the fish community occurred as a result of the spill. Colorado Parks and Wildlife will repeat the same fish population surveys under similar field conditions in 2016 to assess long-term impacts on the fish community.

Investigation of Metal Persistence in Sediments of the Animas River Watershed after the Gold King Mine Spill

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Abstract 17 – Both Oral and Poster

The concentration and speciation of major and trace elements contaminants in water and sediments of the Animas River was investigated in samples collected during August 17^{th}-18^{th}, 2015, after the Gold King Mine spill occurred on August 5, 2015. A combination of spectroscopic, microscopic and water chemistry techniques was used to better understand the short-term impact of the spill, which will contribute to elucidate the long-term consequences of recurrent mine waste contamination events.

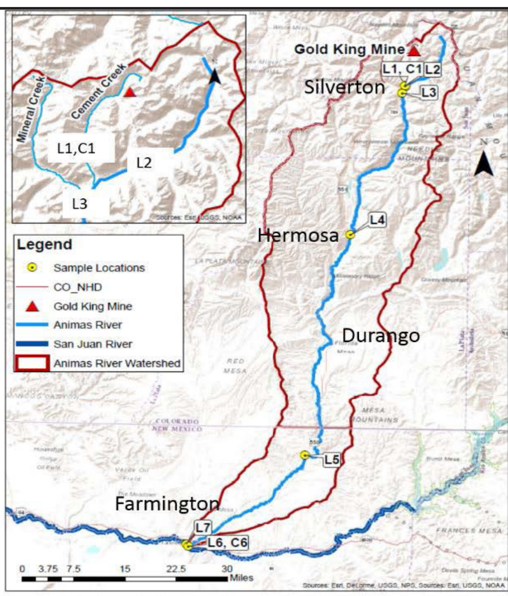

Figure 1 Map of the locations sampled during the trip on August 17^{th} and 18^{th}, 2015. Water samples were collected in all locations, and sediment samples were collected in all the locations but in L2 (Animas River upstream the Cement Creek confluence). In addition, two reference samples (C1 and C6) were collected above the river water level in Cement Creek and in the Animas River in Farmington.

For this study we took water and sediment samples in different locations across the Animas River watershed, trying to select locations similar to those sampled by EPA (Figure 1). Our selected samples include a location in Cement Creek, CO, the Animas River tributary where the spill occurred, and one in the San Juan River near Farmington, NM. The rest of the locations were selected in the Animas River from before the confluence with Cement Creek, CO, downstream to Farmington, NM.

The total concentrations of different metals in the water were within typical background levels at the time of the sampling trip. However, analyses of the data published by the EPA suggest that metals such as Pb and As exceed the drinking water standards of 15 µg 1^{-1} and 10 µg 1^{-1}, respectively, at different locations of the Animas River after high flow events, as shown in Figure 2. In addition, nitrate, nitrite and phosphate were measured in water in the Farmington samples, a highly agricultural area, which suggest nutrient cycling in the river and could have implications in metal mobilization.

We detected the presence of high concentration of metals in the sediments (108.4 ±1.8 mg kg-1 Pb, 32.4 ±0.5 mg kg-1 Cu, 729.6 ±5.7 mg kg-1 Zn and 51,314.6 ±295.4 mg kg-1 Fe). The predominance of clay, jarosite, and alumino-silicate minerals was determined by

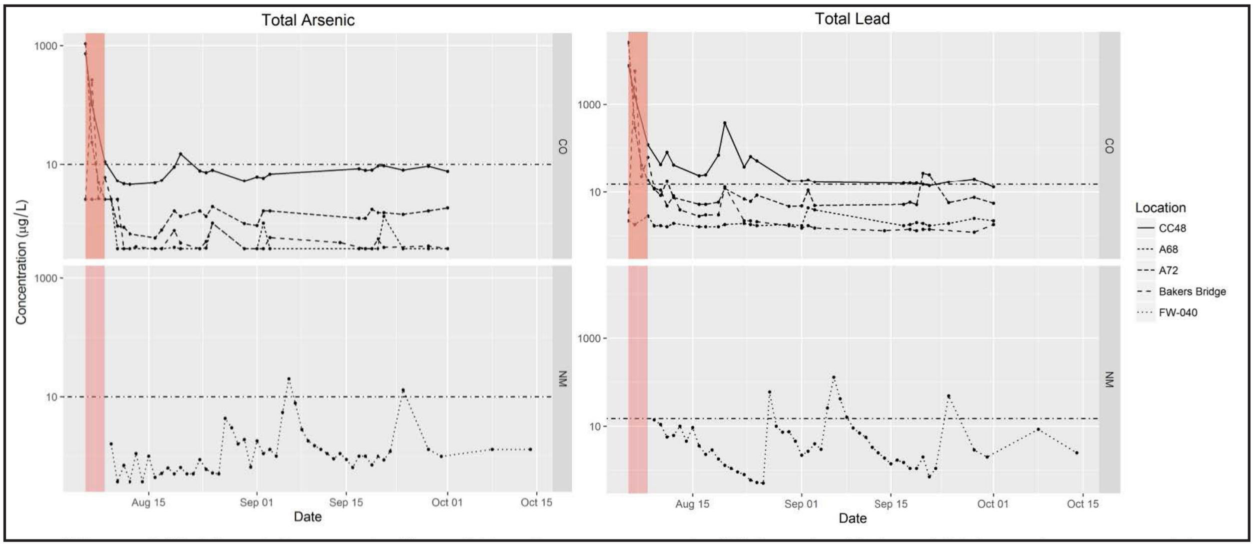

Figure 2. Total metal concentrations (https://www.epa.gov/goldkingmine/date-gold-king-mine-response) in water following the Gold King Mine Spill (marked as the red bar in the graphs). The spikes in total arsenic and lead concentration correspond with high flow events in the Animas River in Colorado (top graph) and in New Mexico (bottom graph). The dashed lines represent the drinking water standard concentration of 10 µg 1-1 for arsenic and 15 µg 1-1for lead

XRD analyses in these sediments, which are relevant primary minerals known to accumulate metals in the environment. Analyses using XPS detected the presence of sulfates, phosphates and nitrogen species in the surface of the sediments; Fe as 75% Fe(II) and 25% Fe(III) upstream the Animas River, but Fe(III) was the predominant specie in the surface of the Farmington sediments; and 100% Pb(II) in the samples from Cement Creek and Hermosa. The co-occurrence of Pb, Cu, Zn and Fe with sulfate was identified in these sediments using TEM, confirming the presence of metal-bearing jarosite ($KFe^{3+}{}_3(OH)_6(SO_4)_2$). The Mössbauer analyses of the samples from Cement Creek and Hermosa also shows the jarosite mineral in the sediments. The water at Cement Creek has a pH 3.3 but it increases into the alkaline range in the Farmington area, thus, the detection of jarosite in sediments from this location confirms the stability of this metal-bearing phase under acidic conditions.

The presence of nutrients in the sediments and water in the Farmington samples and the accumulation of metals in clays and precipitation as metal-bearing minerals highlight the relevance of understanding biogeochemical interactions to further asses the long-term stability of the contamination in the sediments of the Animas River watershed.

Examination of Sediment Microbial Communities in the Animas River Watershed Following the Gold King Mine Spill

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Abstract 18 – Both Oral and Poster

On August 5th, 2015 the EPA conducted an investigation of the Gold King Mine near Silverton, Colorado in order to assess the on-going water releases from the mine, treat mine water, and assess the feasibility of further mine waste remediation. While excavating near the entrance of the mine, pressurized water began to leak from the adit of the mine, spilling approximately 3 million gallons of heavy metal contaminated mine waste into Cement Creek, a tributary of the Animas River. (epa.gov)

On August 17th-18th, 2015 The University of New Mexico visited sites shown in Figure 1 along Cement Creek, Animas River, and San Juan River. At these sites, sediment samples were taken to determine metals composition, and microbial communities associated with the sediment. Basic water quality parameters were also measured such as water temperature, dissolved oxygen, conductivity, pH and oxidation-reduction potential. Sediment samples were sent to Research and Testing Laboratory for DNA extraction and Illumina Next Generation Sequencing.

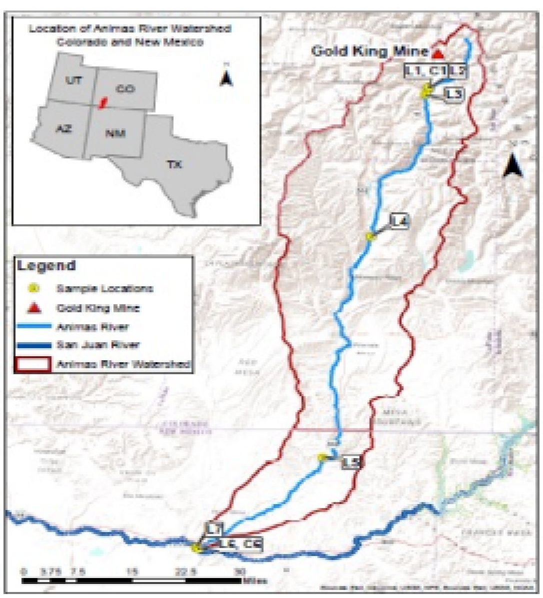

Figure 1: 8/17/15 – 8/18/15 Sample Locations in Animas River Colorado and New Mexico.

L1	Cement Creek 14th St Bridge
L2	EPA A68 Silverton Animas upstream
L3	EPA A72 Downstream of Cement Creek
L4	Animas at Bakers Bridge
L5	Animas Cedar Creek
L6	Animas at Farmington
L7	San Juan River downstream

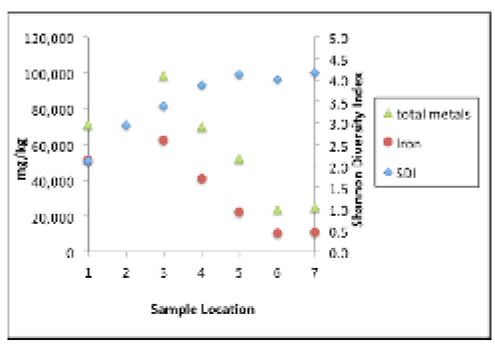

Figure 2: Total Metals, Iron concentrations and Shannon Diversity Index for sediment samples

As shown in Figure 2, Iron and Total metals concentrations are highest in sediment at sample locations closest to Cement Creek where the Gold King Mine discharged. Further downstream, concentrations of metals decrease and level off near the confluence of The Animas and San Juan rivers. The diversity of microbial samples collected at each site has been determined by calculating the Shannon Diversity Index (SDI) (Lande 1996). By this measure, microbial diversity appears to be generally lower at upstream sites with sediment containing high metals concentration. As metal concentrations decrease downstream, microbial diversity appears to recover by the steady increase in the SDI.

Figure 3 shows a dramatic change in sediment bacteria family communities observed in the Animas River upstream and downstream of the Cement Creek confluence. Upstream of the confluence, Cement Creek is rich in Gallionellacae (60.4% relative abundance), where the Animas River upstream of the confluence is all but missing this family (0.07% relative abundance). The family Gallionellacae is well document to consist of Iron oxidizing bacteria (FeOB) that mineralize dissolved Fe(II) to a precipitated Fe(III) in the form of extracellular bio-mineral structures (Krepski et al 2012). This process is important at acid mine draingage impacted sites because iron is usually the most abundant metallic element, and other heavy metals may co-precipitate or adsorb to Fe(III) precipitates formed by FeOB such as Gallionellacae (Stumm et al.1996, Fabisch et al. 2013).

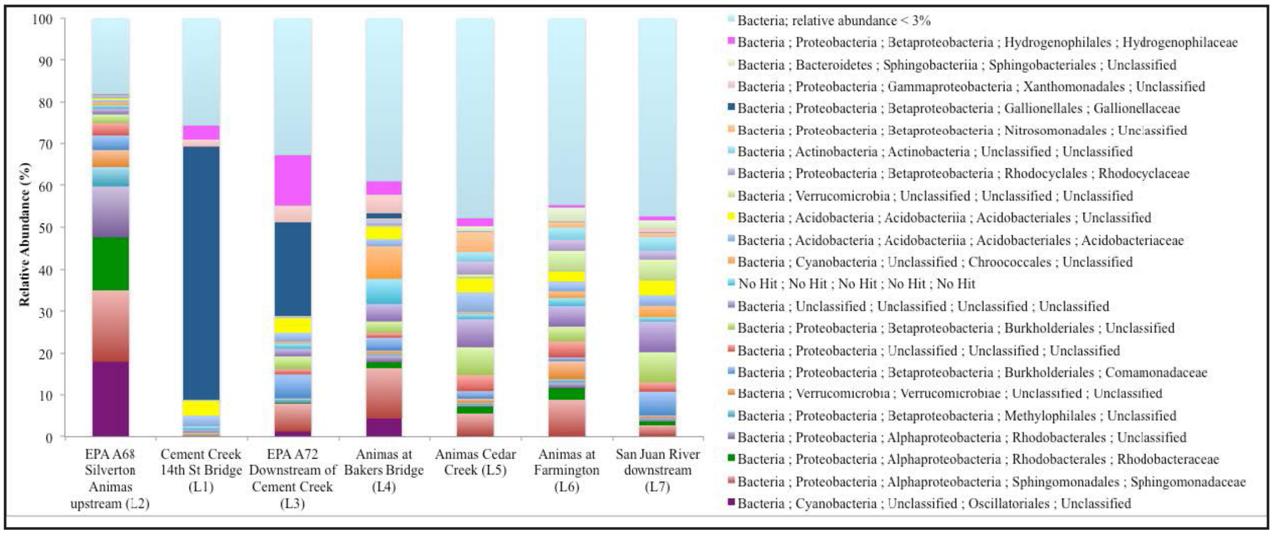

Figure 3. Illumina next generation DNA sequencing results for sediment samples in the Animas River watershed sorted by familiar. Bacteria familiae observed at less than 3% relative abundance across all locations were grouped together for visual simplicity

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Total and Dissolved Surface Water Metals – Post-Gold King Mine Spill Trends in the Animas and San Juan Rivers

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Abstract 19

More than 3 (three) million gallons of heavy metal contaminated water was discharged from the Gold King Mine (GKM) into Cement Creek, a tributary to the Animas River, near Silverton Colorado (CO). The contamination plume, consisting of surface water and sediment, flowed into the Animas River and continued to migrate downstream into New Mexico, eventually flowing into the San Juan River and into Lake Powell, Utah (UT). The Animas and San Juan Rivers have multiple uses throughout the impacted area; uses include recreational (primarily in the state of CO), agricultural, public water supply, and water hauling.

