Hardrock Mining 2012

Advancing Solutions for a New Legacy

April 3-5, 2012

Renaissance Denver Hotel
Denver, CO

EPA
United States
Environmental Protection
Agency

Sponsored by the U.S. Environmental Protection Agency
Office of Research and Development

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April 3-5, 2012 • Denver, CO

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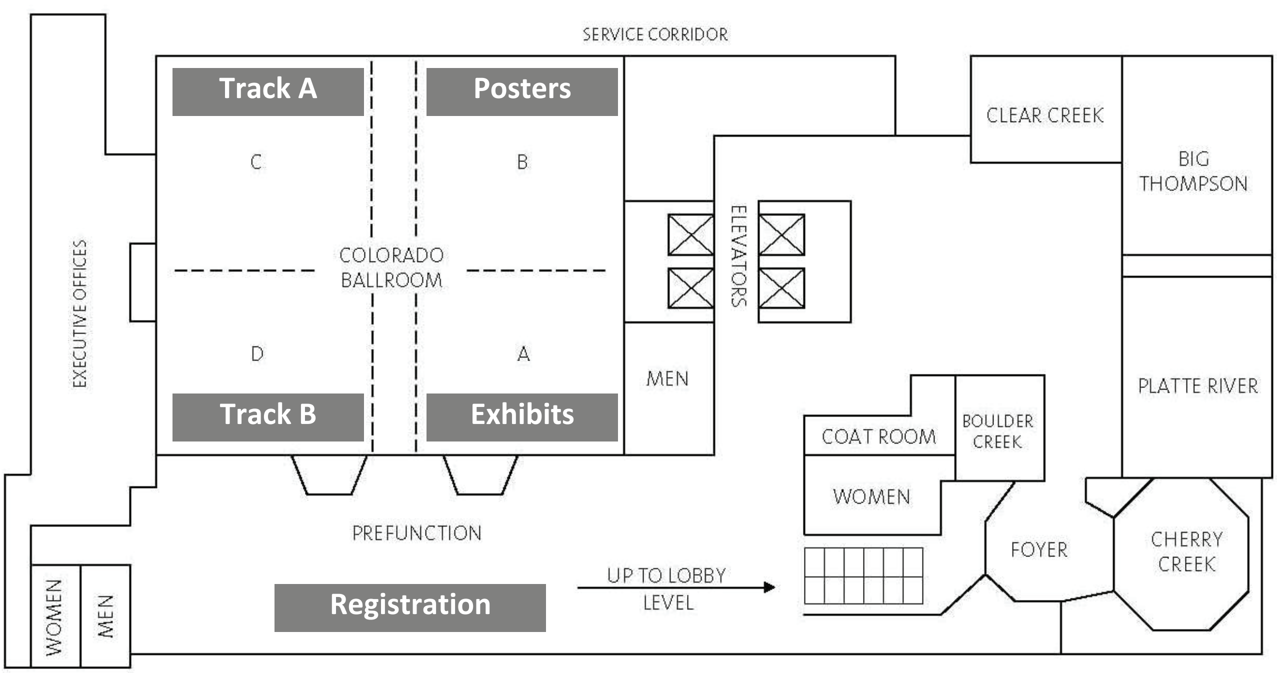
Federal AML Roundtable *Thursday, April 5 – 1:30 p.m. to 3:00 p.m.*	Big Thompson



Hardrock Mining 2012
Conference 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)
	David Reisman, U.S. EPA, ORD, NRMRL
Committee Members:	**Barbara Butler**, Ph.D., U.S. EPA, ORD, NRMRL
	Gwen Campbell, U.S. EPA Region 8
	Chris Impellitteri, U.S. EPA, ORD, NRMRL
	Joy Jenkins, Ph.D., U.S. EPA Region 8
	Jim Lazorchak, U.S. EPA, ORD, National Exposure Research Laboratory
	Michele Mahoney, U.S. EPA, Office of Solid Waste and Emergency Response (OSWER), Office of Superfund Remediation and Technology Innovation (OSRTI)
	Shahid Mahmud, U.S. EPA, OSWER, OSRTI
	John McCready, U.S. EPA, ORD, NRMRL
	Cindy Sundblad, U.S. EPA Region 8
	Robert Weber, U.S. EPA, ORD, Office of Science Policy

Join us for the Poster Sessions!

April 3, 2012 ◆ 4:30 p.m. to 6:00 p.m.

Reception sponsored by

CDM Smith

April 4, 2012 ◆ 5:00 p.m. to 6:30 p.m.

Reception sponsored by

Golder Associates Inc.
Cellular Concrete Solutions
ACZ Laboratories, Inc.
JRW Bioremediation, LLC

CONFERENCE AGENDA

Day 1 – Tuesday, April 3, 2012

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

Colorado Ballroom C/D

	Plenary Session **Session Chairs: Douglas Grosse and David Reisman, U.S. EPA/ORD/NRMRL**
8:30 AM – 8:50 AM	**Greetings and Opening Remarks** – Doug 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)
8:50 AM – 9:10 AM	**EPA Region 8 Legacy Mining Successes – Management Perspectives –** Martin Hestmark, Acting Assistant Regional Administrator, Office of Environmental Protection and Remediation, Region 8, U.S. EPA
9:10 AM – 9:40 AM	**The Mining Legacy and EPA ORD: Past, Present and into the Future** – David Reisman, Director, Engineering Technical Support Center, NRMRL, ORD, U.S. EPA
9:40 AM – 10:00 AM	**Break** (*Colorado Ballroom A/B*)
10:00 AM – 10:30 AM	**The Big Five Tunnel Project: Long-Term Lessons** – Thomas Wildeman, Professor Emeritus, Chemistry and Geochemistry, Colorado School of Mines
10:30 AM – 11:00 AM	**Superfund and Mining Sites: A Review of the Past and Observations Concerning the Future** – Roger Olsen, Ph.D., Sr. Vice President, CDM Smith
11:00 AM – 11:30 AM	**Legacy of Innovative Remediation** – Edward Bates, Remediation Consultant, U.S. EPA (retired)

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

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	1 Case Studies Session Chair: Joy Jenkins, Ph.D., U.S. EPA Region 8	**2 Innovative Technology and Techniques** Session Chair: Robert Weber, U.S. EPA/ORD/OSP
1:00 PM – 1:30 PM	**A Multiple Tracer/Geochemical Approach to Characterizing Water and Contaminant Movement Through Abandoned Mine Workings Near Rico, Colorado** – Mike Wireman, U.S. EPA Region 8	**MiniSipper: A New, High-Capacity, Long-Duration, Automated In-Situ Water Sampler for Acid Mine Drainage Monitoring at the Pennsylvania and Standard Mines, CO** – Thomas Chapin, Ph.D., U.S. Geological Survey
1:30 PM – 2:00 PM	**Acid Mine Drainage Source Control Program Design Investigation Upper Tenmile Creek Mining Area Superfund Site, Rimini, Montana** – Angela Frandsen, CDM Smith	**Identification and Quantification of Arsenic Species in Gold Mine Wastes Using Synchrotron-based X-ray Techniques** – Andrea Foster, Ph.D., U.S. Geological Survey WMESC
2:00 PM – 2:30 PM	**Improving Remediation Planning through Effective Mine Material Delineation, Formosa Mine Superfund Site, Douglas County, Oregon** – Mark Nelson, CDM Smith	**Microanalytical Techniques to Understand Element Leaching from Ore Minerals in Mining Wastes** – Sharon Diehl, Ph.D., U.S. Geological Survey

2:30 PM – 3:00 PM **Break** (*Colorado Ballroom A/B*)

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	3 Case Studies (cont.) Session Chair: Joy Jenkins, Ph.D., U.S. EPA Region 8	**4 Innovative Technology and Techniques (cont.)** Session Chair: Robert Weber, U.S. EPA/ORD/OSP
3:00 PM – 3:30 PM	**A Proposed Semi-Passive Treatment System at Remote AML Sites** – Robert Lambeth, Millennium Science & Engineering, Inc.	**Using Acid Mine Drainage Sludge to Remove Phosphorus and Other Metal Oxyanions from Waste Water** – Philip Sibrell, Ph.D., U.S. Geological Survey - Leetown Science Center
3:30 PM – 4:00 PM	**Captain Jack Mine Superfund Site Subsurface Remedy: Pre-Design Investigation Results and Preliminary Design** – Craig Weber, AMEC E&I	**Results from a Bench Scale Passive Treatment System Designed for Removing Sulfate at a Site on Vancouver Island, British Columbia** – Eric Blumenstein, Golder Associates, Inc.
4:00 PM – 4:30 PM	**Case Studies in Mine Closure and Acid Rock Drainage Management at Rio Tinto** – Victoria Peacey, Rio Tinto	**Engineered Pumpable pHoam™: A New Innovative Method for Mitigating ARD** – James Gusek, Golder Associates, Inc.

4:30 PM - 6:00 PM **Poster Session I** (*Colorado Ballroom A/B*)

Day 2 – Wednesday, April 4, 2012

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

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	5 Remediation and Stabilization Using Natural Materials Session Chair: Michele Mahoney, U.S. EPA/OSWER/OSRTI	**6 Monitoring and Treatment** Session Chair: Erna Waterman, U.S. EPA Region 8
8:30 AM – 9:00 AM	**Using Organic Amendments and Agronomy in Remediation of Hardrock Mining Sites** – Rufus Chaney, Ph.D., USDA-Agricultural Research Service	**Thallium Removal Strategies through Modification of Conventional Metal Hydroxide Precipitation Plants** – Katherine Vatterrodt, Colorado School of Mines
9:00 AM – 9:30 AM	**The Effect of Tailings Characteristics on Cover System Success** – Monisha Banerjee, Ph.D., GeoSystems Analysis, Inc.	**The Biotic Ligand Model: Unresolved Scientific Issues and Site- and Species-Specific Effects on Predicted Cu Toxicity** – Jeffrey Morris, Ph.D., Stratus Consulting Inc.
9:30 AM – 10:00 AM	**Scaling Phytostabilization from Greenhouse to Field-Scale at the Iron King Mine-Humboldt Smelter Superfund Site** – Juliana Gil-Loaiza, University of Arizona	**Water-Quality and Streamflow Time Trends, Upper Clear Creek Watershed (Colorado) - Systematic Long-Term Monitoring Fulfills a Range of Information Needs** – Timothy Steele, Ph.D., TDS Consulting Inc.

