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National Conference on Mining-Influenced Waters

Approaches for Characterization, Source Control and Treatment

August 12-14, 2014

Sheraton Albuquerque Uptown Hotel • Albuquerque, New Mexico

United States Environmental Protection Agency

Sponsored by the U.S. Environmental Protection Agency
Office of Research and Development
Office of Solid Waste and Emergency Response
Region 6, Dallas, TX

U.S. EPA Proceedings of National Conference on Mining-Influenced Waters: Approaches for Characterization, Source Control and Treatment

Edited by:

Diana Bless

Douglas Grosse

EPA Number: EPA/600/R-15/088

The U.S. Environmental Protection Agency (EPA or the Agency), through its Office of Research and Development (ORD), sponsored a conference in Albuquerque, New Mexico on August 12-14, 2014. This document was compiled by Science Applications International Corporation (SAIC) under Contract No. EP-W-09-032 from presentations and open discussion at the conference. The views expressed in these Proceedings are those of the individual authors and do not necessarily reflect the views and policies of the EPA. Scientists in EPA's Office of Research and Development have prepared the EPA sections, and those sections have been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use. The references contained within the presentation abstracts have been provided by the speakers. For questions regarding abstract content or references please contact the speakers directly.

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National Conference on Mining-Influenced Waters Steering Committee

Conference Co-Chairs:

Douglas Grosse, U.S. Environmental Protection Agency (EPA), Office of Research and Development (ORD), National Risk Management Research Laboratory (NRMRL)

Diana Bless, U.S. EPA, ORD, NRMRL

Committee Members:

Barbara Butler, U.S. EPA, ORD, NRMRL

Mark Doolan, U.S. EPA

Gregory Gervais, U.S. EPA Office of Solid Waste and Emergency Response (OSWER), Office of Superfund Remediation and Technology Innovation (OSRTI)

Michael Gonzalez, U.S. EPA, ORD, NRMRL

James Hanley, U.S. EPA Region 8

John Hillenbrand, U.S. EPA Region 9

Stephen Hoffman, U.S. EPA, OSWER

Chris Impellitteri, U.S. EPA, ORD, NRMRL

Scott Jacobs, U.S. EPA, ORD, NRMRL

Jim Lazorchak, U.S. EPA, ORD, National Exposure Research Laboratory

Shahid Mahmud, U.S. EPA, OSWER, OSRTI

Michele Mahoney, U.S. EPA, OSWER, OSRTI

Steven McDonald, USDA Forest Service

John McKernan, U.S. EPA, ORD, NRMRL

Mark Purcell, U.S. EPA Region 6

John Quander, U.S. EPA, OSWER, OSRTI

Carol Russell, U.S. EPA, Region 8

Joseph Schubauer-Berigan, U.S. EPA, ORD, NRMRL

Robert Weber, U.S. EPA, ORD, Office of Science Policy

National Conference on Mining-Influenced Waters

Approaches for Characterization, Source Control and Treatment

August 12-14, 2014 • Albuquerque, New Mexico

Sponsored by the U.S. Environmental Protection Agency

CONFERENCE AGENDA

Day 1 – Tuesday, August 12, 2014

7:30 AM – 5:00 PM **Registration & Name Badge Pickup** (*Grand Ballroom Foyer*)

Grand Ballroom

	Plenary Session **Session Chairs: Douglas Grosse and Diana Bless, U.S. EPA/ORD/NRMRL**
8:30 AM – 8:45 AM	**Greetings and Opening Remarks** – Douglas Grosse, Conference Co-Chair, Senior Environmental Engineer, National Risk Management Research Laboratory (NRMRL), Office of Research and Development (ORD), U.S. Environmental Protection Agency (EPA)
8:45 AM – 9:05 AM	**EPA Region 6 Program and Priorities** – Ron Curry, Regional Administrator, Region 6, U.S. EPA
9:05 AM – 9:25 AM	**Superfund Mine Site Challenges and Opportunities** – Robin H. Richardson, Acting Director, Office of Superfund Remediation and Technology Innovation (OSRTI), Office of Solid Waste and Emergency Response (OSWER), U.S. EPA
9:25 AM – 9:45 AM	**Scientific Assessments Informing Decisions: The Bristol Bay Assessment Example** – Jeffrey Frithsen, Ph.D., Senior Scientist, National Center for Environmental Assessment (NCEA), ORD, U.S. EPA
9:45 AM – 10:10 AM	**Break** (*Grand Ballroom Foyer*)
10:10 AM – 10:15 AM	**Identifying Opportunities for the Sustainable Management of Rare Earth Element (REE) Applications** – Diana Bless, Chemical Engineer, NRMRL, ORD, U.S. EPA
10:15 AM – 10:40 AM	**EPA Report on Treatment Technologies for Mining-Influenced Water** – Michele Mahoney, Soil Scientist, OSRTI, OSWER, U.S. EPA
10:40 AM – 11:05 AM	**Partnering to Support Sustainable Mining** – Terrence Chatwin, Ph.D., Technical Director, INAP
11:05 AM – 11:30 AM	**Dramatic Improvements at Margajita River, Pueblo Viejo Gold Mine, Dominican Republic** – Carlos Tamayo Lara, Ph.D., Environmental Manager, Barrick Gold Corporation

11:30 AM – 1:00 PM **Lunch** (*on your own*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	1 **Characterization** Session Chair: Carol Russell, U.S. EPA Region 8	**2** **Source Control / Mine Closure Approaches** Session Chair: Shahid Mahmud, U.S. EPA/OSWER/OSRTI
1:00 PM – 1:30 PM	**Characterizing Mining-Related Contamination in the Ocoee River, Tennessee** – Thomas Moyer, Ph.D., Black & Veatch Special Projects Corporation	**Land Application of Biochemical Reactor Effluent: An Innovative Method for Mitigating Acid Rock Drainage** – James Gusek, Sovereign Consulting, Inc.
1:30 PM – 2:00 PM	**Application of Tracer Studies in Assessment of Abandoned Mines** – Curt Coover, CDM Smith	**Dissolved Organic Carbon Augmentation: An Innovative Tool for Managing Operational and Closure-Phase Impacts from Mining on Surface Water Resources** – Charles Wisdom, Ph.D., Geosyntec Consultants
2:00 PM – 2:30 PM	**The Continuing Evolution of Ground Water Sampling Methods** – Kent Cordry, GeoInsight, Inc.	**Influence of Pre-Mine Weathering and Rock Type on TDS Release from Appalachian Coal Mine Spoils** – W. Lee Daniels, Ph.D., Virginia Tech

2:30 PM – 3:00 PM **Break** (*Grand Ballroom Foyer*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	3 Session Chair: Krista McKim, U.S. EPA Region 5	**4** **Source Control / Mine Closure Approaches (cont.)** Session Chair: John Hillenbrand, U.S. EPA Region 9
3:00 PM – 3:30 PM	**High Spatial and Temporal Resolution of Contaminated Flows** – Ian Sharp, FLUTe	**Design Aspects of Mine Site Cover Systems** – Stephen Dwyer, Ph.D., Sandia National Laboratories
3:30 PM – 4:00 PM	**Techniques for Successful Storm-Water Monitoring in a Mining-Influenced Watershed** – Thomas McComb, Barge Waggoner Sumner and Cannon, Inc.	**Bio-mediated Soil Improvement Field Study for Erosion Control and Site Restoration** – Christopher Hunt, Ph.D., Geosyntec Consultants
4:00 PM – 4:30 PM	**Insights on Mine Site Characterization from EPA's Optimization Review Initiative** – Tom Kady, U.S. EPA Environmental Response Team	**Long-Term Results of Cover System Monitoring in Semi-arid Western USA** – Monisha Banerjee, Ph.D., GeoSystems Analysis, Inc.

5:00 PM – 6:30 PM **Poster Session** (*Roxy Room*)

Day 2 – Wednesday, August 13, 2014

7:30 AM – 5:00 PM **Registration & Name Badge Pickup** (*Grand Ballroom Foyer*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	5 Session Chair: James Sickles, U.S. EPA Region 9	**6** Session Chair: James Hanley, U.S. EPA Region 8
8:30 AM – 9:00 AM	**Effective Field Techniques and Watershed Modeling for Characterizing Mercury Loading to Surface Water, Black Butte Mine Superfund Site, Lane County, Oregon** – Howard Young, CDM Smith	**The Economics of Water Treatment: Conventional versus High Density Sludge Precipitation** – Mary Boardman, Colorado Department of Public Health and Environment
9:00 AM – 9:30 AM	**On the Problem of Hydraulic Characterization of Gravelly Mine Waste and Cover System Materials** – Tzung-Mow Yao, Ph.D., GeoSystems Analysis, Inc.	**Alkaline Flush: An Emerging Technology for In Situ Treatment of Mine Impacted Alluvial Aquifers** – Olufunsho Ogungbade, Freeport-McMoRan
9:30 AM – 10:00 AM	**Shaft Sampling and Profiling at the Section 27 Mine** – Cynthia Ardito, INTERA, Inc.	**Innovative Contaminant Removal from Mining Water with a Single Pass Advanced Treatment System** – William Roper, Ph.D., Micronic Technologies Corporation

10:00 AM – 10:30 AM **Break** (*Grand Ballroom Foyer*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	7 Session Chair: Mark Purcell, U.S. EPA Region 6	**8** Session Chair: Gary Riley, U.S. EPA Region 9
10:30 AM – 11:00 AM	**Lessons Learned from Mining-Influenced Waters Studies at the New Mexico Bureau of Geology and Mineral Resources** – Virginia McLemore, Ph.D., New Mexico Bureau of Geology and Mineral Resources	**Biochemical Reactors for Treating Mining Influenced Water** – Douglas Bacon, State of Utah Department of Environmental Quality
11:00 AM – 11:30 AM	**Assessing the Influence of Copper-Nickel-Bearing Bedrocks on Baseline Water Quality in Three Northeastern Minnesota Watersheds** – Perry Jones, U.S. Geological Survey	**Enhanced Sulfate Reduction Treatment of Mining-Influenced Water Using Biochemical Reactors - Impacts on Mercury Speciation** – Stephen Dent, Ph.D., CDM Smith
11:30 AM – 12:00 PM	**Evapotranspiration and Geochemical Controls on Groundwater Plumes at Arid Sites: Lessons from Archetype Uranium Milling Sites** – Brian Looney, Ph.D., Savannah River National Laboratory	**Biochemical Reactors for Passive Treatment of Selenium** – James Bays, CH2MHILL

12:00 PM – 1:30 PM **Lunch** (*on your own*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	9 Source Control / Mine Closure Approaches (cont.) Session Chair: Stephen Hoffman, U.S. EPA/OSWER	**10 Water Treatment (cont.)** Session Chair: Joy Jenkins, Ph.D., U.S. EPA Region 8
1:30 PM – 2:00 PM	**Strategy and Design Considerations for Prioritization of Mine Waste Source Area Remediation within the Headwaters of the Tar Creek Watershed** – Marc Schlebusch, CDM Smith	**Treatability Studies for Acidic Mining-Influenced Water** – Angela Frandsen, CDM Smith
2:00 PM – 2:30 PM	**Acid Rock Drainage Source Control and Tailings Pile Closure at the Elizabeth Mine Superfund Site, Orange County, Vermont** – Andrew Boeckeler, Nobis Engineering, Inc.	**Innovative Biological and Molecular Tools Applied to Mine Waste Issues** – Brady Lee, Pacific Northwest National Laboratory
2:30 PM – 3:00 PM	**Passive Interflow Controls: An Approach to Improve Best Management Practices for Water Diversion at Abandoned Mine Sites** – Gary Hazen, CDM Smith	**Electro-Biochemical Reactor Water Treatment Technology Demonstrates Low Selenium and Other Metal Effluents in Hardrock Mining Wastewaters** – A. Ola Opara, Ph.D., Inotec, LLC

3:00 PM – 3:30 PM **Break** (*Grand Ballroom Foyer*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	11 Source Control / Mine Closure Approaches (cont.) Session Chair: Carter Jessop, U.S. EPA Region 9	**12 Water Treatment (cont.)** Session Chair: Michele Mahoney, U.S. EPA/OSWER/OSRTI
3:30 PM – 4:00 PM	**Advances in Groundwater Remediation and Modeling for Mining-Related Contaminants** – Michael Truex, Pacific Northwest National Laboratory	**Iron Mountain Mine Superfund Site – Long Term O&M Challenges** – James Sickles, U.S. EPA Region 9
4:00 PM – 4:30 PM	**Hydrologic and Water-Quality Effects of the Dinero Tunnel Bulkhead, Sugar Loaf Mining District, Near Leadville, Colorado: Implications for Monitoring Remediation** – Katherine Walton-Day, Ph.D., U.S. Geological Survey	**Characterization and Remediation of Iron(III) Oxide-Rich Scale in a Pipeline Carrying Acid Mine Drainage at Iron Mountain Mine, California, U.S.A.** – Kate Campbell, Ph.D., U.S. Geological Survey
4:30 PM – 5:00 PM	**In-Situ Nitrate and Selenium Reduction/Stabilization within Coal Waste Rock: Bench-Scale Evaluation** – A. Ola Opara, Ph.D., Inotec, LLC	**Tackling AMD, Mining Impacted Groundwater and Private Mine Ownership in a Superfund Site that Spans the Panhandle of Idaho** – Ed Moreen, U.S. EPA

Day 3 – Thursday, August 14, 2014

7:30 AM – 12:00 PM **Registration & Name Badge Pickup** (*Grand Ballroom Foyer*)

	Track A (*Regal/Wurlitzer Room*)	Track B (*Ambassador/Registry Room*)
	13 Beneficial Use Session Chair: Scott Jacobs, U.S. EPA/ORD/NRMRL	**14 Prediction and Modeling** Session Chair: Robert Weber, U.S. EPA/ORD
8:00 AM – 8:30 AM	**Extraction of Useful Resources from Mining-Influenced Water (MIW)** – Kate Campbell, Ph.D., U.S. Geological Survey	**Approach for Estimating a Probable Range of Pit Lake Concentrations for Mine Pits with Sulfide Wall Rock** – Steven Lange, Knight Piésold and Co.
8:30 AM – 9:00 AM	**Large-Scale Treatment of Agricultural Effluents Using Mine Drainage Residuals** – Philip Sibrell, U.S. Geological Survey	**Assessing Potential Impacts from Underground Mine Dewatering in the Gallup, Dakota, and Westwater Canyon Aquifers with a Basin-Wide Groundwater Flow Model** – John Sigda, Ph.D., INTERA, Inc.
9:00 AM – 9:30 AM	**Jordan River & Midvale Slag Superfund Site-Beneficial Use** – Marian Hubbard, Salt Lake County Watershed Planning and Restoration	**Contaminated Sediment Fate and Transport Model in the Tri-State Mining District** – Douglas Grosse, U.S. EPA/ORD/NRMRL

9:30 AM – 10:00 AM **Break** (*Grand Ballroom Foyer*)

	Grand Ballroom
	Closing Session Session Chair: Douglas Grosse, U.S. EPA/ORD/NRMRL
10:00 AM – 10:30 AM	**A Semi-Passive Bioreactor for Treatment of a Sulfate and Metals Contaminated Well Field, Nacimiento Mine, New Mexico** – Timothy Tsukamoto, Ph.D, TKT Consulting, LLC
10:30 AM – 11:45 AM	**Panel Discussion**
11:45 AM – 12:00 PM	**Closing Remarks**

12:30 PM – 5:00 PM **Optional Post-Conference Field Trip to the Nacimiento Copper Mine**

Poster Presentations

Characterization

1. **Using ICP Spectrometry Data and Alkalinity Results for Effective Screening of Acidity Samples to Improve Laboratory Efficiency** – Curtis Callahan, U.S. EPA Region 4
2. **Applying Exploration Geophysical Methods to Mine Waters** – Jennifer Hare, Ph.D., Zonge International, Inc.
3. **Evaluation of DGT Samplers for Monitoring Mining-Influenced Water** – Curt Coover, CDM Smith
4. **Environmental Site Investigations under the Chino Administrative Order on Consent** – Matt Schultz, New Mexico Environment Department

Water Treatment

5. **Column Study Treatability Testing for In Situ Remediation of Mining-Influenced Water** – Nicholas Anton, CDM Smith
6. **Biochemical Reactors for Treating Mining Influenced Water** – David Cates, Oklahoma Department of Environmental Quality
7. **Subsurface Barriers and Innovative Geochemistry: Reducing Contaminant Concentrations in Groundwater and Contaminant Discharges to Fourmile Branch at the Savannah River Site, South Carolina** – Carol Eddy-Dilek, Savannah River National Laboratory
8. **Stewardship Concepts for Management of Hard Rock Mining Wastewaters** – John McKernan, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory
9. **Wastewater Treatment of High Total Dissolved Solids and Acidity at the Cerro de Pasco Mine Site** – Melissa Rhodes, Golder Associates, Inc.

Source Control/Mine Closure Approaches

10. **Use of Biochars Produced by Gasification of Grass and Wood in the Remediation of Two Acid Mine Soils of Western Oregon** – Stephen Griffith, USDA ARS
11. **Investigating Biochar as a Tool for Mine Soil Remediation** – Mark Johnson, Ph.D., U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory
12. **Mechanistic Understanding of Biogeochemical Transformations of Trace Elements in Contaminated Mine Waste Materials under Reduced Conditions** – Ranju Rani Karna, Kansas State University
13. **Biochar for Remediation of Solid Source Mine Wastes and Mine Drainage Treatment** – Christopher Peltz, Research Services LLC

Beneficial Use

14. **Chemical Safety and Sustainability of Rare Earth Elements: Selection of a Product System for a LCA Case Study** – Diana Bless, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory
15. **Thermal and Hydrological Characterization of an Abandoned Mine Complex for Low-Enthalpy Geothermal Extraction: The Corning Mine Complex, Perry County, Ohio** – Joshua Richardson, Ohio University

Prediction and Modeling

16. **Predicting Water Quality for a High Altitude Mine Waste Facility in Peru** – Dawn Kaback, Ph.D., AMEC Environment and Infrastructure, Inc.

Exhibits

U.S. Environmental Protection Agency (EPA) Engineering Technical Support Center (ETSC) – Douglas Grosse, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory

U.S. Environmental Protection Agency (EPA) Technology Innovation and Field Services Division (TIFSD) – Michele Mahoney, U.S. EPA, Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation

Organic Substrates for Biochemical Reactors – Michael Sieczkowski, JRW Bioremediation, LLC

ACZ Laboratories Inc. – Michael McDonough, ACZ Laboratories Inc.

Flexible Liner Underground Technologies (FLUTe) – Ian Sharp, FLUTe

CDM Smith Summary of Presentations – Gunnar Emilsson, CDM Smith

Presentation Abstracts
and
Speaker Bios

Tuesday, August 12, 2014

Plenary Session

CONFERENCE OVERVIEW AND INTRODUCTION

Douglas W. Grosse
Conference Co-Chair, Senior Environmental Engineer
U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory
26 W. Martin Luther King Drive, Cincinnati, OH 45268
Phone: 513-569-7844; Email: grosse.douglas@epa.gov

Bio:
Douglas W. Grosse has a B.A. in English literature from Ohio University and an M.S. in environmental engineering from the University of Cincinnati. He has worked as an Environmental Engineer at the U.S. Environmental Protection Agency (EPA) in Cincinnati, Ohio for the past 35 years. Mr. Grosse is currently working in EPA's National Risk Management Research Laboratory (NRMRL) as a Senior Environmental Engineer. Past experiences have included: in-house research at EPA's pilot plant facilities in wastewater and hazardous waste research; pilot facility manager and project officer (Center Hill Laboratory); Superfund Innovative Technology Evaluation (SITE) Program; RCRA corrective action coordinator and technical assistance in Superfund, RCRA and treatability study assistance, as an aqueous treatment specialist, Acting Branch Chief, Technology Transfer Branch, and ETV/AMS Center PO. Currently, Mr. Grosse is working in the Remediation and Redevelopment Branch and Engineering Technical Support Center, as a specialist in site remediation and technical support.

EPA REGION 6 PROGRAM AND PRIORITIES

Ron Curry
Regional Administrator
U.S. Environmental Protection Agency, South Central Region (Region 6)
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Bio:
Ron Curry was appointed as U.S. Environmental Protection Agency (EPA) Region 6 Regional Administrator in September 2012. He has more than 36 years of management experience in local, state and federal government, as well as the private sector. As Regional Administrator, Curry directs federal environmental programs for the states of Arkansas, Louisiana, New Mexico, Oklahoma, Texas and 66 Tribes. He oversees an annual budget of $471 million and 778 employees located in Dallas, Houston, El Paso and other field assignments. Since joining EPA, Curry has taken a number of significant actions:

> **State Partnership:** Since becoming the permitting authority for greenhouse gases (GHG) in Texas, EPA has worked closely with business and the Texas Commission on Environmental Quality (TCEQ) to operate one of the largest GHG permitting programs in the country. EPA has received over 85 applications for Texas-based industries to meet the Clean Air Act requirements. With the passage of authorizing legislation, TCEQ is seeking authorization to run the federally delegated GHG permitting program. EPA and TCEQ worked together to develop an innovative work-share program for processing

applications. EPA and TCEQ are simultaneously processing the state's request for program authorization in order to streamline some portions of the process without jeopardizing public participation.

Safe Drinking Water: EPA proposed state primacy on three new drinking water rules in Oklahoma. EPA implemented these rules in Oklahoma while the state secured additional funding and adopted all three new drinking water regulations. EPA is working with the state to smoothly transition procedures and responsibilities so the state can readily implement the rules.

Enforcement and Compliance: The Region continues to lead the nation in the number of administrative and judicial enforcement actions. This year the region expanded information sharing by posting administrative and non-penalty enforcement actions on its public website and is expanding the program to include inspection reports.

Air Quality: The New Mexico Environmental Improvement Board unanimously approved a collaboration by EPA, the New Mexico Environment Department, PNM Resources and environmental stakeholders on a plan for the San Juan Generating Station to meet the requirements of the Regional Haze Rule. The plan will cut over 80 percent of pollution from the plant and improve visibility in 16 parks in the southwest. Additionally, there is a balanced cost advantage to customers and a significant environmental benefit for years to come.

Clean Water: EPA coordinated closely with Arkansas officials to address implications of a recently-passed state law (Act 954). The law negated some existing state water quality standards, TMDLs, and discharge limits in permits and enforcement orders for minerals, jeopardizing the State's ability to implement its NPDES program. Because EPA successfully communicated the potential impacts, the Arkansas state legislature reversed the legislation.

Environmental Justice: A federal judge approved a buyout plan as part of an agreement with EPA to extend the city's deadline to finish its sewer system upgrades. The City of Baton Rouge agreed to buy out and relocate residents of a low-income neighborhood potentially impacted by the city's planned sewer system expansion. About 44 families will directly benefit from this effort.

In addition, Curry has supported environmental justice (EJ) community-based grass roots organizations with an EJ training workshop in Albuquerque and New Orleans. The workshops help us to: 1) better understand today's environmental justice challenges; 2) exchange strategies, lessons learned and best practices that lead to healthier communities; and 3) participate in a collaborative process to draft a Region 6 EJ Action Plan that addresses region-wide priorities.

Curry worked with the University of New Mexico on the development of their Energy/Water/Environment Nexus Studies program. Prior to that, he spent eight years serving in former New Mexico Governor Bill Richardson's administration as cabinet secretary of the Environment Department and Natural Resource Trustee. In the position as secretary, he oversaw the regulation of the Los Alamos and Sandia National Laboratories and the implementation of standards to protect the air, water and land of New Mexico. He also led the Governor's initiative to join the Western Climate Initiative and led the climate change implementation state team in New Mexico. He developed the Environmental Justice Executive Order signed in November 2005 by Governor Richardson. As trustee, he successfully negotiated a $13 million ground water consent decree in 2010.

He has extensive experience working closely with EPA, the U.S. Department of Energy and the U.S. Department of Defense, as well as industry. He also served as administrator for the Village of Los Ranchos and as a city manager in Santa Fe.