Time-series data collected from 31 U.S. Environmental Protection Agency (EPA) surface water sampling sites in the Animas and San Juan Rivers were evaluated for total and dissolved metal trends following the GKM Spill. Concentrations of total and dissolved metals were plotted over time using the EPA GKM spill response data to evaluate concentration trends over time. Metal concentrations, in both total and dissolved phases, peak following high-flow events in the Animas and San Juan Rivers with the primary contaminants of concern identified as aluminum, arsenic, and lead.

Dissolved and total peak concentrations for arsenic and lead, following high-flow events, are observed to exceed the NMQCC and EPA standards for safe drinking water (Figures 1 and 2). The magnitude of the peak metal concentrations generally increase downstream, with the highest peaks observed in the San Juan River immediately downstream of the Animas-San Juan confluence and near Bluff, UT.

The downstream, increasing trend of metal concentrations is consistent with the conceptual model that sediment drops out of suspension near the NM-CO Stateline as the topography flattens and the river system widens. Additionally, the EPA estimates that approximately 80 percent of the suspended sediment from the spill was deposited in the CO reaches of the Animas River, which as the potential to be remobilized during high flow events associated with spring runoff and storm events. This sediment is a continued source, releasing metals into the surface water to be transported downstream.

The data evaluated is limited to the 2015 late-monsoon season and does not represent trends that may occur during spring runoff with storm event imprints.

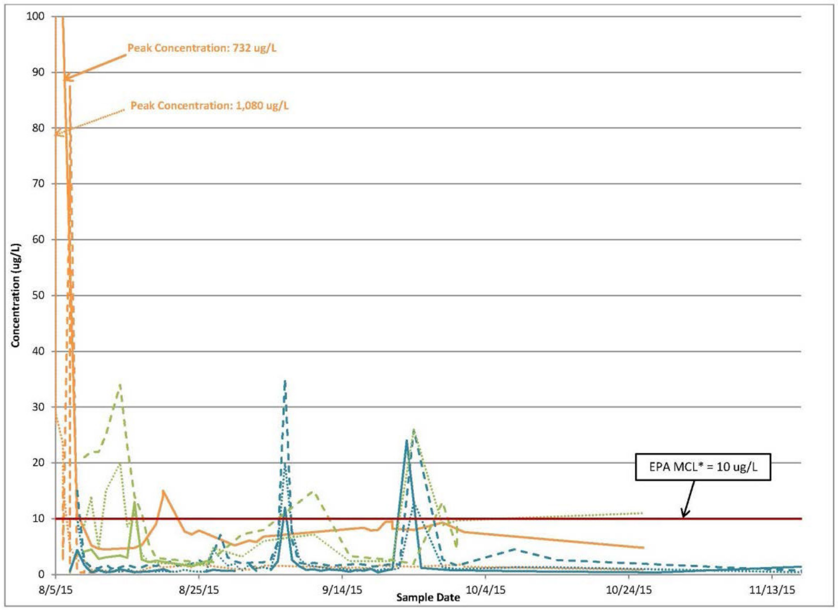

Figure 1. Total Arsenic in the Animas and San Juan Rivers in Colorado (orange), New Mexico (blue), and Utah (green), EPA Sample Locations GKM Spill Response

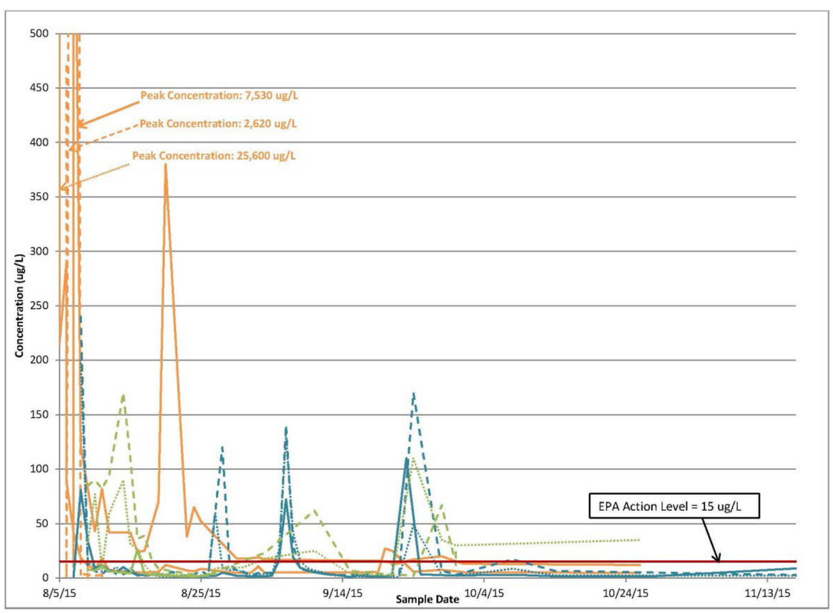

Figure 2 Total Lead Concentration Trends in the Animas and San Juan Rivers in Colorado (orange), New Mexico (blue), and Utah (green), EPA Sample Locations

Stories from the Field: Biomonitoring in San Juan County, NM – October 2015

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Abstract 20

Introduction

Biomonitoring is an opportunity to develop evidence- and science-based knowledge about potential environmental exposures. Over the past two years as part of the Four Corners States Biomonitoring Consortium (4CSBC), the New Mexico Department of Health (NMDOH) has been conducting biomonitoring in communities throughout the state. Following the Gold King Mine Spill in August 2015, San Juan County, New Mexico residents voiced desire for further well-water testing and exposure assessment. This provided a natural opportunity for NMDOH to offer this service and provide residents with the chance to participate and learn about their potential exposure to metals. This presentation will summarize the efforts during the week-long biomonitoring study that was performed in October 2015. It will detail recruitment and sampling methods, and present current aggregated data.

Methods

From October 26, 2015 through October 31, 2015, with the help of staff from the New Mexico Environment Department's Farmington field office we visited 58 households, and enrolled 83 individuals in the study. Participant recruitment included contacting individuals who: 1) self-identified as interested in participating during a state-sponsored well-water sampling event following the spill and/or 2) had their well water tested by the Environmental Protection Agency (EPA) following the spill. Other recruitment methods involved attending community events, advertisements, and phone calls. To be enrolled in the study individuals were required to use their private well water for domestic purposes, such as dinking and/or cooking. Sample collection occurred at the participant's home. In addition to providing a urine and water sample, participants completed an exposure assessment questionnaire that included demographic questions. Water samples were analyzed for total and speciated arsenic, cadmium, manganese, mercury, selenium, and uranium. Urine samples were analyzed for the same six metals and phthalates.

Results

There was a strong interest from community members in participating. Among the 386 households who were contacted through email and/or phone call, 17% enrolled in the study. The most successful recruitment method was over the phone, with 28% of phone calls resulting in enrollment. Among the 83 individuals, 71% of participants reported drinking their well water. Many who did not drink their water reported stopping drinking due to water quality concerns after the spill. We sampled the water from 58 domestic wells. Among those wells, 7% had a water manganese concentration greater than the EPA's health advisory level (HAL), with other metal concentrations below the EPA's maximum contaminant levels (MCL). The other 93% of water samples had manganese concentrations below its HAL and all other metals below their respective MCLs.

***Currently urine analysis is still ongoing. Should we receive results and report these results back to individual participants, they will be presented as aggregate statistics.*

Conclusions

Overall, community members were very receptive, and showed strong interest in participating in our study. Anecdotally, participants were extremely thankful, and viewed this biomonitoring effort as a benefit to them. At its core, biomonitoring aims to provide individuals with data about their potential exposures to contaminants in their environment. These data and resources may empower them to make decisions around living a healthy lifestyle.

Acknowledgement/Disclaimer:

This effort was a partnership between the Environmental Health Epidemiology Bureau's Biomonitoring Program, Environmental Public Health Tracking Program, Private Wells Program and the NMDOH Scientific Laboratory Division. The authors wish to thank Miriam Wamsley, MWR, for her contributions to the participant recruitment and samples collection and Alex Gallegos, MPH, Eric Coker, PhD, MS, and Gabe Silva, BS for their contributions to samples collection.

This work was supported in part by Cooperative Agreement Numbers 5U38EH000949 and 1UE2EH001327 from CDC. The presentation contents are solely the responsibility of the authors and do not necessarily represent the official views of the CDC.

Turbidity as an Indicator of Heavy-Metal in the Animas and San Juan Rivers

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Abstract 21

The August 5, 2015 Gold King Mine spill released an estimated 400,000 Kg of metal-laden solids into the Animas River watershed. Approximately 80% of these solids settled along the Animas River in Colorado, where discolored sediment is visible in the stream bed and/or floodplain at various locations.

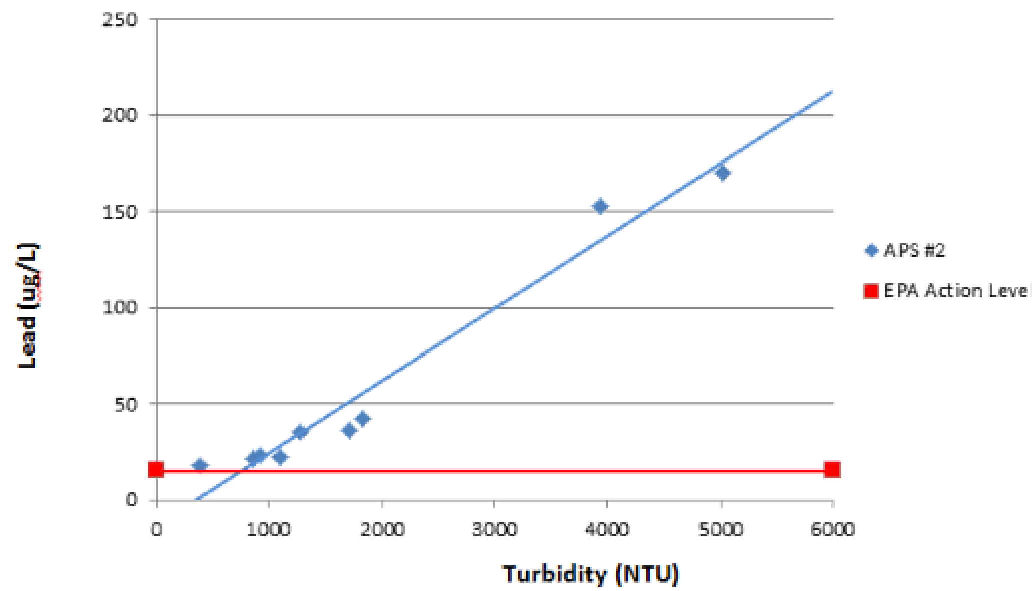
During periods of high flow in the Animas and San Juan Rivers, metals stored in streambed sediment can be remobilized into the water column in both dissolved and suspended phases. Dissolved and total metals in the Animas and San Juan Rivers increased to levels of concern in response to high stream flow associated with monsoonal storm events in 2015 (Agnew et al, this conference). Increases of total metal concentrations in untreated river water are not a violation of National Primary Drinking Water Regulations (NPDWR). Public water systems that divert river water, however, must provide treatment that produces drinking water in compliance with NPDWR, and there is concern about the potential accumulation of metals in treatment infrastructure. In addition to public drinking-water systems, the Animas and San Juan Rivers are used for private domestic water supply, irrigation and livestock watering.

In the Animas River, the source of drinking water for the City of Farmington, a corresponding relationship between increases in total lead and increases in turbidity was observed in data collected from August to October during the 2015 monsoon season. Using this relationship, a turbidity level of 400 NTU corresponds with total lead at the approximate concentration of the NPDWR action level of 15 µg/L. Monitoring is presently underway to define the relationships between streamflow, turbidity, and metals (total and dissolved) during the 2016 Spring runoff season.