10:00 AM – 10:30 AM **Break** (*Colorado Ballroom A/B*)

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	7 Remediation and Stabilization Using Natural Materials (cont.) Session Chair: Michele Mahoney, U.S. EPA/OSWER/OSRTI	**8 Monitoring and Treatment (cont.)** Session Chair: Erna Waterman, U.S. EPA Region 8
10:30 AM – 11:00 AM	**The Use of Municipal Biosolids on Hard Rock Mining Restoration Efforts: Results of a Long-term Field Trial** – Rick Black, Environ International Corporation	**Mine Water Treatment Strategies Resolution Copper Mining and the Eagle Project** – Casey McKeon, Ph.D., Resolution Copper Company
11:00 AM – 11:30 AM	**Soil Treatment at the California Gulch NPL Site for Vegetation Reestablishment and Mitigation of Metal Mobility** – Stuart Jennings, Reclamation Research Group, LLC	**Mine Dewatering and Water Management at Barrick Goldstrike Mine in the Carlin Trend, Nevada** – Johnny Zhan, Ph.D., Barrick Gold of North America, Inc.
11:30 AM – 12:00 PM	**Post-Reclamation Soil Phytotoxicity and Land Management at the Anaconda Smelter NPL Site** – Robert Rennick, CDM Smith	**ARD Remediation with Slag: An Application to Berkeley Pitlake Water** – Courtney Young, Ph.D., Montana Tech of the University of Montana

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

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	9 **Engineered Covers and Capping** Session Chair: Douglas Grosse, U.S. EPA/ORD/NRMRL	**10** **Metals and Metalloids** Session Chair: Barbara Butler, Ph.D., U.S. EPA/ORD/NRMRL
1:30 PM – 2:00 PM	**Ten-Year Performance Evaluation of the Evapotranspiration Cover at Barrick Goldstrike Mine's AA Leach Pad** – Mike Milczarek, GeoSystems Analysis, Inc.	**The Increasing Importance of Biomonitoring Data to Interpret Changing Risk Estimates for Legacy Mining Communities** – Rosalind Schoof, Ph.D., ENVIRON International Corporation
2:00 PM – 2:30 PM	**Characterization and Selection of Waste Rock Borrow Material for Use as Rock Armor to Reduce Tailing Impoundment Side-slope Erosion** – Jason Keller, GeoSystems Analysis, Inc.	**Long-Term Monitoring and Metal Bioaccumulation Modeling Provide Important Feedback Related to Remediation in the Clark Fork River, MT** – Michelle Hornberger, Ph.D., U.S. Geological Survey
2:30 PM – 3:00 PM	**Preliminary Design of Water Balance Covers: A Method Based on the ACAP Data Set** – William Albright, Ph.D., Desert Research Institute	**Evaluating the Bioavailability, Bioaccessibility, Mineralogy, and Speciation of Arsenic in Mine Waste and Soils, Empire Mine Low-sulfide Gold-quartz Vein Deposit, Nevada County, California** – Charles Alpers, Ph.D., U.S. Geological Survey

3:00 PM – 3:30 PM **Break** (*Colorado Ballroom A/B*)

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	11 **Rare Earth Elements** Session Chair: Gwen Campbell, U.S. EPA Region 8	**12** **Sustainability / Life Cycle** Session Chair: Carol Russell, U.S. EPA Region 8
3:30 PM – 4:00 PM	**Rare Earth Elements: A Review of Production, Processing, Recycling, and Associated Environmental Issues** – Robert Weber, U.S. EPA, ORD, OSP located in Region 7	**Hardrock Mining within a Sustainable Development Context** – Terrence Chatwin, Ph.D., INAP
4:00 PM – 4:30 PM	**Geologic and Environmental Characteristics of Rare Earth Element Deposit Types Found in the United States** – Robert Seal, II, Ph.D., U.S. Geological Survey	**Predicting and Managing Waste Impacts through a Holistic and Life-of-Mine Geomet Application** – Karin Olson Hoal, Ph.D., JKTech Pty Ltd.
4:30 PM – 5:00 PM	**Research Initiatives in Recycling and Substitutes of Rare Earth Elements** – Michael McKittrick, Ph.D., U.S. EPA, ORD, NCER, TED	**Life Cycle Assessment Analysis for Active and Passive Acid Mine Drainage Treatment Options for the Stockton Coal Mine, New Zealand** – James Stone, Ph.D., South Dakota School of Mines and Technology

5:00 PM - 6:30 PM **Poster Session II** (*Colorado Ballroom A/B*)

Day 3 – Thursday, April 5, 2012

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

	Track A (*Colorado Ballroom C*)	Track B (*Colorado Ballroom D*)
	13 **Case Studies** Session Chair: Joy Jenkins, Ph.D., U.S. EPA Region 8	**14** **Opportunities for Re-Use and Site Management** Session Chair: Shahid Mahmud, U.S. EPA/OSWER/OSRTI
8:00 AM – 8:30 AM	**Blue Ledge Mine Superfund Site Removal Action, Rogue River-Siskiyou National Forest** – Pete Jones, U.S. Forest Service, Pacific Northwest Region	**What Is Environmental Stewardship and How Can It Be Profitable in the Mining Industry?** – Randy Brandt, Geosyntec Consultants
8:30 AM – 9:00 AM	**Managing Mine Slimes - Jack Waite Mine Remedial Action** – Todd Bragdon, CDM Smith	**Abandoned Mine Reclamation Planning at French Gulch, Breckenridge, CO and the Launching of a New Booklet Series and Legacy Site Web-Portal** – Alan Berger, Massachusetts Institute of Technology and Victor Ketellapper, U.S. EPA Region 8
9:00 AM – 9:30 AM	**Screening and Cleanup Procedures for Libby Amphibole Contaminated Property in Libby, MT** – Mike Cirian, U.S. EPA	**Recycling and Utilization of Mine Tailings as Construction Material through Geopolymerization** – Lianyang Zhang, Ph.D., University of Arizona

9:30 AM – 10:00 AM **Break** (*Colorado Ballroom A/B*)

	Colorado Ballroom C/D
	15 **Opportunities for Re-Use and Site Management (cont.)** Session Chair: Shahid Mahmud, U.S. EPA/OSWER/OSRTI
10:00 AM – 10:10 AM	**Session Introduction** – Shahid Mahmud, U.S. EPA/OSWER/OSRTI
10:10 AM – 10:40 AM	**Economic Recovery of Zinc from Mining Influenced Water** – Kathleen Whysner, Colorado School of Mines
10:40 AM – 11:10 AM	**Using Mine Scarred Lands for Future Renewable Energy Projects** – Timothy Rehder, U.S. EPA Region 8
11:10 AM – 11:40 AM	**Brazil Millsite: Brownfield to Brightfield Renewable Energy Engineering Design Project** – Ed Rapp and Diane Kielty, Clear Creek Watershed Foundation
11:40 PM – 12:00 PM	**Closing Remarks**

POSTER PRESENTATIONS

Poster Session I: Tuesday, April 3, 2012

Legacy Mining Issues

1 **PCBs Mining and Water Pollution** – Dan Bench, U.S. EPA Region 8
2 **Losing Our Nation's Mining Heritage – A New Perspective** – J. Harrison Daniel, Ph.D., Retired
3 **LiDAR and Multispectral Studies of Legacy Mining-Disturbed Lake Superior Coastal Environments** – W. Charles Kerfoot, Ph.D., Michigan Technological University
4 **Arsenic Distribution in Sediment and Pore Waters of the Historical Mining-Impacted Belle Fourche and Cheyenne River Floodplains, South Dakota** – James Stone, Ph.D., South Dakota School of Mines and Technology
5 **Dietary Bioavailability of Cu Bound to Synthetic Hydrous Ferric Oxides** – Daniel Cain, U.S. Geological Survey
6 **Ecological Risk Assessment at the Libby Asbestos Superfund Site, Operable Unit 3** – Dan Wall, Ph.D., U.S. EPA Region 8
7 **Burlington Mine Voluntary Clean-Up: An Ecological Approach to Historic Mine Site Remediation** – Maureen O'Shea-Stone, Walsh Environmental Scientists and Engineers, LLC
8 **CERCLA Removal Action at the Rainy Mine, Washington** – Robert Lambeth, Millennium Science & Engineering, Inc.
9 **Remedial Investigation Challenges at the Former Zonolite Vermiculite Mine in Libby, Montana** – Christina Progess, U.S. EPA Region 8
10 **Assessing the Effectivenes of Hardrock Mine Regulation, Reclamation and Financial Assurances: What is the "bottom line"?** – Joseph Baird, Baird Hanson Williams LLP

Innovative Technology and Techniques

11 **Integrated Resource Assessments: A Framework to Consider the Potential Consequences of Mineral Resource Development** – Katherine Walton-Day, Ph.D., U.S. Geological Survey
12 **Mining Waste Treatment Technology Selection: A Web Based Approach for Remediating Mine Sites** – Paul Eger, Golder Associates Inc.
13 **A Multi-Phased Approach for Deep Tunnel Detection at a Gold Mine Remediation Site** – Nicole Pendrigh, Zonge International, Inc.

Best Management Practices to Achieve Remediation Objectives

14 **Laboratory and Greenhouse Evaluation of the Effects of Enhanced Oxidation and Various Amendments on Sediment Chemical Properties, Plant Growth, and Plant Tissue Metals Concentrations** – Frank Hons, Ph.D., Texas A&M University
15 **How OSM/VISTA Volunteers Facilitate Stakeholder Input and Collaboration** – Rachel Folk, Western Hardrock Watershed Team
16 **Development of Aquatic-Mining Ecosystem Models Using Computational Intelligence** – Michael Friedel, Ph.D., U.S. Geological Survey
17 **Connectivity Mapping Among Variables in a Mining-Aquatic Ecosystem** – Michael Friedel, Ph.D., U.S. Geological Survey

Poster Session II: Wednesday, April 4, 2012

Water Quality, Water Management and Water Treatment

1 **Water-Quality and Streamflow Time Trends, Upper Clear Creek Watershed (Colorado) - Systematic Long-Term Monitoring Fulfills a Range of Information Needs** – Timothy Steele, Ph.D., TDS Consulting Inc.

2 **A Remote High-Altitude Pilot Treatment System for Mining-Impacted Waters** – Ram Ramaswami, Ph.D., Pacific Western Technologies, Ltd.

3 **Electro-Catalytic Flux Technology for Treatment of Mining Waste Water** – William Roper, Ph.D., George Mason University

4 **Use of Hyper-spectral Remote Sensing Systems for Monitoring Mining Operations** – William Roper, Ph.D., George Mason University

5 **Metal and Arsenic Levels in Drinking Water at Two Montana Superfund Sites** – Dennis Neuman, Reclamation Research Group, LLC

6 **Constructed Wetland Treatment Systems for Mine Drainage–Can They Really Provide Green and Sustainable Solutions?** – Paul Eger, Golder Associates Inc.

7 **Assessing Bioremediation of Acid Mine Drainage in Coal Mining Sites Using a Predictive Neural Network-Based Decision Support System (NNDSS)** – Victor Ibeanusi, Ph.D., Spelman College

Abandoned Mine Land Issues

8 **Synoptic Sampling with Replication: Assessing Uncertainty in Estimates of Instream Constituent Loads, Peru Creek, Colorado** – Robert Runkel, U.S. Geological Survey

9 **Do Jarosite Minerals Generate Acid in Legacy Mining Wastes?** – Kathleen Smith, Ph.D., U.S. Geological Survey

10 **Remediation Case Study for Fluvial Deposits and Mountain Meadows at the California Gulch NPL Site** – Jan Christner, URS Operating Services, Inc.

11 **Solute-Transport Modeling to Assist Understanding of the Potential Effects of Remediation, Implementation of Total Maximum Daily Loads, and Pre-Mining Conditions** – Katherine Walton-Day, Ph.D., U.S. Geological Survey

12 **Establishing Site-Specific Background for Abandoned Mined Lands on a Watershed Scale** – Michelle Havey, Hart Crowser, Inc.

13 **Controlling Adit Discharge at the Upper Tenmile Creek Superfund Site, Rimini, Montana** – David Shanight, CDM Smith

14 **Using Time-Series Tripod LiDAR to Quantify the Eroded Volume of Mercury-Contaminated Sediment from Historical Gold Mining in California** – J. F. Howle, U.S. Geological Survey

15 **Characterization of Mercury and Methylmercury Contamination in Stream and Pond Environments and Provenance of Mine Waste from Historical Gold Mining in the Sierra Nevada, California** – Charles Alpers, Ph.D., U.S. Geological Survey

Modern Mining Applications

16 **Biomining Metal Optimization and the Role of Thermoacidophiles** – Tyler Johnson, University of Nebraska-Lincoln

17 **Mercury Bioaccessibility Associated with Calcine Waste in McDermitt, Nevada** – Mark Marvin-DiPasquale, Ph.D., U.S. Geological Survey

Restoration

18 **Implementation of In-Situ Remediation and Revegetation of Mine Tailings** – John DeAngelis, Pacific Western Technologies, Ltd. and Clay Combrink, Frontier Environmental Services, Inc.