Earlier in his career, Curry was a senior public affairs specialist for Gram Inc. and worked on a site-wide environmental impact statement for Los Alamos National Laboratory; and vice president of CEI Enterprises, a manufacturing firm. He has over 20 years of experience in private business including 10 years owning a small business franchise started with his father. His interest in the environment grew during his manufacturing career while marketing products into the South Coast Air Quality District in California. He brings to EPA a keen understanding of federal environmental regulations impacts on business owners and entrepreneurs as well as state and local governments.

SUPERFUND MINE SITE CHALLENGES AND OPPORTUNITIES

Robin H. Richardson
Acting Director
U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation
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Phone: 703-603-9048; Email: richardson.robinh@epa.gov

Bio:
Robin Richardson is the Acting Officer Director for the Office of Superfund Remediation and Technology Innovation, which manages the national Superfund Remedial Program. Robin has more than 20 years' experience working in the Superfund program. She started her Superfund career in 1987 as a consultant to the Superfund Response program providing information technology, and program and resource management support. Robin joined EPA's Office of Solid Waste and Emergency Response (OSWER), Office of Emergency and Remedial Response in 1989 as an analyst working closely with the regions in implementing the Superfund program. Since then Robin has held many positions, both public and private sector, supporting the Superfund program. In January 2010, Robin became the Director of the Superfund Remedial Program's Resources Management Division responsible for managing the Superfund Remedial budget, information technology and acquisition functions. She has a degree in international studies from Grinnell College, Grinnell, Iowa and has completed graduate work in public administration at the George Washington University.

SCIENTIFIC ASSESSMENTS INFORMING DECISIONS: THE BRISTOL BAY ASSESSMENT EXAMPLE

Jeffrey B. Frithsen, Ph.D.
Senior Scientist
U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment
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Phone: 703-347-8623; Email: frithsen.jeff@epa.gov

Bio:
Jeff Frithsen is a Senior Scientist and Special Projects Coordinator within the U.S. EPA's Office of Research and Development (ORD). His work has focused on developing agency scientific assessments that directly inform environmental management and policy decisions. Those assessments span both ecological and human health topics. Ecological assessment topics coordinated by Dr. Frithsen include the U.S. EPA's assessment of mountaintop mining and valley fill practices, and the agency's report to Congress providing an assessment of the environmental consequences of the increased use of biofuels. Dr. Frithsen was also co-lead for the Agency's assessment of Bristol Bay Alaska, a study designed to evaluate the potential impacts of proposed

future large-scale mining on a world class fishery. Human health assessment topics include evaluation of the University of Michigan Dioxin Exposure Study, characterization of PCB exposures to inform agency guidance concerning PCBs in schools, and the development of tools and databases supporting the conduct of human exposure assessments. Dr. Frithsen assisted with coordinating ORD's response to the BP Deepwater Horizon Gulf oil spill so as to address both ecological and human exposure and health issues. Dr. Frithsen is currently coordinating the development of the agency's oil and gas hydraulic fracturing drinking water assessment report.

Dr. Frithsen has worked for the U.S. EPA since 1998, holding a variety of positions within the Office of Research and Development. Dr. Frithsen's academic background includes formal studies at the University of Cambridge, the University of Exeter, and the Harvard School of Public Health. He was awarded a B.S. in biology from Boston College, and a Ph.D. in oceanography from the University of Rhode Island. He was awarded an environmental fellowship with the American Association for the Advancement of Science. He describes himself as a displaced New Englander, a sometimes cyclist, and a passionate sailor who is still learning the ropes and yearning for calm seas and a following wind.

IDENTIFYING OPPORTUNITIES FOR THE SUSTAINABLE MANAGEMENT OF RARE EARTH ELEMENT (REE) APPLICATIONS

Diana Bless[1] (*presenting author*)**, David Meyer and Michael Gonzalez**
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Abstract:
The two major markets for Rare Earth Elements (REEs) that have received significant attention in the area of sustainable materials research are the consumer electronics and information technologies and energy-related technologies. The interest in consumer electronics and information technologies is largely based on concerns for both supply issues and environmental impacts during end-of-life (EOL) activities. Both of these issues can be addressed using sustainable materials management (SMM) practices. The U.S. EPA's Chemical Safety for Sustainability research program is applying SMM tools such as material flow analysis, life cycle assessment (LCA), and sustainable process design to selected REE product systems to better understand how these tools can be improved to meet the needs of decision makers seeking to improve the sustainability of these products. A cross-Agency work group was assembled and identified relevant issues or questions related to energy critical elements/rare earth elements that should be included when considering sustainable materials management. A literature review was used to identify data gaps related to these issues as they pertain to mining, use and potential recovery of REEs for a range of products, including magnets, batteries, and phosphors used in consumer electronics. Recent advances in mining technologies need to be evaluated to better understand their impacts and cost implications (if any) on the consumer product markets. A major concern for most of the recovery processes is the need to isolate the REE-containing portions of the products (i.e., separate the HDDs from computers). This can be time-consuming and has proven to be challenging when REEs occur in low concentrations in e-waste. Furthermore, most recycling technologies are still in their development stage with limited commercial scale deployment. The results from the literature review will be used to perform a life cycle assessment of a key consumer electronic product to determine how potential SMM strategies such as sustainable mining, recycling, reuse, and substitution alter the life cycle impacts. The impact

data will inform the use of EPA's GREENSCOPE sustainable process evaluation and design methodology to identify improvements for proposed technologies within the life cycle.

Bio:
Diana Bless is a staff member of EPA's National Risk Management Research Laboratory in the Office of Research and Development. Diana is a Chemical Engineer with 24 years of experience within the U.S. Environmental Protection Agency. She has conducted research for the prevention and clean-up of toxic/hazardous waste. Her research interests have focused on current and future approaches related to characterization, source control and treatment of mining-influenced waters as they impact aquatic ecosystems. She holds a B.S. in chemical engineering with a minor in biochemical engineering from New Mexico State University. She currently works for the Sustainable Technology Division under the Systems Analysis Branch, but sometimes interfaces with the Land Remediation and Pollution Control Division for specific mining activities. More recently, her research emphasis is on sustainable materials management for rare earth elements in consumer electronics. As a Task Lead for Chemical Safety and Sustainability (CSS) Task 5.1.2, she manages case studies that involve Life Cycle Assessment for plastics in electronic products, contaminants of emerging concerns from surface waters, rare earth elements (REEs) from electronic wastes, nanoremediation and nanotechnology. She is also an alternate Contracts Officer Representative (COR) for several projects/duties and has been a Project Officer for other projects in the past.

EPA REPORT ON TREATMENT TECHNOLOGIES FOR MINING-INFLUENCED WATER

Michele Mahoney
Soil Scientist
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Abstract:
This presentation showcases information in a 2014 EPA technology report on select mining-influenced water (MIW) treatment technologies used or piloted as part of remediation efforts at mine sites. The report provides information on treatment technologies for MIW to federal, state and local regulators, site owners and operators, consultants, and other stakeholders. The technologies described in this report are applicable to treatment of water from both coal and hard-rock mine operations. The report provides short descriptions of treatment technologies and presents information on the contaminants treated, pre-treatment requirements, long-term maintenance needs, performance and costs. Sample sites illustrate considerations associated with selecting a technology. Website links and sources for more information on each topic are also included.

EPA is evaluating more cost-effective and lower-maintenance treatment systems to decrease the costs and improve the efficiency of mine site cleanups. Hence, this report focuses on passive treatment methods, but also includes recently developed or not widely utilized active treatment systems and passive-active hybrid systems. The report does not include all traditional active technologies, such as lime precipitation or high-density sludge systems.

In recent years, development and implementation of passive systems has increased. However, additional pilot studies and case studies are needed to assess their effectiveness. With time, EPA expects that the pool of technology options will expand and shift away from high-energy-use, high-maintenance systems to low-energy-use, low-maintenance systems.

In presenting this information at the National Hardrock Mining Conference, EPA hopes to network with other professionals who are studying and using lower-maintenance and innovative technologies for treating mining-influenced waters.

Bio:
Michele Mahoney works on contaminated site remediation and reuse within EPA's Superfund program. She provides support to practitioners on the use of soil amendments for remediation and redevelopment/reuse, ecological revitalization, terrestrial carbon sequestration, and urban gardening. She also researches and compiles information on mining site remediation technology and land reuse. Michele recently led the development of a resource guide on treatment technologies for mining influenced water. Michele manages content development for both the Cluin.org EcoTools and Mining pages. Michele has worked with EPA for over 14 years. Prior to her current responsibilities, Michele served the Agency as the lead for food waste composting issues and as an environmental fate and ecological risk assessor for pesticide registration.

PARTNERING TO SUPPORT SUSTAINABLE MINING

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Abstract:
This presentation will identify INAP (International Network for Acid Prevention) and describe how this mining company network is partnering with other mining stakeholders to support sustainable mining. The key element to our sustainable mining program is the GARD Guide, an international best practice guide for the prevention of acid-rock, neutral and saline drainage.

Since the GARD Guide was rolled out in 2009, it has become accepted as a major guidance document for the prevention and mitigation of mine-influenced waters and is used by a diverse collection of mining stakeholders ranging from mining companies to regulators, academics and communities to support sustainable mining. The presentation will include examples of its application in a multitude of climatic and geologic conditions, and will illustrate how INAP and its Global Alliance partners are building stakeholder capacity in developing regions including some new activities to enhance our educational tools.

Bio:
Dr. Terrence Chatwin is the Technical Director of International Network for Acid Prevention (INAP), where he participated in the development and publication of the GARD Guide, a best practice guide for the prevention of acid rock drainage (ARD). He also organized INAP workshops and short courses and directed the operation of INAP's programs. He has over 40 years of experience in the mining and minerals industries in research, development and management of process engineering and environmental projects. He has worked for mining companies and consulting firms, as well as the University of Utah, where he was Director of the Utah Engineering Experiment Station for 10 years. He has a B.S. in mechanical engineering from Massachusetts Institute of Technology and a Ph.D. from the University of Utah in metallurgy.

DRAMATIC IMPROVEMENTS AT MARGAJITA RIVER, PUEBLO VIEJO GOLD MINE, DOMINICAN REPUBLIC

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Abstract:
The Margajita River is about six kilometers long, skirting Barrick's Pueblo Viejo mine before winding its way into Hatillo reservoir, one of the largest fresh water bodies in Dominican Republic (DR). As far back as most people in the communities could remember the waters of the Margajita River were colored a dark, ominous red – a product of acid rock drainage (ARD) from the old waste rock dumps and facilities from previous State-owned operator Rosario Dominicana. The local inhabitants called it 'blood' river. For decades, the stream was highly acidic (pH below 3) and metal concentrations exceeded DR quality standards by orders of magnitude.

Pueblo Viejo Dominicana Corporation (PVDC) started commercial operations at this gold mine in 2013. Barrick Gold Corporation (operator) holds a 60 percent interest while Goldcorp holds 40 percent interest. Barrick PVDC efforts to clean up the Margajita water were an extraordinary challenge.

PVDC spent a lot of effort to clean up this brownfield site and implement best industry practices. Prior to final discharge into Margajita, reused ARD process water is treated at the onsite Effluent Treatment Plant (ETP). Approximately 40,000 cubic meters of water is treated daily. ETP operation has helped to bring dramatic improvements in the Margajita River. Communities can see now the evident and extraordinary results of better quality water and fishing.

Also, PVDC has committed $75 million to fund remediation of historical environmental liability that belongs to DR State.

Bio:
Dr. Carlos Tamayo Lara is the Environmental Manager for Barrick Gold Corporation at the Pueblo Viejo Gold mine in Dominican Republic. He is in charge of environmental compliance at this new mining operation as well as he leads the support for the environmental remediation of historical liabilities from this brownfield mining site. Carlos has more than 30 years of experience in mining, consulting business and academics. Carlos' skills include civil engineering, hydrogeology, environmental management systems, remediation programs, hazardous waste management and biodiversity programs. He has work experience in the USA, Mexico and different countries in Latin America and he is an author/co-author of several water publications.

Carlos earned a bachelor's degree in science from the University of Yucatan, Mexico and later earned both a master's and doctoral degrees in civil engineering, with emphasis on environmental, surface and groundwater hydrology from Colorado State University. He also holds a Global MBA from the Thunderbird School of Global Management in Phoenix, Arizona.

CHARACTERIZING MINING-RELATED CONTAMINATION IN THE OCOEE RIVER, TENNESSEE

Thomas Moyer[1] (*presenting author*), **James Eldridge**[2], **Craig Zeller**[3] **and Brian Striggow**[4]

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Abstract:
For nearly 150 years beginning in the mid-1800s, the Ocoee River, southeastern Tennessee, was the receiving water for acid mine drainage, mine wastes, and soil discharged to or eroded from the Copper Basin Mining District. EPA designated 26 miles of the river including flowing reaches and two reservoirs as Operable Unit 5 (OU5) of the Copper Basin Superfund Alternative Site. EPA completed a Remedial Investigation and Feasibility Study of the river in 2009 and issued a Record of Decision for OU5 in 2011.

Mining-related wastes in the Ocoee River originated from two tributary watersheds that hosted underground copper mines and facilities for ore processing and chemical manufacturing. Wastes identified in the river include granulated and pot slag, iron calcine, sulfide-rich waste rock, and debris from demolished chemical production facilities. The river also received various effluent discharges, both treated and untreated, from a variety of manufacturing processes. Severe erosion of the historically denuded watersheds drastically altered the morphology of the creeks and Ocoee River as large volumes of sediment were deposited downstream; the river gradient was further modified by dam construction. Metals, pH and sedimentation adversely impacted the aquatic ecosystem.

Characterizing contamination and risks to aquatic life in the Ocoee River posed many challenges not the least of which was the length and diversity of the affected reach. Other factors included poor cross-channel mixing of the water column; management of river flows and reservoir levels for power generation and recreational use; the substantial volume of sediment present in the river channel, as emergent bars, and as deltas at reservoir inlets; ongoing remediation of the tributary watersheds, which significantly changed river water quality during the study period; and complex contaminant transport mechanisms.

This presentation will discuss the approach taken to characterizing the Ocoee River including the use of conceptual site models (CSM), targeted investigations, and unique sampling strategies to provide data to support risk assessment and remedial alternatives development.

Initial CSMs for flowing river reaches and reservoirs guided development of data quality objectives and sampling approaches. These models were refined as data collection increased our understanding of contaminant release mechanisms and exposure pathways.

Focused investigations were developed to address critical data needs such as chemical exchange between river water and contaminated sediment, a major risk driver. Various characterization techniques were employed: within the river channel, sediment pore water samples collected using temporary well points were co-located with surface water samples collected at various points in the water column. Piezometers installed on emergent sediment bars tracked the movement of river water into and out of sediment in response to managed fluctuations in flow. Wells installed in the Parksville sediment delta were sampled through an annual reservoir drawdown cycle and sondes were deployed to measure field parameters in reservoir water off the delta toe as reservoir pool was lowered.

Other unique sampling strategies included size fractional chemistry of sieved sediment samples, the collection of sediment cores using boat-mounted and hand-held vibracore equipment, and seasonal sampling of reservoir pools. Potential bioavailability was assessed by combining the results of surface water, interstitial pore water, and sediment toxicity tests with sequential extraction and acid volatile sulfide/simultaneously extracted metals analysis of sediment from various depositional environments.

Bio:
Tom Moyer is a Senior Geologist and Task Order Manager with Black & Veatch Special Projects Corp. He has worked on mining environmental issues in EPA Regions 4, 7, 8, 9 and 10 under CERCLA, CWA and NEPA authorities. For EPA, Tom has designed and conducted studies to characterize multi-media contamination at mine sites, which include the Copper Basin, TN; Ore Knob, NC; Brewer Gold, SC; Barite Hill, SC; and Madison Mine, MO. For the U.S. Forest Service he designed investigations at the Bluebird & Blackjack Mines, OR. Tom has been the primary author of numerous RI and EE/CA reports and has contributed to FS reports, Proposed Plans, RODs and EISs. In previous years, Tom supported the U.S. Geological Survey's and U.S. Department of Energy's efforts to characterize tuff deposits at Yucca Mountain. Tom is a member of the Acid Drainage Technology Initiative, NWGA, GSA and AGU. He has a Ph.D. in geology from Arizona State University.

APPLICATION OF TRACER STUDIES IN ASSESSMENT OF ABANDONED MINES

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Abstract:
Tracer studies are hydrologic investigation tools that have broad application in assessment of mine drainage systems, which adversely affect water quality in thousands of streams nationwide. Mining-influenced water (MIW) is produced when surface water or groundwater interact with mineralized rock and is transported either in the subsurface or on the surface toward springs or streams. Although direct discharge of MIW from draining adits to surface water is observed at some abandoned underground mines, transport pathways involved in formation and discharge of MIW

are often complex, and may include subsurface transport via porous media flow, fracture flow and pipe flow. Tracer testing provides an opportunity to evaluate a MIW flow system empirically, enabling more detailed assessment of MIW generation processes, contaminant transport pathways, and effects to surface water quality. Recent tracer tests at two abandoned mine sites in the western United States are reviewed to illustrate tracer testing approaches used by CDM Smith to improve characterization, management and remediation of abandoned mines.

The Tiger Mine in Judith Basin County, Montana is an abandoned underground lead-silver mine that contributes to severe impairment of surface water quality in Galena Creek through discharge of water from mine adits. Tracer testing was conducted to characterize infiltration pathways into the underground mine workings, and to support assessment of potential technologies that could decrease infiltration into the mine. The geometry of the underground mine was evaluated based on surface mapping and compilation of historical mine maps. This information was incorporated into a conceptual model that described the hydrogeological framework, including points of potential infiltration of water into the underground mine flow system. Three different fluorescent tracers were deployed: Eosine, Fluorescein and Rhodamine WT. The tracers were deployed at two mine shafts and in Galena Creek, and were monitored using activated charcoal samplers and surface water samples. The results provided empirical evidence of a direct hydraulic connection between hypothesized points of infiltration and observed discharges, supporting assessment of potential approaches to reduce infiltration into the abandoned mines.

The Blue Ledge Mine is an abandoned underground copper mine located in the Siskiyou Mountains of northern California. Several miles of Joe Creek are adversely affected by MIW discharges from the Blue Ledge Mine. The site conceptual model included several draining adits, and indicated that discharge of MIW from the adits was a primary contributor to poor water quality in Joe Creek. MIW discharge from groundwater to surface water was also identified as a potential contributor to observed effects in Joe Creek, and a tracer test was designed to evaluate the relative importance of dispersed inflows of MIW from groundwater in overall contaminant loading to Joe Creek. The tracer test involved adding a calcium bromide tracer to the stream at a known rate, monitoring dilution of the tracer as it flowed downstream, and collecting numerous surface water samples for analysis of metals and major ions. Changes in the load of mining-related contaminants in Joe Creek were calculated based on contaminant concentrations and stream flows, which were measured using the tracer-dilution method. The results of the tracer test demonstrated that dispersed discharge of MIW from groundwater to surface water is an important contributor to poor water quality in Joe Creek, and that remediation of the adit discharges alone would not be expected to result in compliance with surface water quality standards.

Bio:
Mark Nelson has 26 years of professional experience focused on mine hydrogeology and environmental geochemistry, mine permitting and regulation, exploration and mining geology, and mine reclamation. Mr. Nelson holds a M.Sc. degree in geology and geological engineering from South Dakota School of Mines and Technology and a B.Sc. degree in geology from The Ohio State University. Mr. Nelson is a Certified Professional Geologist with American Institute of Professional Geologists and is a Registered Professional Geologist in several western states.

THE CONTINUING EVOLUTION OF GROUND WATER SAMPLING METHODS

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Abstract:
The potential of ground water contamination occurring from past and ongoing mining operations has resulted in substantial investment in ground water monitoring networks and the associated long-term ground water sampling programs.

Over the past three decades we have seen a gradual evolution of ground water sampling methods, beginning with fixed volume purging in the early 1980s, the transition to low-flow sampling beginning in the early 1990s and most recently, the increased acceptance of no-purge (stressless) ground water sampling methods as a viable alternative to both of the prior sampling methods.

No-Purge (stressless) ground water sampling began to gain acceptance in the mid-2000s and has seen a sustained increase in use since then. Part of its growth can be attributed to the capacity to collect a formation quality ground water sample without generating a large volume of purge water…with a 50 to 80 percent reduction in sample collection time and expense. An added bonus is increased site safety due to the reduction or elimination of purge water and lack of heavy equipment (generators, pumps, compressors, drums and tanks) needed to collect the ground water samples using purge and often low-flow techniques.

The first portion of the presentation will look at the historical evolution of ground water sampling methods, describe the basic procedures used to collect the samples with each method, and examine the advantages and limitations of each method. The latter part will focus on no-purge (stressless) ground water sampling methods and discuss in greater detail the classes of no-purge devices, how they work and the advantages and limitations of this ground water sampling method.

Bio:
Kent Cordry has been active in the ground-water monitoring field for over 30 years. He is the founder and president of GeoInsight; a company established in 1991 that focused on the development and production of innovative direct-push equipment. In 1996, he received the National Groundwater Association Technology Award for major contributions to the groundwater industry related to direct push groundwater sampling. In the summer of 1999, Mr. Cordry began development of the HydraSleeve no-purge (passive) groundwater sampler and has since received two patents for the invention. In total he holds 10 patents, including those covering the HydroPunch I, HydroPunch II and the HydraSleeve. For the last 15 years Mr. Cordry has been teaching classroom, field and online courses pertaining to direct push methods and ground water sampling.

Prior to starting GeoInsight, Mr. Cordry spent 10 years as an environmental consultant, serving as project manager/senior hydrogeologist, managing site assessments throughout the United States. Mr. Cordry also served as a division manager for a Midwestern drilling company. He is a Certified Professional Geologist and Certified Drilling Contractor. Kent has a B.S. in geology from Southeast Missouri State University.

Session 2: Source Control / Mine Closure Approaches

LAND APPLICATION OF BIOCHEMICAL REACTOR EFFLUENT: AN INNOVATIVE METHOD FOR MITIGATING ACID ROCK DRAINAGE

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Abstract:
The concept of in-perpetuity is a very long time. Perpetual treatment (either actively or passively) of acid rock drainage (ARD) is unsustainable; cumulative economic burdens on mining companies and/or government agencies faced with treating ARD will certainly bankrupt future society. ARD suppression at its source is the logical strategy to avoid or lessen ARD impacts. Innovative strategic concepts have been advanced in recent years; this author has contributed to this effort. The concept of land-applying biochemical reactor (BCR) effluent to suppress ARD is another promising strategic tool. This white paper develops the idea in more detail.

The concept's elegance lies with the merging of two well-developed mine remediation/processing technologies: BCRs and heap or dump leaching of metal ores. In the proposed innovative technology, organic-rich effluent from a BCR would be land-applied to acid-producing mine waste (e.g., tailings, waste rock and coal refuse) using solution application methods typically used in precious metal heap leach pads. BCR effluent is typically anoxic and contains biochemical oxygen demand, excess alkalinity, dissolved sulfide ion and dissolved manganese. If all these characteristics can be preserved and the BCR effluent solution can be dispersed over a large area of mine waste (which could be revegetated or barren), the downward percolating solution should coat the mine waste with a film of biosolids that would suppress biological and abiotic pyrite oxidation. In deeper, more-oxidized portions of the rock/waste column, surfaces should be coated with ARD-suppressing MnO_2. It is believed that heap leach solution application techniques could accomplish this inexpensively. The mine waste ARD source would behave similar to a trickling filter in a waste water treatment plant. ARD might be suppressed for decades, perhaps longer, before a "booster shot" of BCR effluent might be required.

Bio:
Jim Gusek is a chief engineer with Sovereign Consulting, Inc. and is based in Denver. He specializes in the design of passive treatment systems for mining influenced water. Since 1987, his work with acid rock drainage prevention and passive water treatment systems has included about 50 projects throughout the United States and internationally. He is on the steering and mitigation committees of the Acid Drainage Technology Initiative - Metal Mining Sector (ADTI-MMS). He recently received the Reclamation Researcher of the Year award from the American Society for Mining and Reclamation. He graduated from the Colorado School of Mines in 1973 with a B.Sc. in mining engineering. He is a founding member and former president of the Denver Professional Chapter of Engineers Without Borders.