Since heavy metal concentrations are related to turbidity, at least during monsoon storm events, and since field instrumentation is capable of measuring turbidity in real time, the City of Farmington and the N.M. Environment

Department have installed a total of six multi-parameter sondes in the Animas and San Juan Rivers from near the Colorado border downstream to Shiprock. Four of the sondes provide real-time data to the U.S. Geological Survey WaterWatch website, where monitoring data can be obtained and users can self-subscribe to email or text alerts when parameters exceed user specified levels. The City of Farmington is using real-time turbidity data to inform decisions on use of the Animas River as a source of raw water during periods of high turbidity. Farmington's Supervisory Control and Data Acquisition (SCADA) system can be programmed to automatically shut down river water intakes when turbidity exceeds specified levels.

Turbidity and Total Lead, City of Farmington, Animas Pump Station #2, During High Flow Events in 2015 Monsoon Season.



Ion Imprinted Polymers for Remediation by Selective Sequestration and Sensing of Hazardous Metal Ions

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Abstract 22

The production of selective metal ion sequestering and separations materials is a growing field with broad application and critical importance. Industry requires vast quantities of metals and generates tons of metal wastes. Nuclear energy production and past weapons production facilities have created unique challenges in the area of metal ion separations. Normal methods of separation are unable to cope with the problem of efficient metal ion sequestration on a large scale due primarily to a lack of selectivity. New technologies are needed immediately to allow for rapid and less costly sequestration from resources with relatively low concentrations of metal ions. Ultimately, technology must reach a point where all metal containing waste streams are treated as recoverable metal resources. An ideal new technology would quickly provide sequestration and subsequently provide a means of reclamation of wastes by converting these wastes to resources of valuable raw materials.

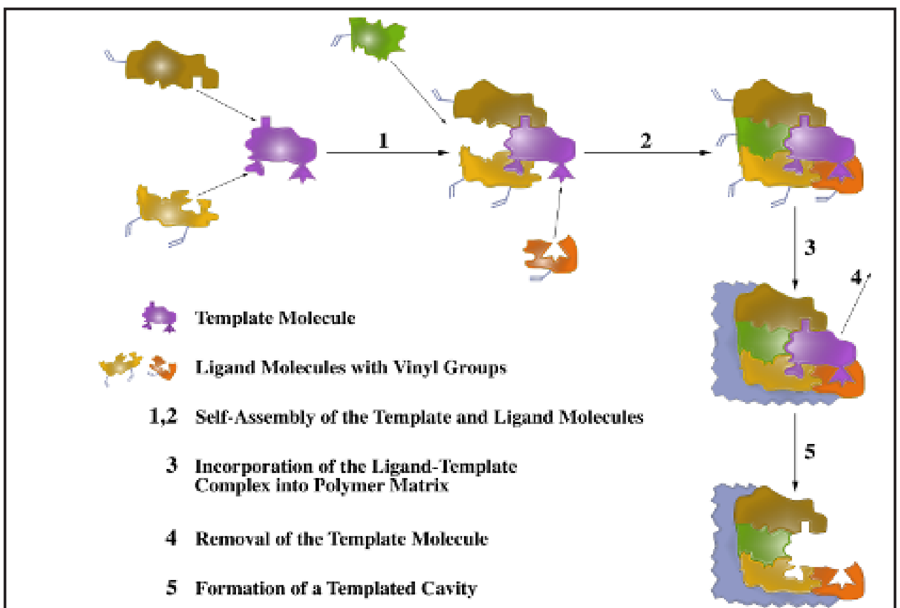

Figure 1. The generic steps involved in preparing a molecularly imprinted polymer.

An emerging technology that can provide these benefits is the application of metal ion imprinted polymers for the selective sequestering and sensing of metal ions. The ability to detect a specific metal ion in a complex matrix is keenly appreciated.

Molecularly imprinted polymers (MIPS) or more specifically ion-imprinted polymers (IIPS), have been prepared as extractants and sensors for highly selective complexation of hazardous metal ions, including uranyl ions, from aqueous solutions. Molecular imprinting is a process for making highly selective binding sites in synthetic polymers. Current imprinting methodologies have been extended and amended in this work by changing the order of the steps, using monomers with improved complexing abilities, reducing the amount of covalent crosslinking, and changing the form factors. Metal ion imprinting is of particular utility since ionic and coordinate covalent bonds are reversible and directional.

This work extends the techniques and methods of previous work to solving a variety of problems in sequestering and sensing of uranyl and other toxic or hazardous metal ions. The work began at the binding site with preparation of improved ligating monomers and extended to the preparation of improved form factors such as macroporous beads, semipermeable membranes, nanoporous substrate coatings and ion selective electrodes.

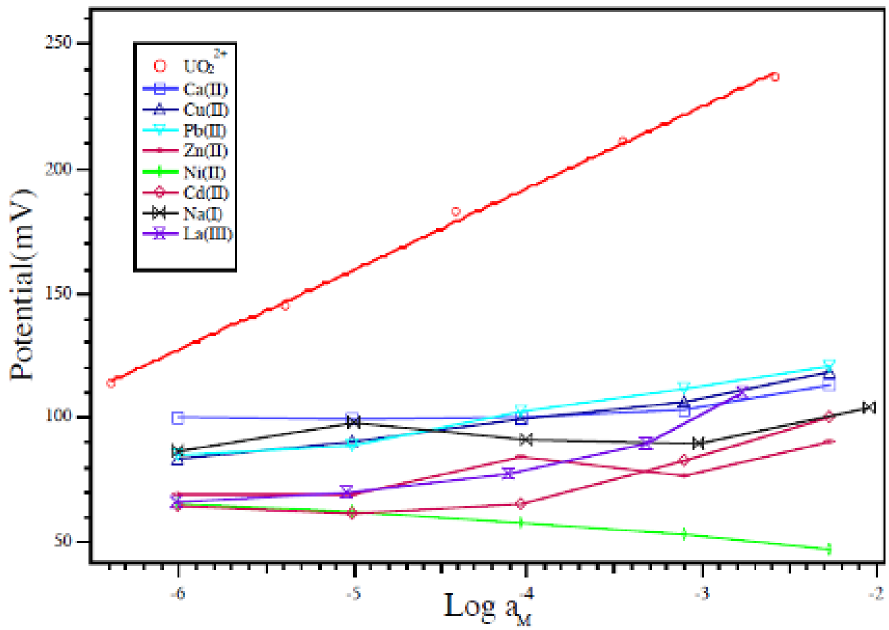

Figure 2. The highly selective performance of a uranyl ion imprinted ion selective electrode.

Modeling and Techniques for Long-term Monitoring and Risk Assessment for Transported Pollutants from the Gold King Mine Release

WITHDRAWN

Monitoring the Animas River Alluvial Aquifer Groundwater Chemistry after the Gold King Mine 2015 Mine-Water Release

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Abstract 24

The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) is a research and service division of New Mexico Tech, serving as the state's geologic survey. After the August 5, 2015 mine-water release into Cement Creek and the Animas River, our agency undertook a hydrologic assessment of the Animas River and its nearby alluvial aquifer in New Mexico, from Colorado-state line to Farmington, NM. The purpose of this project is to evaluate seasonal changes to the hydraulic or groundwater quality conditions along the NM reach of the Animas River.

Our work initially focused on assisting in the compilation and evaluation of water quality data for samples collected in August 2015 by the U.S. EPA. In August 2015, in collaboration with other agencies including U.S. Geological Survey, NM Office of the State Engineer, and NM Environment Department, we measured groundwater level at over 100 locations along the Animas River. Building from this network of wells, with funding from the NM Environment Department, the NMBGMR developed a repeatable monitoring network in the Animas River valley utilizing private domestic wells. This abstract focuses on the water chemistry results, while the groundwater hydraulics is discussed in a companion abstract. An inventory of wells where water chemistry has been sampled is shown on Figure 1.

During the period of January 25-27, 2016, NMBGMR staff collected a total of 16 water samples from private domestic wells along the Animas River. Well selection criteria included 1) proximity to Animas River, 2) proximity to irrigation ditches, 3) wells that were previously sampled by US EPA in August 2015, and 4) wells with owners that were cooperative and willing to permit repeated sampling. In January, we were unable to sample some of the wells due to freezing temperatures and frozen well plumbing. The samples were analyzed for cations, anions, trace metals and the stable isotopes of oxygen and hydrogen.

Results of water chemistry sampling of private domestic wells revealed elevated levels of iron, manganese, aluminum, and sulfate above recommended drinking water standards (although these do not apply to private domestic wells). From our January 2016 results, the highest observed total iron from a groundwater sample was 4.58 mg/L, which is above the secondary recommendation (0.3 mg/L), and total manganese at 6.4 mg/L, which is also above the health advisory level (1.6 mg/L). Well owners have been provided their results in writing, and will continue to be with each sampling event.

We compared results from the January 2016 water chemistry sampling with previous results from samples collected by US EPA in August 2015. Similar to our results, the US EPA samples had elevated levels of Fe, Mn, SO4, and Al. Most samples collected in January 2016 exhibited higher total manganese and iron levels than those sampled in August 2015. It is important to continue to track these trends into the future, utilizing the same sampling protocols over time.

Maps of the water chemistry results show an increase in ion content and total dissolved solids in groundwater in a down river direction from the Colorado-state line to Farmington. Whereas, the elevated levels of iron and manganese appear to be more common in the Cedar Hill and Inca regions. These are areas where we

have noted a decrease in river gradient and minor seasonal reversals of surface to groundwater flow. Perhaps minor seasonal changes in gradient along this reach of the Animas, particularly at baseflow river levels, may have an impact to groundwater quality.

Results from stable isotopes of hydrogen range from -95.9 to -104.1‰, and oxygen from -13.4 to -14.4‰. The very "light" ranges of these values suggest that groundwater in the Animas River valley is predominantly recharged by winter precipitation.

With long-term environmental, mine-related, and anthropogenic impacts to the water quality along the Animas River, it is not surprising to find groundwater with elevated constituents observed in these limited samples. Continued monitoring of groundwater quality, through consistent and repeated measurements, is the only way to accurately examine any affects to groundwater related to the Gold King Mine or other contaminant concerns over time.

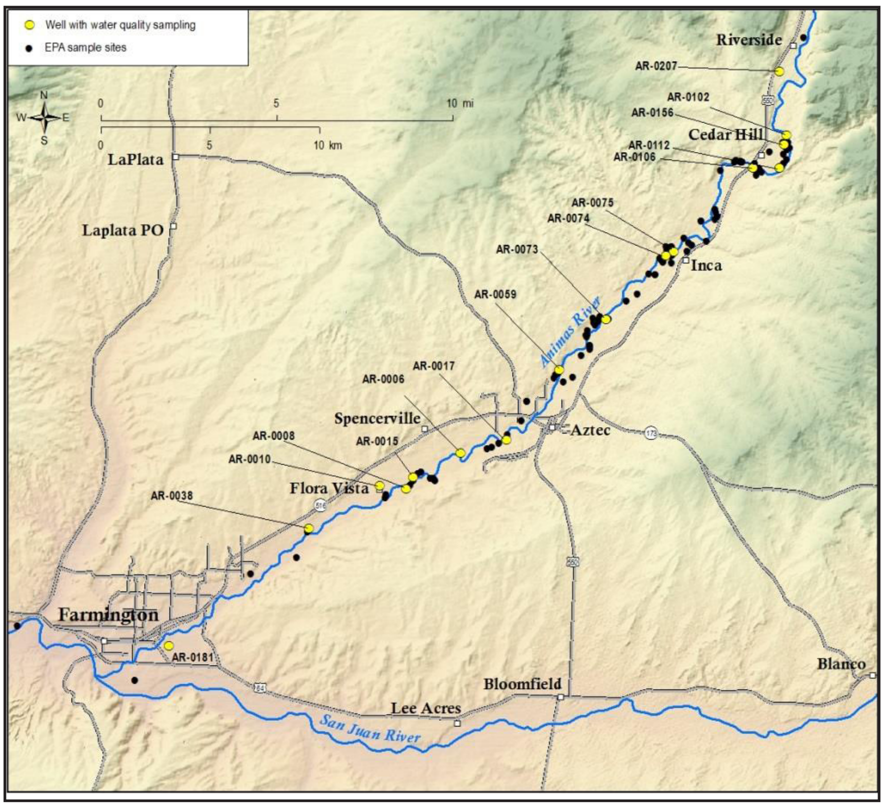

Figure 1. Location map of groundwater sampling sites. Black points are sites sampled by US EPA in August 2015. Yellow points are wells sampled by NMBGMR in January 2016 as part of a groundwater monitoring network.

Solar and Ocean based Hydrologic Forecasts for the Animas River Leading to the end of 2022

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Abstract 25

This author and a colleague recently demonstrated high correlations between stream flows along the Colorado New Mexico border and several important ocean surface temperature and pressure indexes1. The author has continued to develop those correlations and to derive new ones which are now partly based on solar indices. These forecast techniques were shown to lead to high accuracy results when applied to past sub decadal test periods for a client in a nearby watershed.

Accordingly the author has adapted his existing ocean driver and related techniques to produce prototype hydrologic forecasts of the Animas reaching out to the year 2022. The author includes a case study related to his recent forecasts for the City of Santa Fe (Figure 1).