19 **Influence of Phytostabilization on Bacterial Biomass and Nitrogen Cycling Activities in Acidic Metalliferous Mine Tailings** – Karis Nelson, University of Arizona

Presentation Abstracts
and
Speaker Bios

Tuesday, April 3, 2012

Plenary Session

OVERVIEW OF U.S. EPA'S ORD TECHNICAL OUTREACH AND SUPPORT ACTIVITIES

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Abstract:
Hardrock mining has played a significant role in the development of economies, consumer products and defense in the United States from the start of industrialization. Currently, the industry continues to play a critical role in the development of our country. Mining waste which is generated from both operating and abandoned mining sites continues to be a problem for human health and ecosystems. Much of this waste can be attributed to copper, iron ore, uranium and phosphate mining. In addition to generated waste rock, mill tailings, smelter slag and associated dump/heap leaching waste and drainage contribute to this environmental impact. Due to the extent of these problems, the U.S. Environmental Protection Agency (EPA) in conjunction with other federal agencies, including the Department of Energy (DOE), Department of the Interior (DOI) and the Department of Defense (DOD), is continually promoting dialogue and the dissemination of current relevant information on approaches to restoring areas adversely impacted by mining activities. Many organizations are currently involved in developing, evaluating and implementing technologies to assess and remediate impacts from hardrock mining activities. EPA's National Risk Management Research Laboratory (NRMRL) has taken the lead in managing several research programs involved with the treatment and/or remediation of mining sites, primarily in the Western United States. The goal of this research is to develop the scientific framework for establishing ecosystem restoration potential based upon observed stream ecosystem response to known disturbance gradients, such as those generated from mining sites. This presentation will attempt to unveil a new legacy to solve some of the more perplexing challenges pertaining to the eco-restoration and reclamation of these impaired sites from information extrapolated from the historical and current mining programs supported by EPA's Office of Research and Development.

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 EPA in Cincinnati, Ohio, for the past 33 years. He obtained a Certified Electroplater-Finisher certification from the American Electroplaters and Surface Finishers Society in 1988. Mr. Grosse is currently working in EPA's National Risk Management Research Laboratory as a Senior Environmental Engineer. His past experience includes conducting in-house research at EPA's pilot plant facilities in wastewater and hazardous waste research; serving as pilot facility manager and project officer (Center Hill Laboratory); working with the Superfund Innovative Technology Evaluation (SITE) Program; serving as RCRA corrective action coordinator and providing technical assistance in Superfund; and providing RCRA and treatability study assistance, as an aqueous treatment specialist. Mr. Grosse has worked in the Technology Transfer Program by serving as a specialist in site remediation, corrective action, industrial wastewater treatment and environmental

sustainability. Recent activities include: vapor intrusion, hardrock mining and the production of engineering issue papers. Mr. Grosse served in the Environmental Technology Assessment and Verification staff as a specialist in environmental technology assessments and the Project Officer for ETV's Advanced Monitoring Systems Center. Currently, Mr. Grosse works in the Remediation and Redevelopment Branch as a principle investigator and as an associate in the Engineering Technical Support Center.

EPA REGION 8 LEGACY MINING SUCCESSES – MANAGEMENT PERSPECTIVES

Martin Hestmark
Acting Assistant Regional Administrator
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Bio:
EPR is responsible for Superfund, water quality and NEPA activities. Upon the retirement of Carol Campbell, Mr. Hestmark has been assigned the position of Acting ARA. Prior to joining EPR, he worked for 10 years in Enforcement, Compliance and Environmental Justice (ECEJ) as the Program Director for a Technical Enforcement Program with major emphasis in Air and Toxics but also including 3 years experience implementing RCRA enforcement. In addition, he worked almost 2 years as the Director of the Planning and Targeting Program within ECEJ. Prior to becoming a Program Director in the Technical Enforcement Program, Mr. Hestmark worked as the Section Chief and Team Leader of the Rocky Flats Federal Facility Section and started his EPA experience as a RCRA Inspector with state of Colorado responsibilities, including compliance monitoring at the Rocky Flats facility.

Prior to coming to EPA Region 8, Mr. Hestmark worked as a Project Engineer/Estimator for a mechanical/electrical industrial contractor building and estimating the cost of construction for gas plants and other oil and gas related processing facilities. He also worked as a process engineer for a mineral extraction company developing metallurgical processes designed to extract industrial metals from ore. Mr. Hestmark received his chemical engineering degree from the University of Colorado and his master's degree in engineering ecology from the Colorado School of Mines.

THE MINING LEGACY AND EPA ORD: PAST, PRESENT AND INTO THE FUTURE

David Reisman
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Bio:
David Reisman has been the Director of the EPA ORD Engineering Technical Support Center since 1998, when he switched from almost 20 years of risk assessment to risk management. Mr. Reisman has been educated in Ohio, receiving an undergraduate degree in zoology and ecology, and a master's degree in environmental sciences from Miami University. He continued with studies in environmental engineering at the University of Cincinnati. As the ETSC Director, Mr. Reisman

reviews site-specific documents, participates on conference calls, and advises regional project managers on soil and sediment remediation, innovative technology and mine remediation. Mr. Reisman has consulted on over 50 mines across the United States, and he has worked internationally with the World Health Organization, the Central and Eastern European Health and Environment organization and also with several Canadian organizations. For the past 10 years, he has been instrumental in developing a mining influenced water treatment applied research program within EPA, including several state-of-the-art demonstrations in the biochemical reactor area. Mr. Reisman also participates on teams with the Interstate Technology and Regulatory Council (ITRC), and has been influential in its two mine material teams. Mr. Reisman is most proud of the many students that he has advised and mentored throughout his career.

THE BIG FIVE TUNNEL PROJECT: LONG-TERM LESSONS

Thomas Wildeman
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Bio:
Dr. Thomas Wildeman has been teaching, doing research, and consulting for 45 years. He and Jim Gusek have been developing passive treatment systems for 25 years. Along the way, they have been twice awarded Colorado and National awards from the Consulting Engineers Council in the environmental engineering division for work on passive treatment. Dr. Wildeman has been awarded Researcher of the Year and Mr. Gusek has been awarded Engineer of the Year from the American Society of Mining Reclamation.

SUPERFUND AND MINING SITES: A REVIEW OF THE PAST AND OBSERVATIONS CONCERNING THE FUTURE

Roger Olsen, Ph.D.
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Bio:
Dr. Roger Olsen is a Senior Geochemist and Sr. Vice President at CDM Smith in Denver, Colorado. He has more than 30 years of experience in the conduct, planning, and management of environmental and remediation projects in the United States and internationally including evaluations on over 100 mining/milling sites. Dr. Olsen is the author of over 120 publications or presentations. He has a B.S. in mineral engineering chemistry and a Ph.D. in geochemistry from the Colorado School of Mines.

LEGACY OF INNOVATIVE REMEDIATION

Edward R. Bates
Remediation Consultant
U.S. EPA (Retired)
Cincinnati, OH
Phone: 513-317-9691; Email: erbates@hotmail.com

Bio:
Mr. Edward Bates is an independent consultant. He retired in June 2009 from the EPA after 32 years' service with the Office of Research and Development, including over 20 years working as an expert technical advisor on site characterization, remedy design, and remedy construction for nearly 100 CERCLA and RCRA sites including more than 22 mining sites. Mr. Bates has been invited to give lectures/papers at 17 national and international symposia and has written 14 publications on technology and remediation of hazardous waste sites. Mr. Bates has B.S. and M.S. degrees from Michigan State University.

Session 1: Case Studies

A MULTIPLE TRACER / GEOCHEMICAL APPROACH TO CHARACTERIZING WATER AND CONTAMINANT MOVEMENT THROUGH ABANDONED MINE WORKINGS NEAR RICO, COLORADO

Mike Wireman[1] *(presenting author)*, **Rory Cowie[2], Mark W. Williams[2] and Robert L. Runkel[3]**
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1595 Wynkoop Street, Denver, CO 80202-7206
Phone: 303-312-6719; Email: wireman.mike@epa.gov
[2]University of Colorado Boulder, Boulder, CO
[3]U.S. Geological Survey, Denver, CO

Abstract:
The Rico Argentine mine is a long-term acid mine drainage (AMD) site where current management of contaminated discharge from the St. Louis tunnel consists of a series of passive treatment settling ponds. The settling ponds have a limited lifespan and do not provide a permanent solution to controlling the AMD. A relatively new but challenging approach to hydrologic characterization of AMD sites is using tracers to help identify and characterize the sources and flow paths of contaminants, thereby creating an opportunity for a targeted hydraulic control remedy. At the Rico Argentine mine a suite of inorganic salt and organic dye tracers were used to characterize flow paths and the interactions of surface and ground waters. At several sites the organic and inorganic tracers were applied simultaneously to account for potential problems associated with chemical and physical interactions between organic dyes and AMD geochemistry. Constant injection and slug injection tracer techniques were used to determine if water from Silver Creek was lost to groundwater and/or mine workings. Tracers were also injected at discrete locations within the mine workings to better understand the interior connections of the mine system. Additionally, isotopic and geochemical data from numerous water samples were analyzed to further identify source waters, flow paths, and residence times of waters moving throughout the mine workings and discharging to the settling ponds. Initial results indicate that Silver Creek losses are small (<5%) and are potentially moving through a shallow alluvial ground water system, but not directly into underground workings

associated with the Blackhawk fault. Results also indicate significant, connectivity of the inner mine workings with arrival times of 17 hours and 10 hours for tracers traveling approximately 5,000 feet and 1,000 feet respectfully. The rapid arrival times indicate significant structural integrity of the abandoned mine system and may aid in the development of more localized hydraulic control remediation strategies at the historic Rico Argentine mine system.

Bio:
Michael Wireman is a hydrogeologist currently employed by the U.S. EPA in Denver, Colorado, where he serves as a National Ground-Water Expert. He has a master's degree in hydrogeology from Western Michigan University in Kalamazoo, Michigan, post M.S. work at the Colorado School of Mines and 25 years of experience in ground-water investigations in the Rocky Mountain west. He has served as a project manager for a private consulting firm where he directed ground-water exploration and development projects. In his current position he provides technical and scientific support to several EPA programs, other federal agencies, international programs and ground-water protection/management programs in several western states. Mr. Wireman manages research projects related to mine-site hydrology/geochemistry, ground-water sensitivity/vulnerability assessment, isotope hydrology, ground-water/surface water interaction and aquifer characterization. He has significant experience in the legal, scientific and programmatic aspects of ground-water resource management. He also has extensive experience in ground-water related work in the Baltic countries, Ukraine, Romania and Georgia. He has served as an adjunct professor at Metropolitan State College in Denver where he taught a class on contaminant hydrology and he teaches a class on fractured rock hydrology for the NGWA. He is a member of the Colorado Ground - Water Association, the National Ground Water Association, the Geological Society of America, and is the current President of the U.S. Chapter of the International Association of Hydrogeologists.

ACID MINE DRAINAGE SOURCE CONTROL PROGRAM DESIGN INVESTIGATION UPPER TENMILE CREEK MINING AREA SUPERFUND SITE, RIMINI, MONTANA

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Abstract:
This presentation will describe the status of the acid mine drainage source control program at the Upper Tenmile Creek Mining Area Superfund site in Montana. The site contains approximately 150 abandoned mines. Remediation has not addressed mine-influenced water (MIW) from discharging adits.

Remediation of discharging adits is prioritized by contaminant loading of arsenic, cadmium, lead and/or zinc. MIW from three adits – the Susie, Lee Mountain and Red Water – is considered a principal threat waste by EPA. Principal threat wastes are highly toxic or highly mobile materials that cannot be contained in a reliable manner that present a significant risk to human health or the environment. Under Superfund law, principal threat wastes must be treated.

To reduce or potentially eliminate the need for active water treatment at these three adits, the design investigation is focused on identifying potential water infiltration sources that may reduce or eliminate MIW. The data were collected during this effort to better understand the structural

features of the mines so that information can be used in the planning of pilot-scale source control efforts to minimize discharge of poor-quality water from the adits.