DISSOLVED ORGANIC CARBON AUGMENTATION: AN INNOVATIVE TOOL FOR MANAGING OPERATIONAL AND CLOSURE-PHASE IMPACTS FROM MINING ON SURFACE WATER RESOURCES

Charles Wisdom, Ph.D.[1] (*presenting author*) **and Felix Kristanovich, Ph.D.**[2]
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Abstract:
Managing water quality compliance commitments and preventing or minimizing surface water quality impacts can involve substantial effort and cost in each phase of the mine life cycle, and are subject to increasing levels of stakeholder concern over the effects of mining operations on surface water quality. These efforts can be particularly challenging in streams and lakes receiving mine runoff and process discharge waters, where mine operations and changes in land use can significantly reduce dissolved organic carbon (DOC) exported to aquatic environments. These changes can result in enhanced sensitivity to metallic contaminants and reduced productivity in receiving waters. Loss of riparian vegetation can reduce DOC levels up to 90 percent in streams and 15 percent in lakes, leading to pronounced changes in the transport, bioavailability, and toxicity of metals. Recent advances in our understanding of metal toxicity, expressed as the Biotic Ligand Model (BLM), offer the mining industry a new and innovative approach to managing and minimizing mine water quality impacts. The BLM predicts metal toxicity by accounting for the binding action of metals by DOC in adjacent streams and lakes. Augmenting and managing DOC in streams and lakes can therefore be an important element in an integrated treatment approach for mine wastewater, mining-impacted stormwater, and process water discharges. DOC levels can be increased through short-term augmentation and long-term wetland and riparian restoration to enhance stream and lake health and resilience. Predicted bioavailability and toxicity, using the BLM model, of a number of metals (e.g., copper, cadmium, lead, silver and zinc) can be used to develop DOC augmentation requirements to set cost-effective treatment goals protective of beneficial uses of streams and lakes. These treatment goals can then be incorporated into closure plan remediation strategies and post-closure monitoring programs. Integrating DOC management into mine reclamation activities such as erosion control and re-vegetation can, at the same time, help to preserve water quality, minimize environmental effects, and reduce overall closure costs.

The basic steps in this approach involve 1) establishing target DOC levels based on pre-development conditions, 2) developing-short-term DOC addition approaches such as incorporation of leaf litter into riparian soils, and 3) incorporation of long-term DOC additions in riparian and wetland restoration designs. A proof-of-concept case study was conducted to develop a predictive model to estimate bulk carbon application rates, soil organic matter pool formation, DOC soil export rates, and assessed treatment targets for a variety of receiving water conditions (based on pH, temperature and hardness). The results of this study confirm that: DOC augmentation offers a relatively simple but comprehensive way to: 1) develop cost-effective approaches to achieving effluent treatment goals and limits, 2) establish off-site mitigation strategies for mining/refining operations, 3) integrate closure restoration efforts with the ongoing management of water quality, and 4) enhance the value of habitat restoration.

Bio:
Charles Wisdom is a Senior Consultant at Geosyntec Consultants. In this role, he provides both public and private clients with water quality regulatory and remediation solutions addressing the toxicity and fate and transport of metals and organic contaminants. Prior to Geosyntec, Charlie was at ENVIRON International Corporation, focusing on risk assessment and NPDES permit compliance strategies. Charlie has conducted ecological risk assessments for mining companies and public utilities for the exposure of fish, birds, mammals and humans to chemicals, physical effects and habitat modifications to assess mine operating plans, determine NRDA Damage Assessments and design CERCLA cleanup plans. His research and presentation on the application of the Biotic Ligand Model provides both cost-effective and environmentally protective treatment goals for stormwater and wastewater discharges. Charlie has a Ph.D. in chemical ecology from the University of California, Irvine.

INFLUENCE OF PRE-MINE WEATHERING AND ROCK TYPE ON TDS RELEASE FROM APPALACHIAN COAL MINE SPOILS

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Abstract:
Appalachian coal mines have been implicated as major stressors to biota in headwater streams due to discharge of total dissolved solids (TDS). Large volumes of blasted sedimentary rock spoils are placed into highwall backfills and head-of-valley fills during the mining and reclamation process. While the industry has made great advancements since the 1970s in utilizing acid-base accounting procedures to limit low pH and high metal discharge waters, bulk TDS release in excess of 500 mg/L is common and is typically dominated by SO_4 and alkali cations. Unweathered sedimentary rock overburden materials can contain carbonates, feldspars, micas and pyrite, which react rapidly following mining disturbance to produce TDS. Our primary objective was to evaluate a column leaching approach for TDS prediction. Over 45 typical non-acid forming ground spoils ($\leq$ 1.25 cm) were leached (unsaturated) with 2.5 cm of simulated precipitation (pH 4.6) for 20 weeks (2X per week) in lab columns (7.5 cm x 40 cm). Leachates were analyzed for pH, electrical conductance (EC), Ca, SO_4 and other parameters. Initial leachate EC was moderate ($\leq$ 1000 uS/cm) for most samples, although some ranged to >3000. Leachate EC decreased rapidly within several pore volumes and most samples achieved a steady-state with relatively low EC levels (< 500 uS/cm) within 20 leaching cycles. Rock strata that have undergone significant pre-mining oxidation and leaching generate much lower EC when compared to local unweathered materials from the same strata. Finer textured siltstones and shales typically generate higher leachate EC than sandstones, but total pyritic-S content is a better predictor of both initial and long-term TDS release than rock type. Ongoing research conducted by the Appalachian Research Initiative for Environmental Science (ARIES) is focused on (1) developing and validating new quick static tests to predict both peak and long-term TDS production and (2) determining appropriate scaling factors to relate both column and static test data to predict field conditions.

Bio:
W. Lee Daniels is the Thomas B. Hutcheson Professor of Environmental Soil Science at Virginia Tech in Blacksburg, Virginia. He received his Ph.D. in soil science from VPI & SU in 1985. Dr. Daniels' areas of specialization include stabilization and restoration of disturbed lands including areas disturbed by mining, road building, waste disposal, urbanization and erosion. In particular, he

has focused his research and consulting experience in mine reclamation, wetland impact mitigation and soil-waste management systems. His teaching programs at Virginia Tech focus on soil geomorphology and landscape analysis with particular emphasis on the relationships among surficial geology, hydrology, soil patterns and long term landscape evolution processes. Major awards include the Reclamation Researcher of the Year by the American Society for Surface Mining and Reclamation (ASMR) in 1993, U.S. Environmental Protection Agency's National Biosolids Utilization Research Award in 2000 and the Lifetime Achievement in Research Award by ASMR in 2012.

Session 3: Characterization (cont.)

HIGH SPATIAL AND TEMPORAL RESOLUTION OF CONTAMINATED FLOWS

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Abstract:
Information on the distribution of impacted water and the flow paths associated with the transport of that water is difficult to obtain in fractured rock sites. The drilling is expensive and the location and composition of the water is not easy to obtain. Information on the flow characteristics in fracture rock sites is even more difficult to assess. However that information is essential to the assessment of the current state, the prediction of future transport, and the design of remediation measures. The need is for high resolution measurements of conductivity, composition and head distribution.

Those kinds of measurements are being made, using the methods described herein, at many EPA Superfund sites, especially in the Eastern States where much of the contamination is in the shallow bedrock. The measurements are being made with high spatial and temporal resolution using available flexible liner methods as produced by a company in New Mexico called FLUTe. This presentation is focused on the kinds of measurements performed and the results of those measurements as relevant to the characterization of contaminant flow in fractured rock.

The measurement methods consist of several kinds, but that most relevant to mine and tailings water sites for conductivity distribution measurements uses the installation of a flexible liner. Those measurements have a resolution of better than one foot in space and a transmissivity resolution of better than 1 percent of the total transmissivity of the borehole. A typical measurement is performed in 1-2 hours in a 100 m borehole. This measurement is used for assessing the hydrologic flows near mines in Canada. In general, the spatial resolution is far better than obtained with straddle packers and much less expensive. Results of such measurements are provided in this presentation.

The second measurement of use for site characterization in fractured rock is the multi-level sampling liner system, which allows water sample collection and head measurements at many discrete elevations in a single borehole. This can greatly reduce the drilling costs of a site characterization. Because the entire hole is sealed with a flexible liner, there is no bypass concern as with straddle packer systems. Also, there is no need for grout as a seal of the borehole, which can affect the water chemistry. The entire system is removable for other use of the borehole. It can be installed in vertical, angled or horizontal holes. Pressure transducers are often incorporated in the system for the head history, which is useful for seasonal fluctuations. Examples of results are provided.

The situations where these methods are best used are described as well as the circumstances that limit their use. These methods have been in use for over 15 years, in most states, in many other countries at sites from Denmark to Australia. However, they are not yet widely known. EPA is one of the major users of these flexible liner methods, but also large companies such as Exxon Mobile, Boeing, Army Corps of Engineers and many others are regular users. The main thrust of this paper is to explain the methods and to provide examples of results for those unfamiliar with the technology.

Bio:
Ian Sharp is currently the Chief of Field Operations for all FLUTe installations. He also assists in the design and fabrication of special instrumentation in the development of new FLUTe methods. He has been installing FLUTe's many systems for over 12 years. He currently manages all FLUTe fielding personnel in FLUTe's several field offices and coordinates all installation schedules with FLUTe customers in the United States and internationally. He assists the Principal Scientist in the development of hardware and procedures for extraordinary or challenging fielding circumstances.

TECHNIQUES FOR SUCCESSFUL STORM-WATER MONITORING IN A MINING-INFLUENCED WATERSHED

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Abstract:
Barge Waggoner Sumner and Cannon, Inc. (BWSC) has been actively involved with the investigation, characterization, and remediation/reclamation of mining-influenced watersheds in southeastern Tennessee for over 15 years. Work performed in the watersheds is being managed as a State voluntary site and as an EPA Superfund Alternative Site. Actions have been conducted using the adaptive management approach with recovery of benthic macroinvertebrate communities as the remedial goal. A key element in the adaptive management approach for the site has been base-flow and storm-flow stream monitoring. The data from these events was used to document changes in water quality trends at specific stream reaches and over the entire watershed to locate sources of surface-water contamination and to determine when sufficient remedial actions have been conducted in specific areas and tributaries. BWSC has conducted over 20 storm-water monitoring events and has developed proven techniques for the design, installation, implementation, and evaluation of data from storm-water monitoring events.

Design – The design of the event needs to take into account areas of known sources, areas with completed remediation activities, and areas with active remediation activities. Other factors include

stream access, locations with existing weirs or flumes, and potential safety issues during storm events.

Installation – The storm-water monitoring equipment needs to be calibrated and installed prior to the anticipated storm-water monitoring event. The typical equipment to be installed would include: a weather station, autosamplers, recording pH, conductivity, and temperature meters, area velocity meters, weir plates, and pressure transducers. Considerations for installation would include stream geomorphology, estimated flood heights, water-quality variations within the stream transect, and potential security issues.

Implementation – Experience has shown that storm-water monitoring must be initiated prior to beginning of the precipitation due to rapid changes in water quality at the transition between base flow and storm flow. Sampling during the storm-water event is not steady state; during the event a stream hydrograph is monitored to aid in the selection of the samples to be retained for analyses and to determine when the stream has returned to near base-flow conditions. The key to a successful event involves selecting the correct analytical suite, having the right field crew, and developing repeatable and simple methods for field data collection, sample collection and sample preparation.

Evaluation – The data evaluation can reveal information on the water quality trends at a single location over time as well as upstream to downstream trends at specific times and long term trends from event to event. Data quality needs to be considered, particularly the inherent ranges of measurement errors with different types of flow measurement devices.

Bio:
Tom McComb is a Senior Geologist and Project Manager with Barge Waggoner Sumner and Cannon, Inc. (BWSC) in Nashville, Tennessee. Tom has over 13 years of experience working as BWSC's Lead Geologist for the assessment activities associated with the reclamation of the Copper Basin Mining District in Copperhill, Tennessee. The work at the Copper Basin is being conducted using an adaptive management approach. The activities conducted within the Copper Basin have included site inventories, storm-water monitoring, comprehensive base-flow monitoring, bathymetric investigations of mine pits and collapses, prioritization of remedial actions, and implementation of a CERCLA Remedial Investigation. Currently, Tom is the president-elect from the Tennessee Region of the American Institute of Professional Geologists (AIPG), and is a certified Project Management Professional. He received a master's degree in geology from the University of Cincinnati.

INSIGHTS ON MINE SITE CHARACTERIZATION FROM EPA'S OPTIMIZATION REVIEW INITIATIVE

Tom Kady
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Abstract:
"Overwhelming" comes to mind when describing the complexities of characterizing and remediating mine sites. With mountains of waste rock, acres of tailings ponds, miles of watershed impacts, and dozens of mill sites, mines seeps and adit discharges, where does one begin? Investigation can take decades and tens of millions of dollars. Remediation takes many decades and hundreds of millions more. Based on observations from mining site optimization reviews, this

presentation describes basic concepts to help navigate these complex sites and determine early actions that best put time, money and Mother Nature, working in your favor.

Bio:
Tom Kady is a member of EPA's Environmental Response Team (ERT). As the field support arm of the Office of Superfund Remediation and Technology Innovation, the ERT provides first-responders to national and international incidents as well as technical field support to Remedial Project Managers and On-Scene Coordinators at Superfund sites and oil spills across all 10 EPA regions. Tom's area of focus is advancing the state of the art in real-time, direct-sensing technologies to streamline crucial aspects of remedial investigations, remediation system designs and system performance monitoring. Tom also serves as a lead on optimization reviews for mine sites and other Superfund sites in various phases of investigation and remediation. Prior to joining ERT, Tom served for 20+ years as regional manager for several national consulting/engineering and remediation/construction firms. Tom has a B.S. in chemical engineering from The Pennsylvania State University.

Session 4: Source Control / Mine Closure Approaches (cont.)

DESIGN ASPECTS OF MINE SITE COVER SYSTEMS

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Abstract:
Mine site closure designs can be governed by a variety of regulations that are not necessarily written for mine sites but other solid, hazardous or radioactive waste sites. Closures at mine sites typically include cover systems that must adhere to these adopted regulations. Because of the size and uniqueness of mine closures, fitting this regulatory framework can prove difficult and expensive.

Cover systems employed in mine site closures may require controlling applicable release vectors that may include the minimization of flux, mitigation of erosion, control or prevention of biointrusion, account for differential settlement, allow for stability for relative steep and long slopes, allow for establishment of native vegetation, be aesthetically acceptable; all while keeping costs down. Typical prescriptive cover systems will not satisfy all or many of these design requirements.

An alternative cover system referred to as a 'water balance' or an Evapotranspiration (ET) cover can achieve the majority of design issues related to mine site closures. Furthermore, it can be constructed with onsite soils saving significant costs.

The cover system employs a unique design and water balance approach referred to as the Point of Diminishing Returns (PODR) method developed by Dwyer et al (2007). This method minimizes the depth of cover profile required to achieve meteoric water flux criteria for the site. Unsaturated flow modeling is utilized to identify the depth of soil required to effectively minimize flux. Additionally,

the cover design includes a surface layer referred to as a 'desert pavement' that incorporates rock and soil mixed to a ratio that minimizes soil loss due to erosive forces while preventing the formation of rills or gullies. The cover soil minimizes gas omissions such as radon from uranium tailings impoundments to acceptable levels. Because the cover is composed of local soils, it is well suited to provide a medium for native vegetation establishment.

The multifaceted design approach has been successfully deployed at cover systems throughout the country for solid waste landfills, hazardous waste landfills, radioactive waste landfills, mine tailings; mine site evaporation ponds, and uranium tailings impoundments. Post-closure monitoring at many of these sites has validated the design approach for water balance, erosion, slope stability, vegetation establishment, and gas emissions control.

Bio:

Dr. Stephen F. Dwyer is the Principal Engineer for Dwyer Engineering, LLC. Dr. Dwyer enjoys an international reputation for excellence in alternative earthen cover systems. Dwyer Engineering has significant experience in solid waste landfills, site closures, mine reclamation, hazardous and radioactive waste remediation. Dr. Dwyer is a registered professional engineer in New Mexico as well as multiple other states with over 32 years of engineering experience. Dr. Dwyer has designed, reviewed, monitored, and/or provided construction oversight for over 200 hazardous, radioactive, mine, and/or municipal solid waste site closures and cover systems in the United States, Australia, Israel, Canada, the South Pacific and Mexico. Dr. Dwyer has a B.S., M.S. and Ph.D. in civil engineering as well as an M.B.A. Dr. Dwyer was the principal investigator on a long-term research project at Sandia National Laboratories that developed and demonstrated the evapotranspiration (ET) cover and capillary barrier concepts. Dr. Dwyer has authored multiple closure design guidance's including: the EPA Design Guidance for Landfill Covers (EPA-909-R-11-007); Los Alamos National Laboratory/DOE landfill and site closure design guidance; and a contributing author of the Interstate Technology & Regulatory Council (ITRC) guidance documents on site closures. Dr. Dwyer serves as a technical expert for EPA Regions 6, 8 and 9.

BIO-MEDIATED SOIL IMPROVEMENT FIELD STUDY FOR EROSION CONTROL AND SITE RESTORATION

M.G. Gomez, B.C. Martinez, C.E. Hunt[1] *(presenting author)*, **L.A. deVlaming, J.T. DeJong, D.W. Major and S.M. Dworatzek**

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Abstract:

Microbially Induced Calcite Precipitation (MICP), a bio-mediated cementation process that improves the geotechnical properties of soils through the precipitation of calcium carbonate, is becoming a promising alternative to traditional soil improvement methods. MICP has been shown to increase soil stiffness, reduce permeability, and increase shear strength in laboratory experiments. The current study presents a field-scale, surficial application of MICP to improve the erosion resistance of loose, sandy soils and provide surface stabilization for dust control and future re-vegetation. The project was performed at a mine site in the province of Saskatchewan, Canada during summer 2012. Four test plots were established on loose, poorly graded medium to fine grained sands generated from excavation of overburden materials at the site. Three of the plots were treated with a bacterial culture and nutrient solution, and the fourth plot served as a control (water only addition). The applied cell density of the bacterial culture was the same for each plot, whereas

the nutrient solution concentration was varied across the plots to evaluate the impact on treatment depth. The culture and nutrients were applied through a surficial spray application system over 20 days. Soil improvement was assessed to a depth of 30 cm using dynamic cone penetration (DCP) resistance, calcite content, and biological activity measurements. The most improved test plot developed a competent, sandstone-like crust measuring 2.5 cm thick, which exhibited strong resistance to erosion and could easily support the weight of field personnel. DCP resistance and calcite content measurements indicated improvement to a depth of approximately 25 cm. The results are promising and suggest that further optimization could make the MICP technology viable for large-scale mining applications, including dust and erosion control, as well as other applications where permeability reduction or strength increase may be beneficial.

Bio:
Christopher Hunt, Ph.D., P.E., G.E. is a Principal Geotechnical Engineer with Geosyntec Consultants in Oakland, California, with more than 15 years' experience managing and supporting a variety of geotechnical and geoenvironmental projects. In this role, he has been a key participant in the analysis, design, and construction of both municipal solid waste and hazardous waste landfills, including expansion, closure, and master planning of existing facilities. In addition, through Geosyntec, Chris has been a key industry sponsor and collaborator on the University of California at Davis research into applications of Microbial Induced Calcite Precipitation (MICP) for ground modification, including strength increase and permeability reduction. He has been a co-author on several publications on this topic, including Bio-mediated Soil Improvement Field Study to Stabilize Mine Sands (Geo-Montreal, 2013). Chris has B.S., M.S. and Ph.D. degrees in civil and geotechnical engineering from the University of California at Berkeley.

LONG-TERM RESULTS OF COVER SYSTEM MONITORING IN SEMI-ARID WESTERN USA

Jason Keller[1], Mike Milczarek[2] *(corresponding author)* **and Tzung-mow Yao[3]**
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Presented by Monisha Banerjee, Ph.D.
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Abstract:
Monitoring subsurface air flow, water percolation processes, and vegetation characteristics at reclaimed mine waste facilities provides a quantitative assessment of reclamation success in controlling net percolation (i.e., recharge) and promoting vegetation establishment as well as their function over time. The monitoring data also provides the opportunity to guide future reclamation tailored to site specific conditions such as climate, waste material chemistry, and cover material hydraulic properties. This presentation provides case studies from over a decade of reclamation performance monitoring at hard rock mine facilities in the southwestern United States.

Data from evapotranspiration cover monitoring at a reclaimed leach pad in north-central Nevada provide clear indications of the factors contributing to cover system function and success. South-facing slopes were more effective at reducing percolation than east- and west-facing slopes due to their receiving more direct solar radiation. Greater leach ore drying in the summer were observed in

areas with greater shrub and deeper rooting density. Slight differences in net percolation were observed based on slope position; however, percolation was greatest for those stations near runoff channels.

Data also collected from closed waste rock facilities in Nevada was used to evaluate the relative contribution of net infiltration and air ingress to ongoing geochemical reactions in the waste. Vadose zone monitor wells instrumented at various depth intervals allow collection of in-situ air and pore-water samples as well as automated measurements of temperature, oxygen content and water content. Data indicate that internal temperature gradients within the interior of the waste rock facility should be considered when evaluating long-term potential discharges in addition to net percolation through the cover system.

Monitoring of cover systems at several mines in Arizona indicate that both circumneutral and acid tailings can be reclaimed with relatively shallow covers. The effective depth of a cover system in supporting vegetation and controlling net percolation can range from 15 cm for circumneutral tailings to 60 cm or greater for acidic tailings. At several reclaimed copper tailing sites, plant roots have been observed to actively root into circumneutral and moderately acidic tailings. Soil moisture dynamic monitoring data indicates that the underlying tailings material has a significant effect on cover systems efficiency and that tailings should be considered a component of the overall cover system.

Bio:
Monisha J. Banerjee, Ph.D. is a Senior Scientist at GeoSystems Analysis, Inc. She has experience in a broad range of vegetation, physical, and hydraulic soil characterization, and microbial analyses and survey techniques. Her research has included monitoring vegetation, landscape function, and erosion of reclaimed mine sites; analyzing the bacterial diversity of reclaimed mine tailings; designing and testing experimental mine waste covers; and evaluating ore based on physical and hydraulic properties for heap leaching. She has publications on the reclamation of disturbed desert environments, including Bacterial Populations within Copper Mine Tailings: Long-term Effects of Amendment with Class A Biosolids (Journal of Applied Microbiology, 2012) and Native Plant Regeneration on Abandoned Desert Farmland: Effects of Irrigation, Soil Preparation, and Amendments on Seedling Establishment (Restoration Ecology, 2006). Monisha has a B.S. in biology from the George Washington University in Washington, DC and a Ph.D. in soil, water, and environmental science from the University of Arizona in Tucson, Arizona.

Presentation Abstracts and Speaker Bios

<u>Wednesday, August 13, 2014</u>

EFFECTIVE FIELD TECHNIQUES AND WATERSHED MODELING FOR CHARACTERIZING MERCURY LOADING TO SURFACE WATER, BLACK BUTTE MINE SUPERFUND SITE, LANE COUNTY, OREGON

Howard S. Young, L.G.[1] (*presenting author*)**, Scott E. Coffey, L.Hg.**[2] **and Steve Wolosoff**[3]
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Abstract:
This presentation will summarize the techniques and tools employed at an abandoned mercury mine site in Oregon to characterize the mercury load discharging from sources at the mine into the downstream watershed. Studies have shown that mercury loading to surface water changes significantly throughout the year and vary with intensity of storm events. Effective characterization of mercury loading requires a clear understanding of stream discharge rates and mercury concentrations in surface water, as well as information about the atmosphere throughout the year and at different storm intensities. At the Black Butte Mine Superfund Site, stream discharge rates and mercury concentrations in surface water and rainwater were analyzed through automated water level and water quality sensors, a dedicated atmospheric deposition sampler and collection of multiple discrete surface water samples throughout storm event hydrographs. These data are being used to construct and calibrate a site-specific watershed model that will be used to predict mercury loading to stream catchments upstream and downstream of the mine throughout the year. The model enables users to evaluate mercury loading at critical stream catchments and will aid in future source control decisions.