The final prototyped product projects a 5 year trailing average of stream flow for the Animas at Farmington out to the year 2022. The projection technique offers the potential for unprecedented granularity and exceptionally long lead times for anticipation of sustained high and low flow regimes for the Animas River.

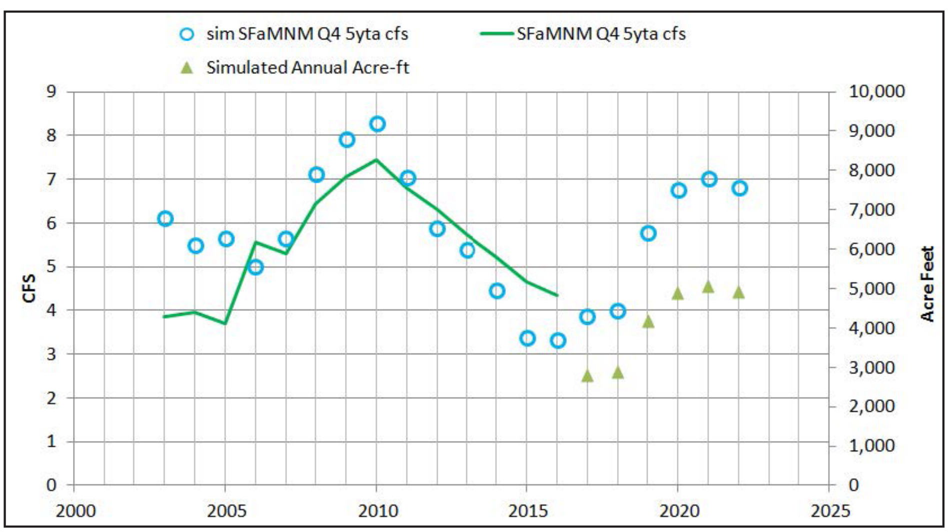

Figure 1. Example of a 6 year forecast exercise for the nearby Santa Fe River

For example, Figure 2 illustrates the author's employment of a "stochastic landscape" profile of the Animas River monthly flows over the entire available Farmington time series.[1] The unique mapping shows clear similarities on many levels with a western element of the author's prior study area.

This similarity lends further confidence to the projected Animas flow results. It is anticipated that improved forecasting will lead to more efficient utilization of resources for ongoing and planned Animas restoration work.

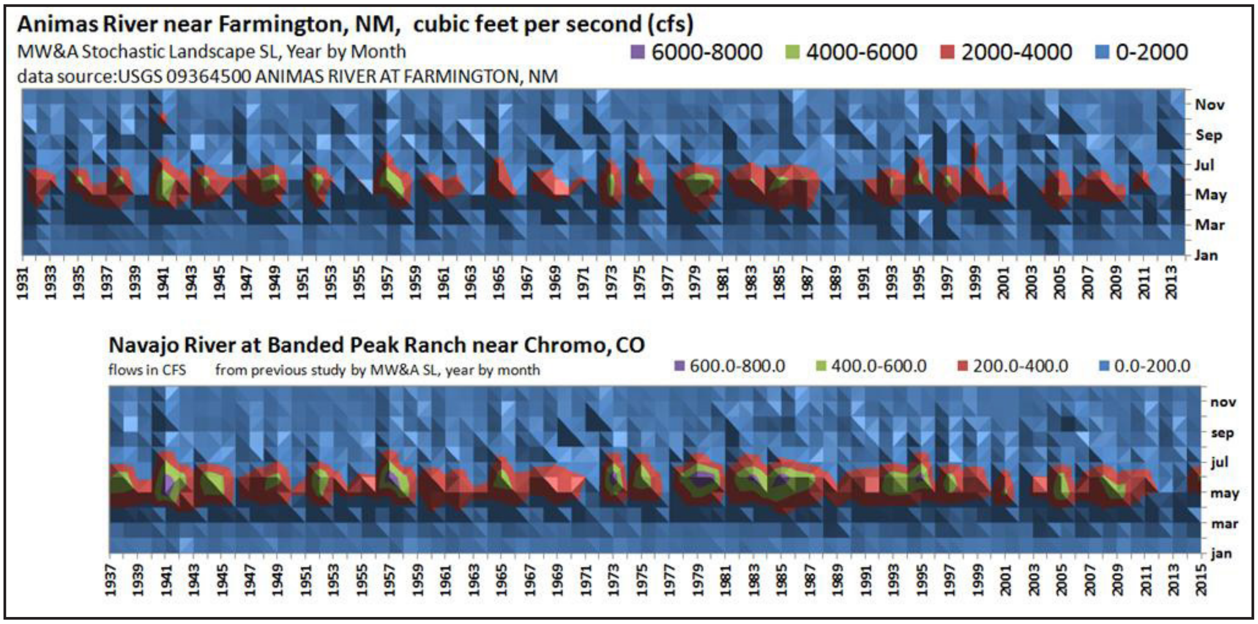

Figure 2. Example of a Stochastic Landscape quantitative representation of the full available monthly flow record for a site on the Animas River and for a site along the Navajo River from a previous study by the author at an adjacent watersjed watershed.

[1] Wallace, MG and P. Chylek, 2016, Dominant Correlations of ocean indices to hydroclimatology metrics of the southwestern United States. In review Journal of Hydrology, Elsevier Press

Before the River Turned Orange: Bacteria and Nutrient Pollution in the Animas and San Juan Rivers

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Abstract 28 – Both Oral and Poster

While pollution from legacy mining and the mineralized San Juan Mountains has always been of concern on the Upper Animas River, local watershed groups downstream of Silverton have been focused on other water pollution issues over the last 15 years. The orange color of the Animas River following the Gold King Mine spill captured the attention of people nationwide in August 2015, but it was a different color that catalyzed local groups to take action in 2002. Excessive growth of filamentous green algae in the Animas River spawned the development of the Animas Watershed Partnership and numerous studies investigating nutrient pollution in the watershed. Similarly, high levels of bacteria and sediment loading have been a long-term concern on the San Juan River. The San Juan Watershed Group has been working to identify and address sources of bacteria loading to the rivers since 2001, and has recently completed a Microbial Source Tracking (MST) study that investigated sources of fecal pollution on both the Animas and San Juan Rivers in 2013 and 2014.

This study measured E.coli, total phosphorus (TP), nitrate+nitrite (NO3/NO2), total Kjeldahl nitrogen (TKN), turbidity, conductivity, pH, temperature, and optical brighteners, as well as a set of PCR analyses testing for the presence/absence of specific DNA markers that represent different host organisms. By testing for these Bacteroides markers, we were able to detect the presence of bacteria originating from humans, birds, horses, dogs, cows, and ruminants (cows, sheep, goats, deer & elk).

Ruminant source bacteria were the most prevalent; this marker was detected in 94% of all samples, and was found in similar concentrations across all sites (cattle sources could not be distinguished from other ruminants). Bird sources were present about a third of the time, while human sources were detected in 77% of all samples. The San Juan River showed a more consistent bacteria problem than the Animas, with 94% of samples testing positive for human bacteria, and 46% of E.coli samples exceeding the single sample maximum criteria for primary contact (ie: swimming). The San Juan site at Hogback exhibited the most serious human bacteria problem: 99% of samples were positive for Human Bacterioides, and concentrations of this marker were significantly higher than all other sampling sites ($p<0.001$).

Animas River sites had 60% of samples test positive for human bacteria, with 13.5% exceeding the single sample E.coli maximum. Maximum concentrations of E.coli, total nitrogen, and total phosphorus were all seen between July and October, and are likely influenced by monsoon storm events. Primary contact standards for E.coli were exceeded at all four NM sampling sites, and Colorado standards were exceeded on the Florida River site.

Nutrient concentrations followed a trend similar to the bacteria, with the San Juan exhibiting consistently higher concentrations than the Animas. While no nutrient criteria currently apply to large rivers like the San Juan, sites on the Animas River exceeded the target criteria set forth in its Total Maximum Daily Loads (TMDLs) for nutrients and total phosphorus, which are set to avoid eutrophication and algae blooms. TKN and TP both correlated positively with E.coli and with turbidity, lending evidence to the conclusion that if bacteria and stormwater erosion problems are addressed, these could also reduce inputs of nutrients to the rivers.

The average water sample tested positive for 2.2 bacteria source markers, meaning that addressing a single pollutant source will not fully address the bacteria problem in the Animas and San Juan Rivers. That said, while pollution from legacy mining remains a problem that must be addressed far upstream, expanding wastewater infrastructure, improving sewage handling practices, restoring riparian buffers, and addressing stormwater runoff from pastures and uplands within San Juan County are all ways to reduce some of New Mexico's "homegrown" water pollution problems.

Figure 1. Map of 2014 sampling sites

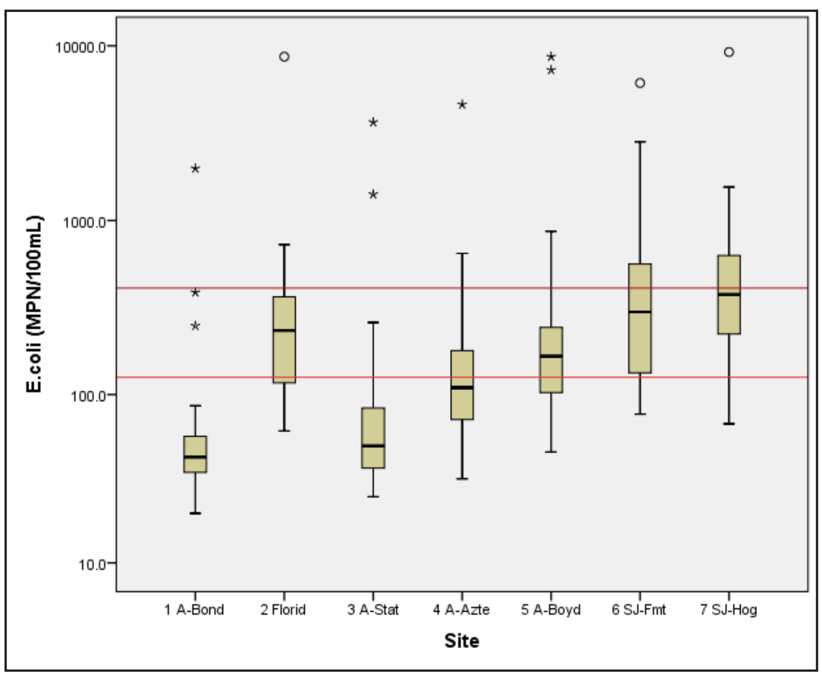

Figure 2. Boxplot of E.coli concentrations at 7 sites sampled in 2014. Light red line is 126 cfu/100mL monthly geometric mean criteria, dark red line is single sample 410 cfu/100mL criteria.

Utah's response to the Gold King Mine release and Long-term Monitoring and Assessment Plan

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Abstract 29

In the weeks that followed the release of 3 million gallons of contaminated water from Gold King Mine in Colorado, the Utah Department of Environmental Quality worked closely with other state, local, and federal agencies to assess and monitor the impacts of the release on Utah waters and Utah residents. UDEQ collected water column and sediment samples before the leading edge of the plume arrived in Utah and for several weeks following the event. Although initial samples did not indicate a level of concern for human health and aquatic life, samples collected by the EPA during fall monsoonal storms indicate several exceedances of Utah's water quality standards. EPA estimates that most of the material spilled during the Gold King Mine release overwintered in the Animas River and could be mobilized during spring runoff. UDEQ is currently implementing a plan in partnership with other states and tribes to monitor the San Juan River and Lake Powell during spring runoff. UDEQ is also developing a long-term monitoring strategy to evaluate the legacy effects of mine releases from the Silverton area, including Gold King Mine, on Utah's waters. The contaminants from Gold King Mine and other mines in the Bonita Peak Mining District will largely come to rest in Utah's Lake Powell, the first major depositional area downstream of the Animas and San Juan Rivers. The long-term monitoring and assessment efforts will evaluate the effects of the cumulative metals loading in the watershed on San Juan River and Lake Powell aquatic life and recreational uses.

The Samarco Mine Tailings Dam Failure, November 2015: Effects and Observations

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Abstract 31

On November 5, 2015, a tailings dam failed at the Samarco Iron Mine complex in the state of Minas Gerais, Brazil, spilling over 32 million cubic meters (over 8 billion gallons) of sediment and water into the headwaters of the Rio Doce. The spill affected the entire 650-kilometer (390 miles) downstream reach of the river, extending to where the river meets the Atlantic Ocean, and creating a plume in the ocean visible from the Landsat satellite. Effects of the spill included loss of human life, suspension of power generation at four hydroelectric power plants along the Rio Doce, fish kills, and temporary water-quality degradation, including increased turbidity that persisted at least two months after the spill. The effects of the spill were somewhat moderated by the Candonga Dam, located at the upstream-most hydroelectric power plant. It filled almost completely with sediment from the spill, which reduced the amount of sediment transmitted downstream by about 30%. A delegation from the U.S. Geological Survey was invited by the Brazilian National Water Agency (Agéncia Nacional de Águas, ANA) to visit Brazil in January 2016 to observe the effects of the spill and to advise ANA regarding studies and techniques to consider that will aid understanding the potential long-term effects of the spill. This presentation will summarize the effects of the spill and present observations resulting from the January 2016 USGS tour of the Rio Doce.