The two mines make an interesting case study because, even though they are located approximately 1,500 feet apart, the mines will require different source control strategies. Initial findings show that the Susie discharge responds slowly or not at all to precipitation and stream flow changes, indicating catchment-wide recharge. Discharge at the Lee Mountain adit responds quickly to precipitation, indicating direct connections to the surface. Results of the investigation will be used to develop pilot infiltration reduction measures.

Bio:
Angela Frandsen is an environmental engineer and project manager with CDM Smith in Helena, Montana. She has provided technical support to EPA Region 8 on many of the mining-related NPL sites, with a focus on water quality impacts and mine water treatment. She has been involved in all aspects of the Superfund process on both PRP-lead and EPA fund-lead projects, from the remedial investigation/feasibility study, to the record of decision, and through remedial design and remedial action. She was a major author for completion of the record of decision for the Butte Priority Soils superfund site in Butte, and co-author of five complex technical impracticability waivers for groundwater and surface water for sites in Butte and Anaconda, Montana.

IMPROVING REMEDIATION PLANNING THROUGH EFFECTIVE MINE MATERIAL DELINEATION, FORMOSA MINE SUPERFUND SITE, DOUGLAS COUNTY, OREGON

Mark R. Nelson, P.G.[1] *(presenting author)*, **Nicholas R. Anton, P.E.**[2] **and Howard Young, L.G.**[2]
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Abstract:
Effective remediation of large-scale mines commonly includes actions that address contaminants in mine materials such as waste rock and tailings. This applies to conventional mine remediation practices such as capping in-place and consolidation into lined repositories, and innovative approaches such as re-mining to recover valuable metals or treatment to remove sulfide minerals. In all cases, effective mine material remediation depends on accurate characterization of contaminant concentrations, acid rock drainage (ARD) potential, metals leaching (ML) potential, and delineation of the horizontal and vertical extent of mine materials. Mine materials are inherently heterogeneous and often contain varying proportions of ARD-generating minerals, ML potential and total metals. At the Formosa Mine site, a coupled approach using rapid field geochemical characterization combined with specialized laboratory analyses of a subset of field samples was implemented to accurately characterize and delineate mine materials. These data were evaluated using a weight-of-evidence approach to delineate mine materials in sufficient detail to support future remedial action decisions.

The coupled characterization approach enabled efficient collection of a large number of samples with real-time field geochemical results to adequately describe mine material heterogeneity and guide investigation activities. A subset of these samples was submitted for specialized laboratory analyses to better define mine material environmental characteristics. The rapid field characterization methods used at Formosa included field paste pH and conductivity measurements, visual

examination of lithology, mineralization and alteration, and field portable X-Ray fluorescence (FPXRF). Sampling was conducted in near-surface mine materials using hand tools and in subsurface mine materials using a Geoprobe® direct-push rig and a track-mounted excavator. Laboratory analyses included acid base accounting (ABA), total metals analyses, and modified synthetic precipitation leaching procedure (SPLP). More than 900 samples from the surface and subsurface were analyzed using the rapid field characterization procedures to characterize an area of approximately 30 acres. Approximately 100 samples were analyzed using the suite of laboratory analyses. A small set of samples was analyzed using scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) to characterize the sulfide mineralogy of the mine materials. Collection of an adequate number of samples during the remedial investigation ensures sufficient data to support the feasibility study, reduces uncertainty in future remedial action decisions, and improves the likelihood that the future remedial action will be successful.

Weight-of-evidence criteria were developed to identify and delineate mine materials with ARD/ML potential based on contaminant release and transport mechanisms identified in the site conceptual model, statistical relationships between field and laboratory data, and lithologic characteristics indicative of ARD/ML potential. Characteristics of mine materials are generally not normally distributed. Bimodal or multimodal statistical populations are commonly encountered. Therefore, data assessment included non-parametric statistical approaches, exploratory data analysis, and spatial data analysis. Mine material delineation considered weight-of-evidence metrics, light detection and ranging [LIDAR] topographic data, aerial imagery, and professional judgment regarding site-specific conditions and contaminant transport mechanisms. This process resulted in efficient and accurate characterization and spatial delineation of mine materials to support subsequent feasibility study analyses and remedial action decisions.

Bio:
Mark Nelson is a geologist who has worked in various facets of the mining industry since 1988 with a focus on mine hydrogeology, geochemistry, environmental management, permitting and remediation. He has worked on over 70 mining projects including gold, copper, molybdenum, lead, zinc, uranium and industrial minerals projects located across the western United States. He has experience working with mining corporations ranging in size from juniors to majors, state regulatory agencies, and federal agencies including U.S. Forest Service, U.S. Bureau of Land Management and U.S. Environmental Protection Agency. Mr. Nelson has completed 28 previous publications and presentations focused on mining and environmental issues. He holds an M.S. degree in geology and geological engineering from the South Dakota School of Mines and Technology, and a B.S. degree in geology from the Ohio State University. He is a certified professional geologist with the American Institute of Professional Geologists, a licensed professional geologist in Wyoming, and a registered geologist in Oregon and Arizona.

MINISIPPER: A NEW, HIGH-CAPACITY, LONG-DURATION, AUTOMATED IN-SITU WATER SAMPLER FOR ACID MINE DRAINAGE MONITORING AT THE PENNSYLVANIA AND STANDARD MINES, CO

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Abstract:
Abandoned hard-rock mines in Colorado are often located in remote, high elevation areas that are very challenging to sample, especially during the inaccessible 7-8 month winter period. Many abandoned mines also have extensive underground workings which are difficult or dangerous to access and collect samples. Automated samplers could provide water sampling at these remote, difficult to access, or snowbound sites, but currently available samplers are typically large, heavy, collect 24 samples, and are not well suited for operation in freezing conditions.

The USGS has developed a small, light, low-cost, high-capacity, in-situ water sampler, the MiniSipper, to overcome the limitations of current automated samplers. The MiniSipper injects 2 to 10 mL discrete or integrated water samples into a Telfon sample coil. Nitric acid is added to stabilize samples and adjacent MiniSipper samples are separated with a gas bubble. Over 220 five mL water samples can be collected with <5% carryover. After recovery, samples are pumped out of the sample coil and analyzed by high sensitivity multi-element methods such as ICP-MS (inductively coupled plasma mass spectrometry). ICP-MS only require a few mLs of sample per analysis so the large sample volumes collected by traditional automated water samplers are often unnecessary.

The in-situ design of the MiniSipper allows for easy concealment under streambed rocks and the MiniSipper has successfully collected samples during 8 month deployments under surface ice for over-winter sampling. MiniSippers are especially useful in underground monitoring at dangerous or difficult to access sites, providing some of the first high-resolution data from these locations. New applications of MiniSipper technology include a Borehole MiniSipper (<2" ID) for long-term, high-resolution sampling of monitoring wells and an Event Response MiniSipper which is capable of increasing sampling frequency in response to transient rain events.

We have deployed MiniSippers in support of two U.S. Environmental Protection Agency (EPA) projects evaluating metal inputs from acid mine drainage sites at the Pennsylvania and Standard mines in Colorado. The Penn Mine discharge has the highest metal concentrations during peak snowmelt or large rain events. Our Penn Mine results reveal high correlations between potentially toxic metals (Al, Cd, Cu, Zn) and specific conductivity. The Standard Mine shows a very different response with transient spikes of high metal concentrations during initial snowmelt runoff followed by the lowest metal concentrations during peak snowmelt runoff.

The MiniSipper is ideal for monitoring difficult to access sites and difficult to sample hydrologic events such as snowmelt runoff, storms pulses, or winter low-flow periods. The large number of

water samples collected (>200) and long deployment duration (>8 months) of the MiniSipper greatly reduces field-site visits and costs. MiniSipper results will help guide EPA sampling strategy and remediation efforts at these acid mine drainage sites.

Bio:
Dr. Thomas Chapin is a Research Chemist at the USGS in Denver, Colorado. His research focuses on the design, development, and application of new, low cost instrumentation for high-resolution, long-duration water sampling and chemical analysis. Dr. Chapin has developed a number of new instruments at the USGS including an in-situ Zinc analyzer, the MiniSipper, the Event Response MiniSipper and the Borehole Sipper. These instruments have been used for long-term, high-resolution monitoring of metals in watersheds impacted by abandoned mines and watersheds burned by wildfire. Dr. Chapin has a Ph.D. in chemical oceanography from the University of Washington. Prior to joining the USGS, Dr. Chapin worked as a post-doc and research associate at the Monterey Bay Aquarium Research Institute, where he developed high-resolution, in-situ chemical analyzers for long-term monitoring of metals in hydrothermal vents and nutrients in estuaries.

IDENTIFICATION AND QUANTIFICATION OF ARSENIC SPECIES IN GOLD MINE WASTES USING SYNCHROTRON-BASED X-RAY TECHNIQUES

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Abstract:
Arsenic (As) is an element of concern at many of the major types of base and precious metal deposits currently mined in the world, including the quartz-hosted, low-sulfide (lode) gold deposits of California. In that state, total arsenic-based regulatory standards currently limit the redevelopment of many mine-scarred lands due to the high "total arsenic" values found there. However, *in vitro* and *in vivo* studies to date suggest that much of the As present in these lands is present in low-bioavailability/bioaccessibility species. This presentation will review the major research conclusions about As speciation in mine-scarred lands that have been provided by synchrotron-based, X-ray techniques, culminating with a presentation of data from the Empire Mine State Historic Park, where a study is being conducted to quantify the links between As speciation and bioavailability/ bioaccessibility. Case studies will also be presented for As speciation in Brake Fern, which has been studied for its potential use in phytoremediation, and As species in native microbiological communities being considered for use in an augmented passive bioremediation system. Most of the case studies will be drawn from the author's own work, but the (referenced) work of numerous others will be included in the major conclusions.

The allied synchrotron techniques include X-ray absorption spectroscopy (XAS), X-ray Fluorescence (XRF), and X-ray diffraction (XRD). They can each be conducted on large (several millimeter) or small (micro- and nanometer) scale samples, with a minimum (or absence) of pretreatment. Together, these techniques allow quantification of the forms (chemical species) of arsenic in complex, heterogeneous materials such as mine wastes, contaminated soils, plant material and microbiological specimens. The techniques can be performed *in-situ*, meaning that the sample is not digested or significantly altered prior to analysis. Detection limits vary with technique from a few ppm to a few hundred ppm total As. Species mixtures can be quantified with a confidence of 5-10%, and with empirically-determined detection limits ranging from about 10% to as low as 1%. The

quality of quantitative species analysis is dependent on the quality of the library of arsenic model compounds used in that analysis, and for some systems, inherently limited by the similarity of the XAS spectra of some arsenic species.

One of the most important conclusions from the body of synchrotron studies on arsenic in gold mine wastes is that the majority of toxicological studies on arsenic have been conducted using forms that are not common in the natural environment. Although in part this is a necessary requirement to inform relative bioavailability/bioaccessibility studies, there is currently a need for focused studies to define the toxicity of key environmentally-relevant compounds, and for studies that provide some predictive capacity for toxicity of a compound by considering its solubility and dissolution kinetics (for elements such as arsenic, in which the dissolved, inorganic forms are among the most toxic).

Another important conclusion is that although the overwhelmingly predominant form of arsenic is associated with iron oxyhydroxides, all oxyhydroxides are not created equal. A huge variation in the loading of As on iron oxyhydroxides exists that is a reflection of the weathering history of the system. Arsenic can be associated with iron oxyhydroxides through multiple mechanisms, each having a different bioavailability/bioaccessibility. A final conclusion is that high-solubility arsenic-bearing phases of minor abundance may have a disproportionately large impact on measured bioavailability/bioaccessibility due to their higher solubility under test conditions.