At the Black Butte Mine Site, the U.S. Environmental Protection Agency (EPA) conducted one of its earliest optimization reviews for the remedial investigation phase of a Superfund site. As part of the optimization process, immediate needs for source control were identified through focused evaluation of discharges from the mine site to surface water. A number of innovative methods were used to rapidly evaluate mercury loading of surface water downstream of the mine. A Light Detection and Ranging (LIDAR) survey was flown to obtain high-resolution topographic data throughout the watershed. The LIDAR dataset served the dual purposes of providing information on catchment areas needed for the watershed model and enabling delineation of waste dumps, mine adits and disturbed areas in the densely wooded area of the abandoned mine site. In the key drainages affected by the mine, stream monitoring stations consisting of staff gauges and stilling pipes equipped with automated water level, temperature, pH, conductivity, and turbidity sensors were installed. These automatic sensors allow for year-round monitoring of stage and water quality. Longitudinal surveys of the stream stations, supplemented by manual stream discharge measurements, were used to develop rating curves so that the stream discharge could be estimated throughout the year using automated stream stage sensors. During three storm events in 2013 and 2014, field crews were rapidly deployed to the remote site to collect multiple surface water samples throughout the rising and falling limb of the storm event hydrograph. More than 300 surface water samples collected from four stream stations were analyzed for mercury and other key constituents to determine changes in mercury concentrations and water quality throughout the hydrograph curve of each storm event.

The presentation will include a discussion on the field techniques (e.g., clean hands sampling) and equipment used to collect the low level mercury data from rainfall and streams, results of the first three storm events and the preliminary development of the watershed model. Strategies and tools used to address challenging logistics of deploying field instrumentation and crews at a remote field site on weather-dependent schedules will also be discussed.

Bio:
Howard S. Young is a Senior Geologist at CDM Smith in Seattle, Washington. He has worked on a number of remedial investigations and feasibility studies at a number of Superfund sites in Regions 9 and 10. His focus is on the evaluation of impacted groundwater systems and watersheds at abandoned mine sites with recent projects including the Formosa Mine, the Blue Ledge Mine, and the Black Butte Mine Superfund sites located in Oregon and California. Prior to CDM Smith, he worked in the mining industry evaluating precious and base metal deposits in Nevada and Alaska. Howard has a B.S. in geology from Washington State University.

ON THE PROBLEM OF HYDRAULIC CHARACTERIZATION OF GRAVELLY MINE WASTE AND COVER SYSTEM MATERIALS

Jason Keller[1], Mike Milczarek[2], Tzung-Mow Yao[3*] (*presenting author*) **and Robert C. Rice[3]**
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Abstract:
Successful mine waste facility closure design requires accurate understanding of the hydraulic properties of the cover material and underlying mine waste for purposes of estimating cover system performance, heap leach draindown rates, and facility water balances, to name a few. The consequences of inaccurate estimates may include oversizing or under sizing water treatment facilities, excess percolation into mine waste, and under predictions of drainage response to storm events. Mine waste and frequently available borrow material for cover systems may contain a significant fraction of gravel material (>4.75 mm), which influence the material hydraulic properties. Small amounts of gravel can act as barriers to flow, whereas large amounts can create macropores and preferential flow paths. MOSA and ASTM standard laboratory methods for determining hydraulic properties were developed for the fine-grained soil fraction and were not designed for gravelly materials. Moreover, removing the gravel fraction and using published gravel correction factors is generally not accurate for materials with greater than 20 percent gravel content. Over the last decade, we have developed several laboratory methods to quantify saturated and unsaturated flow behavior in gravelly materials. These consist of using large diameter cores, directly measuring the hydraulic conductivity function at near saturation, and using flexible wall methods to minimize wall effects. Results from characterization work on waste rock and heap leach samples indicate that 1) unsaturated flow parameters derived from material without gravel cannot represent the actual hydraulic behavior; 2) basing the hydraulic conductivity function on saturated hydraulic conductivity cannot describe measured unsaturated flow data; 3) a dual-permeability model can improve predictions of flow behavior, and; 4) a flex-wall column design allows for successive measurements of hydraulic conductivity and air permeability under variable bulk density conditions evaluated during the cover system design phase.

Bio:
Mike Yao is a Senior Hydrologist and the Laboratory Director at GeoSystems Analysis, Inc. He has extensive experience both in the field and laboratory in vadose zone and groundwater hydrology. For the past 20 years, he has conducted large field-scale research in water and solute movement through the unsaturated and saturated zones and the application of computer models to these processes. His expertise also includes the use of invasive and non-invasive geophysical techniques, measurement of field, laboratory hydraulic properties, characterization of the unsaturated porous media, field subsurface monitoring system design, artificial recharge, mine waste cover design and monitoring, heap leaching monitoring and optimization, and preferential and fracture flow in the porous media. The results of his research have been applied to modeling of subsurface flow, characterization of the hydraulic properties of waste disposal sites, heap leaching and environmental monitoring. He also has three years of experience as an exploration geologist in Chinese Petroleum Cooperation. Mike has B.S. and M.S. degrees in geology from the National Taiwan University and M.S. and Ph.D. degrees in hydrology from the New Mexico Institute of Mining and Technology.

SHAFT SAMPLING AND PROFILING AT THE SECTION 27 MINE

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Presented by Cynthia Ardito
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Abstract:
The Section 27 Mine is an underground uranium mine located approximately 30 miles north of Grants, NM. The ore deposit is part of the Grants Uranium Belt within the Ambrosia Lake Valley, a broad, elongated valley that was once the site of some of the most productive uranium mines in the United States and remains undercut by layers of mine workings. Mine workings are known to be connected from one end of Ambrosia Lake Valley to the other.

The sandstone formations at and above the location of the ore were dewatered in the vicinity of the mines beginning in the late 1950s and ending by 1986, forming a regional cone of depression. Since 1986, water levels in these units have been recovering as groundwater flows back into the dewatered areas. Concentrations of sulfate, several metals, uranium, and radium currently exceed the New Mexico State Groundwater. The process of mine dewatering introduced oxygen into previously reduced ore zones, causing uranium to be oxidized from its relatively insoluble tetravalent state to its more soluble hexavalent form. Once the mine cavities are completely flooded, oxygen will be consumed and, if there are no other sources of oxygen, conditions will return to pre-mining conditions, which will favor the removal of soluble uranium from groundwater.

INTERA is currently four years into a five-year plan to collect water quality data at the Section 27 Mine, in support of NMED's effort to collect data in the entire Ambrosia Lake Valley. On a semi-annual basis, INTERA collects continuously profiled geochemical water quality indicator parameters from two vent shafts at Section 27. Parameters include temperature, pH, conductivity, oxidation reduction potential (ORP), rugged dissolved oxygen (RDO), and depth of water (via barometric pressure). On an annual basis, INTERA collects discrete depth water samples that are analyzed by a

laboratory for a wide range of dissolved metals and anions. Sample depths were selected based on significant vertical changes in the continuously-profiled water chemistry indicator parameters to represent the full range of variability in groundwater quality in the groundwater column.

Collection of indicator data is fast and allows continuous sampling of the entire water column so that a large body of data can be built in a relatively short time. Collection of a smaller body of laboratory data will provide a way to tie indicator data to a larger number of chemical parameters. INTERA's method of continuous shaft profiling coupled with discrete depth samples provides a detailed look into the geochemical conditions of the shafts at various depths within the water column, which cannot be seen with standard sampling methods. This could potentially provide information about the oxidation-reduction state of the uranium at various locations in the sandstone formations within the shafts.

Bio:
Amy Andrews, P.E., is an Engineer at INTERA Incorporated who leads mine-water and mine reclamation projects with a focus on uranium mining. She has experience in mine reclamation planning and design, engineering design of water retention structures, groundwater and soil remediation, radiation safety and site radiation surveys, hard rock drilling and coring, aquifer testing, remediation system design and maintenance, and site characterization. Amy has applied this experience at a wide variety of sites including landfills, uranium mines, potash mines, petroleum storage tank sites, superfund sites, CERCLA sites, fuel terminals and military bases. Amy was part of a team of four INTERA colleagues who won the 2010 Excellence in Reclamation Award from the New Mexico Mining and Minerals Department for reclamation of the JJ No. 1/L-Bar Uranium Mine. Amy serves as the INTERA Corporate Health and Safety Officer in charge of OSHA HAZWOPER and MSHA requirements. She has a B.S. in mineral engineering from New Mexico Tech and a professional engineering license in mining and mineral processing from the state of New Mexico.

Session 6: Water Treatment

THE ECONOMICS OF WATER TREATMENT: CONVENTIONAL VERSUS HIGH DENSITY SLUDGE PRECIPITATION

Mary Boardman[1] (*presenting author*) **and Jim Stefanoff, P.E.**[2]
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Abstract:
The Argo Tunnel Water Treatment Facility (ATWTF) was constructed in 1998 in Idaho Springs, CO, to treat acid mine drainage associated with the Central City/Clear Creek Superfund Site.

As the lead agency on the site, the Colorado Department of Public Health and Environment (CDPHE) is responsible for operation and maintenance (O&M) activities. In an effort to reduce long term O&M costs, several minor process modifications have been implemented over the years.

In 2009, the CDPHE assumed the full financial obligation of operating the ATWTF. In preparation of the transfer of ownership from EPA to CDPHE, an optimization review was performed and funding was made available from EPA to convert the treatment process from conventional lime precipitation to high density sludge (HDS).

This presentation gives a brief introduction into the theory of conventional and HDS treatment, summarizes how the conversion was accomplished, and provides treatment cost information for both the conventional and HDS processes.

Bio:
Mary Boardman is a project manager in the Remedial Programs Unit of the Colorado Department of Public Health and Environment. She has worked on many aspects of Superfund projects, from performing preliminary assessments to managing the design, construction, and operations and maintenance of remedial actions. Current projects include the Central City/Clear Creek, Captain Jack Mill and Summitville Mine Superfund sites. Prior to joining Remedial Programs, Mary worked as an Analytical Chemist in the State Inorganic Chemistry Laboratory. Recently, Mary was a contributing member of the Interstate Technology and Regulatory Council's *Mining Waste Treatment Technology Selection* and *Biochemical Reactors of Mining Influence Waters* teams. Mary has a B.A. in chemistry and M.S. in environmental science from the University of Colorado.

ALKALINE FLUSH: AN EMERGING TECHNOLOGY FOR IN SITU TREATMENT OF MINE IMPACTED ALLUVIAL AQUIFERS

Olu Ogungbade[1] (*presenting author*)**, Parvathy Kochunarayanan, Madhu Raghav, Dan Ramey and Erick Weiland**[2]
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Abstract:
Alkaline Flush (ALF) Technology introduces an alkali reagent to adjust groundwater and sediment pH and the surface chemistry of sediments to provide *in situ* remediation of acidic-metals impacted alluvial aquifers. Along with the reduction in groundwater and sediment acidity, this technology may precipitate metals of concern into stable mineral forms significantly reducing their aqueous concentrations over both the short-term and long-term. Application of ALF technology may provide a "*resiliency period*" or an "*acceleration period*." This technology offers an opportunity for remediation of alluvial aquifer systems at costs lower than those associated with other potential remedial alternatives.

Bio:
Olu is a research engineer within the Environmental Technology/Life Cycle team of Freeport-McMoRan based in Oro Valley, Arizona. In this role, he investigates emerged and emerging technologies to manage environmental liabilities within the company's portfolio. He has an M.S. in environmental engineering from New Mexico Tech and a B.S. in civil engineering from Obafemi Awolowo University, Ile-Ife, Nigeria.

INNOVATIVE CONTAMINANT REMOVAL FROM MINING WATER WITH A SINGLE PASS ADVANCED TREATMENT SYSTEM

William E. Roper, Ph.D., P.E.[1] *(presenting author)* **and Kelly P. Rock**[2]
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[2]Inventor, CTO, Micronic Technologies

Abstract:
Micronic Technologies has developed and patented MicroDesal™, a mechanical evaporation system that removes contaminants from mining source water including surface, ground, brackish, turbid, and industrial water. The treatment unit mechanically creates a turbulent highly dynamic tornado flow, causing a rapid-evaporation process by increasing the air speed and surface area of the micro-water droplets. Using low-pressure and recycled thermal energy, the water/air flow processor vaporizes micron-size water particles into water vapor and then later during the condensation process water vapor is reconstituted into pure water. With increased requirements for mine water treatment and reuse, MicroDesal™ could make a major contribution.

MicroDesal™ is currently in second-generation closed-loop system development. With support from the Navy a flow bench testing platform is being developed to conduct performance experiments for designing higher through-put efficiency and capacity units. The tornado effect in the evaporator also creates a concentrated brine on the outer wall, which is separately collected. This attribute allows for recovery of metals and other materials that may be reused or sold for their commercial value. The condensed product water from the system is highly purified and could be reused on site for multiple water requirements. The system is able to remove many of the contaminants associated with mining operations. The presentation will include performance data that are third-party validated test results from water samples provided by a number of the company's partners in the mining and industrial sectors. In most cases the removal rate is in the very high 95-99 percent range.

The presentation will describe the results of bench-scale testing with the MicroDesal™ system over the last two years from a variety of mining and industrial wastewater samples. Treatment is accomplished without using filters, membranes or chemicals. Testing and development studies with the system have shown low maintenance and no water pretreatment requirement. Other characteristics of the system include a small footprint, and projected low operating/life cycle cost compared to alternative technologies.

Bio:
William E. Roper, Ph.D., P.E. is the Director of Research for Micronic Technologies where he manages and supports research activities for advanced water treatment systems. His technical expertise and executive management experience includes extensive energy and water technology applications at Army and other DOD facilities and public utilities nationwide. Dr. Roper is the former Director of the Army Corps of Engineers World-Wide Civil Works Research and Development Program, which involved water related research, development and execution at seven major laboratories and five research centers located throughout the United States involving over 2,200 scientists and engineers. He has authored over 150 technical papers and 5 books and is a former member of the Federal Senior Executive Service. Dr. Roper also serves as a research professor at George Mason University and a visiting Professor at Johns Hopkins University. He received his B.S. in mechanical engineering and Ph.D. in environmental engineering.

LESSONS LEARNED FROM MINING-INFLUENCED WATERS STUDIES AT THE NEW MEXICO BUREAU OF GEOLOGY AND MINERAL RESOURCES

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Abstract:
Scientists at the NMBGMR have studied the effects of mining-influenced waters (MIW), acid drainage, and other environmental issues from mines and mills since it was created in 1927. Geochemical databases are available for selected mining districts in areas where NMBGMR scientists have had funded projects (Hillsboro, Pecos, Red River, Questa, Española Basin, etc.). Some of the lessons learned in these studies, include:

(1) The NURE data provides a first order of geochemical background conditions in New Mexico, especially for uranium. The NURE stream-sediment data provides geochemical analyses for >27,000 samples collected throughout New Mexico during 1970s. The NURE hydrogeochemical data provides analyses for >12,000 surface and well water samples. In addition to uranium, the NURE data contains limited analyses of other elements, including pH and conductivity. Examination of the NURE data is beneficial when used with caution and understanding of the problems with the data. Several areas examined in New Mexico are a result of contamination from mining and other anthropogenic inputs; other areas are a result of natural processes related to local rock chemistry, weathering, or formation of mineral deposits. More detailed sampling is required in these areas.

(2) Uranium prospects and geochemical uranium anomalies in both water and stream-sediment samples are found in the Tesuque Formation, San Jose district, Santa Fe County and residents locally have high concentrations of uranium and radon in their drinking water. The uranium mines and occurrences found in the Tesuque Formation probably represent natural precipitation and concentration from uraniferous groundwater, not MIW, and are most likely a result of weathering of uranium from rocks in the Tesuque Formation and the adjoining mountains and subsequent migration of uranium and radon in the ground water. Uranium then precipitated from the waters to form the uranium anomalies found in the groundwater.

(3) The area southeast of the Orogrande district, Otero County exhibits anomalous copper concentrations in stream-sediment samples (23-41 ppm). No mineralized areas were identified during field examination and no other geochemical anomalies were observed. The most likely source for this copper anomaly is the abandoned copper smelter located in the northern part of the town of Orogrande.

(4) Geochemical analyses of surface-water samples indicate that drainage from the Terrero (Pecos) mine, Willow Creek district did not significantly affect the composition of the surface water in the area, except in the immediate vicinity of the mine and mill site. Elevated concentrations of Cu, Pb, Zn, and Cd occurred in stream sediments below both the Terrero mine and Alamitos Canyon mill sites, before reclamation began. Collectively, multi-disciplinary studies suggest that Cu, Pb, Zn, and

other metals were eroded and leached from the Terrero mine waste rock pile and the tailings piles in Alamitos Canyon. The overall metal concentrations dramatically decreased in stream sediments below Pecos Village, mostly due to dilution of sediment derived from the red bed sedimentary units. Since reclamation of the Pecos mine, Alamitos Canyon mill, campgrounds and roads began in 1990-1991, Cu, Pb and Zn concentrations have decreased overall.

(5) Multidisciplinary studies of the Questa rock piles indicates that predominant weathering reactions in the GHN mine waste rock pile involve the oxidation of pyrite, dissolution of carbonate, and formation of sulfate minerals, mainly gypsum, jarosite, and soluble, efflorescent salts (depending on pH). The chemical composition of waters from the Questa rock piles (i.e., seeps and runoff waters from the rock piles, chemistry of leachate waters) imply that silicate dissolution is occurring within the rock piles. Little if any clay minerals are forming as a result of weathering; instead the clays are from pre-mining altered rocks.

In conclusion, these and other studies indicate that the differences in chemistry of MIW due to mining within the various mining districts in New Mexico are due to differences in geology, type of mineral deposits, and alteration of adjacent rocks, including weathering. Each area is site-specific and must be examined in detail and over a period of time to determine the cause of the adverse MIW.

Bio:

Ginger McLemore is a Senior Economic Geologist with the New Mexico Bureau of Geology and Mineral Resources, a research division of New Mexico Tech. She holds B.S. degrees in geology and geophysics, an M.S. degree in geology from New Mexico Tech, and received her Ph.D. in geoscience from University of Texas at El Paso in 1993. Ginger began work with the Bureau in 1980 as an economic geologist specializing in uranium deposits. She has published numerous articles (>150 articles) on mineral resources and on environmental impacts of those resources in New Mexico. Her current projects include the study of alkaline magmatism, carbonatites, and geology and environmental geology of mineral deposits in New Mexico. Numerous New Mexico Geological Society field conferences have benefited from her expertise. She also is an adjunct professor and teaches Geology of the Industrial Minerals, a graduate level course for the Department of Earth and Environmental Sciences and Department of Mineral Engineering at New Mexico Tech.

ASSESSING THE INFLUENCE OF COPPER-NICKEL-BEARING BEDROCKS ON BASELINE WATER QUALITY IN THREE NORTHEASTERN MINNESOTA WATERSHEDS

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Abstract:
Mineral exploration is occurring and mines are being proposed to extract copper, nickel, cobalt, titanium, and platinum-group-metals (PGM) from the basal part of the Duluth Complex in northeastern Minnesota. The Duluth Complex is a series of Middle Proterozoic igneous intrusive rocks, which crop out from Duluth to near Grand Portage, Minnesota (Miller and others, 2002). The basal part of the complex contains world-class mineral deposits that represent the third-largest copper and nickel resource and the fourth-largest precious metals resource in the world (Myers, 2012).

The U.S. Geological Survey, Natural Resources Research Institute, and Minnesota Department of Natural Resources are conducting a cooperative study from 2012 to 2016 to: (1) assess copper, nickel, and other constituents in surface water, rock, streambed-sediment, and soil (including parent material) in watersheds that cross the mineralized basal contact of the Duluth Complex; and (2) determine if natural metal concentrations are currently influencing regional water quality in areas of potential mining. Water, streambed-sediment, soil, and bedrock samples are being collected and analyzed in three unmined watersheds with the following different mineral-deposit settings: (1) copper-nickel-cobalt-platinum group metal mineralization (Filson Creek watershed), (2) titanium-oxide mineralization (headwaters of the St. Louis River watershed), and (3) no identified mineralized deposits (Keeley Creek watershed). Water samples are being analyzed for 12 trace metals (total and dissolved concentrations), 14 other inorganic constituents (dissolved concentrations), alkalinity, pH, total organic carbon, dissolved organic carbon, and stable isotopes (oxygen, hydrogen and sulfur). Soil, streambed-sediment, and bedrock samples are being analyzed for 44 major and trace elements, total carbon, inorganic carbon, and 10 loosely bound metals. Continuous streamflow data are being collected at three USGS stream gages. Streamflow and water-quality data are being applied to new conceptual hydrologic models and existing biotic ligand models to assess the influence of existing geochemistry and possible mining activities on regional water quality.

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Myers, J., 2012, Digging into the promise of copper, Minnesota Conservation Volunteer, vol. 75, no. 443, p. 8-19.

Bio:
Perry Jones is a Hydrologist for the U. S. Geological Survey, Minnesota Water Sciences Center where he has conducted water resources research for 18 years. He received his B.S. in geology from State University of New York at Cortland and his M.S. in geology at the University of Minnesota. He previously worked for seven years at the U.S. Bureau of Mines. Besides his research into baseline characterization of potential mining areas in northern Minnesota, Perry is currently conducting hydrologic research in the areas of groundwater/surface water exchange in Minnesota lakes and hydrogeologic characterization of low-permeability formations in Minnesota.

EVAPOTRANSPIRATION AND GEOCHEMICAL CONTROLS ON GROUNDWATER PLUMES AT ARID SITES: LESSONS FROM ARCHETYPE URANIUM MILLING SITES

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Abstract:
Data from several former uranium milling processing sites in the western United States affirm a conceptual model in which the climate and geomorphology, and the associated geochemical and hydrological conditions, control the subsurface fate and transport of contaminants. In arid settings, typical for many milling sites, shallow groundwater is transferred into the vadose zone and atmosphere via evaporation, transpiration and diffuse surface seepage. During these transfers, dissolved constituents precipitate as evaporitic minerals (e.g., blödite, thenardite and halite) along with accessory minerals (e.g., carnotite) containing trace elements such as uranium. In locations where the water table is relatively deep (> 2m), these precipitates will accumulate as nonpedogenic intervals in the deep vadose zone near the capillary fringe, around the roots of phreatophyte plants, and near surface seeps. In areas where the water table is shallow, precipitates will also accumulate at the soil surface as a result of capillarity and evaporation. The accumulation and distribution of constituents associated with milling and extraction operations is analogous to natural evaporite ore deposits in North America, Australia, Europe and Africa.

The sites in Tuba City, Arizona and Riverton, Wyoming are archetype mill sites in arid settings, representing deep and shallow water table cases, respectively. Available hydrological, geochemical and radiological (aerial gamma) data from these sites provide key insights related to contaminant fate and transport. At Tuba City, hydrological and geochemical processes limit the size of the groundwater plume and reduce the potential for contaminated groundwater to crop out at Moenkopi Wash, while eolian processes have resulted in limited surficial dispersal of milling related constituents along the primary wind vectors. At both sites, milling-related evaporitic minerals that have formed in the near-field and mid plume area will sustain elevated groundwater concentrations of anthropogenic constituents such as sulfate and uranium for an extended timeframe.

Bio:
Brian B. Looney is a research engineer in the U.S. Department of Energy (DOE) Savannah River National Laboratory (SRNL) and an adjunct professor at Clemson University. Brian received his B.S. in environmental science from TCU in 1978 and his Ph.D. in environmental engineering from the University of Minnesota in 1984. Over the past 31 years, Brian has successfully developed and deployed a wide range of innovative environmental characterization and clean-up technologies for soil and groundwater. His applied science research addresses radionuclides, metals and organic contaminants and focuses on approaches that beneficially couple active environmental clean-up and natural attenuation processes. Brian serves as a technical advisor supporting the national DOE Environmental Management and Legacy Management Programs. He has received a number of national awards for technology development and innovation. Dr. Looney has 11 patents for environmental technologies and many scientific publications including the book Vadose Zone Science and Technology Solutions.

Session 8: Water Treatment (cont.)