The Gold King Spill – How Did We Get Here

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Abstract 32

The presenter has over twenty years of involvement in mine remediation in the Upper Animas River Basin. He will discuss the history of the projects and changes in water quality and aquatic life that have occurred over time. There will be a particular focus on why U.S. EPA was working on the Gold King Mine in the first place.

Geologic Setting and History of Mining in the Animas River Watershed, Southern Colorado

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Abstract 33

On August 5, 2015, EPA contract personnel caused the release of wastewater at the Gold King mine, CO. into the Animas River. Approximately 3 million gallons of acid mine water containing metals and iron oxyhydroxide sediments were released. The aftermath of this uncontrolled rapid release of mine waters has resulted in re-evaluation of reclamation of legacy mines throughout the U.S. and examination of potential consequences along the Animas River. The purposes of this presentation is to provide geologic and historical background of mining in the Animas River watershed, and to begin to address the path forward in preventing similar spills. Most of the information presented is from previous work, including Church et al. (2007), Church (2014), and Gobla et al. (2015) among other references and the Animas River Stakeholders Group website (http://animasriverstakeholdersgroup.org/blog/)

LOCATION

The Animas River Watershed is in the northernmost headwaters of the Animas River in San Juan County, CO. It includes the drainage basins of the Animas River upstream from Silverton, CO. and its two main tributaries, Cement and Mineral Creeks (Church et al., 2007). Elevations are extreme; Silverton is at 9,305 ft and some of the mountain peaks in the headwaters rise to more than 13,800 ft. The Animas River Watershed encompasses an area of approximately 150 sq miles.

GEOLOGIC SETTING

A Late Oligocene volcanic center erupted many cubic miles of lava and volcanic tuff and formed the Silverton caldera at approximately 22-25 million years ago. Volcanism was followed by multiple episodes of hydrothermal activity along faults that produced widespread areas of pyrite alteration and quartz-pyrite-metals veins. Most of the host rock is very fractured and permeable, which results in complex, interconnecting groundwater flow paths. Subsequent weathering of hydrothermally mineralized veins and altered rocks, particularly the acid sulfate and the quartz-pyrite-sericite alteration that is extensive in the watershed, results in the generation of natural acid drainage and mobilizes metals from the host rocks (Church et al. 2007, among other studies). Thus, not all elevated concentrations of metals and low-pH conditions found in streams are the result of historical mining. In 1874, it was noted that water in both Cement and Mineral Creeks contained iron sulfate, making the water undrinkable (Rhonda, 1876). Weathering of the mine wastes is another major source of metals and acidity.

MINING HISTORY

Early mining was by the Spanish. An arrastra, used to recover gold and silver, was found in the district. The district was rediscovered about 1860. Development began in 1871 with the Little Giant mine. However, extensive mineral exploration did not begin until after the signing of the Bernot Treaty with the Ute Tribe in 1873. Gold and silver production increased once the railroad to Silverton was built in July 1882. Once milled, most sulfide concentrates were shipped to Durango, CO. for smelting. Production occurred during four periods: (1) the Smelting Era 1871–1889, (2) the Gravity Milling Era 1890–1913, (3) the Early Flotation Era

1914–1935, and (4) the Modern Flotation Era 1936–1991. The production from the watershed amounted to more than $529 million, including >2.2 million oz Au, >51 million oz Ag, >112 million lbs Cu, >765 million lbs Pb and >604 million pound Zn from more than 300 mines (Church et al., 2007).

More than 5,000 prospects, mines and mills are found in the Animas River Watershed (Church et al., 2007). Of the 18.1 million short tons of ore produced in the Animas River Watershed from 373 mines and mills, an estimated 8.6 million short tons of mill waste (about 48%) was discharged directly into surface streams or adjacent land prior to about 1935.

At the time the General Mining Law of 1872 was passed by the U.S. Congress, there was no recognition of the environmental consequences of direct discharge of mine and mill wastes into the nation's rivers and streams or the impact of this activity on the availability of drinking water supplies, and riparian and aquatic habitats. Miners operating on federal lands had little to no requirement for environmental protection until the 1960s and 1970s, although the dumping of mine wastes and mill tailings directly into the nation's 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 and most miners were utilizing acceptable standard mining practices at that time.

By 2007, more than $20,000,000 had been spent on remediation, largely on removal of mill tailings deposited in the riparian zone of the Animas River (Church et al., 2007). Both private and public (EPA, USFS, State of Colorado, BLM) funds have been used for these remediation efforts.

CHALLENGES FOR RECLAMATION EFFORTS

Some of the challenges for reclamation efforts in the Animas River Watershed include (Church et al., 2007; Church, 2014; Gobla et al., 2015):

- Complex land ownership (USFS, BLM, orphaned properties held by San Juan County for delinquent taxes, private property)
- Rugged mountain geography and climate (access is difficult during winter months)
- Issues of financial liability
- Technical approaches needed to mitigate acid mine drainage without resorting to costly treatment facilities
- The need for adequate space to build new repositories to move those mine wastes that cannot be mitigated in place
- Effect of reclamation on tourism in a historical mining district Silverton.

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‘on behalf of water’ – Diné art as an Act of Healing Navajo After the Gold King Mine Disaster

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Abstract 36

On August 4, 2015 the Environmental Protection Agency (EPA) “accidentally” released heavy-metal laden contaminated water from the abandoned Gold King Mine into the flow of the Animas River in southwestern Colorado. The warning to the people and communities down river was not given until the next day. In southwestern Colorado, later to the state of New Mexico a formal acknowledgement of the river contamination was finally admitted four days later by the EPA when the federal entity began a series of public meetings throughout the communities affected.

As an Indigenous citizen of the river area and as a member of the eastern Navajo Nation in New Mexico I watched in distress because I understood how the Animas River and San Juan rivers play an extremely pivotal role in contemporary Diné people’s lives. It was instilled in me that my Indigenous matrilineal clans are derived from the sacred element of water. I was raised in the San Juan Valley in northwestern New Mexico, my family history includes story about the Animas and San Juan River community called *Tó* by the *Diné.* The river was named a ‘sacred’ place or site and to this day the river is a place of spiritual power, but it is only known to those who understand and recognize it for the true purpose of it. Respect for desert water is the Beautyway.

As a way or means of healing I have gathered and curated an art exhibition of Navajo artists who have create art ‘on behalf of water.’ The work exhibited is the concerns the reflection of each artist, and their extended families who live in the area of Durango, Farmington and onto Navajoland farming communities in New Mexico.

The participating Navajo artists include: Shaun Beyale, Randy Sabaque SABA, Ruthie Edd, Chamisa Edd-Belin, Julius Badonie, Fidel Frank, and Venaya Yazzie, Navajo/Hopi

Tó'Łítso, the water is yellow: Investigating short term exposure and risk perception of Navajo communities to the Gold King Mine Spill

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Fort Lewis College

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To' Bee Nihi Dziil

Mae-Gilene Begay
Navajo CHR

Abstract 38

On August 5, 2015, 3 million gallons of acid mine drainage was released from the Gold King Mine, eventually reaching the San Juan River – the lifeblood of the Navajo Nation. Many Native American communities have subsistence livelihoods and strong spiritual beliefs that are deeply connected to the natural environment. As a result, environmental contamination from catastrophic mine spills severely impacts indigenous people to the core of their spiritual and physical livelihoods and there is potential for unique exposure pathways and greater health risks. This talk will share the experiences of building community partnerships to develop and implement a time-sensitive proposal to National Institute of Environmental Health Sciences entitled "Tó'Łítso, the water is yellow: Investigating short term exposure and risk perception of Navajo communities to the Gold King Mine Spill." This is a partnership between Navajo Community Health Representatives (CHR) Program, University of Arizona (UA) and Northern Arizona University (NAU). The first aim is to determine levels of exposures in three Navajo communities within 9 months of the spill and prior to the growing season. The second aim is to assess temporal and spatial changes in sediment, agricultural soil, river and well. The third aim is to determine the association between Navajo community members' perception of health risks and measured health risks from the Gold King Mine. This project is time-sensitive because it is essential to obtain baseline short-term exposure measurements prior to spring runoff which is likely to re-mobilize river sediment and prior to the start of the Navajo growing season.

2016 Poster Abstracts

1989 – Memories from the Sunnyside Mine

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Abstract 1 – Both Oral and Poster

In the late 1980s the Sunnyside Mine was an active underground gold mine operation. As a member of the mine engineering staff from 1987-1991, the author had the opportunity to explore many aspects of the underground and surface expression of the mine. Hired to support the underground survey crew in 1987 and later working as the mine ventilation engineer and water treatment plant operator, the author shares memories of the physical characteristics of the operating mine. The presentation uses publicly available maps and diagrams coupled with personal descriptions of the underground workings, the Lake Emma glory hole on C-Level, lime treatment plants and settling ponds constructed to treat acid mine drainage at the American and Terry Tunnels, tailings effluent water quality adjustment at the Mayflower Mill, and surface water sampling in the upper Animas River Watershed in the years just prior to the mine shutdown. The intention of the presentation will be to give the audience a first-hand account of underground mining in the Gladstone area and associated environmental activities circa 1989 and provide an opportunity to improve understanding of mining and the mine area geography affecting the Upper Animas watershed.

Rapid Assessment of Soil Metal Concentrations Along the Animas River, New Mexico

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Abstract 9 – Both Oral and Poster

On August 5th, 2015 an inadvertent breech of a mine shaft holding metal laden waters in Colorado was spilled into the Animas River and ultimately into the San Juan River confluence in Farmington, NM and beyond into the Navajo Nation. Farming communities draw irrigation water from the Animas and San Juan Rivers, raising concerns that metal-laden water in the river was spread across farm fields as irrigation water. As the pollutant plume moved down the river, a reddish sludge was deposited in the river sediment and along the riverbanks. Initially, the water containing the plume was cloudy as the sludge was suspended in the water. However, after several weeks, the initial plume ran its course downstream and the water running down the Colorado portion of the Animas River near Durango appeared quite clear in September 2015; so clear in fact that the coating of the orange sludge on the bottom of the river and adjacent banks was readily apparent. The concern now is the remaining sludge in the river will slowly be carried downstream as irrigation ditches are once again activated for the 2016 growing season.

In an effort to rapidly respond to the threat to soil health in the farm fields of the area, the Natural Resources Conservation Service (NRCS), New Mexico State University (NMSU), and Texas Tech University (TTU) partnered to use state of the art portable X-ray fluorescence spectrometry (PRXF) for rapid, on-site analysis of soil elemental composition. PXRF spectrometry is a novel, yet widely accepted means of rapid elemental assessment in soils and sediments. Reference methods for the technique have been developed both by the NRCS (Soil Survey Staff, 2014) and Environmental Protection Agency (US-EPA, 2007) (Method 6200) and NRCS referenced methods for use in soils and sediments. The operational theory, optimized uses, limitations and applications are summarized by Weindorf et al. (2014).

Materials and Methods

On-site rapid PRXF field scans were undertaken Sept. 1-3, 2015 using a Delta Premium (DP-6000) PXRF featuring a Rh X-ray tube operated at 10-40 keV with elemental quantification accomplished via integrated ultra-high resolution (<165 eV) silicon drift detector. Multiple types of land were evaluated including: irrigated lands (water taken from the Animas River), non- irrigated lands (Control), and riverbank sediment. The location of each soil scan was georeferenced with GPS. Scanning was conducted in a proprietary software configuration known as Geochem Mode which offers elemental quantification of the following elements: V, Cr, Fe, Co, Ni, Cu, Zn, W, Hg, As, Se, Pb, Bi, Rb, U, Sr, Y, Zr, Th, Mo, Ag, Cd, Sn, Sb, Ti, Mn, Mg, Al, Si, P, S, Cl, K, and Ca. Geochem mode consists of two beams; each was set to scan for 30 sec, such that one complete sample scan took 60 sec. PXRF performance was assessed via scanning of two NIST certified soil standards.

Results and Discussion

Notably, the riverbank sediment was observed to be a mix of natural alluvial sediment and Gold King Mine sludge; the two of which had substantively different elemental signatures. In total, 140 samples were scanned in three days. Summary results are provided in Table 1.