Bio:
Dr. Andrea L. Foster has worked as a Research Geologist at the USGS in Menlo Park, since obtaining her Ph.D. from Stanford University in 1999. Dr. Foster specializes in the use of synchrotron-based X-ray techniques to elucidate the specific forms (species) of elements present in environmental samples (rocks, sediments, plants, microbial mats and animal tissues). Since graduate school, Dr. Foster has studied arsenic (As) species in environmental samples from mined areas of California's Mother Lode (a region of numerous low sulfide, quartz-hosted gold deposits), but she has also investigated Se and Cr (Phosphoria Formation), Cu (Cu-sulfide deposit), Cd and Zn (mineralized, unmined areas). She performed field-based research on As speciation at the Lava Cap Mine Superfund site (California) under USGS (1999-2002) and EPA (2006-2009)-funded projects, and is currently working on As speciation for an EPA-funded project at the Empire Mine State Historic Park (California). The overall goal of Dr. Foster's work is to use speciation information to refine predictive models of the processes controlling trace element dispersion, retention and bioavailability at the site scale in natural and engineered systems.

MICROANALYTICAL TECHNIQUES TO UNDERSTAND ELEMENT LEACHING FROM ORE MINERALS IN MINING WASTES

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Abstract:
Abandoned mine-waste and tailings piles are potential reservoirs of sulfides and other minerals that can continue to weather and release acid, metals and other constituents. Alteration products of sulfide minerals are sinks for mobile metals, and our leaching tests provide an indication of water-based readily leachable metal concentrations from abandoned mining wastes. Micromineralogic characterization and analysis is useful to improve predictive models of trace-element release and acid mine drainage generation from mine waste. The data we acquire on the mobility of elements and degree of solubility of ore minerals will contribute to the broader understanding of minerals in natural systems and their importance in environmental and human-health studies.

Characteristic element abundances are often associated with different types of ore deposits, depending on geologic setting. Mining waste chemistry and mineralogy is complex because most ore minerals can host many trace elements that are not a part of the mineral's stoichiometric formula. The presence of these trace-element impurities affects the physical and chemical behavior of the minerals as they weather in waste piles and tailings ponds. As part of the U.S. Geological Survey Development of Mineral Environmental Assessment Methodologies Project, we used detailed mineral and chemical techniques such as X-ray diffraction (XRD), scanning electron microscope (SEM), electron microprobe (EPMA), and leaching studies on concentrated ore mineral samples to understand their weathering characteristics and potential to release constituents into the environment.

The bioavailability of a potentially toxic element depends on the element speciation in the host mineral, the physical properties of the mineral, and the distribution or mode of occurrence of the element of interest in the mineral. The focus of our study is to understand the potential bioavailability of elements such as Fe, Cd, Cu, Co, Ni, Pb, Zn, Mn, Hg and As in complex mine-waste material through detailed studies of ore mineral samples.

Findings from our first study focused on four Cu bearing minerals (Driscoll et al., in press). Here we discuss results from the second study, a suite of concentrated zinc ore minerals: sphalerite (ZnS), hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$), smithsonite ($ZnCO_3$) and hydrozincite/willemite ($Zn_5(CO_3)_2(OH)_6/Zn_2SiO_4$). Sphalerite was collected from two different ore-deposit types in order to compare chemistry. SEM and EPMA studies show that both sphalerite samples are intergrown

with other sulfide minerals, such as pyrite and galena, as well as host to oxidation alteration minerals. Leachate from the Fe-rich sphalerite sample from the SEDEX (sedimentary exhalative) Balmat, NY deposit was enriched in Al and Cu, whereas leachate from the Fe-poor sphalerite sample from the epithermal vein Creede, CO deposit was enriched in Cd, Co, Mn, Pb and Zn. This illustrates that ore minerals from different locations can have different chemical and mineralogical properties, which is important in their leachability. The hydrozincite/willemite sample, which is the finest grained and most porous sample, showed the highest concentration of leachable elements such as Ag, Cd, Ni and Pb.

Driscoll, R., Hageman, P., Benzel, W., Diehl, S., Adams, D., Morman, S., and Choate, L., in press, Assessment of the Geoavailability of Trace Elements from Minerals in Mine Wastes: Analytical Techniques and Assessment of Selected Copper Minerals: U.S. Geological Survey Scientific Investigation Report SIR 11-5211, 68 pages, http://pubs.usgs.gov/sir/2011/5211.

Bio:
Dr. Sharon Diehl is a Research Geologist with the USGS, stationed in Denver, Colorado. Dr. Diehl earned her bachelor and master degrees at the University of Colorado, and her Ph.D. at Colorado School of Mines. Her expertise is in conducting microanalytical studies of mine-waste materials to determine the mineralogic source of potentially toxic trace elements, their exact mode of occurrence and methods of transport. She has 36 years of experience as a geologist. The first years were spent in the gold and base metals minerals industry, but the bulk of her career has been with the USGS as a petrologist.

Session 3: Case Studies (cont.)

A PROPOSED SEMI-PASSIVE TREATMENT SYSTEM AT REMOTE AML SITES

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Abstract:
Millennium Science and Engineering, Inc. (MSE) was commissioned to perform an Engineering Evaluation/Cost Assessment (EECA) for treatment of acid mine drainage (AMD) from an underground mine portal at a remote, confidential, abandoned mine (Site) in the northwest United States. The site is located at the bottom of a steep canyon and along the bank of a Wild and Scenic River. Access is limited to unimproved road access by 4x4 or boat, and snow often prevents access by vehicle during winter. Most of the limited, relatively flat terrain, which is a veneer of alluvial gravel, is within the 20-50 year flood and the portal is in the 2 year floodplain. The orebody is a massive sulfide which was exploited by several levels interconnected underground, but discharge is only from the lowest adit. Discharge ranges from 5 to 15 gallons per minute (gpm) with measured pH ranging from 2.5 to 3.23 standard units. Human health and aquatic criteria are variously exceeded by arsenic (up to 1.48 mg/L), cadmium (up to 0.06 mg/L), copper (up to 5.04 mg/L), iron (up to 196 mg/L), lead (up to 0.65 mg/L), selenium (up to 0.048 mg/L), and zinc (up to 11.2 mg/L). Through a separate contractor, the owner had evaluated the possibility of sealing the lower

adit. The contractor's conclusion was that a plug could be used to reduce but not terminate discharge. The owner also tested two neutralization procedures for application at the site: lime addition and caustic addition. Both methods are viable, each with their own concerns. However, neither approach effectively dealt with sludge densification and disposal. MSE was required to consider alternatives incorporating an adit plug, lime addition, caustic addition and wetland application. As required, a "No Action" alternative was also evaluated. A major concern for all alternatives is that flooding will probably inundate the lower adit and may flood any settlement basins. MSE concurs with the prior contractor that a complete sealing plug is probably not viable at the site. Evaluation of a wetland treatment indicated the wetland would be located within the 50-year flood plain and subject to wash out. In addition, the discharge may require neutralization before wetlands introduction. Also the low discharge rate may not be adequate to maintain a wetland without supplemental flow from the river. Both options were rejected.

MSE evaluated six alternatives during the EECA:

- Alternative 1 – No Action (A Required Alternative)
- Alternative 2 – Dam and Treatment with Simple Basin
- Alternative 3 – Full-Span Bulkhead and Treatment with Simple Basin
- Alternative 4 – Plug and Treatment with Simple Basin
- Alternative 5 – Plug and Treatment with Complex Basin
- Alternative 6 – Plug and Treatment with GeoTube (Fabric) Filters

Alternative 6 is recommended. This alternative consists of a concrete plug behind which is a 20-foot standpipe to maintain head. The plug contains an access door for the future. Treatment will be a simple caustic and polymer addition system operated by batteries and photovoltaic solar panels, eliminating commercial power. All reagents will be stored underground to prevent vandalism and prevent freezing of the caustic, and all electronics and pumps will be in waterproof housings. This discharge will be piped to a nearby series of Geotube containers within large standard dumpsters that can be loaded by standard refuse truck for transport to disposal. The dumpsters will be maintained in a secured, below ground level concrete pit with roof as an option. Filtrate will discharge to a central drain that pipes the effluent through a protective bag filter system to an infiltration gallery for final treatment by soil sorption. This approach prevents inundation of the adit during flooding, and the filter systems are far less susceptible to flooding than settlement basins. Only post-flood cleaning will be needed. The footprint is relatively small, and sludge disposal is simple as opposed to removal from settlement basins. Construction and 5-year operating cost is $2,838,000 excluding access road improvement.

Bio:

Bob Lambeth is a Senior Mining Engineer with Millennium Science & Engineering, a division of EW Wells Group LLC, in the Spokane, Washington office. He oversees CERCLA actions at abandoned mines on federal land and permitting and mine closure activities for industry. He has 42 years of experience, including production, exploration, and environmental mitigation in coal and metal deposits throughout the United States. He became involved in mining environmental issues in 1987 with the USBM ARD Research Group and has published numerous papers and made multiple presentations relating to ARD prevention and mitigation. With closure of the USBM in 1996, he became a consultant to government and industry during which he completed closure activities at active mines and abandoned mines, including design and installation of effluent treatment systems. Mr. Lambeth earned a B.S. in geological engineering and a B.S. in mining engineering from Montana Tech and an M.S. in environmental geology from Eastern Washington University.

CAPTAIN JACK MINE SUPERFUND SITE SUBSURFACE REMEDY: PRE-DESIGN INVESTIGATION RESULTS AND PRELIMINARY DESIGN

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Abstract:
The Captain Jack Superfund Site is located west of Boulder, Colorado near the small historic mining town of Ward. The site includes the Big Five mine tunnel and adit -- an abandoned underground gold mining operation dating to the early 1900s. Low pH water containing elevated concentrations of metals discharges from the adit at seasonally variable flowrates that range from 30 to 140 gpm. This acidic mine drainage (AMD) enters Left Hand Creek a short distance from the mine.

The site Record of Decision (ROD) was issued by the Colorado Department of Public Health and Environment (CDPHE) and U.S. EPA on September 31, 2008. The selected remedy for the underground mine and AMD called for the design and installation of a flow control bulkhead in the Big Five Tunnel, and construction of an in-situ treatment system for the impounded mine pool that forms behind the bulkhead. The intent of remedy is to avoid long-term treatment system operations. AMEC E&I was awarded a contract in May 2011 to conduct pre-design investigation work followed by preparation of conceptual designs and completion of final design and bid documents for the selected remedial action. The remedial design will include three major components: 1) a flow-through bulkhead; 2) in-situ mine pool treatment; and 3) long-term monitoring.

The underground workings are accessible for approximately 900 feet, at which point a collapse has made further exploration impossible. Historical records indicate that the workings extend for perhaps a mile or more, with a major cross-cut (Niwot Cross-cut) connecting the Big Five system to the Columbia Vein system beneath the town of Ward. Non-invasive and invasive techniques were used in an attempt to "map" the historical mine workings. The project team conducted an extensive review of historical mine records to develop a rough map of the workings. Geophysical specialty contractors employed a variety of innovative surface and borehole geophysical and hydro-physical techniques to image the underground workings and assess the fracture system in the vicinity of the mine. These images were used to successfully direct the placement of boreholes that targeted the mine tunnel. Borehole depths ranged from 300 to over 500 feet into the granite subsurface. The boreholes will ultimately be used as part of the mine pool treatment and monitoring system.

The conceptual design for a massive concrete bulkhead with flow-through pipes has been completed. Design of the bulkhead was supported by mapping the competency of tunnel rock, geotechnical cores and analysis, and hydraulic conductivity testing in the cored zones using packers and high pressure water. Bench-scale treatability testing using caustic and lime slurry, along with geochemical modeling was completed to evaluate the potential efficacy and cost of mine pool neutralization and potentially *in situ* biological treatment.