BIOCHEMICAL REACTORS FOR TREATING MINING INFLUENCED WATER

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Abstract:
Innovative approaches and technologies need to be developed and implemented that solve environmental issues and remove existing regulatory barriers. The Interstate Technology and Regulatory Council (ITRC) is a state-led, national coalition helping regulatory agencies, site owners, and technology developers and vendors achieve better environmental protection through the use of innovative technologies. Through open communication among its partners, ITRC is streamlining and standardizing the regulatory review process for better, more cost-effective, environmental technologies. Funding comes from the Departments of Defense and Energy, the U.S. Environmental Protection Agency as well as industry and is used to support teams to address state environmental priorities. The ITRC mine waste team was formed in 2008 to address mine impacted solids and water and produced a web-based guidance to help select technologies that address a wide variety of mine waste issues (ITRC MW-1, 2010 at http://www.itrcweb.org/miningwaste-guidance). During the development of the first guidance, the team felt that although biochemical reactors (BCRs) were a promising technology, more information on their design, use and success was needed. As a result, in 2013, the team completed a guidance on their use. (http://itrcweb.org/bcr-1/). The guidance contains information on the applicability, design, construction, monitoring and maintenance of BCRs as well as discussions on the related regulatory and public stakeholder issues. Fifteen case studies are included.

Bio:
Douglas Bacon is a project manager for the Utah Division of Environmental Response & Remediation, Utah Department of Environmental Quality. He began working for UDEQ in 1997, and has over 15 years' experience overseeing Rio Tinto Kennecott Copper's Superfund response actions. Douglas has been integrally involved with the selection, implementation, and oversight of response actions addressing both solid mine waste and mining-influenced water. Since 2007 Douglas has represented Utah on two Interstate Technology Regulatory Council (ITRC) technical teams investigating remedial technologies for mining influenced water and solid mine waste. He has assisted with the development and publication of two technology guidance documents and authored an overview and case study on the use of pressure driven membrane separation to address the treatment of mining influenced ground water. Douglas has been an instructor and now serves as Utah's point of contact for ITRC's State Engagement program. Douglas earned a bachelor of science degree in environmental biology from Plymouth State College in Plymouth, New Hampshire in 1997 and earned his credentials as a Certified Public Manager from the State of Utah in June 2007.

ENHANCED SULFATE REDUCTION TREATMENT OF MINING-INFLUENCED WATER USING BIOCHEMICAL REACTORS – IMPACTS ON MERCURY SPECIATION

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Abstract:
This paper/presentation will summarize and compare a bench top laboratory study and a treatability study conducted to evaluate ex situ passive treatment options for the Formosa Mine adit discharge as part of an ongoing remedial investigation/feasibility study program. The study was performed to evaluate the effectiveness of passive pre-treatment technologies and biochemical reactors (BCRs) for treating acidic adit discharge. A BCR's biologically mediated process provides an organic substrate as an electron donor to various aqueous sulfide species for sulfate-reducing bacteria (SRB) to reduce sulfate present in mining-influenced water (MIW). Subsequently, the metals present in MIW react with the sulfide species to form metal sulfide precipitates such as iron, copper, nickel and zinc sulfides. One issue of particular concern with harnessing sulfate reduction for the treatment of MIW when mercury is present is the potential effects on mercury speciation. Mercury present in MIW is primarily in the inorganic form Hg(II); however most of the mercury that accumulates in biota is in the organic form methylmercury (CH_3Hg^+ or more commonly MeHg). SRB are one of the organisms primarily responsible for the conversion of Hg(II) to MeHg. The Formosa adit has trace mercury concentrations of approximately 3 nanograms per liter (ng/L), similar to average natural concentrations observed in unimpacted streams. Average concentrations for MeHg in unimpacted streams are much lower, approximately 0.2 ng/L.

One goal of this study was to answer the question: what is the contribution of MeHg coming from the column and BCR effluent, if any, to the receiving water body? In this study, a series of bench top laboratory column tests were compared to a series of onsite treatability BCR tests. The bench top columns consisted of three columns packed with ChitoRem®, two columns packed with a woody substrate and manure mixture, and one control packed with sand. The ChitoRem® and woody substrate columns were tested with untreated anoxic MIW and pH 6.5 specific units (su) adjusted anoxic MIW, with one extra ChitoRem® column and one extra sand column fed with a sodium azide treated water as abiotic controls. Six field BCR configurations were tested, one woody substrate and one ChitoRem® BCR with no pre-treatment of the influent MIW, one woody substrate and one ChitoRem® BCR with successive alkalinity producing system (SAPS) pre-treatment, and one woody substrate and one ChitoRem® BCR with ChitoRem® pre-treatment of the MIW. Each laboratory and field treatment configuration was evaluated; (1) for its ability to maintain redox conditions sufficient to induce sulfate reduction and metal removal efficiency (MRE) greater than 90 percent, and (2) for its effect on the mercury concentration and speciation in the BCR effluent. Parameters were measured to evaluate: 1) MIW pH neutralization; 2) sulfate reduction surrogate indicators such as sulfate, sulfide, alkalinity and redox; 3) MRE with target metals such as cadmium, copper, and zinc which drive risk, and other metals such as iron and aluminum, which are present in high concentrations; and 4) trace mercury speciation, both total and methylmercury. This study will inform choices on the configuration of a biochemical treatment system and will help mitigate potentially negative effects of MeHg release.

Bio:
Dr. Stephen (Steve) R. Dent is a staff Engineer/Scientist in the technical services group at CDM Smith. In this role, he provides technical support for several Superfund Sites in EPA Regions 9 and 10. Prior to CDM Smith, Steve was a research assistant at Washington State University (WSU), where he pursued and received a Ph.D. in civil engineering. The focus of Steve's dissertation was evaluating the effects of lake and reservoir treatments and management strategies on the cycling of metals in aquatic ecosystems. During his tenure at WSU, Steve constructed and maintained a trace mercury analytical laboratory. He received his bachelors and masters degrees in environmental engineering from Montana Tech of the University of Montana, where he investigated the flux of mercury from remote forest areas. Steve has several publications relating to mercury and lake assessments as well as educational outreach and has presented at multiple conferences and workshops.

BIOCHEMICAL REACTORS FOR PASSIVE TREATMENT OF SELENIUM

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Abstract:
Passive biological treatment systems rely on naturally occurring biological, chemical and physical processes to achieve treatment. Typically more land-intensive than active treatment systems, passive biological systems can be less expensive to operate and manage because of lower or negligible energy or chemical inputs. Labile organic carbon released from an organic substrate serves as an electron donor. Substrates composed of wood chips, sawdust, mushroom compost, manure, hay,

yard wastes, and limestone granules have been used in varying proportions. Termed biochemical reactors (BCRs), these passive systems have been employed previously for treatment of a variety of mine-influenced waters and in a variety of forms but their incorporation into passive treatment systems for selenium (Se) reduction is relatively new with a variety of forms and applications. In passive treatment systems, oxidized forms of Se (selenite and selenate) can be transformed to selenite, elemental selenium, selenides, and organic Se through microbial reduction, followed by sequestration in soil and sediments. Common electron acceptors that must be removed before or concurrent with oxidized selenium reduction include dissolved oxygen and nitrate.

Recent advances have come through implementation of Se treatability pilot studies and full-scale systems by CH2MHILL for mining and power companies and the U.S. Bureau of Reclamation, along with additional projects discovered through professional contacts and continuing review of the literature. Pilot studies have indicated consistently that total Se can be reduced to <5 μg/L and below to method detection limits. These projects have demonstrated that, where feasible, passive treatment is a practical, cost effective, and technologically appropriate way to manage Se, particularly for mine-influenced waters, which may be located remotely without power access, have elevated salinity, and originate in extreme climates that may range from arid desert to cold locations. Similar solutions for other contaminated water sources are expected when siting and sizing constraints can be met.

Multiple pilot studies and full-scale passive biological treatment projects undertaken since 2010 have demonstrated successful and sustained reduction of Se from diverse water sources, such as coal mine drainage, gravel mine seepage, reverse osmosis (RO) membrane concentrate, and FGD scrubber wastewaters. Findings indicate that Se concentrations spanning a range of 10-1000 μg/L have been demonstrated to be treatable down to 1-10 μg/L. Zero-order volumetric removal rates have spanned a range of <10 to >30 mg Se/d m^{-3} of substrate. First-order, area-based removal rates show a central tendency of approximately 400 m/yr, depending upon inlet oxidized nitrogen, and vary in response to mass and hydraulic loading rates. Nominal BCR hydraulic residence times range from <1 to >3 days. Nitrate reduction is a necessary step to achieve effective Se reduction, and is typically accounted for by increasing BCR size. The systems have been shown to maintain satisfactory performance even with maximum inlet flows up to 3x average, and under ambient air temperatures <0˚C. BCRs export organic carbon, color, sulfide, manganese, iron, ammonia and phosphorus that can affect receiving water quality and may exceed compliance limits. Treatment of these "byproducts" typically incorporates passive or active aerobic systems such as oxidation ponds and constructed wetlands. Management of organic substrates must factor in long-term replacement, disposal and closure requirements. Toxicity characteristics of the substrate must be determined to establish disposal methods. Construction and operational costs of Se BCRs can often be substantially less than conventional treatment systems.

By summarizing the key findings of these recent projects, the paper captures the range of progress in sustainable Se treatment using passive biochemical reactors and prospects for future applications.

Bio:
Jim Bays is a Technology Fellow with CH2MHILL. Jim provides technical guidance and direction for projects using wetlands or other natural treatment systems for water quality improvement. From 1999-2007, Jim served as Global Technology Leader for Natural Treatment Systems for CH2MHILL. Now in his 30th year with CH2MHILL, Jim has consulted on constructed wetland projects throughout North America, Europe, India, southeast Asia and Australia. Recent publications focus on the use of biochemical reactors for selenium reduction in mine-influenced water and membrane concentrate, constructed wetlands for treatment of stormwater and combined

sewer overflows, and floating wetland islands for nitrogen reduction in reclaimed water. Jim has a B.S. in environmental biology from Ohio University and an M.S. in environmental engineering sciences from the University of Florida.

Session 9: Source Control / Mine Closure Approaches (cont.)

STRATEGY AND DESIGN CONSIDERATIONS FOR PRIORITIZATION OF MINE WASTE SOURCE AREA REMEDIATION WITHIN THE HEADWATERS OF THE TAR CREEK WATERSHED

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Abstract:
This presentation will summarize the phased remediation strategy for the affected portions of the Tar Creek watershed in southeastern Kansas. Large-scale underground mining of ore bodies containing lead and zinc occurred throughout the Tri-State Mining District of Kansas, Oklahoma, and Missouri from the 1870s until 1970. The deposition of waste rock and tailings from ore mining and processing has adversely affected the watershed of Tar Creek in southeastern Kansas and northeastern Oklahoma. The headwaters of the Tar Creek watershed and its adjacent mine waste source areas span 115 square miles and are part of the Cherokee County Superfund Site Operable Unit 4 – Treece (OU-4). Cleanup of OU-4 is managed by the U.S. Environmental Protection Agency (EPA) Region 7 and the Kansas Department of Health and Environment (KDHE). The remediation of the lower reaches of Tar Creek is managed by EPA Region 6 and the Oklahoma Department of Environmental Quality (ODEQ). Since periodic monitoring began within the Tar Creek watershed in 1993, surface water samples have exceeded the chronic aquatic life criterion for cadmium, lead and zinc. EPA Region 7 is developing a remediation strategy for the headwaters of Tar Creek, its tributaries and the adjacent mine waste areas north of the Kansas-Oklahoma state line. The OU-4 project encompasses 3.8 miles of Tar Creek and 445 acres of wetlands and open water, adjacent to 3.4 million cubic yards of mine waste and tailings dispersed between nine distinct source areas.

The 2006 Record of Decision (ROD) for OU-4 planned for remediation of contaminated sediments in Tar Creek and its tributaries only after all OU-4 mine waste areas were addressed. The OU-4 project team determined that a phased remediation approach will make best use of limited resources to meet the ROD remedial action objectives and stakeholders' expectations. Under the phased

approach, the team will holistically remediate and restore Tar Creek, its tributaries and adjacent mine waste areas in the OU-4 project area progressing upstream to downstream in a minimum of five phases. The cleanup sequence will prevent recontamination of previously remediated areas.

Remediation of the streambed within Tar Creek and its tributaries concurrent with adjacent mine waste areas will provide a comprehensive remedial approach and increase long-term cost efficiency. Rather than remediating mine waste areas first and then addressing contaminated sediments, as was originally planned, the comprehensive approach will reduce the number of contracts and field mobilizations, make better use of mine waste consolidation areas and allow for earlier restoration of wetland habitat. Contaminated watershed runoff will be reduced by excavating mine waste and relocating them out of the immediate flood plain, consolidation and covering mine waste in adjacent upland areas and reestablishment of wetland habitat. Mine waste consolidation areas adjacent to Tar Creek in high-water-velocity locations will be protected through realignment of Tar Creek in key areas, benching of overbank areas to reduce water velocities, and the use of geosynthetic materials and armoring. Short-term and long-term monitoring will serve to assess achievement of short-term remediation expectations and assist in prediction of the long-term success of the remedy.

Bio:
Mr. Schlebusch is an Environmental Engineer with CDM Smith. He manages several Superfund remediation projects in U.S. Environmental Protection Agency (EPA) Regions 7 and 8 ranging from solvent-contaminated groundwater to mine waste impacted land and water. His Superfund experience includes site characterization, remedy design, cost estimation, remedy construction, and operation and maintenance. Marc has a B.S. in civil engineering and an M.S. in environmental engineering both from the University of Iowa.

ACID ROCK DRAINAGE SOURCE CONTROL AND TAILINGS PILE CLOSURE AT THE ELIZABETH MINE SUPERFUND SITE, ORANGE COUNTY, VERMONT

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Abstract:
The Elizabeth Mine Superfund Site, located in Orange County in Central Vermont, is one of the largest and most intact historic mining sites in New England. The Mine operated between 1830 and 1958, producing more than 50,000 tons of copper. Acid rock drainage (ARD) and dissolved metals discharges from tailings, waste rock, and slag resulted in severe ecological impacts to downstream streams and rivers. To reduce or eliminate the primary ARD sources, the U.S. Environmental Protection Agency implimented a non-time critical removal action (NTCRA) targeting a 45-acre area of tailings and waste rock (TP-1/TP-2) containing over 3 million cubic yards (CY) of waste as well as several satellite waste areas. The NTCRA included the construction of a geosynthetic cap consisting of double sided LLDPE geomembrane, high-transmissivity drainage geocomposite, and vegetative support soils.

The TP-1/TP-2 containment construction began in 2011 with subgrade preparation to achieve slope stability and drainage requirements. GPS-guided machinery was used to automate grade control,

greatly reducing rework and manual surveying effort. A lime amendment rotating cylinder treatment system was operated and maintained during the NTCRA to reduce iron and ARD impacts from approximately 16 million gallons of TP-1/TP-2 leachate. Other NTCRA activities included the construction of over 2 miles of surface water drainages, building demolition and hazardous materials removal, and preservation of historically sensitive features. The waste consolidation and geosynthetic cap installation was completed in 2012 and other NTCRA work is ongoing.

A Greening Policy was implemented during closure construction and restoration activities to promote green and sustainable practices. These practices included the use of biodiesel fuels in modified heavy equipment and on-site borrow and topsoil sources that eliminated the need for over 10,800 off-site truck deliveries. These two initiatives resulted in ~500 tons of greenhouse gas reductions. Environmentally preferable products, such as a 100 percent biodegradable high performance flexible growth medium, were also selected to support the Greening Policy. Site restoration activities have included the restoration of satellite waste removal areas to natural habitats using native soils and seed mixtures to encourage vegetative growth, and the return of native bird species and pollinators. In addition, approximately 11 acres of wetlands have been constructed.

As a result of the cap construction, TP-1/TP-2 leachate flow has declined from 55 gallons per minute (GPM) to 22 GPM between 2011 and 2013. The ultimate effectiveness of the TP-1/TP-2 closure is demonstrated by a 90 percent reduction in copper concentrations entering downstream surface water, resulting in significant improvements to the quality of downstream water resources and aquatic biota.

Bio:
Andy Boeckeler is Vice President of Engineering and Science at Nobis Engineering. For the past 17 years, he has conducted investigations and remedial actions at numerous Superfund sites, primarily for EPA and the Army Corps of Engineers. His technical focus areas include fractured bedrock hydrogeology, in-situ chemical oxidation, isotope geochemistry, and mine site investigation and remediation. Andy has a B.S. in geology and an M.S. in geochemistry from the University of New Hampshire.

PASSIVE INTERFLOW CONTROLS: AN APPROACH TO IMPROVE BEST MANAGEMENT PRACTICES FOR WATER DIVERSION AT ABANDONED MINE SITES

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Abstract:
Passive interflow controls (PICs) are a simple yet significant improvement to standard best management practices (BMPs) commonly used at abandoned mine sites to minimize generation of mining-influenced water (MIW). PICs were installed by CDM Smith at an abandoned open pit gold mine in the Black Hills of South Dakota (herein referred to as "the site") to replace surface water diversion structures, a previously-existing BMP that addressed only the overland flow component of runoff from upgradient watershed areas. PICs improve performance of the water diversion

structures by addressing both the interflow component and the overland flow component of runoff from these upgradient areas.

Runoff is defined as the proportion of precipitation that reaches surface water bodies after a precipitation or snow melt event. Runoff includes two components: overland flow and interflow. Overland flow is lateral movement of precipitation that occurs over the land surface. Interflow is subsurface lateral movement of precipitation, which occurs due to contrasts in vertical hydraulic conductivity, such as at the interface between crystalline bedrock and overlying unconsolidated soil or sediment. The U.S. Geological Survey has identified interflow as a substantial component of runoff and a major contributor to stream flow in areas underlain by crystalline igneous and metamorphic bedrock in the Black Hills of South Dakota. Because this type of geology is common in many mountainous mining regions throughout the world, interflow from areas upslope of mines may be contributing to significant generation of MIW at abandoned mine sites.

By addressing both interflow and overland flow, PICs improve performance of water diversion systems, which reduce the volume of MIW that is generated through interaction of runoff with waste rock or other mine materials. Monitoring data collected at the site after installation of PICs show that these systems reduce the annual volume of MIW requiring collection, management and treatment by approximately 35 million gallons. PICs are inexpensive, passive in operation and easy to construct using readily obtained and low-cost system components. The PICs at the site are constructed of perforated collection pipe placed within the interflow zone, solid transfer pipe, aggregate, riprap, geotextile and soil.

PICs reduce the overall environmental footprint of mine remediation through: 1) a decrease in power consumption for MIW management; 2) a decrease in chemical reagent consumption typically used during MIW treatment; 3) a decrease in the volume of MIW treatment sludge typically generated; and 4) a reduction in disturbance to the overall watershed hydrologic balance by conveying collected upgradient water into the watershed immediately downstream from the mine. These environmental benefits translate into reductions in operation and maintenance (O&M) activities and related costs, and overall improvement in the sustainability of the remedy.

PICs should be designed to maximize effectiveness of interflow diversion, reduce long-term O&M requirements, and minimize costs using the concepts of gravity flow and year-round passive operation. PIC design can be modified or adapted to a wide range of site conditions and topographies; thus they are widely applicable at many mine sites in mountainous regions and should be considered as a standard BMP of any mine remediation program.

Bio:
Gary L. Hazen is a Senior Environmental Engineer with CDM Smith in Kansas City, Missouri. Mr. Hazen has 19 years of experience in the investigation and remediation of contaminated waste sites across the United States for private and governmental clients, including dozens of large-scale mines. While Mr. Hazen has a diverse background in remediation, he specializes in the study, design, and successful reclamation of operating and abandoned mines in a variety of locations. Mr. Hazen has co-authored several publications and presentations for national and international conferences related to the management and reclamation of abandoned hard rock mines. Mr. Hazen received a B.S. in geological engineering (cum laude) from the University of Missouri-Rolla, now known as Missouri University of Science and Technology. Mr. Hazen is also a licensed engineer and/or geologist in several Midwestern states including South Dakota and his home state of Missouri.

TREATABILITY STUDIES FOR ACIDIC MINING-INFLUENCED WATER

Angela K. Frandsen, P.E.[1] *(presenting author)*, **Nicholas R. Anton, P.E.**[2], **Douglas L. Miller, P.E.**[3], **Nathan T. Smith**[4] **and David J. Reisman**[5]
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Abstract:
CDM Smith conducted treatability studies to evaluate passive treatment options for acidic mining-influenced water (MIW) at the Barker-Hughesville Mining District National Priorities List Site (Barker) in Montana and at the Blue Ledge Mine Superfund Site in California (Blue Ledge). The treatability studies were conducted as part of the EPA remedial investigation/feasibility studies (RI/FS) to evaluate the effectiveness of conventional treatment (i.e., alkaline addition), various passive/semi-passive pre-treatment technologies, and biochemical reactors (BCRs) to treat the acidic MIWs at these remote sites. The studies provide site-specific data that can be used for analysis of remedial alternatives and development of scaled designs and costs for the FS.

Prior to field testing, bench-scale studies were conducted on each site's MIW. Conventional and pre-treatment titrations were completed with alkaline reagents on both site waters. Blue Ledge water was used in proof-of-principle BCR batch tests conducted with several organic and inorganic material mixtures. The Barker bench study included short-term column pre-treatment tests followed by BCR batch tests.

Bench-testing was followed by construction of barrel pilot studies at each site. MIW was collected in basins, fed by gravity to feed tanks, and 55-gallon treatment barrels filled with BCR substrate mixtures. The Blue Ledge barrels consisted of two woody substrate BCR mixtures, a ChitoRem® (mixture of ground crab shells, calcium carbonate, and protein) BCR, a successive alkalinity producing system (SAPS), and an ethanol BCR. The system was operated for 10 weeks in 2012 with weekly sample collection. Due to the short field season and inconclusive results, the system was re-started in 2013. All substrates were replaced for a total of four treatments: 1) woody substrate BCR; 2) SAPS pre-treatment followed by woody substrate BCR; 3) ChitoRem® BCR; and 4) ethanol BCR. All substrate mixtures were revised based on performance observed in 2012, flow rates were modified, a pre-treatment SAPS was added, and an automated ethanol metering pump was installed. The 2013 test was operated for 19 weeks with bi-weekly sample collection. Results indicate excellent removal of aluminum, cadmium, copper, iron, and zinc for the ChitoRem® and ethanol BCRs, and moderate removal in other BCRs potentially due to acidity overloading.

Using lessons learned from the first year Blue Ledge study, the Barker test was designed with a focus on implementing effective pre-treatment to condition the more acidic MIW for BCR treatment. Three pre-treatment methods were tested: 1) SAPS pre-treatment; 2) ChitoRem® pre-treatment; and 3) magnesium hydroxide pre-treatment. Each fed into a separate woody substrate BCR. A fourth BCR without pre-treatment was operated as a control. The Barker system was operated for 11 weeks with bi-weekly sample collection. The short field season limited the ability to assess data trends in 2013 and signs of acidity overloading were observed. A second year of the Barker study is planned for summer 2014, with modifications that include increased barrel retention time, substrate composition and alkaline material changes, increased study time length, and post-treatment oxidation testing using a constructed wetland.

Bio:

Angela Frandsen is an Environmental Engineer, Project Manager, and team leader with CDM Smith in Helena, Montana. Her areas of expertise include supporting EPA on all aspects of the Superfund process, particularly at mining "megasites," with a focus on water quality impacts and mine water treatment evaluations. Her project work has focused recently on the Barker Hughesville and Upper Tenmile Creek mining sites in Montana, remote watershed sites severely impacted by mine water discharges. Last year she served on the Interstate Technology and Regulatory Council (ITRC) group to develop national guidance on the use of biochemical reactors for treatment of mining-influenced waters. Angela has a B.S. in chemical engineering from Montana State University and M.S. in environmental engineering from Montana Tech in Butte, Montana.

INNOVATIVE BIOLOGICAL AND MOLECULAR TOOLS APPLIED TO MINE WASTE ISSUES

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Abstract:

Disposal of wastes associated with plutonium-separation and uranium recovery operations at U.S. DOE sites has led to the contamination of millions of cubic meters of soil and sediment as well as groundwater associated with these sites. Contaminant plumes contain mixtures of radionuclides, such as uranium, technetium-99, iodine-129 and tritium. In addition, metals such as chromium and other chemicals such as nitrate and sulfate, are often found co-mingled with radionuclide contamination. This complex and extensive contamination has led to the development of an array of innovative remediation and monitoring tools that could be readily adapted for use in abandoned and currently operating mine sites. While physical, chemical and biological remedies have been developed, this presentation will focus on bioremediation tools developed for metals and radionuclides for water treatment, as well molecular tools developed to monitor microbial communities important for remediating sites. In addition, potential application of similar tools for beneficiation of tailings and low grade ores will also be discussed.