Table 1. Elemental concentration ranges and averages for soils and sediments scanned with PXRF in the Animas River Valley in Colorado and New Mexico. All units are in mg kg-1.

n	Location	Al Avg	Al Range	Fe Avg	Fe Range	Cu Avg	Cu Range	Zn Avg	Zn Range	As Avg	As Range	Pb Avg	Pb Range
29	Control	64087	25413-83540	28987	9047-50892	33	ND-94	117	25-330	7	ND-13	53	12-230
67	Irrigated	53541	7281-80325	28514	4430-48232	36	11-100	175	39-819	7	ND-13	67	5-271
35	Riverbank	37749	4218-80108	38302	5818-293194	77	ND-220	365	19-1068	11	ND-38	153	10-487
9	Riverbank-Sludge	21018	8730-38781	48355	38292-75959	137	90-176	474	277-1174	40	ND-54	637	509-859
140													

Generally, the properties of the river sludge sent down the Animas River had Pb levels of ~600-800 mg kg-1; and higher levels of Fe, Cu, and Zn. Notably, the residential screening limit for Pb in soils is 400 mg kg-1 (Brevik, 2013). These sludge materials were found both in New Mexico and Colorado, both on the stream banks and underwater. Irrigated lands along the Animas River tended to have slightly higher levels of metals than non-irrigated "control" areas, although these were below agricultural loading rates notably for Pb. Nevertheless, it is essential we monitor these areas over time as more sludge sediment washes down the river and potentially spreads out via irrigation. It is unclear whether contaminated sludge will move down into New Mexico over time in response to hydrologic pulses (snow melt, flash floods, etc). The level of metals found in sludge along the Animas River warrant careful observation and extensive spatial and temporal sampling are recommended such that the levels of metals in soils of the Animas

River Valley will be more thoroughly understood in an effort to protect and optimize soil health. If areas of accumulation are noted, phytoremediation or other remediation strategies should be undertaken to ensure that the metal laden soils do not pose a risk for metal bioaccumulation in plants or feedstocks used by humans or animals.

This technology will be put to use in two phases of the project: 1) initial, rapid, on-site assessment of metal levels in soils of the Animas River Valley, and 2) long term monitoring whereby temporal accumulations of metals can be studied and documented as irrigation with river water once again resumes.

Acknowledgements:

We thank the NRCS (Richard Strait) and NMSU Experiment Station (David Thompson) for funding.

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What are the Effects of the Gold King Mine Spill on San Juan County, NM Agricultural Irrigation Ditches and Farms?

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Abstract 10 – Both Oral and Poster

Livestock production in San Juan County, NM is an 18-million-dollar industry with over 700 producers owning livestock (NMSU San Juan County Cooperative Extension). Alfalfa and other forage hays dominate much of the irrigated agricultural landscape. There are commercial apple orchards and grape vineyards in addition to farms that grow high value specialty horticultural crops including vegetables, herbs and cut flowers. Irrigation ditches that divert water from the Animas/San Juan rivers consist of intake points directly from the Animas River which are regulated by the New Mexico (NM) Office of the State Engineers and Federal Government (on the Navajo Nation) and operated by community ditch cooperatives and farm boards. The irrigation season typically begins around late April and ends late October, at which point the main ditch intakes are closed for the winter.

Typical furrow irrigated system in San Juan County, NM.

In August 2015, three million gallons of heavy metal contaminated water were accidentally released from the Gold King Mine (GKM) into the Animas River (EPA 2015; https://www.youtube.com/watch?v=ZBlR05tDCbI). Orange colored sediment laden with heavy metals including Pb, As, and Mn was evident along the river one month after the spill. Significant amounts of river sediments accumulate in irrigation ditches, smaller laterals, and gated irrigation areas during the growing season and constitute a potential threat to agricultural lands.

As a precaution against contaminating irrigation ditches, ditch cooperatives in NM and the Navajo Nation closed main diversion points into the 20 or so irrigation canals about 48 hours before the mine spill plume arrived in NM (San Juan Agricultural Water-Users Association 2015). The majority of irrigation ditches

reopened after the EPA declared the river "safe" and irrigation resumed. The Navajo Nation made the difficult decision to open some ditches, while leaving others closed. In Northwest NM, some irrigators on and off the Navajo Nation ceased irrigating crops for the 2015 growing season, just at the time most crops were maturing for harvest.

The GKM spill is hitting the region just as there is a resurgent interest in local food production among both Anglo and Indo-Hispano cultures. Contamination of the Animas and San Juan Rivers following the Gold King Mine blow-out raises a number of questions by farmers and ranchers in San Juan County who are still anxious about the safety of the water and soil. Because the ditches were dry for about 10 days during the closure of the river, this gave our team the unique opportunity to establish base-line measures of irrigation ditch sediment in dry irrigation ditches for future long-term monitoring of the river/irrigation ditch/agricultural field interface and potential contamination threats to agricultural lands.

One of the objectives of our response to the mine spill centered on the following questions:

- What was in the ditch sediment before the spill?
- What is in the ditch sediment after the spill?

Methods, Procedures and Facilities: Thirteen irrigation ditches in San Juan County from the Colorado border to Farmington, NM were sampled August 11-August 14, during the ban on irrigating crops. We sampled only non-contaminated sediments. Where possible, sample transects were made downstream of a NM Office of the State Engineer (NMOSE) gage station. These gage stations monitor flow data in real time and may provide clues to ditch sedimentation. The following week, three main ditches on the Navajo Nation were sampled. Permission to sample was obtained by ditch companies, the NMOES, Navajo EPA and Navajo community farm board members. In one main ditch, we pulled transects at six locations from various points along approximately 15 miles (24 km). Sample sites were recorded with GPS. Through repeated measures, we resampled the same irrigation ditch locations during the winter 2015-2016, once the main intakes were closed for the winter. Because ditch sedimentation during the irrigation season can vary, at each sample point, we attempted to auger to 18-24 inches (46-70 cm) deep in three separate core pulls (6-8 inches long per core). Total metals from soil was measured following USEPA method 3051A (USEPA, 1998) using inductively coupled plasma optical emission spectrometry (ICP-OES) analysis. Baseline samples are now analyzed and we are beginning to analyze time 2 ditch sediment samples.

Our goal is to help restore consumer confidence and grower trust in the region by continuing to sample ditches and fields to ascertain if soil contaminant concentrations are below or similar to pre-August 2015 levels. These evaluations are critical to reassure growers and consumers in the region that the products grown on soils in the Animas and San Juan River Watersheds are safe.

Acknowledgements: We thank the NMSU Agricultural Experiment Station for salary and material support.

Investigation of Metal Persistence in Sediments of the Animas River Watershed after the Gold King Mine Spill

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Abstract 17 – Both Oral and Poster

The concentration and speciation of major and trace elements contaminants in water and sediments of the Animas River was investigated in samples collected during August 17th-18th, 2015, after the Gold King Mine spill occurred on August 5, 2015. A combination of spectroscopic, microscopic and water chemistry techniques was used to better understand the short-term impact of the spill, which will contribute to elucidate the long-term consequences of recurrent mine waste contamination events.

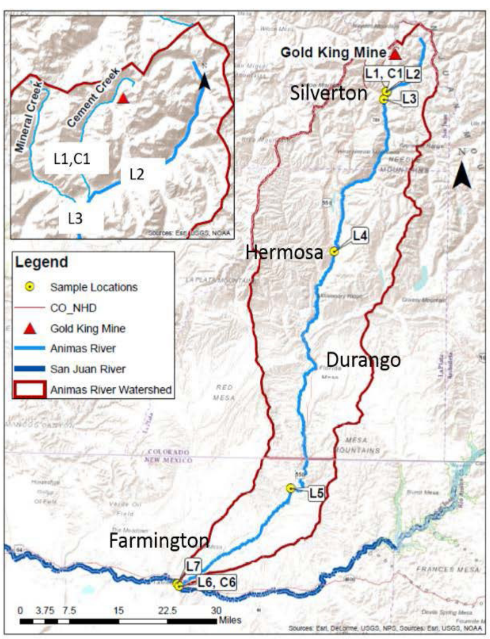

Figure 1 Map of the locations sampled during the trip on August 17th and 18th, 2015. Water samples were collected in all locations, and sediment samples were collected in all the locations but in L2 (Animas River upstream the Cement Creek confluence). In addition, two reference samples (C1 and C6) were collected above the river water level in Cement Creek and in the Animas River in Farmington.

For this study we took water and sediment samples in different locations across the Animas River watershed, trying to select locations similar to those sampled by EPA (Figure 1). Our selected samples include a location in Cement Creek, CO, the Animas River tributary where the spill occurred, and one in the San Juan River near Farmington, NM. The rest of the locations were selected in the Animas River from before the confluence with Cement Creek, CO, downstream to Farmington, NM.

The total concentrations of different metals in the water were within typical background levels at the time of the sampling trip. However, analyses of the data published by the EPA suggest that metals such as Pb and As exceed the drinking water standards of 15 μg l^{-1} and 10 μg l^{-1}, respectively, at different locations of the Animas River after high flow events, as shown in Figure 2. In addition, nitrate, nitrite and phosphate were measured in water in the Farmington samples, a highly agricultural area, which suggest nutrient cycling in the river and could have implications in metal mobilization.

We detected the presence of high concentration of metals in the sediments (108.4 ±1.8 mg kg-1 Pb, 32.4 ±0.5 mg kg-1 Cu, 729.6 ±5.7 mg kg-1 Zn and 51,314.6 ±295.4 mg kg-1 Fe). The predominance of clay, jarosite, and alumino-silicate minerals was determined by XRD analyses in these

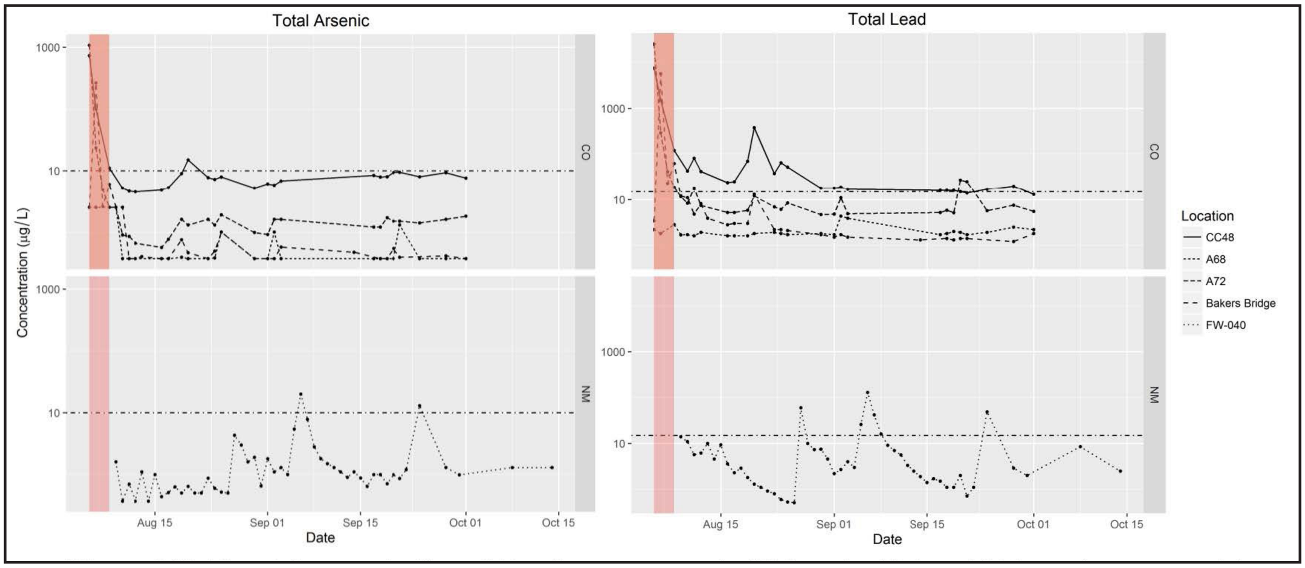

Figure 2. Total metal concentrations (https://www.epa.gov/goldkingmine/date-gold-king-mine-response) in water following the Gold King Mine Spill (marked as the red bar in the graphs). The spikes in total arsenic and lead concentration correspond with high flow events in the Animas River in Colorado (top graph) and in New Mexico (bottom graph). The dashed lines represent the drinking water standard concentration of 10 μg 1-1 for arsenic and 15 μg 1-1for lead

sediments, which are relevant primary minerals known to accumulate metals in the environment. Analyses using XPS detected the presence of sulfates, phosphates and nitrogen species in the surface of the sediments; Fe as 75% Fe(II) and 25% Fe(III) upstream the Animas River, but Fe(III) was the predominant specie in the surface of the Farmington sediments; and 100% Pb(II) in the samples from Cement Creek and Hermosa. The co-occurrence of Pb, Cu, Zn and Fe with sulfate was identified in these sediments using TEM, confirming the presence of metal- bearing jarosite ($KFe^{3+}{}_3(OH)_6(SO_4)_2$). The Mössbauer analyses of the samples from Cement Creek and Hermosa also shows the jarosite mineral in the sediments. The water at Cement Creek has a pH 3.3 but it increases into the alkaline range in the Farmington area, thus, the detection of jarosite in sediments from this location confirms the stability of this metal-bearing phase under acidic conditions.

The presence of nutrients in the sediments and water in the Farmington samples and the accumulation of metals in clays and precipitation as metal-bearing minerals highlight the relevance of understanding biogeochemical interactions to further asses the long-term stability of the contamination in the sediments of the Animas River watershed.

Examination of Sediment Microbial Communities in the Animas River Watershed Following the Gold King Mine Spill

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Abstract 18 – Both Oral and Poster

On August 5th, 2015 the EPA conducted an investigation of the Gold King Mine near Silverton, Colorado in order to assess the on-going water releases from the mine, treat mine water, and assess the feasibility of further mine waste remediation. While excavating near the entrance of the mine, pressurized water began to leak from the adit of the mine, spilling approximately 3 million gallons of heavy metal contaminated mine waste into Cement Creek, a tributary of the Animas River. (epa.gov)

On August 17th-18th, 2015 The University of New Mexico visited sites shown in Figure 1 along Cement Creek, Animas River, and San Juan River. At these sites, sediment samples were taken to determine metals composition, and microbial communities associated with the sediment. Basic water quality parameters were also measured such as water temperature, dissolved oxygen, conductivity, pH and oxidation-reduction potential. Sediment samples were sent to Research and Testing Laboratory for DNA extraction and Illumina Next Generation Sequencing.