Alternatives for the treatment system include: 1) neutralization via recirculation of mine water with the addition of caustic and air; 2) placement of a mass of crushed limestone on the upgradient side of the bulkhead (with or without caustic recirculation); and 3) placement of a solid biomass fill upgradient of the bulkhead to create a sulfate-reducing bioreactor. A long-term monitoring system is being designed to track water quality and pressure head within the mine workings at selected

locations where borings can successfully penetrate the tunnel from the surface. In addition, the fractured bedrock around the mine pool will be monitored using geophysical techniques including electrical resistivity tomography (ERT). The ERT arrays are expected to be installed in borings (borehole to borehole) and in shallow buried surface arrays (borehole to surface). The ERT system will be placed so that changes in the electrical resistivity of the fractured rock mass surrounding the tunnel can be identified as the mine pool forms.

There are significant logistical issues with the various approaches, including property access, rugged terrain, lack of utilities, highway crossing, security and cultural resource designations. The selected conceptual approach will undergo a value engineering review, with the detailed design to follow in early 2012.

Bio:
Craig Weber manages the Environmental Engineering Group for AMEC E&I's Colorado Operations. He specializes in subsurface remediation technologies, and supports remedial efforts at sites throughout the United States and overseas. Clients include private industry, federal and state agencies, the U.S. Army Corps of Engineers, and Department of Defense organizations. He has particular expertise with various applications of multi-phase vacuum extraction. In addition to directing the Captain Jack in-situ remedy design, he is actively involved in acid mine drainage treatment efforts at the Leviathan Mine Superfund site in California. He began his consulting career in 1986 and has previously worked at Radian Corporation, URS, and most recently Geomatrix prior to their acquisition by AMEC E&I. Mr. Weber has a B.S. in wildlife biology from the University of Montana and an M.S. in environmental engineering from Washington State University.

CASE STUDIES IN MINE CLOSURE AND ACID ROCK DRAINAGE MANAGEMENT AT RIO TINTO

R. Borden and Victoria Peacey[1] *(presenting author)*
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Abstract:
Rio Tinto is committed to systematic mine closure and acid rock drainage (ARD) management. Rio Tinto has an extensive portfolio of active and closed mines in the United States. Consistent with Rio Tinto's corporate framework on HSE management, a number of these properties have been successfully closed and feature innovative practices in closure and ARD management. This presentation highlights closure and ARD management practices at the Ridgeway mine, Barneys Canyon mine, Daybreak land development and Flambeau mine. It is believed that practices applied at these sites and the underlying systems can lead to successful closure at other mine sites.

Bio:
Vicky Peacey is Manager of Permitting and Approvals for Resolution Copper Mining. In this role, she oversees all federal and state permitting and approvals for the project in addition to baseline environmental studies. Prior to Resolution Copper, Ms. Peacey worked at a number of mine sites and projects including the Kennecott Eagle Project in Michigan and Kennecott Utah Copper and Kennecott Barneys Canyon Mine in Utah. At those sites she held various roles related to state and federal permitting and approvals, baseline studies, air permitting, groundwater remediation and reclamation, as well as ARD management and prevention. Ms. Peacey has several publications on

various case studies in management of acid rock drainage. She has B.S. and M.S. degrees in environmental engineering.

Session 4: Innovative Technology and Techniques (cont.)

USING ACID MINE DRAINAGE SLUDGE TO REMOVE PHOSPHORUS AND OTHER METAL OXYANIONS FROM WASTE WATER

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Abstract:
The treatment of acid mine drainage (AMD) often results in the formation of iron- and aluminum-rich hydroxide sludge materials that are usually disposed of at cost in landfills or other waste dumps. The development of practical uses of these waste products would decrease AMD treatment costs while, at the same time, providing a beneficial application for the sludge. It is well known that iron and aluminum hydroxides are used as sorbents for the removal of phosphorus (P) from municipal drinking and waste water streams. Over the past several years, we have investigated the sorption of P from both synthetic and actual waste waters using AMD sludges in batch and continuous treatment modes. In particular, the use of fixed-bed sorption systems has been investigated, as liquid-solid separation would not be necessary after treatment. A series of fixed-bed sorption tests has shown that AMD sludge can effectively adsorb P with up to 96% removal of P from influent wastewater over 46 days of continuous treatment. The P can also be desorbed from the sludge at high pH values and precipitated to produce a marketable fertilizer product. Preliminary investigations have also been conducted for arsenic removal from wastewater, given its chemical similarity to P, with up to 98% removal in batch contact tests. Other possible contaminants that might be expected to sorb onto iron or aluminum hydroxide media include selenium, chromium and molybdenum. These results confirm that AMD sludges, in many cases, can be a valuable resource for waste water remediation rather than a waste product requiring disposal.

Bio:
Dr. Philip Sibrell is a research engineer with the USGS, at the Leetown Science Center in Kearneysville, West Virginia. He is currently investigating innovative uses for acid mine drainage sludge as well as limestone-based remediation of acid mine drainage. 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 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.

RESULTS FROM A BENCH SCALE PASSIVE TREATMENT SYSTEM DESIGNED FOR REMOVING SULFATE AT A SITE ON VANCOUVER ISLAND, BRITISH COLUMBIA

E. P. Blumenstein, P.E.[1] *(presenting author)* **and J.J. Gusek, P.E.**
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Abstract:
Sulfate is beginning to gain attention and be regulated in mining influenced water (MIW) discharges worldwide. Currently, the effective options are limited with reverse osmosis (RO) filtration and/or chemical precipitation most commonly implemented. These systems are burdened by high capital costs (equipment, construction) as well as high operational and maintenance (O&M) costs (power consumption, chemical usage, sludge production and operations staff). There is a need to develop an alternative technology that can economically remove sulfate from MIW and achieve compliance with these anticipated regulations.

Until recently, anaerobic passive treatment cells such as biochemical reactors (BCR), also known as sulfate reducing bioreactors (SRBR), successive alkalinity producing systems (SAPS), and reducing alkalinity producing systems (RAPS), have primarily focused on increasing pH to circum neutral levels and removing metals (aluminum, cadmium, copper, iron, mercury, nickel, lead, selenium, thallium, uranium, vanadium, zinc, among others). In contrast, a hybrid passive demonstration system has been built at a coal mine site on Vancouver Island, British Columbia for the primary purpose of removing sulfate from MIW. The demonstration system was based on bench test results.

The demonstration hybrid passive treatment system has a design flow rate of approximately 70 gallons per minute (4.5 L/sec) and consists of a BCR, a separate sulfide polishing cell, and an aerobic polishing system. Power is required to pump MIW influent from an underground mine pool to the BCR and for active aeration and mixing in the aerobic polishing system. Active aeration was used in lieu of a constructed wetland due to space constraints on the site. Bench results, construction of the demonstration system, and preliminary demonstration system results will be discussed.

Bio:
Eric P. Blumenstein is a Senior Project Engineer for the Water Treatment and Automation Division out of Golder Associate Inc.'s Denver, Colorado office. At Golder, his focus is on alternatives analysis, design, implementation, and start up of passive and active water treatment systems. Over his six years at Golder, Mr. Blumenstein has successfully completed the process of selecting a process treatment train, designed and provided construction oversight and start-up support for several treatment systems in the United States, Canada, Brazil and Equatorial Guinea. He has published a variety of papers, from occupational health and safety to microbial bioassay toxicity to design and analysis of active and passive biological treatment systems. Mr. Blumenstein received a B.S. in environmental engineering and an M.S. in environmental science and engineering from the Colorado School of Mines and is a registered professional engineer in the state of Colorado.

ENGINEERED PUMPABLE pHOAM™: A NEW INNOVATIVE METHOD FOR MITIGATING ARD

James Gusek[1] *(presenting author)*, **Brian Masloff**[2] **and John Fodor**[2]
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[2]Cellular Concrete Solutions LLC, Golden, CO

Abstract:
If one can embrace the medical analogue, many mining sites (both abandoned and active) suffer from a massive bacterial infection. When pyrite-bearing or sulfide-bearing rock formations, tailings, or mine wastes are infected by *Acidithiobacillus ferro-oxidans*, the likelihood of forming acid rock drainage (ARD) is almost guaranteed. The "pharmacy" of antibiotics available is extensive, ranging from solid alkaline amendments like limestone to liquid "medicines" such as sodium lauryl sulfate, sodium thiocyanate, waste milk and bipolar lipids. Unfortunately, the "geo-medical" teams of geochemists, microbiologists, engineers and mine managers lack the tools to surgically apply these active ingredients where they are needed most with a minimum of waste. Distribution of fine grained limestone on the surface of an acidic mine waste dump is analogous to applying a bandage soaked in antacid to treat an upset stomach. There have been a few isolated cases of in situ ARD suppression success, which will be addressed in the presentation. However, the implementation of up-to-date best management practices has not healed the numerous patients. An equivalent combination of hypodermic needle, cyber knife and arthroscopic probe is clearly needed, especially in the unsaturated vadose zones of mining sites where most ARD typically forms.

Using an engineered, flow-able or pumpable ***foam*** or pHoam™ as the medicinally analogous "dextrose delivery solution" for solid and/or liquid "geo-antibiotics," the authors have combined off-the-shelf technologies that have been previously applied in solving geotechnical problems in the mining industry. A patent for the innovative process is pending. This paper discusses method concepts and the advantages it could provide over conventional BMPs.

Bio:
Jim Gusek is a Senior Consultant with Golder Associates, Inc. based in Lakewood, Colorado and a registered professional engineer. He specializes in mine closure, mine land reclamation and 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 over 50 projects throughout the United States and in England, Malaysia, Fiji, Slovakia, Peru, Brazil and Chile. He was honored with the 2008 Reclamationist of the Year Award by the American Society of Mining and Reclamation.

He has presented many short courses about passive treatment of acid rock drainage and has co-authored/co-edited two books on the subject. He graduated from the Colorado School of Mines in 1973 with a B.S. in mining engineering. He is a founding member and ex-president of the Denver Chapter of Engineers Without Borders.

Presentation Abstracts
and
Speaker Bios

Wednesday, April 4, 2012

Session 5: Remediation and Stabilization Using Natural Materials

USING ORGANIC AMENDMENTS AND AGRONOMY IN REMEDIATION OF HARDROCK MINING SITES

Rufus L. Chaney, Ph.D.[1] *(presenting author)*, **Sally L. Brown**[2], **Michele Mahoney**[3], **Mark Sprenger**[4] **and Harry Compton**[4]
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[3]U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation, Washington, DC
[4]U.S. Environmental Protection Agency, Emergency Response Team, Edison, NJ

Abstract:
Many hardrock mining metal contaminated problem sites (mine debris, mine tailings and smelter emission contaminated land) are severely phytotoxic and/or infertile and remain barren of vegetation for decades. Sites may also comprise risk through plant uptake of soil contaminants or soil ingestion. Over the last 20 years we have developed methods to remediate/restore metal contaminated soils and mine wastes. In addition to metals issues in each case, severe infertility must be dealt with, including the lack of soil organic matter, organic-N, and soil microbes in these dead soil materials. Combining organic amendments such as livestock manure, biosolids, or composts, which include manure or biosolids, plus alkaline byproducts (wood ash, limestone byproducts) or other needed soil fertility amendments (FGD-gypsum for Ca deficient asbestos mine wastes) can provide the needed agronomic remediation and metal inactivation.

For Zn-Pb-Cd rich acidic sites, Zn phytotoxicity usually limits plant growth, and ingestion of soil Pb may require remediation. We have found that combining surface applied biodegradable organic matter with alkaline materials can support leaching of alkalinity into the contaminated soil layer. This combination can deal with some acidity, but not with severe pyrite derived acidity. With deep pH 3 soil, enough alkalinity must be mixed with the surficial material to make it calcareous after neutralizing existing and potential acidity, preferably 60 cm deep or more so that a non-toxic rooting zone will allow persistent vegetative cover. For alkaline Pb-Zn mine wastes, severe infertility can be readily addressed with organic amendments rich in phosphate. All these sites need the organic-N, organic matter and soil microbial inoculum to become persistently fertile and to remain vegetated; enough organic N must be included in the mixtures, as well as allowing the amended soil to support persistent legume growth. Otherwise unpractical annual N fertilization is required for persistent revegetation.