Metal and radionuclide bioremediation technologies discussed will include direct and indirect transformation technologies, as well as removal of metals in solution through biosorptive processes. Contaminants, such as technetium, chromium and uranium can be removed from solution through reductive processes catalyzed by the oxidation of simple and complex carbon sources by anaerobic bacteria. Similar reductive processes, such as sulfate reduction, can lead to the indirect precipitation of metals in solution through the production of sulfide which complexes with the metals and

precipitates as metal sulfides. Finally, metals in solution can be removed via biosorption to microbial cells which can then be separated from solution concentrating and removing contamination. Examples of past and ongoing research focusing on these individual technologies will be discussed.

Molecular tools, such as quantitative polymerase chain reaction (qPCR) and fluorescent in situ hybridization (FISH) have been developed to target microbial communities active in metal and radionuclide remediation, allowing optimization of remedial processes. In addition, high-throughput molecular techniques such as metagenomes can be used to characterize phylogenetic and functional diversity in microbial communities in contaminated environments. These molecular tools could be applied to develop and optimize treatment strategies for wastes associated with abandoned mines.

Finally, application of these techniques for recovery and/or purification of metals or rare earth elements from mine tailings will be discussed.

Bio:
Brady is a Senior Staff Scientist in the Energy and Environment Directorate at the Pacific Northwest National Laboratory. For the past 25 years he has gained experience in management and technical oversight of numerous U.S. Department of Energy (DOE), U.S. Department of Defense (DoD) and private industry supported projects. Mr. Lee has performed research scaling from the laboratory bench to field-scale application. He has acted as principal investigator and directed projects related to the development of bioprocesses for the treatment of environmental contamination, including chlorinated solvents, petroleum hydrocarbons and metals and radionuclides. Numerous microbiological and molecular techniques were developed and employed during this research. Brady has nearly 40 publications cataloging his environmental and industrial research activity, as well as patents and awards related to industrial and environmental processes. Brady has an M.S. in microbiology from the Idaho State University, and is currently working on his Ph.D.

ELECTRO-BIOCHEMICAL REACTOR WATER TREATMENT TECHNOLOGY DEMONSTRATES LOW SELENIUM AND OTHER METAL EFFLUENTS IN HARDROCK MINING WASTEWATERS

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Abstract:
Selenium is a naturally occurring element and often associated with sulfide metal ore deposits in low to high concentrations. Management of selenium containing groundwaters, concentrated in underground works, and mill processing waters influenced by various flotation reagents including frothers, activators, depressants and pH adjusting agents are difficult challenges for wastewater treatment to low ppb discharge criteria.

The Electro-Biochemical Reactor (EBR) is a biological water treatment system based on redox reactions that directly supplies electrons to the microbes and reactor environment. Where conventional biotreatment systems rely on chemicals and excess nutrients to provide required electrons, the EBR technology provides many of the electrons directly, significantly reducing the amount of nutrients (electron donor) needed. Electrons needed for microbial contaminant transformations are directly supplied using an applied voltage potential of 1 to 3 volts and very low current; 1 mA supplies 6.24×10^{15} electrons per second. These electrons represent a 'free' energy

source that is available independent of microbial nutrient metabolism. The provided electrons make bioreactors more controllable, economical and robust than past generations of conventional biological treatment systems. Moreover, the directly supplied electrons result in better bioreactor performance; enhanced contaminant transformation kinetics and better performance at low temperatures.

EBR technology was evaluated at bench- and pilot-scale for selenium removal at an underground zinc, lead, copper, gold and silver mine in the Yukon Territory, Canada. The selenium-containing wastewaters also had high levels of residual flotation reagents and other co-contaminants, such as cyanides, Sb, Cd, Cu, Pb, Mo, Ag, and Zn that needed to be removed to meet mine water discharge criteria. Selenium concentrations ranged from 2 to >4 mg/L; the mine discharge criteria for selenium is 20 ug/L. Environment Canada's best available technology, and other examined selenium removal technologies, had not been successful at meeting selenium or other contaminant discharge criteria at this site. Both the bench- and pilot-scale EBR system demonstrated an average 99 percent Se removal to ≤2.0 ug/L, significantly exceeding the discharge standard for selenium and other co-contaminants present. Average co-contaminant removals of 93.5 percent to 99.7 percent were achieved during both bench- and pilot-scale tests.

Based on successful onsite pilot-scale EBR technology validation, a full-scale design is underway and construction is expected to be completed during 2015. The EBR process offers an economical solution for difficult to treat mining influenced wastewaters containing selenium and/or other metals and inorganics.

Bio:
Ola Opara is the R&D Manager at Inotec. With over 5 years of experience, she directs the Bioprocess Development Laboratory, which focuses on testing and implementation of water treatment technologies in the mining industry. Ola has been actively involved in development of an Electro-Biochemical Reactor technology, from bench and pilot-scale tests to a full-scale implementation. She has published papers in peer-reviewed and trade journals, and presented her research at the Society for Mining, Metallurgy, and Exploration (SME) conferences. Ola has a Ph.D. in environmental engineering from a joint graduate program at the Department of Metallurgical Engineering and the Department of Civil Engineering, University of Utah. She currently holds an Adjunct Assistant Professor position at the University of Utah, where she teaches classes on energy resources, water issues and sustainability.

ADVANCES IN GROUNDWATER REMEDIATION AND MODELING FOR MINING-RELATED CONTAMINANTS

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Abstract:
Contamination of groundwater by metals and radionuclides such as uranium is prevalent at Department of Energy sites. Significant effort has been applied to developing remediation and management approaches for these plumes, much of which is relevant to mining sites. Geochemical manipulation technologies to create permeable reactive barriers or for source treatment can be important components of addressing contaminant plumes. Several examples will be discussed to provide technology information and design factors. While it is important to evaluate individual technology performance, recent efforts have highlighted the importance of understanding natural attenuation processes and use of appropriate enhancements to these processes as a remediation strategy. With recognition of the complexity of many sites, adaptive remediation management and the associated predictive assessments and monitoring approaches advancements have been made. These remediation strategies will be discussed in the context of mining site applications.

A key element for successful groundwater remediation is developing a suitable conceptual-model-based understanding of the site and applying this understanding to developing the remediation strategy. For instance, field and laboratory studies conducted at a shallow former uranium/vanadium mill tailings site and a deep uranium in situ recovery site have demonstrated that biostimulation of indigenous microorganisms can effectively remove uranium, as well as vanadium and selenium from groundwater. Remedy design elements were based on understanding of site-specific conditions, including information about electron acceptors and microorganisms present and information about the biogeochemistry response to the biologically-mediated reactions. Field-scale coupled-process modeling was applied to provide a systematic and mechanistic framework for understanding the interplay of geochemical and biological reactions as a basis for the restoration design strategy. These examples of recent advances in remediation approaches related to Department of Energy efforts, highlighting the uranium mill tailings site as a case study, will be discussed in the context of potential groundwater remediation and modeling applications associated with mining sites.

Bio:
Mr. Truex has 22 years of experience at Pacific Northwest National Laboratory in remediation research and field applications. His experience includes providing clients with technical support for remediation decisions through technology assessments, applications of numerical fate and transport modeling, and feasibility and treatability assessments. He specializes in evaluation and application of in situ remediation and attenuation-based remedies. Field experience includes work at U.S. Department of Energy, U.S. Department of Defense and private remediation sites.

HYDROLOGIC AND WATER-QUALITY EFFECTS OF THE DINERO TUNNEL BULKHEAD, SUGAR LOAF MINING DISTRICT, NEAR LEADVILLE, COLORADO: IMPLICATIONS FOR MONITORING REMEDIATION

Katherine Walton-Day[1] (*presenting author*)**, Taylor J. Mills**[2]**, Kato T. Dee**[3]**, Craig Bissonnette**[4] **and Melissa Smeins**[5]

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Abstract:

Dinero tunnel is an abandoned, draining mine tunnel located in the Sugar Loaf Mining District near Leadville, Colorado, and is a major contributor to zinc and manganese loads in Lake Fork Creek, a tributary to the Arkansas River. Consequently, in 2009, a bulkhead was installed in Dinero tunnel to reduce mine drainage and improve water quality and aquatic habitat downstream in Lake Fork Creek. A spatially detailed monitoring program enabled characterization of hydrologic and geochemical changes resulting from bulkhead emplacement. These changes included increased discharge and decreased water quality (lower pH, and higher zinc and manganese concentrations) in the two surface drainages adjacent to the ridge containing Dinero tunnel and its bulkhead. In addition, similar changes also occurred in Nelson tunnel, another abandoned mine tunnel that is likely hydrologically connected to Dinero tunnel via a mineralized vein, but not by mine workings. In spite of this local water-quality degradation, bulkhead emplacement caused reductions in discharge and metal loading at Dinero tunnel sufficient to improve water quality downstream in Lake Fork Creek except during extreme high flow. Sustained or increased water-quality degradation in Nelson tunnel and in the drainages adjacent to Dinero tunnel could decrease or negate the improvement that has occurred in Lake Fork Creek. Continued water-quality monitoring can help provide information about the balance between the positive and negative water-quality effects of the bulkhead that, if necessary, can be used to make decisions about potential future remediation actions. Although the study is specific to Dinero tunnel, the monitoring approach and the results emphasize how detailed hydrologic and water-quality monitoring of remediation provides information about the sometimes unanticipated effects of remediation. This information can be used to assess the effectiveness of remediation and also inform future decisions about additional remediation actions, if necessary.

Bio:

Katie Walton-Day holds bachelor's (Smith College), and master's and doctoral degrees (Colorado School of Mines) in geology. After a brief stint in the metal-exploration industry, she joined the U.S. Geological Survey (USGS) in 1983 and is currently a research Hydrologist. During her USGS career she has focused on understanding metal transport and transformation in historic and active mining areas and in understanding the environmental effects of remediation of mine sites. She currently leads the Hard Rock and Uranium Mining Project in the Toxic Substances Hydrology Program at USGS.

IN-SITU NITRATE AND SELENIUM REDUCTION/STABILIZATION WITHIN COAL WASTE ROCK: BENCH-SCALE EVALUATION

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Abstract:
The weathering of coal mine waste rock releases selenium and other co-contaminants, such as sulfate and iron, into the seepage waters. Additionally, various levels of nitrate are released into these waters from residual blasting compounds. Since nitrate is the preferred electron acceptor in nitrate and selenium containing waters, effective management approaches for water treatment should include in situ denitrification treatments to reduce nitrate loads. In situ denitrification treatment also holds promise for significant selenium reduction and stabilization within the source materials; both of which could significantly reduce active treatment CAPEX and OPEX costs.

To reduce treatment costs, especially where higher nitrate concentrations are present, INOTEC has proposed a combined nitrate/selenium management strategy for water treatment at coal mining sites. In situ nitrate reduction has been successfully implemented at full-scale at several U.S. gold mining sites. For example, amended Electro-Biochemical Reactor (EBR) water treatment system effluents have been used to inoculate waste rock in place and waste rock as it is mined and placed in depositories. This approach has a potential for both immediate and long-term contaminant reductions to active treatment systems, along with reduced active treatment costs.

A column testing program for coal mining waste rock was designed based on screening results obtained. Three bench-scale columns were constructed with the following goals: 1) EBR effluent, treating mine waters, was used to produce an amended microbial inoculum for the in-situ column nitrate/selenium reduction tests; 2) a control, down-flow column filled with coal waste rock source materials was used to determine baseline selenium and nitrate elution rates; and 3) down-flow columns filled with coal waste rock source materials was inoculated periodically with EBR amended effluents to evaluate in-situ denitrification and selenium reduction/stabilization.

Average nitrate concentration in the control column effluent was 20 mg/L, while it was below the detection limit in the EBR inoculated column effluent. Average selenium concentration in the control column effluent was 25 ug/L, with initial concentrations as high as 33 ug/L and stabilizing with time at around 20 ug/L. The average Se concentration in the EBR effluent inoculated column was 2.7 ug/L.

The holistic approach proposed by the INOTEC team includes integration of source control measures (in-situ nitrate reduction and selenium stabilization) and active treatment processes for a comprehensive water flow management. Active EBR bench-scale and onsite pilot-scale treatment systems were used to treat five British Columbia coal mine wastewaters; influent Se concentrations ranged from 35 μg/L to 531 μg/L. Se treatment targets for the tested waters ranged from 5 to 10 μg/L. Mean EBR effluent Se concentrations ranged from 0.5 μg/L to 1.4 μg/L. Average influent NO_3-N concentrations varied between 11 and 170 mg/L and were removed to below 1 mg/L in all the performed tests.

The test data demonstrate that a holistic approach using the in-situ reduction/stabilization and the active treatment using the EBR technology is an effective nitrate and Se removal option for British Columbia's coal-mining wastewaters.

Bio:
Ola Opara is the R&D Manager at Inotec. With over 5 years of experience, she directs the Bioprocess Development Laboratory, which focuses on testing and implementation of water treatment technologies in the mining industry. Ola has been actively involved in a development of an Electro-Biochemical Reactor technology, from bench and pilot-scale tests to a full-scale implementation. She has published papers in peer-reviewed and trade journals, and presented her research at the Society for Mining, Metallurgy, and Exploration (SME) conferences. Ola has a Ph.D. in environmental engineering from a joint graduate program at the Department of Metallurgical Engineering and the Department of Civil Engineering, University of Utah. She currently holds an Adjunct Assistant Professor position at the University of Utah, where she teaches classes on energy resources, water issues and sustainability.

Session 12: Water Treatment (cont.)

IRON MOUNTAIN MINE SUPERFUND SITE – LONG TERM O&M CHALLENGES

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Abstract:
Nearly 100 years of mining at the Iron Mountain Mine Site in Shasta County, California resulted in multiple waste rock and tailings piles, extensive fracturing of the formations overlying extensive mine workings and remaining sulfide ore bodies, and created sinkholes, seeps and contaminated sediments in adjacent water bodies, particularly the Sacramento River. The extensive workings and fractured rock create extremely effective pathways for water and air to reach the massive sulfide deposits, which are oxidized and produce mining-influenced water (MIW), with pH as low as -3.6 and released heavy metals averaging 10,000 pounds of iron, 650 pounds of copper, and 1,800 pounds of zinc per day into the surrounding drainages and water bodies before remediation reduced the metals loading by more than 97 percent.

The site remedy consists of five major components: 1) MIW collection systems consisting of sumps, drains in the Richmond and Lawson Adits, extraction wells and a surface water retention reservoir and surface water controls; 2) MIW conveyance systems consisting of pipelines carrying MIW to the Minnesota Flats Treatment Plant; 3) clean water diversion systems; 4) mine waste disposal facilities comprised of Brick Flat Pit, various waste rock cells, and a confined disposal facility used for dredged precipitates, which formed in the Spring Creek Arm of Keswick Reservoir; and 5) the MIW treatment plant, which is a lime neutralization/high density sludge facility at Minnesota Flats. All of these components experience extremely acidic conditions, widely varying temperatures and flow volumes, due to intense high-runoff storm events, and need to address the expected generation of MIW for the next 1,800 years.

Unusual O&M issues at the site are comprised of: a) the formation of mineral precipitates in MIW conveyance pipelines due to microbial Fe(II) oxidation of the MIW, within periods of less than an hour, resulting in reductions of up to 40 percent of the pipe capacity and causing spills; b) the accelerated deterioration of the urethane liner for the Upper Spring Creek Diversion, which diverts uncontaminated water to Flat Creek, due to an elevation drop of 280 feet along its route, which generates flows of 70 ft/sec versus the typical 15 ft/sec design flows for such systems; c) the significant loss of filtrate from the lined Brick Flat Pit, used to store the HDS sludge from the treatment plant, implying that the land fill is leaking into mine workings below; and d) the ongoing deterioration of the concrete ore chute plugs in the Richmond Adit along with the location of the Lawson Adit in the Boulder Creek landslide, both of which are key parts of the MIW collection systems.

Unique to Iron Mountain is the O&M issue of the ongoing deterioration of the MIW collection system in the Richmond Adit. The Richmond Adit, characterized by pH ranging from 0.6 to 1.4 (and lower in the stopes above), was rehabilitated in 1989-1990 and 2001-2003, resulting in the current system of the 5-Way catch basin (sump) where four haulage drifts intersect, located approximately 1,400 feet inside the adit portal. Timber and stainless steel dams were installed in the drifts to collect MIW and muck, which is the term for the waste rock, mine debris and the fine-grained, silty and pyritic quick material found throughout the workings. In portions of the haulage drifts 22 ore chutes from the mine stopes above were plugged with concrete and shotcrete due to past surges of up to 3,000 gallons of extremely acidic MIW and mine debris. Current seepage from the failing ore chute plugs ranges from 1 to 2 gallons per minute (gpm) with the more severely compromised plugs seeping at 5 to 10 gpm. EPA is working to address the problems through the creation of an electronic database with 3-D mapping based on historical maps to better understand the location of MIW in workings and driving forces in the structural integrity of the mine.

Bio:
James M. Sickles is a Remedial Project Manager in the Superfund Division of the U.S. Environmental Protection Agency in Region 9 located in San Francisco, California. In this role, he oversees Superfund projects such as the operations and management oversight of the Iron Mountain Mine Site and is leading the investigation and remediation of the Klau/Buena Vista Mines Site. As a geologist he has worked in mineral and petroleum exploration and started in environmental geology in 1990 in consulting and working for the EPA since 2002. Past environmental work has involved investigation and cleanup ranging from closing military bases to abandoned mine sites. James has B.A. degree in geology from Sonoma State University (1970) and M.Sc. from the University of California, Davis (1974) and is a Certified Geologist in the State of California since 1992.

CHARACTERIZATION AND REMEDIATION OF IRON(III) OXIDE-RICH SCALE IN A PIPELINE CARRYING ACID MINE DRAINAGE AT IRON MOUNTAIN MINE, CALIFORNIA, U.S.A.

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Abstract:
A pipeline carrying acid mine drainage (AMD) to the treatment plant at the Iron Mountain Mine Superfund Site (California, U.S.A.) has developed substantial scaling over the past several years, resulting in spillage of AMD and requiring frequent and costly clean-out. The objectives of this work

are to characterize the pipe scale composition, identify biogeochemical processes leading to its formation, and identify possible strategies to prevent or retard its formation in the pipeline. Samples of the scale and AMD water samples from five points along the pipeline were collected prior to clean-out during a low-flow period in August 2012. Additional AMD samples will be collected at various times during high-flow conditions to evaluate seasonal variation in water chemistry and possible effects on scale formation. The mineralogy and microbial community of the scale samples were characterized. The scale is composed predominantly of hydrous ferric oxides; goethite is present according to powder X-ray diffraction along with poorly crystalline phases, primarily schwertmannite. Additional solid phase characterization is planned using other methods. For the low-flow sampling, the influent AMD into the pipeline where scale had formed had a pH of 2.6 and contained 25 mM Fe(II). Measurable Fe(II) oxidation (approximately 30 percent) was observed as the water flowed from the start of the pipeline to the treatment plant, taking approximately one hour to travel five km. The pipeline was lined with scale 2-7 cm thick, which had accumulated over 3-4 years. Laboratory batch experiments with fresh AMD from the site showed that scale formation was caused by microbial oxidation of Fe(II) to Fe(III), and that the rate of Fe(II) oxidation increased once scale had been established. A biogeochemical model using PHREEQC was developed to simulate the rates and processes involved in scale formation. Potential remediation options to prevent scale formation are to lower the pH of the influent AMD by continuously mixing it with water from the Richmond portal (approximate pH 0.5-1.0) or to periodically flush the pipeline with Richmond portal water. The potential viability of these options will be evaluated in laboratory batch experiments with AMD from the pipeline and the Richmond portal, mixed with scale removed from the pipeline.

Bio:

Kate Campbell is a biogeochemist with the National Research Program of the Water Mission Area, U.S. Geological Survey, Boulder, Colorado. She received a B.S. in chemistry from Georgetown University and an M.S. and Ph.D. in environmental engineering from the California Institute of Technology. She worked on bioremediation of uranium for her postdoctoral work at the USGS in Menlo Park, California before joining the chemical modeling of acid waters group. Her research focuses on abiotic and biotic redox chemistry of natural waters, including acid rock drainage, geothermal waters, and groundwaters; biogeochemical modeling of kinetically controlled processes, especially iron, arsenic, antimony, and uranium redox chemistry; coupled biotic-abiotic controls on microbial ecology in geothermal and mining environments; and novel sampling techniques for redox processes for field application.

TACKLING AMD, MINING IMPACTED GROUNDWATER, PRIVATE MINE OWNERSHIP IN A SUPERFUND SITE THAT SPANS THE PANHANDLE

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Abstract:

The Bunker Hill Mining and Metallurgical Complex Superfund Site is located within one of the largest and most productive historical mining districts in the world. The Site, which spans the panhandle of Idaho and extends along the Spokane River in Washington, resulted from historic disposal practices that led to the mining-related hazardous substances being dispersed in nearly every

aspect of the environment. The facility was placed on the NPL in 1983 and has been undergoing remediation for several decades. During this time excellent progress has been made from both an aesthetic and risk reduction standpoint but many more years of work are necessary to fully achieve the cleanup goals for human health and water quality standards.

Through the bankruptcy of the Gulf Resources and Chemical Company in 1983 and subsequent PRPs, EPA ended up being responsible for the defunct Bunker Hill Lead Smelter Complex, which included a zinc plant, acid, fertilizer and phosphorus plants and the Central Treatment Plant (CTP). EPA has been operating that plant since 1995, which now treats acid mine drainage from the Bunker Hill Mine at a flow rate of 2 million gallons per day. As a result of the cleanup actions undertaken by EPA and Idaho Department of Environmental Quality to address exposure to lead and other heavy metals, there has been a significant decline in blood lead levels to national averages. However, due to the direct discharge of heavy metals into the environment from the Mine and the construction of a 220 acre Central Impoundment Area (CIA) by the Bunker Hill Company into the channel of the South Fork of the Coeur d'Alene River (SFCDR), significant loading of dissolved metals continues to occur. This area accounts for approximately 40 percent of all the zinc metal loading in the Upper Basin and is the most significant metal loader of any other reach or tributary to the SFCDR.

In 2012 EPA issued the Upper Basin Record of Decision Amendment (UB RODA) that called for upgrading the aging and outdated CTP, which was originally constructed by the Bunker Hill Company in 1974 for the treatment of AMD from the Bunker Hill Mine and industrial discharges from the Bunker Hill Industrial Complex. The selected remedy of the RODA called for the collection of groundwater that comes into contact with contaminants under the CIA and the alluvial aquifer that releases dissolved metals to the SFCDR. EPA will treat this water in addition to that from the Bunker Hill Mine in an upgraded CTP that meets current required discharge criteria. In addition to the technical challenges add in a mine that is owned and operated by a private party, who has had history of being non-cooperative, and that has significant fractures at the surface that results in an entire sub-drainage completely infiltrating into the mine and seasonally increasing the flows from the mine by a factor 2 to 3.

This presentation will provide a little history on this famous and storied site and EPA ownership and management of a treatment plant. It will also provide an in depth look at the 2MGD+ Acid Mine Drainage water quality, the groundwater collection system being designed that will almost double the flows to be treated at the CTP, and recent optimization study and value engineering exercise that were pursued to ensure the most cost effective remedial action.

Bio:
Ed Moreen is a licensed Civil Engineer in Idaho and a 1994 graduate of Washington State University in civil/environmental engineering. Ed has worked for the EPA since 2003. Prior to joining EPA, he was employed by the U.S. Army Corps of Engineers as a project engineer working at the Hanford Nuclear Reservation, civil works projects and Bunker Hill Superfund Site. Ed's current responsibilities include management and upgrade of the Central Treatment Plant in Kellogg and investigating contaminated sediment transport in the Lower Coeur d'Alene River Basin. Ed has coauthored several formal presentations and posters including: Channel-Floodplain Sediment Dynamics and the Redistribution of Contaminated Mine Wastes in the Lower Coeur D'Alene River, Idaho – River Restoration Northwest, January 2012; Channel-Floodplain Sediment Dynamics and the Movement of Contaminated Mine Wastes in the Lower Coeur D'Alene River, Idaho – ASCE, Water Resources Congress 2014; Bunker Hill Mining and Metallurgical Complex Superfund Site Transformations of the Landscape – National Association of Remedial Project Managers 2012. In

2013 Ed was a member of recipient teams for The Superfund Team of the Year and National Notable Achievement Award for Community Engagement. He was personally awarded the 2014 Silver Eagle Award "Communicator of the Year Award" for EPA Region 10.