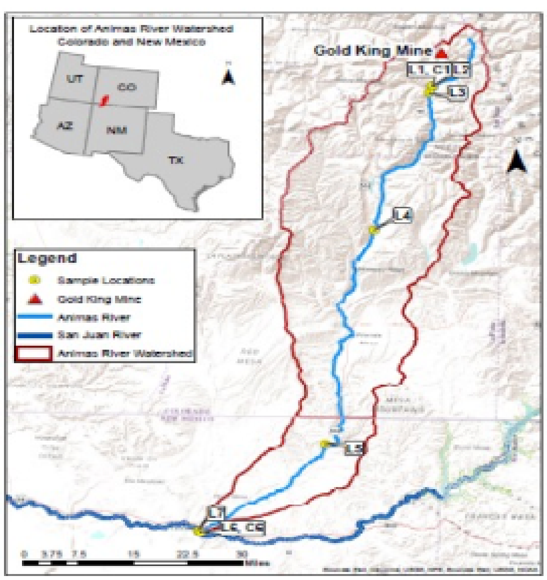

Figure 1: 8/17/15 – 8/18/15 Sample Locations in Animas River Colorado and New Mexico.

L1	Cement Creek 14th St Bridge
L2	EPA A68 Silverton Animas upstream
L3	EPA A72 Downstream of Cement Creek
L4	Animas at Bakers Bridge
L5	Animas Cedar Creek
L6	Animas at Farmington
L7	San Juan River downstream

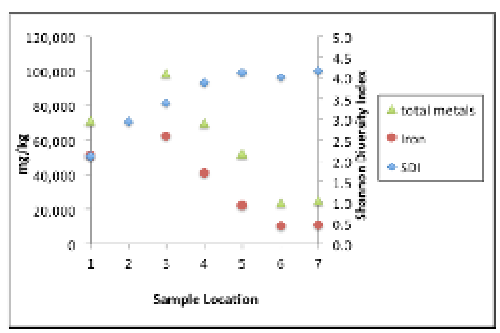

Figure 2: Total Metals, Iron concentrations and Shannon Diversity Index for sediment samples

As shown in Figure 2, Iron and Total metals concentrations are highest in sediment at sample locations closest to Cement Creek where the Gold King Mine discharged. Further downstream, concentrations of metals decrease and level off near the confluence of The Animas and San Juan rivers. The diversity of microbial samples collected at each site has been determined by calculating the Shannon Diversity Index (SDI) (Lande 1996). By this measure, microbial diversity appears to be generally lower at upstream sites with sediment containing high metals concentration. As metal concentrations decrease downstream, microbial diversity appears to recover by the steady increase in the SDI.

Figure 3 shows a dramatic change in sediment bacteria family communities observed in the Animas River upstream and downstream of the Cement Creek confluence. Upstream of the confluence, Cement Creek is rich in Gallionellacae (60.4% relative abundance), where the Animas River upstream of the confluence is all but missing this family (0.07% relative abundance). The family Gallionellacae is well document to consist of Iron oxidizing bacteria (FeOB) that mineralize dissolved Fe(II) to a precipitated Fe(III) in the form of extracellular bio-mineral structures (Krepski et al 2012). This process is important at acid mine draingage impacted sites because iron is usually the most abundant metallic element, and other heavy metals may co-precipitate or adsorb to Fe(III) precipitates formed by FeOB such as Gallionellacae (Stumm et al.1996, Fabisch et al. 2013).

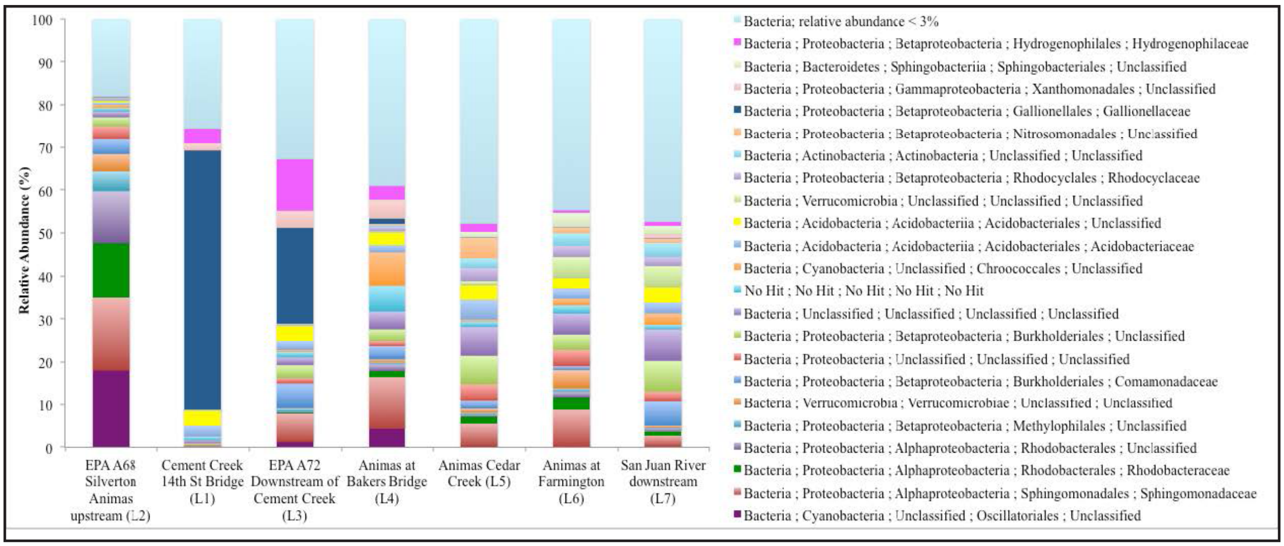

Figure 3. Illumina next generation DNA sequencing results for sediment samples in the Animas River watershed sorted by familiar. Bacteria familiae observed at less than 3% relative abundance across all locations were grouped together for visual simplicity

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Surface-Water Quality in Northwestern New Mexico after the Gold King Mine Release

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Abstract 26

The Gold King Mine Release of August 5, 2015 mobilized three million gallons of water and sediment into a tributary of the Animas River, which flows south from Colorado into New Mexico. The Animas enters the San Juan River at Farmington, New Mexico, the sixth largest city in the state and one of several communities that rely on the Animas and San Juan rivers for drinking water and (or) crop irrigation. Mines such as the Gold King are sources of metals and acidity to streams of the area, leading to concerns regarding the effects of the release on water quality. Potential problem constituents such as lead and arsenic (among others) were analyzed in surface water and sediment samples collected by the U.S. Geological Survey (USGS) in August 2015. Surface-water samples collected from the San Juan River at Farmington on August 8, 2015 (a time when the orange color indicative of the release was observed) had concentrations in whole water (unfiltered) samples of 552 µg/L lead and 26.3 µg/L arsenic. The concentrations of lead and arsenic were above the lead action level of 15 µg/L and the maximum contaminant level of 10 µg/L for arsenic, as set by the U.S. Environmental Protection Agency for drinking water. In contrast, the dissolved concentrations (0.45 µm filter) of these elements at the same site and time (lead <0.04 µg/L and arsenic 0.23 µg/L) were about two to three orders of magnitude below drinking-water standards and three to 5 orders of magnitude below the whole water sample concentrations. At the San Juan River at Farmington streamgage, located approximately two river miles downstream from the Animas River at Farmington streamgage, concentrations measured in whole water samples collected 4 hours after the samples on the Animas River ranged from 122 µg/L for lead, and 7.89 µg/L for arsenic. These concentrations were likely affected by dilution from the San Juan River which had discharge on August 8, 2015 of about 1,300 cfs, whereas discharge on the Animas River at Farmington was about 800 cfs.

Based on the results for total and dissolved water samples, constituents of concern generally were associated with particulates in the water. Bed sediment samples collected from the Animas River at Farmington on August 12, 2015 had lead concentrations ranging from 33.0 to 179 mg/kg and arsenic concentrations ranging from 3 to 11 mg/kg (n =4). Concentrations of these constituents in bed sediments were generally lower at the San Juan River at Farmington, similar to the trend in water-quality data for the same sites. Concern related to suspended particulates and bed sediment in these rivers continues months after the release. Continuous monitoring of pH, temperature, specific conductance, and turbidity is expected to help to understand the current geochemical interactions in the rivers. Additionally, water-quality sampling during snowmelt and storm events will provide valuable information about sediment and metal mobility during high-discharge events in the Animas and San Juan Rivers.

The Legacy Uranium Mining and Milling Cleanup Plan: Evacuation of the EPA Five-Year Plan, Grants Mining District, New Mexico

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Abstract 27

Uranium mining and milling in northwestern New Mexico (NM) impacted soils, stream sediments, surface water, and ground water with elevated levels of radioactivity and toxic heavy metals. Uranium and its radioactive decay products such as radium and radon gas present a significant public health and safety hazard and environmental health risk. The exposure of people and the environment to heavy metals and radionuclides in soil, air, and water in the vicinity of legacy uranium operations in the Grants District requires mitigation through the systematic assessment and cleanup of materials and sites bearing these hazardous contaminants. In August 2010 EPA released the Five-Year Plan Grants Mining District, New Mexico to assess and cleanup hazards from legacy uranium in northwestern NM. An evaluation of the activities in the first five years (2010-2014) of such a large-scale project was performed to determine if there has been measurable progress toward major goals and specific tasks in the Plan. The Six Objectives of the Plan address the following areas: 1. ground water; 2. mines; 3. mills; 4. structures; 5. Jackpile Mine, and 6. biomonitoring. The Plan accomplishments and progress during 2010-2014 toward completion of these six Objectives indicates that Jackpile Mine and Biomonitoring (Objectives 5 and 6, respectively) were achieved. Objectives 3 and 4 (mill sites and residential structures, respectively) show accomplishments and continuing work. Objectives relating to ground water and mine cleanup (Objective 1 and 2) show some progress but these two objectives were not fully achieved. Constraints and complexities related to regulatory practices, uncertainties, financial burden, and health impacts were identified as hindrance to full completion of the Six Objectives. Recommendations to support future work include development of an implementation plan for ground water, full enforcement of state ground water protection regulations, enhanced public involvement, and better collaboration among five-year plan agencies.

Before the River Turned Orange: Bacteria and Nutrient Pollution in the Animas and San Juan Rivers

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Abstract 28 – Both Oral and Poster

While pollution from legacy mining and the mineralized San Juan Mountains has always been of concern on the Upper Animas River, local watershed groups downstream of Silverton have been focused on other water pollution issues over the last 15 years. The orange color of the Animas River following the Gold King Mine spill captured the attention of people nationwide in August 2015, but it was a different color that catalyzed local groups to take action in 2002. Excessive growth of filamentous green algae in the Animas River spawned the development of the Animas Watershed Partnership and numerous studies investigating nutrient pollution in the watershed. Similarly, high levels of bacteria and sediment loading have been a long-term concern on the San Juan River. The San Juan Watershed Group has been working to identify and address sources of bacteria loading to the rivers since 2001, and has recently completed a Microbial Source Tracking (MST) study that investigated sources of fecal pollution on both the Animas and San Juan Rivers in 2013 and 2014.

This study measured E.coli, total phosphorus (TP), nitrate+nitrite (NO3/NO2), total Kjeldahl nitrogen (TKN), turbidity, conductivity, pH, temperature, and optical brighteners, as well as a set of PCR analyses testing for the presence/absence of specific DNA markers that represent different host organisms. By testing for these Bacteroides markers, we were able to detect the presence of bacteria originating from humans, birds, horses, dogs, cows, and ruminants (cows, sheep, goats, deer & elk).

Ruminant source bacteria were the most prevalent; this marker was detected in 94% of all samples, and was found in similar concentrations across all sites (cattle sources could not be distinguished from other ruminants). Bird sources were present about a third of the time, while human sources were detected in 77% of all samples. The San Juan River showed a more consistent bacteria problem than the Animas, with 94% of samples testing positive for human bacteria, and 46% of E.coli samples exceeding the single sample maximum criteria for primary contact (ie: swimming). The San Juan site at Hogback exhibited the most serious human bacteria problem: 99% of samples were positive for Human Bacterioides, and concentrations of this marker were significantly higher than all other sampling sites ($p<0.001$).

Animas River sites had 60% of samples test positive for human bacteria, with 13.5% exceeding the single sample E.coli maximum. Maximum concentrations of E.coli, total nitrogen, and total phosphorus were all seen between July and October, and are likely influenced by monsoon storm events. Primary contact standards for E.coli were exceeded at all four NM sampling sites, and Colorado standards were exceeded on the Florida River site.