Cd in such mine sites is seldom an actual risk because Zn is 100-fold higher. If the site is sufficiently contaminated that Cd requires consideration, Zn will be killing plants so Cd cannot cause risk, and killing earthworms so that pathway is not a Cd risk. Remediation of the Zn toxicity risk reduces Cd uptake and bioavailability which limits Cd risk.

Pb contaminated sites where soil ingestion is the dominant risk can be addressed by a combination of phosphate (to force formation of non-bioavailable pyromorphite) and organic amendments to

support strong revegetation which limits soil ingestion. Urban soils rich in Pb can have risk substantially reduced by phosphate amendment using manure or biosolids composts. Leafy composts are not rich in phosphate and are not as useful in soil remediation.

For Mo or Se contaminated sites, other approaches are required that do not raise soil pH because high pH promotes plant uptake which causes risk to ruminant animals.

Addressing metal contaminated hardrock mining sites requires one to deal with all soil fertility and agronomic issues as well as the metal issues. A comprehensive fertility-toxicity risk assessment will identify the metals issues and how to deal with them, but the fertility issues must be handled for persistent remediation. For acidic sites, application of limestone equivalent in excess of the existing and potential acidity can provide a buffer against future acidity from rainfall; 100 t/ha of limestone equivalent in excess provides good assurance that metal toxicity is prevented for the long term. Our reported soil metal remediation field studies at Bunker Hill, ID, Leadville, CO, Joplin, MO, Palmerton, PA, Katowice, Poland, and the VAG superfund site in Vermont have demonstrated the power of this approach to difficult barren site remediation.

Bio:
Dr. Rufus Chaney is a Senior Research Agronomist with USDA-Agricultural Research Service in Beltsville, Maryland. Since 1969 he has worked in various USDA-ARS laboratories, and is presently in the Environmental Management and Byproducts Utilization Laboratory where he conducts research on phytotoxicity and food-chain risks from soil metals, remediation of toxic mine waste and smelter contaminated soils, beneficial use of agricultural, municipal and industrial byproducts. He has cooperated with EPA and states in revegetation and ecosystem restoration at severely phytotoxic Superfund sites in Bunker Hill, Idaho, Leadville, Colorado, Palmerton, Pennsylvania and the Vermont Asbestos Group (Lowell, VT). Each case involved evaluation of potential toxicities and deficiencies for cover plants, testing of amendments to alleviate risk and/or reduce bioavailability of soil metals, with testing for food-chain protection. He developed the concept of phytoextraction of soil metals, participated in development of the Clean Water Act Section 503 Rule for Biosolids, and has over 420 publications.

THE EFFECT OF TAILINGS CHARACTERISTICS ON COVER SYSTEM SUCCESS

Jason Keller[1,A], Mike Milczarek[2], Tzung-mow Yao[2], Margaret Buchanan[1] and Monisha Banerjee, Ph.D.[1,B] *(presenting author)*

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Abstract:
Mine tailing properties significantly differ from other mine waste (e.g., waste rock and heap leach material) such that evapotranspiration (ET) cover system design criteria for tailings and post-closure monitoring necessitates different approaches. Tailings can generally be classified into three material types corresponding to location within the impoundment; each material type possesses distinct physical and hydraulic properties. This presentation provides case studies and a general summary of findings from over a decade of copper tailings reclamation research and performance monitoring at copper tailings facilities in the southwestern United States.

Data from several mines in central and eastern Arizona indicate that circumneutral tailings can be directly revegetated with organic amendments or by using very shallow covers. If directly amending tailings, low to moderate amendment rates with appropriate carbon to nitrogen ratios should be used to limit high nutrient conditions that favor undesirable non-native species. 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. The implications for reclamation planning are that rooting into tailings material extends the depth of plant water extraction and makes the tailings a component of the overall cover system. Revegetation seed mixes should consider differences between beach sand and slimes areas as well as cover depth, as mesic species can be used in slimes areas and xeric species will be more successful in beach/mixed areas. Salt tolerant grasses and shrubs are also more successful due to moderately saline conditions in circumneutral tailings. Nonetheless, the highly erosive nature of tailings requires capping of the side-slopes with erosion resistant material and direct revegetation or very shallow covers should be limited to generally flat areas.

Data from several sites with shallow covers over acid tailings that range in reclamation age up to 19 years show that upward acidity and salinity migration appears to be limited to shallow depths above the cover-tailings contact. These data also indicate that occurrence of upward salinity migration is highly variable and also greatly affected by the neutralization capacity of the cover material. Multi-year soil water dynamic monitoring of shallow covers over acid tailings and unsaturated flow modeling indicate that the low permeability tailings reduce infiltration rates at the tailings/cover contact and increase the overall storage capacity of the cover material. Moreover, tailings are highly layered which significantly affected the downward movement of water. Water balance modeling therefore should account for the hydraulic properties of the tailings up to depths of several meters. These findings indicate that tailings significantly affect the performance of ET cover systems and their physical and hydraulic properties and spatial variability in properties should be considered during cover system design.

Bio:
Dr. Monisha Banerjee is an Environmental Scientist at GeoSystems Analysis, Inc. She has eight years of experience restoring and reclaiming disturbed desert lands. Her work focuses on mine waste reclamation and abandoned farmland and riparian restoration. She has experience in a broad range of vegetation monitoring, physical and hydraulic soil characterization, and microbial analyses and survey techniques. Her research has included analyzing the bacterial diversity of reclaimed mine tailings, designing and testing experimental mine waste covers, and exploring water conservation and augmentation in the Southwest. Dr. Banerjee has a Ph.D. in soil, water, and environmental science from the University of Arizona in Tucson, Arizona.

SCALING PHYTOSTABILIZATION FROM GREENHOUSE TO FIELD-SCALE AT THE IRON KING MINE-HUMBOLDT SMELTER SUPERFUND SITE

Juliana Gil-Loaiza[1] *(presenting author)*, **Scott White**[2], **Fernando A. Solis-Dominguez**[3], **Corin Hammond**[2], **Robert Root**[2], **Alexis Valentin-Vargas**[2], **Karis N. Nelson**[2], **Jon Chorover**[2] **and Raina M. Maier**[2]
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Abstract:
The Iron King Mine-Humboldt Smelter Superfund Site (IKMHSS) in Dewey-Humboldt, Arizona is an abandoned mine placed on the National Priority List in September 2008. Mining wastes located at the site comprise 153 acres of barren acidic tailings (pH 2 to 3) with elevated levels of lead and arsenic (≥ 3000 mg/kg each) and high levels of salts (EC 6.5–9 ds/m). This waste is susceptible to wind and water erosion, increasing the risk of environmental and health problems in neighboring communities and ecosystems. Phytostabilization was the strategy chosen to mitigate the erosion of the tailings, as well as the bioavailability of toxic metals. This technology is based on the establishment of a vegetative cap using native drought and metal tolerant plants that do not shoot accumulate toxicants, but do stabilize metals in the root zone. The goal of this study is to determine whether successful results from previous greenhouse studies using IKMHSS tailings can be translated to the field. In May 2010, a 0.5 acre study area was established on the IKMHSS site with six treatments in quadruplicate using a random block design. Five native plants (buffalo grass, Arizona fescue, quailbush, mesquite and catclaw acacia) were seeded directly on tailings amended with 10, 15, or 20% (w/w) compost amendment and approximately 25.53 inches of irrigation from May 2010 to September 2011. Controls included composted (15 and 20%) but unseeded treatments as well as an uncomposted unseeded treatment. To evaluate the phytostabilization process, the following variables were measured: canopy cover, neutrophilic heterotrophic bacterial counts and shoot metal uptake. Results showed that canopy cover ranged from 30% to 39% after 5 months in the compost amended planted treatments, decreasing to 20% to 26% after 17 months. Quailbush had the best germination rate of the plants tested and was the dominant plant present. For compost amended unseeded tailings, volunteer plants germinated, resulting in canopy cover ranging from 7% to 16% after 17 months. No plants grew on unamended tailings. Neutrophilic heterotrophic bacterial count increased from 3 to 5 orders of magnitude after 17 months, in comparison with the unamended control plots. Shoot tissue samples from each treatment were analyzed for metal(loids) accumulation including As, Pb, Zn, Cd, Cu, Ni, Al and Cr. Metal(loid) concentrations were below Domestic Animal Toxicity Limits for cattle. It is noteworthy that the vegetation cap established after 17 months survived several heavy rain events during fall 2010. Also, it became dormant over the winter, but largely grew back over the summer of 2011. In summary, the results of canopy cover, neutrophilic heterotrophic bacterial count and metal accumulation translated well from the greenhouse to the field study. Thus, these are promising criteria when evaluating the phytostabilization process. This study will be continued through 2015 to determine the long-term potential for plant survival in these tailings.

Bio:
Juliana Gil-Loaiza has a B.S. in industrial microbiology from the Pontifical Xavierian University and is currently pursuing a master's degree in soil, water and environmental science at The University of Arizona. Her work is funded by the University of Arizona Superfund Research Program and focuses on revegetation of mine tailings in arid environments like the desert southwest. Previously, she worked as a consultant for Environmental Solutions Group Company in Bogota, Colombia, her native country. She also worked at Merck Sharp & Dohme in Colombia as a data analyst for clinical drug trials. In 2003, she was selected to do an internship at the laboratory of Environmental Microbiology at the University of São Paulo, in Brazil for 5 months, which sparked her interest in environmental work.

Session 6: Monitoring and Treatment

THALLIUM REMOVAL STRATEGIES THROUGH MODIFICATION OF CONVENTIONAL METAL HYDROXIDE PRECIPITATION PLANTS

Katherine M. Vatterrodt[1] *(presenting author)*, **Morgan Davies**[2], **Linda Figueroa**[3], **Thomas Wildeman**[4] **and Charles Bucknam**[5]
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Abstract:
Thallium is not significantly removed from mining influenced water (MIW) in calcium hydroxide precipitation plants. Thallium removal methods from MIW that can be cost effectively integrated into existing calcium and sodium hydroxide precipitation schemes are lacking. Our goal was to evaluate thallium removal methods that would require minimal modifications to the calcium and sodium hydroxide precipitation process.

Oxidative precipitation was chosen as a strategy. Batch tests using synthetic MIW as well as real MIW at a pH of 2, containing approximately 1 mg/L thallium were conducted with the addition or presence of iron, aluminum, and manganese to form metal oxyhydroxides. Oxidants used were permanganate and hydrogen peroxide. Calcium and sodium hydroxide were used for pH adjustment. Significant reduction (<2ppb) of thallium was achieved using permanganate in the real MIW. Dose optimization is critical in order to avoid residual permanganate in the treated water. Synthetic water showed removal of up to <99% in the presence of manganese with permanganate as an oxidant. Up to 90% removal of thallium was achieved in the presence of iron or manganese precipitates at alkaline pH. Batch testing done with real MIW demonstrated the importance of aeration and the effect of MIW composition on the oxidation of thallium and the consumption of the permanganate. Our results suggest that thallium removal can be integrated into a MIW hydroxide treatment plant with very little modification.