Presentation Abstracts
and
Speaker Bios

<u>Thursday, August 14, 2014</u>

EXTRACTION OF USEFUL RESOURCES FROM MINING-INFLUENCED WATER (MIW)

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Presented by Kate Campbell, Ph.D.
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Abstract:
Mining-influenced water such as acid mine drainage could be a source of hydrogen, metals, and sulfur for energy and commercial products. For example, discharge from the Richmond Tunnel at Iron Mountain, California and the Reynolds adit at the Summitville mine, Colorado, each release between 30 and 200 metric tons per year of dissolved copper. Instead of treating this drainage water with lime or limestone to produce an uneconomic sludge, the copper and other metals could be recovered and recycled into copper resources for commercial products. The challenge is (1) to separate the valuable components from each other in a manner that is efficient and economically viable, (2) to stockpile components in an environmentally safe manner, and (3) to transport the components to an industry that can use them as source material for production. Every site must be assessed individually to ascertain what types of extraction, stockpiling, and transport are most appropriate.

From a brief literature review, potential extraction techniques include electrochemical, microbiological, and evaporative methods, as well as precipitation, solvent extraction, ion exchange, and reverse osmosis. Many of these techniques have been tried before with variable and usually limited success either from an economic or technical perspective. However, from the point of view of getting aqueous contaminants out of the environment and into recycled production, these technologies may be considered effective. With considerable emphasis on sustainable practices today, these techniques need to be evaluated, improved, and further developed alone and in combination for both inactive and active mine sites.

Electrochemical techniques offer considerable versatility but can suffer from competing electrode reactions and high energy demands depending on the type of cells used. Copper cementation, which takes advantage of electrochemical replacement of scrap iron by copper, is a very old, efficient, and inexpensive technique that could be used at Iron Mountain and Summitville and many other mine sites without applying electrical current. At many mine sites, tailings and/or waste-rock piles could be run through a copper cementation or solvent extraction plant. With the application of current in specially designed electrochemical cells, hydrogen gas can be obtained as well as selective removal of metals depending on pH and composition of the solution. Fuel cells can be built based on iron oxidation and oxygen reduction.

Microbial bioreactors have been built for sulfate reduction to produce aqueous sulfide, which can be used to precipitate metal sulfides. Recent investigations have shown that microbial sulfate reduction can be accomplished at relatively low pH (circa 3-4). The metal sulfides can then be transported to smelters for metal recovery. Bioreactors also oxidize dissolved ferrous iron and precipitate ferric iron. With careful control of pH, sulfate concentration, and ratios of ferrous to ferric iron, different iron phases can be precipitated that include schwertmannite, jarosite, goethite, and magnetite with variable recovery of other metals.

Most sites considered for possible resource extraction of MIW will require a combination of several techniques. For inactive mines, the capital outlay for an optimal design could be expensive and difficult to fund. However, for active or planned mines, resource-recovery techniques could be introduced to decrease environmental contamination, provide an additional source of income, and reduce future liability.

Bio:
Kate Campbell is a biogeochemist with the National Research Program of the Water Mission Area, U.S. Geological Survey, Boulder, Colorado. She received a B.S. in chemistry from Georgetown University and an M.S. and Ph.D. in environmental engineering from the California Institute of Technology. She worked on bioremediation of uranium for her postdoctoral work at the USGS in Menlo Park, California before joining the chemical modeling of acid waters group. Her research focuses on abiotic and biotic redox chemistry of natural waters, including acid rock drainage, geothermal waters, and groundwaters; biogeochemical modeling of kinetically controlled processes, especially iron, arsenic, antimony, and uranium redox chemistry; coupled biotic-abiotic controls on microbial ecology in geothermal and mining environments; and novel sampling techniques for redox processes for field application.

LARGE-SCALE TREATMENT OF AGRICULTURAL EFFLUENTS USING MINE DRAINAGE RESIDUALS

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Abstract:
Disposal of the residuals generated by neutralizing acid mine drainage often constitutes a significant fraction of the operating costs of mine drainage treatment plants. Alternative uses for these waste iron and aluminum oxides would not only decrease operating costs for mine drainage treatment plants, but would also open up markets for any newly developed valuable by-products. One promising possibility for the reuse of these waste materials is the treatment of agricultural wastewaters for the removal of phosphorus (P). Release of P from animal operations, crop production, and aquaculture growers has had deleterious impacts on receiving water bodies worldwide, including the Chesapeake Bay and the Gulf of Mexico. We are testing this approach to remove P from a recirculating aquaculture operation using a large-scale (over 200,000 gallons per day) treatment plant at the Leetown Science Center, in Kearneysville, West Virginia. In this plant, mine drainage residuals from the Blue Valley mine drainage treatment plant, near Brandy Camp, Pennsylvania, are used in gravity flow contactors as a sorbent to remove soluble P from the wastewater. The media was prepared by air drying the residuals as-received from the filter press at the mine drainage treatment plant, followed by screening and crushing of oversize material to give a particulate media with a size range of 5 to 30 mesh (4 to 0.6 mm). Saturation of the media with P

depends on influent flow rate and P concentration, and can take from 10 to 60 days. After the sorbent has reached saturation, the P is stripped and the media regenerated using a 1.0 M sodium hydroxide solution, followed by a tap water rinse, and then returned to service. The P can be precipitated from the stripping solution by adding calcium chloride, resulting in the formation of hydroxyapatite, a potentially saleable fertilizer product, thus recycling the P content of the wastewater. The purpose of this demonstration plant is to show the feasibility of the process at an operational scale.

Bio:
Philip L. Sibrell, Ph.D. is a Research Engineer with the U.S. Geological Survey, at the Leetown Science Center in Kearneysville, WV. He is currently investigating the application of acid mine drainage residuals for the recovery of phosphate from agricultural and municipal wastewaters. Prior to his employment with the USGS, Dr. Sibrell worked at the U.S. Bureau of Land Management, the U.S. Bureau of Mines, and in the mining industry, as an engineer conducting research in resource recovery and environmental restoration. He is also a Professional Engineer, and has over 100 publications and presentations. He received his B.S. from the Colorado School of Mines, and M.S. and Ph.D. from the University of Utah, all in metallurgical engineering.

JORDAN RIVER & MIDVALE SLAG SUPERFUND SITE-BENEFICIAL USE

Erna Waterman[1] and Marian Hubbard Rice[2] (*presenting author*)
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Abstract:
The U.S. Environmental Protection Agency (EPA) utilized a variety of skill, knowledge, though grants, contracts and graduate student contract work to restore and create an ecosystem that enhances adjacent business and residential areas.

About five years ago, most of the onsite repository and redevelopment of the Midvale Slag Superfund Site was underway. Today over 70 percent of the former mine smelting site is redeveloped for commercial and residential purposes, including a light rail corridor. Also, about five years ago EPA began studies, plans and design/build to improve the adjacent Jordan River corridor using small contracts with small and veteran-owned businesses, direct hire of graduate students as well as grant funds for the local county. In addition, the USGS was hired though an interagency agreement to investigate the river energy and flow to assess the best remedy for replacement of a damaged and torn sheet pile dam, which crossed the river.

Plant and soil studies conducted by graduate students as well as input from local experts on invasive plant treatment helped to make the eventual three-year phased effort successful in establishing current ecological restoration. Currently, specific endpoint goals are being established to lead to even further improvements with minimal additional funding. In short, this presentation will be a guide to others who hope to do more with less (less water, less maintenance), to apply to other areas blighted by mine/smelter operations in the past.

Bio:
Marian Hubbard joined the Salt Lake County Engineering Division, Watershed Planning and Restoration Program in 2007 as a Watershed Scientist and Planner. She has a bachelor of science degree in biology from Portland State University, a M.P.A in natural resource management from University of Utah, and is currently working on a Ph.D. at University of Utah. Marian's core responsibilities include, but are not limited to, collaboration with agencies, local stakeholders, and the general public; writing, updating and implementing the Salt Lake Countywide Water Quality Stewardship Plan (WaQSP); performing ecosystem restoration; and water quality monitoring in the Jordan River Watershed. Prior to the County, Marian worked in the Portland, Oregon Metro area in environmental management. After which she moved to Utah to work with the U.S. Forest Service performing ecosystem restoration in the beautiful Strawberry River Watershed.

Session 14: Prediction and Modeling

APPROACH FOR ESTIMATING A PROBABLE RANGE OF PIT LAKE CONCENTRATIONS FOR MINE PITS WITH SULFIDE WALL ROCK

Sarah Doyle[1], Cory Conrad[1], Colleen Kelley[2], Steve Lange[1] (*presenting author*)**,**
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Abstract:
Environmental impact statements and pollution-control permits for modern hardrock mines require quantitative estimates of future water quality that are consistent with established conceptual models, transparent for reviewers, and bracket reliably-predicted concentrations. We present here a model of water-quality evolution in open-pit mine lakes designed to address these permitting requirements. The model includes solute loading from wall-rock runoff, oxidation products released from sulfide minerals exposed in pit walls, groundwater, and catchment runoff. Sulfate is released directly by oxidation of sulfide minerals in wall rock subject to reaction rates, sulfide concentrations in wall rock, and properties of the blasted zone of the pit walls. Estimation of the quantity of secondary solutes released during sulfide oxidation (heavy metals and other acid-soluble constituents) is bounded using geochemical tests that simulate minimal oxidation (synthetic precipitation leaching procedure), moderate oxidation (humidity cells), and complete oxidation (peroxide-oxidation "net-acid" generation extraction). Water quality calculations use GoldSim software and Monte Carlo simulations. Probabilistic variables, derived from testing of either onsite material or analog studies, include: 1) oxidation rate in reactive (i.e., <~25 mm) fragments, 2) quantitation of the fraction of reactive fragments in wall rock, 3) thickness of wall-rock blast zone, 4) secondary solutes released by oxidation, and 5) quantitation of the fraction of wall rock in contact with runoff. Prediction of the evolving water composition is then refined by estimating precipitation of selected mineral phases using the geochemical equilibrium model PHREEQC. By presenting model inputs as ranges and thereby bracketing the estimated pit lake concentrations, this method may produce more credible output and thus streamline the regulatory review process associated with pit lake predictions.

Bio:
Steven Lange is the Director of the Geochemistry, Groundwater and Surface Water Group at Knight Piésold USA. He brings over 35 years of experience related to investigation, evaluation, and remediation of mining and industrial sites throughout the United States and internationally with a focus on projects in EPA Regions 6, 7, 8 and 9. His current experience is as a consultant for the mining industry in the fields of geochemical and hydrological studies, ARD assessments, geochemical modeling, geology, hydrogeology and groundwater modeling. He has conducted baseline geochemical evaluations, ARD assessments, and geochemical modeling for feasibility, operational, closure, and remedial investigation studies at mine sites in the USA, Canada, Europe, South America and the Philippines. He has conducted baseline studies, MARSSIM compliant surveys of sites with elevated radionuclides, geochemical modeling of uranium and radium transport in groundwater impacted by mining and processing operations, assisted in the design of closure and reclamation plans, and conducted post closure verification surveys of air, soil and water. Steven has several publications on site investigation and modeling and has a B.S. in geology and an M.S. in geochemistry from Kansas State University at Manhattan, Kansas.

ASSESSING POTENTIAL IMPACTS FROM UNDERGROUND MINE DEWATERING IN THE GALLUP, DAKOTA, AND WESTWATER CANYON AQUIFERS WITH A BASIN-WIDE GROUNDWATER FLOW MODEL

John M. Sigda, Ph.D.[1] *(presenting author)*, **Cheng Cheng, Ph.D.**[2] **and Cynthia Ardito, P.H.**[3]
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Abstract:
Energy Fuels Resources Incorporated (EFRI) is proposing to construct the new Roca Honda underground uranium mine at the eastern edge of the Grants uranium mineral district in the southern San Juan Basin. Developing the Roca Honda mine workings will require temporary dewatering in three regional aquifers: Gallup Sandstone, Dakota Sandstone, and Westwater Canyon Member of the Morrison Formation during the course of the 13-year mine plan. INTERA was asked to assess potential impacts from dewatering to the basin's limited water resources as input to a U.S. Forest Service Environmental Impact Statement (EIS) and a mine dewatering permit application to the New Mexico (NM) State Engineer.

In collaboration with the Roca Honda team and EIS hydrology technical group, INTERA developed, calibrated, and applied a regional three-dimensional MODFLOW SURFACT groundwater flow model of the San Juan Basin to estimate mine dewatering rates and evaluate potential effects of mine dewatering on wells, springs and perennial rivers. Founded on the U.S. Geological Survey (USGS) model of steady-state groundwater flow in the San Juan Basin prior to historical uranium mining (Kernodle, 1996), the Roca Honda groundwater flow model simulates the current and historical groundwater conditions within the Gallup, Dakota, and Westwater aquifers. The model covers an area of approximately 21,000 square miles, primarily in New Mexico with smaller portions in Colorado, Utah and Arizona. Built using newly available data on aquifer structures, properties, and stresses, the Roca Honda model is the first to be calibrated to the dewatering stresses from historical uranium mining in the Grants Uranium Mineral Belt district. The transient calibration, which spans the mining and post-mining periods from 1930 to 2012, closely

matches the head declines observed from historical dewatering and the subsequent observed rebound.

The Roca Honda model was successfully applied to evaluate potential impacts to wells, springs, and rivers, including Horace Springs and the Rio San Jose. The model was accepted by the EIS hydrology technical group for use in the draft EIS, which was published in early 2013. The dewatering and impact assessment models helped EFRI secure the first mine dewatering permit (December 2012) issued by the NM State Engineer since passage of the state's Mine Dewatering Act in 1978.

Bio:
Dr. Sigda serves as Senior Hydrogeologist at INTERA, Inc. in Albuquerque, New Mexico. He has 30 years of experience in quantitative hydrology in saturated and vadose zones, mine hydrology, flow and transport modeling, groundwater remediation, field and lab measurement of hydraulic properties, geologic controls on hydrologic processes, geostatistics, and water supply and sanitation in developing countries. Dr. Sigda has provided technical expertise to the public and private sectors with projects located in California, Texas, Nevada, New Mexico, Minnesota, Indiana, Massachusetts, Rhode Island, New Jersey, Washington and Australia. He also spent six years promoting improved water supplies, sanitation, and child survival and development in Kenya and Tanzania. He has published in Water Resources Research, Geophysical Research Letters, American Geophysical Union Monographs, and Applied and Environmental Microbiology. Dr. Sigda has an engineering A.B. from Harvard College and M.S. and Ph.D. degrees in hydrology from New Mexico Institute of Mining and Technology.

CONTAMINATED SEDIMENT FATE AND TRANSPORT MODEL IN THE TRI-STATE MINING DISTRICT

Mehran Niazi, Ph.D.[1] *(corresponding author)*, **Joseph Schubauer-Berigan, Ph.D.**[2] **and Mohamed Hantush, Ph.D.**[3]
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Presented by Douglas Grosse, U.S. Environmental Protection Agency
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Abstract:
The Tri-State Mining District (TSMD) of southwestern Missouri, southeastern Kansas, and northeastern Oklahoma has been the center of mining activities to extract ores containing lead, zinc, cadmium and other metals for decades. Transport of remaining debris from mining activities via overland runoff led to the listing of Spring River as an impaired surface water. A Geospatial Statistical Platform (GSP) as well as the Soil and Water Assessment Tool (SWAT) model was developed and calibrated as part of an integrated modeling system to investigate fate and transport of heavy metals in the overland flow and stream network for The Spring River Watershed comprising approximately 6,000 km^2. The primary goals of developing the GSP and SWAT model were a) to identify hotspots for heavy metals where concentration of the metals exceeds the standard

levels, and b) to estimate annual average mass flux for sediment and heavy metals for the Spring River and its tributaries in order to determine how many years will be required for natural recovery to achieve reduced toxicant level in the sediments and water column necessary to minimize the risks to human health and the environment.

To do this, several GIS layers from federal and state counterparts were utilized to develop the GSP and two USGS gages, Spring River and Shoal Creek, were selected to calibrate the SWAT model for flow, total suspended sediment (TSS) and heavy metals (lead, cadmium and zinc) on yearly and monthly basis from 2003 to 2010. While the results shows a satisfying goodness of fit (R^2 = 0.95 yearly and R^2 = 0.73 monthly) for flow, the results for sediment is fair (R^2 = 0.68 yearly and R^2 = 0.35 monthly) and the calibration for heavy metals is ongoing. Karst formation of geology in the watershed could be the primary reason for achieving the lower R^2 values.

Bio:
Douglas W. Grosse has a B.A. in English literature from Ohio University and an M.S. in environmental engineering from the University of Cincinnati. He has worked as an Environmental Engineer at the U.S. Environmental Protection Agency (EPA) in Cincinnati, Ohio for the past 35 years. Mr. Grosse is currently working in EPA's National Risk Management Research Laboratory (NRMRL) as a Senior Environmental Engineer. Past experiences have included: in-house research at EPA's pilot plant facilities in wastewater and hazardous waste research; pilot facility manager and project officer (Center Hill Laboratory); Superfund Innovative Technology Evaluation (SITE) Program; RCRA corrective action coordinator and technical assistance in Superfund, RCRA and treatability study assistance, as an aqueous treatment specialist, Acting Branch Chief, Technology Transfer Branch, and ETV/AMS Center PO. Currently, Mr. Grosse is working in the Remediation and Redevelopment Branch and Engineering Technical Support Center, as a specialist in site remediation and technical support.

Session 15: Closing Session

A SEMI-PASSIVE BIOREACTOR FOR TREATMENT OF A SULFATE AND METALS CONTAMINATED WELL FIELD, NACIMIENTO MINE, NEW MEXICO

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Abstract:
The use of semi-passive sulfate-reducing bioreactors to treat metals contaminated water has advantages over active treatment technologies. The operational requirements are reduced when compared with conventional lime treatment, which typically requires daily monitoring. Semi-passive systems require more labor when compared to traditional passive bioreactors but can treat water with higher concentrations of metals and can operate for longer periods of time without replacement of the matrix due to plugging or depletion of carbon from the matrix. These systems utilized sulfate-reducing bacteria that consume ethanol to reduce sulfate to sulfide and precipitate metals as metal-sulfides. Because alcohols do not freeze under normal site conditions, this carbon and energy source can be metered at specific concentrations to feed the bacteria continuously and

efficiently throughout the year. The majority of the metals are settled and removed outside of the bioreactor in a separate settling pond and a rock matrix with large pore spaces is utilized to reduce the chance of plugging and short circuiting within the bioreactor. The largest and newest semi-passive bioreactor is located at the Nacimiento Mine in New Mexico. This bioreactor treats contaminated ground water that is pumped from 9 wells to the bioreactor. The system has been operating for approximately 4 years with effective sulfate removal and treats iron and copper at concentrations as high as 270 and 120 mg/L respectively. Sulfate is reduced from an average influent concentration of 1,094 mg/L to an average discharge concentration of 556 mg/L with an average removal of 538 mg/L.

Bio:
Tim has a B.S. in biology and a Ph.D. in environmental chemistry from the University of Nevada, Reno where he was also a Research Professor. He is currently manager of TKT Consulting, and Director of Technology at Ionic Water Technologies. He has worked in mining over 24 years and has presented and published over 40 technical papers and presentations. He currently provides consulting and design to private and public clients throughout North America and develops AMD treatment and prevention technologies.

Poster Presentations

USING ICP SPECTROMETRY DATA AND ALKALINITY RESULTS FOR EFFECTIVE SCREENING OF ACIDITY SAMPLES TO IMPROVE LABORATORY EFFICIENCY

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Abstract:
Standard Methods Acidity (SM 2310 B) analysis is a labor intensive analysis requiring the addition of H_2SO_4 until the pH < 4.00, followed by adding H_2O_2, then boiling for 3-5 minutes, cooling and finally adding NaOH to the endpoint (pH 8.5). However, using Standard Methods 2320 B Alkalinity analysis coupled with an ICP spectrometry metals scan, the acidity results can be calculated prior to full analysis to determine if the results have a potential to surpass the reporting limit, reducing the number of samples analyzed for the acidity parameter. A full review of in-house data indicated that samples screened according to the described procedure have comparable results, with reduced total analysis time. The developed screening procedure has been operationally applied at EPA Region IV SESD laboratories since August 2011 and has reduced man-hours spent on acidity analysis by over 50 percent while continuing to provide the reliable, high quality data necessary for Superfund project management.

APPLYING EXPLORATION GEOPHYSICAL METHODS TO MINE WATERS

Jennifer Hare[1] (*presenting author*) **and Norman Carlson**
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Abstract:
Water and water problems are often valid targets for the same electrical and electromagnetic methods that are commonly used in minerals exploration, since water alters the electrical properties of the subsurface. For example, dry subsurface material is more electrically resistive than saturated material, and fresh or low TDS water is often more resistive than contaminated or high TDS water. The geophysical methods we have used to address water problems at mines include galvanic resistivity and induced polarization (IP) in various arrays, time-domain electromagnetics (TDEM or TEM), and controlled source audio-frequency magnetotellurics (CSAMT). Given different environments and goals, each method has advantages and disadvantages.

Examples include the use of CSAMT in monitoring an in-situ copper leaching operation. The leachate is very low resistivity, and zones of leachate are clearly distinguishable as anomalously low resistivity relative to the surrounding materials. Multiple surveys over an 8-year period were useful in verifying fluid flow, as well as in locating fluids that accumulated in unexpected areas.

Similarly, fluids moving through leach pads have been successfully mapped. Flow barriers in pads, which can affect the economics of the operation, have been successfully detected, as well as liner leaks, which can be of significant environmental concern. The CSAMT, TEM, and galvanic

resistivity methods have all been used on leach pads; the choice of method is usually based on the size and thickness of the pads, as well as the surface conditions. For relatively thick pads, in excess of 200 feet, CSAMT provides better lateral resolution at depth than other methods. On pads where electrical contact with the surface is difficult, however, TDEM has been useful, since it also provides resistivity information but uses ungrounded loops of wire to transmit and receive signal.

The ability to acquire resistivity data with an ungrounded system (i.e., without pounding stakes into the ground as electrodes) also allows the TDEM methodology to be used as a floating system on evaporation ponds, for example, or mounted on a wheeled cart to rapidly map levees or benches. Depth of investigation with these mobile systems is more limited, but if the goal of the survey is a better understanding of the upper few tens of feet, TDEM systems have become a very economic mapping and monitoring tool given improvements in electronics and computing power in the last decade.

Acidic mine fluids also provide a good electrical target. Acid mine drainage moving through old, abandoned mine workings has been used to successfully map the old tunnels. In a version of the minerals exploration geophysical method known as mise-a-la-masse, in which an electrode is placed in a low resistivity target (such as an ore body or vein) and a signal is transmitted directly into the target, the target can often be mapped in plan view by measuring the resulting electric fields on the ground surface. By placing an electrode in the acidic fluids flowing from an old collapsed mine, surface measurements were successful in mapping the target tunnel at a depth of 400 feet, and drilling successfully intersected the mine tunnel.

The increasing usage of minerals exploration methods for water and environmental applications is largely the result of improvements in technology over the last 15 years, as field-portable, battery-powered equipment has become more sophisticated. For example, although IP has been one of the primary methods for porphyry copper exploration for many decades, it is only recently that electronics and computing power have improved enough that IP can be acquired on a small scale rapidly enough to be economic for groundwater, environmental and engineering applications.

EVALUATION OF DGT SAMPLERS FOR MONITORING MINING-INFLUENCED WATER

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Abstract:
Diffusive gradients in thin films (DGT) samplers contain gel that accumulates metals from surface water which is later analyzed to determine average metals concentrations over the period of deployment. The DGT samplers are highly portable, simple to deploy and designed to be placed in surface water and left for days or weeks. Tests were conducted to evaluate if commercially available samplers from DGT Research, Ltd. could be used under routine conditions by sampling personnel using the simplest calculations with default values to supplement or replace standard sampling of mining-influenced water at mine sites.