Nutrient concentrations followed a trend similar to the bacteria, with the San Juan exhibiting consistently higher concentrations than the Animas. While no nutrient criteria currently apply to large rivers like the San Juan, sites on the Animas River exceeded the target criteria set forth in its Total Maximum Daily Loads (TMDLs) for nutrients and total phosphorus, which are set to avoid eutrophication and algae blooms. TKN and TP both correlated positively with E.coli and with turbidity, lending evidence to the conclusion that if bacteria and stormwater erosion problems are addressed, these could also reduce inputs of nutrients to the rivers.

The average water sample tested positive for 2.2 bacteria source markers, meaning that addressing a single pollutant source will not fully address the bacteria problem in the Animas and San Juan Rivers. That said, while pollution from legacy mining remains a problem that must be addressed far upstream, expanding wastewater infrastructure, improving sewage handling practices, restoring riparian buffers, and addressing stormwater runoff from pastures and uplands within San Juan County are all ways to reduce some of New Mexico's "homegrown" water pollution problems.

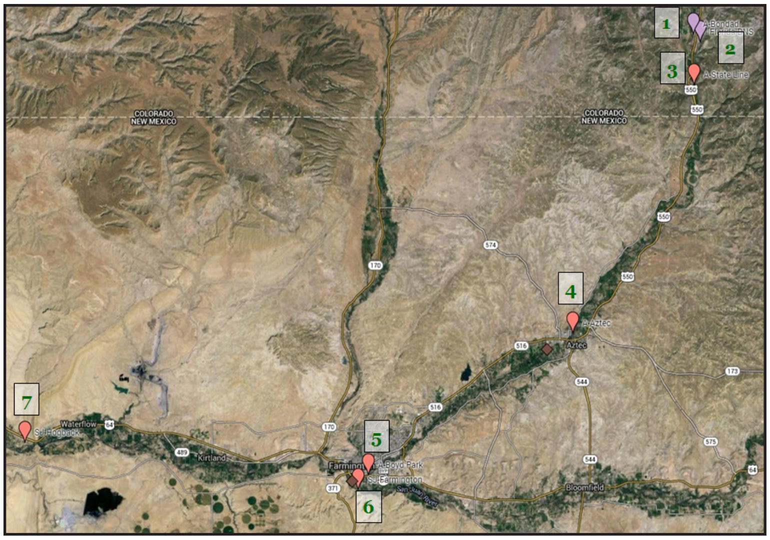
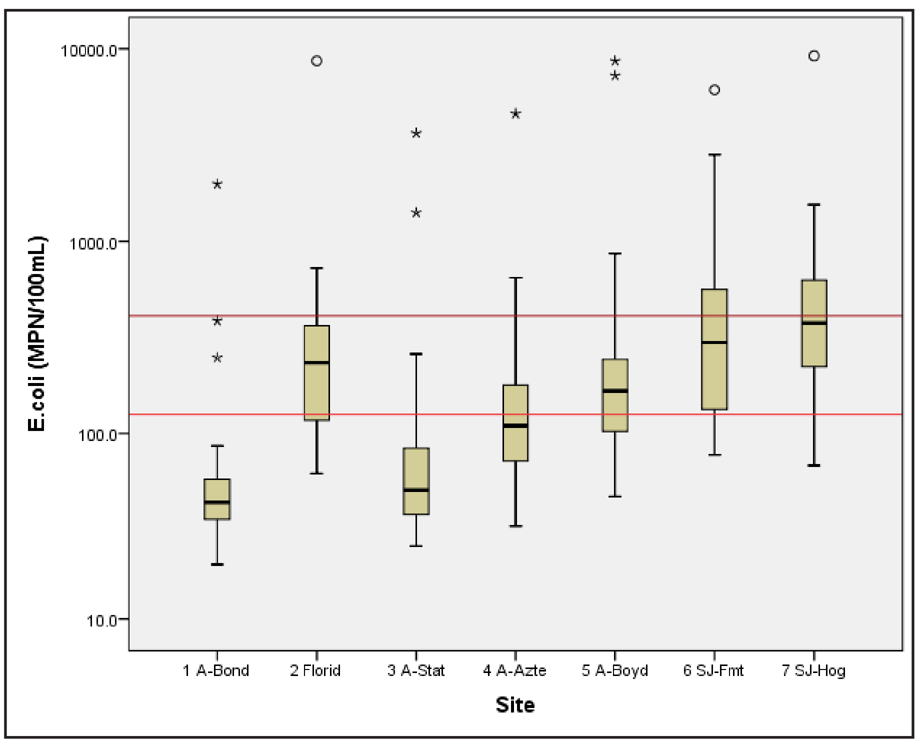


Figure 1. Map of 2014 sampling sites

Figure 2. Boxplot of E.coli concentrations at 7 sites sampled in 2014. Light red line is 126 cfu/100mL monthly geometric mean criteria, dark red line is single sample 410 cfu/100mL criteria.



The Use of Geochemical Data to Model Diffuse Leakage from a Mine's Tailings and Settling Ponds, with an Emphasis on Subsurface Flow, Malmberget/Vitåfors Iron Mine, Norrbotten County, Sweden

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Abstract 30

The Malmberget/Vitåfors mining facility, located in Norrbotten County, Sweden, is the world's second largest underground iron ore mine, comprised of roughly 20 steeply dipping magnetite-hematite ore lenses, with an underground area of approximately 5 x 2.5km. Since its' opening in 1892, over 350Mt of ore have been removed from Malberget, and another 350Mt of iron reserves have been declared proven and probable.

The state-owned Swedish mining company, Luossavaara-Kiirunavaara Aktiebolag (LKAB), owns and operates the facility. They have seen an increase in production in the past years, effectively doubling the amount of ore processed at the Vitåfors facility, from 8Mton/year in 1998 to 16Mton/year in 2013, and they intend to maintain this steady increase into the future. Despite these changes, the amount of water used within the system has not increased proportionally, and is not predicted to do so in the future. This is due to increases in process-water recycling, which adds to the demands placed on this water. As the water is reused, the conservative and trace element concentrations grow, affecting the overall water quality.

Some portion of the spent process water is released on a daily basis into the nearby Lina River. This discharge is generated in two ways: (1) By means of monitored release via outlet pipes, and (2) through diffuse leakage and subsurface flow originating at the facility's tailings and settling ponds. As yet, the volume, flow rate, and composition of this second discharge source have not been quantified. These characteristics can be estimated, however, by means of inverse geochemical modeling that utilizes historical water quality records from various sampling points throughout the Malmberget facility. Similarly, groundwater flow modeling takes advantage of local topographic and stratigraphic information generated almost entirely by the Geological Survey of Sweden (SGU).

The combined model generated by geochemical and groundwater flow modeling software (PREEQ-C and MODFLOW, respectively) that will answer questions of leakage quantity and quality is constructed broadly, by means of a three-part process. Initially, a rough three-dimensional model of groundwater flow within the local watershed is created in MODFLOW, employing geologic and topographic data collected by the SGU, as well as meteorological records from the Swedish Meteorological and Hydrological Institute. This is used to determine the relative path that groundwater will travel from the tailings and settling ponds to the Lina River. A second two-dimensional flow model illustrates this cross-section in greater detail. Inverse modeling with PHREEQC finally generates a one-dimensional model of the path between initial and final sampling locations (i.e., the tailings and settling pond, and the Lina River). The goal is to generate a plausible chain of mineral and gaseous phases that is both appropriate to the geology and chemistry of the site, and accounts for the changes in composition between initial and final water quality analyses.

The Characterization of Abandoned Uranium Mines in New Mexico

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Abstract 34

Not only has mining played a significant role in the United States, but for hundreds of years mining has aided in the economic and social development of New Mexico as early as the 1500s. One of the earliest gold rushes in the West was in the Ortiz Mountains (Old Placers district) in 1828, 21 years before the California Gold Rush in 1849. At the time the U.S. General Mining Law of 1872 was written, there was no recognition of the environmental consequences of direct discharge of mine and mill wastes into the nation's rivers and streams or the impact of this activity on the availability of drinking water supplies, and riparian and aquatic habitats. Miners operating on federal lands had little to no requirement for environmental protection until the 1960s and 1970s, although the dumping of mine wastes and mill tailings directly into the nation's 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.

In New Mexico, there are tens of thousands of inactive or abandoned mine features in 273 mining districts and prospect areas (including coal, uranium, metals, and industrial minerals districts and prospect areas; McLemore et al., 2005a, b). The New Mexico Abandoned Mine Lands Bureau (NMAMLB) of the New Mexico Energy, Minerals and Natural Resources Department estimates that there are more than 15,000 abandoned mine features in the state (http://www.emnrd.state.nm.us/MMD/AML/amlmain.html). NMAMLB has safeguarded more than 2,300 mine openings in about 250 separate construction projects. The U.S. Bureau of Land Management recently estimated that more than 10,000 mine features are on BLM land 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 New Mexico Bureau of Geology and Mineral Resources 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.

Many 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. However, a complete inventory and prioritization for reclamation has not been accomplished in New Mexico. 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 that contain deadly gases, highwalls, encounters with wild animals, radon and metal-laden waters. Some sites have the potential to contaminate surface water, groundwater and air quality. Heavy metals in mine waste or tailings and acid mine drainage can potentially impact water quality and human health.

A recent example is the Gold King mine 'blowout' incident in Colorado where approximately 3 million gallons of acid mine water eroded soil and rock debris from the mine portal, pyritic rock and soil from adjoining waste rock dump, and were deposited in Cement Creek, and ultimately, flowing downstream to contaminate the Animas and San Juan Rivers (Gobla et al., 2015). Environmental accidents also have occurred at some New Mexico mine sites, mostly before the 1980s. In July 1979, 370,000 cubic meters of radioactive water containing 1,000 tons of contaminated sediment from a failure of the United Nuclear uranium tailings

dam traveled 110 km downstream in the Rio Puerco in western New Mexico. Evidence of slope instability at the Goathill North waste rock pile at Questa molybdenum mine was observed as early as 1974, but was not stabilized until 2004.

Many state and federal agencies have mitigated the physical safety hazards by closing these mine features, but very few of these reclamation efforts have examined the long-term chemical effects from these mine sites. 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 and Questa mines; McLemore et al., 2001, 2009, 2010). Some of these observations only come from detailed electron microprobe studies that are not part of a government remediation effort (McLemore et al., 2009, 2010).

The objective of our research is to develop a better procedure to inventory and characterize inactive or abandoned mine features in New Mexico, using the Lucky Don and Little Davie uranium mines in the Churapedero mining district, Socorro County, New Mexico as an example. Hazard ranking of mine openings and features, using BLM ranking methodology will be utilized for most sites (Bureau of Land Management, 2014). Also we want to suggest remedial activities that would manage or mitigate dangers to the environment and public health, while taking into consideration historical, cultural and wildlife issues and mineral resource potential.

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Aeolian Transport of Dust-Borne Uranium Contamination

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Abstract 35

Closed mines pose significant risks to environmental and human health. While some work has been done on uranium mine waste contamination of surface water, ground water, and soil, little has been done to investigate the health risks to humans and wildlife from the aeolian transport of contaminated dust particles. In arid environments this is of particular concern due to the frequency of dust storms. At the Jackpile mine in Laguna Pueblo, NM, 15 sets of dust traps have been installed on vertical posts at heights of 0.25 m, 0.5 m, 1.0 m. and 1.5 m above the ground surface. The dust traps were installed at a range of distances from the source, from within the mine pit to approximately 4 km away. Soil samples have been collected at each site and dust samples were collected every other month as well as collected after individual windstorm events. Soil and dust samples were sieved into different size classes using 2 mm, 1.5 mm, 1.00 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.09 mm and 0.063 mm sieves. The samples were digested and uranium content analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). We analyzed our samples for correlation between dust and soil contamination to 1) evaluate if soil contamination can be used as an indicator for the risk of airborne contamination, and 2) gain insight into the possibility that dust is the source of soil contamination. Secondly, we will investigate whether uranium has an affinity for a particular size class of dust. Of special interest are the particles small enough to be completely inhaled by humans. Results show that surface concentrations of uranium vary substantially across the landscape. Distance from the pit shows no correlation with concentration of uranium in the upper 5 cm of soil. Thus other factors besides distance may be controlling accumulation. Vegetation height and density is known to have a significant impact on wind speeds and related soil erosion and dust deposition. A confounding factor is topographic relief. At our study site there is 153 m difference in elevation between the highest site and lowest site. Furthermore the mesa cliffs and mine walls can constrict wind, increasing speeds at some sites and decreasing it at others. I have collected dust and soil samples from 15 sites in the area around the Jackpile mine and analyzed them for uranium concentration. The soil uranium content has been compared to site elevation and vegetation height. Preliminary analysis suggest that elevation and vegetation height may impact local erosion and deposition of uranium.

Standard Addition Method in Analysis of Animas River Samples

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Abstract 37

On August 5, 2015, approximately 3 Million gallons of mine waste containing various heavy metals was released into the Animas River from the Gold King Mine in Silverton, Colorado. This spill severely impacted the four corners area. Samples from Farmington, NM, and Silverton, CO, were analyzed for uranium, mercury, and cadmium using ICP-MS via standard addition. Results suggested an incredibly different concentration than what would be found via a normal calibration curve due to the complex nature of the river causing a matrix affect. Additionally, we exposed the river water to montmorillonite clays and observed a qualitative abatement of uranium and mercury.

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