DGT samplers were tested in a tributary stream heavily impacted by adit discharge and runoff from waste rock and containing significantly elevated concentrations of dissolved metals. Samplers were

deployed in pairs to obtain 100 percent duplicate samples. Discrete water samples were collected at the beginning and end deployment of the DGT samplers to obtain benchmark water quality. A second test was conducted in the laboratory using bulk stream water from a slightly impacted site with low concentrations of dissolved metals. DGT samplers were deployed in four parallel tanks under controlled conditions with conventional sampling of the water conducted twice during deployment.

For the DGT samplers placed in the stream, analysis of the duplicate samples attained a relative percent difference (RPD) for metals concentrations ranging from 25 to 60 percent. For the DGT samplers in the tanks, the natural and three duplicate sample results for metals had a relative standard deviation (RSD) ranging from 7 to 36 percent. For precision measurements, RPD was used for pairs, but more than one duplicate allowed the use of the more robust RSD. All but one measurement of precision fell outside the normally acceptable goal of less than 20 percent RPD/RSD. Overall, the precision of the DGT samplers when used to measure metals concentrations was not as good as conventional sampling.

Accuracy of the samplers is more difficult to measure because the gel in the sampler collects free metal ions not bound by ligands in the stream to simulate only the metals that are bioavailable rather than all the metals measured by water sampling. The DGT sampler result should be no greater than the dissolved concentration; however, results for metals concentrations by the DGT method were approximately double the dissolved metals in discrete stream samples. For the laboratory evaluation, metals concentrations by the DGT method were approximately one order of magnitude higher than the dissolved metals concentrations. The accuracy of the DGT samplers was not acceptable and was biased high compared to the discrete water sampling results.

Overall, the DGT samplers did not have good precision and accuracy in these tests compared to conventional water sampling and did not perform well under these conditions at these locations.

ENVIRONMENTAL SITE INVESTIGATIONS UNDER THE CHINO ADMINISTRATIVE ORDER ON CONSENT

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Abstract:
An environmental investigation is being conducted under the Chino Administrative Order on Consent (AOC) to study the possible effects of historical mining and mineral processing activities occurring before current environmental regulations in the area surrounding Chino's operation covering approximately 50 square miles. The Chino AOC was formed in 1994 to protect public health and the environment, and is a voluntary agreement between Chino Mines Company and the New Mexico Environment Department. The chemicals of potential concern are primarily metals. The Chino AOC is divided into the following investigation units (IU) each with their own contaminant sources, transport mechanisms, affected media and exposure pathways: Hurley Soils, Hanover and Whitewater Creeks, Smelter and Tailing Soils, and Lampbright Draw. Following a "CERCLA" type process, the environmental site investigation for each unit typically involves the summary of existing data, identification of additional data needs, remedial investigation of the nature and extent of contamination, probabilistic risk assessment of human and environmental health due

to potential exposure pathways and the length and amount of exposure, feasibility study of remediation alternatives, record of decision, remediation if necessary, completion report, and site maintenance and effectiveness monitoring. An update on each investigation unit will be provided.

Water Treatment

COLUMN STUDY TREATABILITY TESTING FOR IN SITU REMEDIATION OF MINING-INFLUENCED WATER

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Abstract:
As part of an internal research and development program, CDM Smith conducted bench-scale proof-of-principle tests in 2012 for three different mining-influenced waters (MIWs) using a variety of liquid and/or slurried solid substrates. In 2013, CDM Smith continued the treatability testing with laboratory column studies. The goal of the research is to implement *in situ* treatment of MIW within abandoned mine workings and groundwater systems. The use of *ex situ* passive treatment methods for remediation of MIW continues to grow; however, while these methods are sometimes more cost-effective than active treatment, they may have limited applicability due to space requirements, flow rates, and seasonality of MIW discharge. *In situ* MIW treatment has the potential to significantly decrease the amount of space required, treats the contaminant source, and alleviates the issue of fluctuating flow that can cause issues in *ex situ* systems.

In 2013, CDM Smith completed the second year of internal research to determine whether *in situ* remediation is a viable option for treating MIW. CDM Smith completed column studies using a strongly-acidic, high-metal content MIW. Phase 1 evaluated injection of treatment substrates into columns packed with acidic waste rock and pea gravel. Substrates included a guar gum / ChitoRem® suspension, and a mixture of propylene glycol, sodium hydroxide, and inoculum. Several injections were conducted, with continuous pumping of MIW through the columns. Samples were collected and evaluated. Phase 2 consisted of two columns, each loaded with inert gravel, and saturated with MIW. The first column contained ChitoRem® for MIW treatment, and the second column acidic waste rock to mimic the natural mine environment. The columns were recycled continuously, and MIW was periodically pumped into the columns for sample collection and to maintain saturated conditions. Periodically, flushing events were simulated by transferring a portion

of the water from the ChitoRem® column into the waste rock column. Samples were collected and evaluated. Initial testing indicates substantial buffering and metal removal was achieved within the ChitoRem® columns, and apparent passivation of the acidic waste rock.

BIOCHEMICAL REACTORS FOR TREATING MINING INFLUENCED WATER

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Abstract:
Innovative approaches and technologies need to be developed and implemented that solve environmental issues and remove existing regulatory barriers. The Interstate Technology and Regulatory Council (ITRC) is a state-led, national coalition helping regulatory agencies, site owners, and technology developers and vendors achieve better environmental protection through the use of innovative technologies. Through open communication among its partners, ITRC is streamlining and standardizing the regulatory review process for better, more cost-effective, environmental technologies. Funding comes from the Departments of Defense and Energy, the U.S. Environmental Protection Agency as well as industry and is used to support teams to address state environmental priorities. The ITRC mine waste team was formed in 2008 to address mine impacted solids and water and produced a web-based guidance to help select technologies that address a wide variety of mine waste issues (ITRC MW-1, 2010 at http://www.itrcweb.org/miningwaste-guidance). During the development of the first guidance, the team felt that although biochemical reactors (BCRs) were a promising technology, more information on their design, use and success was needed. As a result, in 2013, the team completed a guidance on their use. (http://itrcweb.org/bcr-1/). The guidance contains information on the applicability, design, construction, monitoring and maintenance of BCRs as well as discussions on the related regulatory and public stakeholder issues. Fifteen case studies are included.

SUBSURFACE BARRIERS AND INNOVATIVE GEOCHEMISTRY: REDUCING CONTAMINANT CONCENTRATIONS IN GROUNDWATER AND CONTAMINANT DISCHARGES TO FOURMILE BRANCH AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA

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Abstract:
The Savannah River Site (SRS) produced tritium, plutonium, and special nuclear materials for national defense, medicine, and the space programs. The F and H Area Seepage Basins at SRS were used until 1988 for the disposition of deionized acidic waste water from the F and H Separations Facilities. The waste water contained dilute nitric acid and low concentrations of non-radioactive metals, and radionuclides, with the major isotopes being Cs-137, Sr-90, U-235, U-238, Pu-239, Tc-99, I-129 and tritium. The acid content of the waste water during the operational period of the basins was equal to 12 billion liters of nitric acid. The seepage basins were closed in 1988 and backfilled and capped by 1991.

The groundwater plumes associated with the F and H basins cover an area of nearly 2.4 square kilometers (600 acres) and discharge along ~2,600 meters of Fourmile Branch have been addressed in a phased approach. In 1997, two large pump and treat systems were operated until 2003 in an attempt to capture and control the releases to Fourmile Branch. The operating cost, including waste disposal, for the two systems was ~$1.3 million/month. Both systems employed reinjection of tritiated water up gradient of the extraction, and produced large quantities of waste from non-tritium isotopes and metals removal prior to reinjection. After it became apparent that there was very little benefit to continued operation of the systems, a new remedy was developed. This new system uses vertical subsurface barriers to redirect groundwater flow to limit the transport of contaminants to the stream. The barriers, constructed of acid-resistant grout, were installed using deep soil mixing techniques. The grout mixture used low swelling clay, fly ash, and sodium hydroxide to form a low permeability barrier.

At the F Area Basins, the subsurface barriers extend to 18 meters below the surface, and form a funnel and gate system 1,036 meters long. The system contains three gates that have openings set in the upper portion of the water table, which promotes water movement mostly in the top of the stratigraphic section. The gates contain a base injection treatment system to neutralize nitric acid and cause the precipitation of metals onto aquifer materials. Construction of the subsurface barriers was completed in 2005. Periodic injection of base in the gates and down gradient of the barriers has allowed SRS to meet groundwater protection requirements for radioactive metals in Fourmile Branch.

The F-area site is the pilot field testing site for a DOE-EM sponsored research initiative focused on field testing and implementation of innovative, long-lived attenuation-based remedies. For these remedies to gain regulatory approval, they must demonstrably reduce contaminant flux to compliance points for long periods of time. Initial field studies have been done in conjunction with the Lawrence Berkeley Laboratory that show sorbed humates strongly bind uranium at mildly acidic pH which would be applicable for contaminant stabilization at a wide variety of sites; current studies are focused on optimization of this approach. In addition, a passive reactive treatment for I-129 using silver chloride is being tested. These pilot field-scale tests should provide the technical basis to move from basic science to actual field deployment and eventual regulatory acceptance. In addition, researchers are investigating the viability of an innovative approach to long term monitoring of residual contamination that should improve performance while significantly lowering costs. The F-Area experience demonstrates the value of using innovative in situ geochemical treatments to address inorganic and radionuclide contaminants that are present in persistent groundwater plumes typical of mining, milling and processing sites.

STEWARDSHIP CONCEPTS FOR MANAGEMENT OF HARD ROCK MINING WASTEWATERS

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Abstract:
Hard-rock mines generate waste material including overburden, waste rock, tailings, and hazardous constituents that can be mobilized or solubilized through contact with water. Typically, approaches

for managing wastewaters, drainage, and runoff from mining sites are designed to meet regulatory requirements while minimizing capital and operating costs. Environmental stewardship concepts can provide long-term solutions for managing mining wastes while incorporating current and future regulatory and economic drivers. Material recovery and water reuse from industrial use practices could potentially be adapted for mining sites. Minimizing environmental impacts of U.S. hard-rock mining involves an integrated approach including:

- Industry-specific controls for solid and liquid wastes
- Reliable treatment for managing liquid waste streams, recovering resources and water, and controlling runoff
- Long-term stewardship.

WASTEWATER TREATMENT OF HIGH TOTAL DISSOLVED SOLIDS AND ACIDITY AT THE CERRO DE PASCO MINE SITE

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Abstract:
Vulcan SAC has retained Golder Associates to expand the capacity of the existing mine drainage water treatment plant (WTP) at the Cerro de Pasco mine site. The extremely elevated acidity and metals concentrations are unusual for a typical mine wastewater. This high strength water results in significant operating costs due to the quantities of lime required for neutralization and the cost of lime. Golder performed bench testing of several treatment approaches in order to reduce lime consumption rates for the expanded WTP. A treatment approach using limestone as a pre-neutralizing agent was found to be surprisingly effective.

Typically, lime is used as a neutralizing agent in mine water treatment instead of limestone, because it cannot reach the pH to precipitate out most metals. Lime is required to reach higher pH values. It also is generally less effective in waters with high metals concentrations due to armoring, leading to low utilization and long reaction times. However due to the high cost of lime, limestone may represent a significant cost savings. Limestone was chosen for testing, despite its proven disadvantages. High density sludge (HDS) was chosen as a typical treatment process, while copper sulfide recovery was chosen due to the water's high copper concentration.

Bench results indicate that treatment to the LMP standards occurs at pH 8.0 for HDS and limestone/lime neutralization. Limestone resulted in the highest sulfate removal, as well as metals removal comparable to the HDS process. Limestone prevented gypsum armoring, thereby reducing the required reaction time by up to 66 percent and decreasing the amount of lime required for neutralization. Copper sulfide recovery had difficulty separating arsenic to produce a marketable copper sulfide concentrate, and high sludge generation rates will inhibit implementation.

Cerro de Pasco is notable for its elevated acidity and TDS. Conventional lime treatment processes (LDS, HDS) are effective but require high chemical costs. Alternate methods using limestone or

copper sulfide precipitation may decrease operating costs. Limestone as a pre-neutralization step offers benefits for high sulfate, low pH waters, including a reduction in reagent cost and armoring, resulting in better reaction rates. Copper recovery was believed to have potential application at the site, in that copper may be sold to offset costs. However, difficulty in separating out the marketable copper as well as high sludge generation rates inhibits use of the technology. The sulfide and limestone processes are projected to reduce annual chemical costs by 15 percent and 20 percent, respectively.

Source Control / Mine Closure Approaches

USE OF BIOCHARS PRODUCED BY GASIFICATION OF GRASS AND WOOD IN THE REMEDIATION OF TWO ACID MINE SOILS OF WESTERN OREGON

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Abstract:
Unfavorable acid soil conditions exist in both natural and agricultural landscapes and can have deleterious effects on the health of plants, wildlife, humans, and ecosystems by affecting biological and chemical processes. Under extreme acidic conditions (i.e., pH <3), establishment of vegetation can be very difficult; the lack of vegetation leaves bare ground that is highly susceptible to erosion, which in turn leads to contamination and sedimentation of surface waters. Biochars produced by gasification of Kentucky bluegrass seed cleanings or mixed wood debris were used as soil amendments at rates of 0, 10, 20, 40, 90 and 150 g kg^{-1} in two acid mine soils (pH < 3.5) collected from western Oregon. Wheat was planted in each soil combination and maintained in a greenhouse for 58 days when plant tissues were collected and quantified. Amendment of the acidic soils with each level of biochar raised the soil pH, but greater than 20 g kg^{-1} was required to observe significant increase in wheat biomass production. Wheat growth did not occur in non-amended soils while significant increases in growth occurred in soils amended at higher levels of biochar. It is likely that increases in soil pH associated with the biochar amendment were to a large degree responsible for the improved wheat growth although it is possible that sorption of metals from the contaminated soil also improved growth conditions.

INVESTIGATING BIOCHAR AS A TOOL FOR MINE SOIL REMEDIATION

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Abstract:
Biochar is a cost-effective, carbon negative soil amendment that can lead to improved soil quality. Research has also demonstrated the efficacy of biochar to sorb heavy metals and agricultural chemicals from contaminated soils, thus effectively reducing the potential for metal and chemical contamination of surface and ground waters. In this study we investigated the ability of biochar produced from a single feedstock (Douglas fir wood chips) across a range of charring temperatures (300-700°C) to bind with metals. Our goal in this research is to link metal sorption to specific biochar properties, and then use these relationships to engineer biochar with specific properties to achieve various remediation and soil quality outcomes. We characterized our biochars using a variety of techniques including total elemental analysis, pH, FTIR spectroscopy, surface area and pore size analysis, and proximal carbon analysis. We used batch experiments of biochar with either Cu (II) solutions or simulated rainwater extracts of soils contaminated with mine tailings to investigate metal sorption. Sorbed metals were characterized using synchrotron-based XAS, XANES, EXAFS and XRF-Tomography. We found that higher temperature biochars, while having a decreased abundance of oxygen containing functional groups, had an increased capacity for metal sorption over biochar produced at lower temperatures. Concomitantly, these biochars also have greater ash contents, surface areas, abundance of small pores and higher pH values. Results of our sorption studies indicate that metal sorption on biochar may be competitive and preferential, and that as the charring temperature goes up, physisorption may become more important as a mechanism of metal sorption to biochar.

MECHANISTIC UNDERSTANDING OF BIOGEOCHEMICAL TRANSFORMATIONS OF TRACE ELEMENTS IN CONTAMINATED MINE WASTE MATERIALS UNDER REDUCED CONDITIONS

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Abstract:
The milling and mining operations of metal ores are one of the major sources of heavy metal contamination at earth's surface. Due to historic mining activities conducted in the Tri-State mining district, large area of land covered with mine waste, and soils enriched with lead (Pb), zinc (Zn) and cadmium (Cd) still remain void of any vegetation influencing plant productivity, ecosystem and human health. It has been hypothesized that if these mine waste materials are disposed of in the flooded subsidence pits; metals can be transformed back into their sulfide forms under reduced conditions limiting their mobility and toxicity. However, these mine waste materials are high in pH,

low in organic carbon (OC) and sulfur (S) limiting the effectives of this remediation approach. The objective of this study was to examine the effect of OC and S addition on the biogeochemical transformations of Pb, Zn and Cd in submerged mine waste materials containing microcosms. Advanced molecular spectroscopic and microbiological techniques were used to obtain a detail, mechanistic, and molecular scale understanding of the effect of natural and stimulated redox conditions on biogeochemical transformation and dynamics of Pb and Zn essential for designing effective remediation and mitigation strategies.

The results obtained from these column studies indicated that Pb, Zn and Cd were effectively immobilized upon medium (119-day) and long-term (252-day) submergence regardless of treatment. Synchrotron based bulk-, and micro-X-ray fluorescence and X-ray absorption spectroscopy analyses indicated enhancement of sulfide formation with OC plus S treatment. The microarray analysis revealed change in microbial community structure on OC and S addition with the evidences of enhanced sulfur reducing bacteria genes (dsrA/B), and decreased metal resistance genes over time. Through the combined kinetic and thermodynamic evaluation of effluent water chemistry, molecular scale spectromicroscopy and microbiological analyses, we have evidences that the long-term submergence of existing mine tailings with OC plus S addition reduced the trace metals mobility through dissimilatory sulfate reduction under stimulated reduced conditions.

This research enhances our understanding of the redox processes associated with the sequestration of non-redox sensitive metals through dissimilatory reduction of sulfates in mine waste materials and/or waste water and provides regulators with useful scientific evidence for optimizing remediation goals.

BIOCHAR FOR REMEDIATION OF SOLID SOURCE MINE WASTES AND MINE DRAINAGE TREATMENT

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Abstract:
Soil amendments are often required for re-vegetating and stabilizing solid mine wastes such as waste rock, tailings and heap leach pads, in order to reduce the migration of metals to air, surface and ground water; reduce soil toxicity; and meet liability requirements. The presence at many sites of metal rich waste rock and mill tailings pose major impediments to successful reclamation. Stabilization and isolation strategies can be improved and reinforced when re-vegetation is incorporated into reclamation designs, and achieves success. Additionally, acid rock drainage and metal leachate originating from mine sites requires treatment, sometimes into perpetuity at high costs.

The carbon rich product of a pyrolysis reaction, biochar has been utilized as a soil amendment for mining affected soils at sites in the United States, Spain, and the United Kingdom achieving varying degrees of success in facilitating vegetation growth and soil pedogenesis. Though previous work has demonstrated that biochar can be an effective tool for mine reclamation, questions remain regarding material type and application rates under varying soil conditions. Furthermore, as interest in passive treatment of mining affected waters has increased, matrix materials that can provide adsorptive and chemically reactive beneficial effects have been sought.

Presented here are the results from a range of studies and implementation projects, with examples from Colorado, Nevada and Utah. These projects and studies focused on biochar application as a soil amendment for mining affected spoil piles and tailings, and as a component of passive treatment for acid mine drainage.

Beneficial Use

CHEMICAL SAFETY AND SUSTAINABILITY OF RARE EARTH ELEMENTS: SELECTION OF A PRODUCT SYSTEM FOR A LCA CASE STUDY

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Abstract:
The two major markets for Rare Earth Elements (REEs) that have received significant attention in the area of sustainable materials research are the consumer electronics and information technologies and energy-related technologies. The interest in consumer electronics and information technologies is largely based on concerns for both supply issues and environmental impacts during end-of-life (EOL) activities. Both of these issues can be addressed using sustainable materials management (SMM) practices. The U.S. EPA's Chemical Safety for Sustainability research program is applying SMM tools such as material flow analysis, life cycle assessment (LCA), and sustainable process design to selected REE product systems to better understand how these tools can be improved to meet the needs of decision makers seeking to improve the sustainability of these products. A cross-Agency work group was assembled and identified relevant issues or questions related to energy critical elements/rare earth elements that should be included when considering sustainable materials management. A literature review was used to identify data gaps related to these issues as they pertain to mining, use and potential recovery of REEs for a range of products, including magnets, batteries, and phosphors used in consumer electronics. Recent advances in mining technologies need to be evaluated to better understand their impacts and cost implications (if any) on the consumer product markets. A major concern for most of the recovery processes is the need to isolate the REE-containing portions of the products (i.e., separate the HDDs from computers). This can be time-consuming and has proven to be challenging when REEs occur in low concentrations in e-waste. Furthermore, most recycling technologies are still in their development stage with limited commercial scale deployment. The results from the literature review will be used to perform a life cycle assessment of a key consumer electronic product to determine how potential SMM strategies such as sustainable mining, recycling, reuse, and substitution alter the life cycle impacts. The impact data will inform the use of EPA's GREENSCOPE sustainable process evaluation and design methodology to identify improvements for proposed technologies within the life cycle.

THERMAL AND HYDROLOGICAL CHARACTERIZATION OF AN ABANDONED MINE COMPLEX FOR LOW-ENTHALPY GEOTHERMAL EXTRACTION: THE CORNING MINE COMPLEX, PERRY COUNTY, OHIO

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Abstract:
Ground Source Heat Pump (GSHP) or Geothermal Heat Pump systems exchange heat with the either saturated or unsaturated shallow bedrock or soils at an increased efficiency for heating and cooling applications compared to traditional heat pump heating and cooling systems. Waters within flooded abandoned underground mines could provide a valuable heat reservoir for both extraction and injection using GSHP technologies. The Corning Mine Complex in Perry County, Ohio was evaluated to characterize the modes of heat transfer in the mine with respect to atmospheric and hydrologic controls. Temperature and hydraulic head sensors were placed into monitoring wells drilled into the mine void. Time series analysis was performed on temperature and hydraulic head data using precipitation and ambient air temperature data from a nearby weather station to determine the thermal response of the mine to atmospheric heat and mine recharge events. Using water levels within the monitoring wells, the volume of water within the mine void and the residence times of water within the mine complex was calculated. Based upon the estimated volume of waters within the mine void calculation, the amount of heat available for exchange within those waters was quantified.

The results of this study show a thermally stable reservoir of water within the mine void which water temperature varies locally with overburden thickness. The temperatures within the mine void did not vary with precipitation events or other short-term recharge events, except for wells with clear damage that connect the reservoir with the surface. The amount of heat extractable from the mine void was calculated to be 3.12 x 10^{10} kJ/°C. Overall, these results show that temperature is stable within the mine system and is controlled by the separation between the thermal reservoir of the mine and the thermal reservoir of the atmosphere. These results could be valuable for further understanding heat transfer within mines and for the implementation of GSHPs in flooded abandoned mines in Ohio.

PREDICTING WATER QUALITY FOR A HIGH ALTITUDE MINE WASTE FACILITY IN PERU

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Abstract:
AMEC Environment & Infrastructure (AMEC) was retained by M3 Engineering and Technology Corporation (M3) to provide an assessment of the acid rock drainage and metals leaching potential (ARD/ML) of waste rock and ore to be produced at an open pit copper mine located at high elevation (3,000 – 4,500 masl) in Peru. The mine is expected to produce about 573 Mt of ore for milling, 173 Mt of low-grade ore for heap leach, and about 1,360 Mt of waste rock over 25 years of operation. The current plan is to construct an onsite waste storage facility (WSF) by co-blending milled tailings with waste rock in an alpine valley. The WSF, which will also partially cover the heap leach residue pad located at the top of the valley, will contain underdrains directed to a single pond at the toe. Geochemical testing included analyses of 1,000 samples from five major lithologies representing waste rock and ore for acid base accounting and content of total metals. Selected samples of waste rock, simulated tailings, and heap leach residue were submitted for mineralogical, humidity cell, and other geochemical testing. Geochemical results were modeled by considering the configuration of the WSF to predict water quality of the leachate at the toe. Leachate pH is expected to be mildly alkaline due to alkalinity generated primarily by the tailings. Although the heap leach residue is expected to contribute some acidity, alkalinity from the tailings will minimize the contribution. The results indicate that arsenic, chromium, mercury, and zinc may be of possible concern, requiring treatment prior to discharge.

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