Bio:
Katherine Vatterrodt is currently pursuing her master's degree in environmental science and engineering at the Colorado School of Mines. She works closely with Dr. Linda Figueroa and Dr. Thomas Wildeman at the Colorado School of Mines and Charles Bucknam at Newmont Mining to assist in the research and development of new water remediation methods for Mining Influenced Water. Prior to attending Colorado School of Mines, Ms. Vatterrodt attended the University of Minnesota-Twin Cities where she received her B.S. in recreation resource management along with minors in Spanish and environmental science, policy and management. The focus of her degree was sustainable development in Central America, specifically Costa Rica, where she studied for several weeks during her degree. Working in this developing landscape inspired an interest in water use. With the help of Colorado School of Mines and Newmont Mining, Ms. Vatterrodt is working to develop her expertise specifically on water treatment for Mining Influenced Water.

THE BIOTIC LIGAND MODEL: UNRESOLVED SCIENTIFIC ISSUES AND SITE- AND SPECIES-SPECIFIC EFFECTS ON PREDICTED CU TOXICITY

Jeff Morris[1,2] *(presenting author)*, **Ann Maest[3], Alison Craven[4] and Josh Lipton[1]**
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Abstract:
The U.S. EPA has approved use of the Biotic Ligand Model (BLM) to calculate site-specific water quality criteria. Although the BLM is an important advance that considers all major-element chemistry, in a number of situations the BLM appears to be under protective of sensitive aquatic organisms, particularly salmonids. The issues discussed relate to the WHAM V model and the biotic ligand binding constants used in the BLM.

At hardness values <20 mg L^{-1} as $CaCO_3$, the BLM predicts lower Cu, Zn and Cd toxicity to rainbow trout than at somewhat higher hardness values. The effect is more pronounced with increasing dissolved organic carbon (DOC) concentrations but is noticeable at DOC values as low as 1 mg L^{-1}. The lower predicted toxicity appears to be related to modeled metal binding between the gill and DOC. At very low hardness values, the BLM predicts that Cu and other metals will preferentially bind with DOC, and modeled LC_{50} values decrease with increasing hardness. At higher hardness values, the LC_{50} is predicted to rise by ~4 or 5 μg Cu L^{-1} for each ~ 20 mg L^{-1} increase in hardness. There is no empirical evidence to suggest that aquatic biota are more tolerant of metal concentrations at low hardness values, and the hardness-based equations do not produce this peculiarity. A number of headwater streams around the country have low-hardness waters, and use of the BLM at those sites should proceed with caution.

The log K value of the gill, which controls Cu binding to the gill, is set at 7.4 for Cu and rainbow trout in the BLM. No values are currently included in the model for other salmonid species. Plots of Cu LC_{50} and gill log K values show that a gill log K of 7.4 is close to the inflection point for predicted toxicity, and even small changes in gill log K can produce large changes in predicted copper toxicity. The uncertainty in gill log K values should be explored, including the extent to which they change with different salmonid species.

The BLM was used to estimate concentrations of free Cu (Cu^{2+}) in site water near the Pebble deposit in Alaska and to predict the toxicity of Cu^{2+} to rainbow trout. Visual MINTEQ was also used to predict Cu^{2+} concentrations using conditional log K values derived from actual site waters. The BLM predicted considerably lower free Cu concentrations under modeled site conditions. The discrepancy could be reconciled by decreasing DOC input values to the BLM by ~7 times (actual stream value was 2.17 mg L^{-1}). Other researchers have suggested that inputting one-half the measured DOC concentrations to the BLM yields a better fit with fish toxicity data in some cases. These findings and the issues discussed above suggest that the BLM appears to apply higher net Cu-dissolved organic matter (DOM) binding strengths across a range of Cu:DOM ratios and water qualities found in many site waters.

Bio:
Dr. Jeffrey Morris is a Managing Scientist at Stratus Consulting. Dr. Morris is an aquatic toxicologist with experience in aquatic biology, biogeochemistry, contaminant fate and transport, and environmental remediation. He has years of experience conducting laboratory and field investigations on the fate and effects of contaminants on fish, invertebrates and biofilm, as well as developing unique technologies to enhance bioremediation of groundwater and sediments impacted by acid mine drainage and petroleum hydrocarbon contaminants. His research has focused on acute and chronic investigations of the effects of oil, metals, ammonia, and bacterial infections on freshwater and marine invertebrate and fish species. He has also published peer-reviewed manuscripts in numerous scientific journals including *Aquatic Toxicology*; *Environmental Toxicology and Chemistry*; *Archives of Environmental Contamination and Toxicology*; *Water, Air, and Soil Pollution*; *Biogeochemistry*; *Hydrobiologia*; *Mine Water and the Environment*; *Journal of Environmental Science and Health*; and *Chemical Engineering Journal*. Dr. Morris holds a Ph.D. in zoology and physiology and a B.S. in wildlife and fisheries biology and management from the University of Wyoming.

WATER-QUALITY AND STREAMFLOW TIME TRENDS, UPPER CLEAR CREEK WATERSHED (COLORADO) – SYSTEMATIC LONG-TERM MONITORING FULFILLS A RANGE OF INFORMATION NEEDS

Timothy D. Steele, Ph.D.[1] *(presenting author)*, **J. David Holm**[2], **Mary Boardman**[3] **and Michael Holmes**[4]
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Abstract:
This 400-mi^2 mountain watershed in central Colorado has benefited by a long-term, systematic hydrologic (stream-gaging and water-quality/trace-metals) monitoring programs since 1994. This presentation highlights results of data monitoring and assessments, with focus on benefits of mining-related remediation projects in coordinated and collaborative efforts among the Colorado Department of Public Health & Environment (CDPHE), the U.S. Environmental Protection Agency (U.S. EPA), the Clear Creek Watershed Foundation (CCWF), and the Upper Clear Creek Watershed Association (UCCWA). One example was development of a common and comprehensive database for hardness and TMDL-related trace metals (TMs) concentrations. This

was used for application by various parties involved in setting and evaluating water-quality stream standards at a recent (June 2009) hearing convened by Colorado's Water Quality Control Commission. This database, combining results from several data sources, enhanced the technical basis for deliberations regarding desired target levels, reasonableness of attainment, and evaluation of stream segments for protection of the watershed's surface-water resources. More critically, this effort helped overcome previous differences portrayed by vested interests due to selection or inconsistencies in the data used to present their arguments.

Various statistical and graphic presentations of site-specific or segment-related data facilitated the 2009 regulatory deliberations. It is envisioned that the database, with periodic updates, continues to provide a sound technical basis for future stream-standards deliberations by the various interested parties as well as for assessment of benefits of ongoing and planned remediation work underway in the watershed. An updated evaluation is made of the 18 years of systematically collecting samples and analyzing trace-metals data, complemented by monitoring results for several localized special projects (EPA targeted watershed grant, 319 NPS grants, etc.). Aided by 17 years of stream-gaging data for streamflows at key monitoring sites, TMs loads were calculated, from which potential benefits of remedial-action projects can be assessed. These data evaluations, along with the Upper Clear Creek Watershed Plan, have helped to delineate high-priority projects for remediation as well as post-project TMs characterization at downstream locations. Seasonal and year-to-year variability in hydrologic and water-quality conditions are taken into consideration for evaluating ambient/pre-project as well as during-construction and post-project conditions. The benefits of the systematic monitoring efforts are demonstrated.

The longevity of the upper Clear Creek watershed's monitoring programs has been sustainable, due to the analytical support of U.S. EPA Region 8 and the Standley Lake Cities, along with the continuing interest by local watershed stakeholders as well as State of Colorado and federal agencies responsible for regulatory control and protection of the watershed's water resources.

Bio:
Dr. Timothy Steele is President of TDS Consulting Inc., located in Denver, Colorado. His career encompasses over 45 years in water-quality hydrology and regional assessments of water resources. For 13 years, he was with the U.S. Geological Survey's Water Resources Division, holding technical positions in research, headquarters and project management. During the last 32 years as a consultant, he has managed many multidisciplinary projects and has directed hydrologic baseline and modeling studies for water-resources planning and management studies as well as mining of minerals and coal, oil-and-gas properties and several oil-shale projects. Dr. Steele has consulted on numerous projects dealing with hydrogeochemical interactions, ground-water contamination, aquifer and lake restoration, tailings disposal, hazardous waste and residuals management, design and evaluation of hydrologic/water-quality monitoring networks, statistical analysis of hydrologic/water-quality data, stream and subsurface water-quality modeling, use-attainability analyses, pollution-control plans, water-quality stream standards and total maximum daily loads (TMDLs) assessments, and regional/international ground-water planning and integrated water-resources management (IWRM). Dr. Steele has an A.B. *magna cum laude* in chemistry from Wabash College and M.S. and Ph.D. degrees in hydrology from Stanford University.

THE USE OF MUNICIPAL BIOSOLIDS ON HARD ROCK MINING RESTORATION EFFORTS: RESULTS OF A LONG-TERM FIELD TRIAL

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Richard Borden
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Abstract:
The application of municipal biosolids during reclamation has been gaining acceptance in recent years. Municipal biosolids are often an inexpensive source of organic material, nitrogen and other minerals. A series of reclamation test sites were established at the Bingham Canyon Mine in Utah in the late 90s. These test sites were established on the tailings impoundment surface, on capped waste rock surfaces and on a gravel-borrow area. At each site, biosolids were applied to plots at rates of between 10 and 30 dry tons/acre, and control plots received identical treatments with the exception that biosolids were not applied. Vegetative community surveys were conducted at seven of these paired plots in the summer of 2001. After five to six years of growth, the biosolids plots generally contained a higher percentage of vegetative cover, appearing to be a greater success. However, about 75% of all vegetative cover was provided by volunteer weed species. On average, cheat grass (*Bromus tectorum*) alone accounted for over half of the total cover at the biosolids plots. The control plots, where biosolids were not applied, generally had less total cover, but weedy species accounted for much less of the cover that was present. On average, the absolute cover provided by non-weedy species at the control plots was about twice as high as at the biosolids plots. The species diversity of non-weedy species at the control plots was also higher than at the biosolids plots. Forbs and woody shrubs were most common on the control plots. These differences between biosolids and control plots were found to be statistically significant at a 0.05 significance level using an ANOVA analysis. The application of biosolids at these rates may favor the growth of weedy species and inhibit the establishment of favorable species. The mine responded rapidly to these findings and discontinued the use of biosolids alone. All subsequent reclamation has been performed without biosolids, or with light applications of biosolids and woodchip mixtures. These study results indicate that biosolids application may not always be beneficial, and that application rates of less than 10 tons/acre may be optimal at many reclamation sites. Depending on the manager's goal, biosolids may or may not be a useful tool. If fugitive dust control is highest priority and the substrate is a poor growth medium, the use of some biosolids may be beneficial, but at a cost of a likely higher weed component in the resulting vegetation.

Bio:
Rick Black has recently opened the Salt Lake City office for ENVIRON, and serves as a Senior Science Advisor and Manager. Mr. Black has more than 25 years of ecological research and consulting experience and a diverse background in biology, ecology, policy and management. Mr. Black's experience has taken him throughout most western states, and the Gulf of Mexico, working on private and public lands, including National Forests and Bureau of Land Management lands. Mr. Black has over 20 years of mining restoration experience, performing multiple research projects for Rio Tinto and Kennecott Utah Copper. He is also working for the National Mining Association assessing impacts from a proposed new stream protection rule nationwide. He has also developed several Indices of Biological Quality, and implemented Habitat Suitability Indices for terrestrial impacts. Mr. Black has a B.S and M.S. from Brigham Young University, and went on to pursue his Ph.D. at Texas A&M University.

SOIL TREATMENT AT THE CALIFORNIA GULCH NPL SITE FOR VEGETATION REESTABLISHMENT AND MITIGATION OF METAL MOBILITY

Stuart Jennings[1] *(presenting author)*, **Jan Christner**[2] **and Mike Holmes**[3]
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Abstract:
Revegetation technologies are a common component of remediation at abandoned hardrock mine sites. Topsoil or suitable growth media is commonly unavailable or extremely costly. In-situ reclamation techniques or phytostabilization is often required where seeded species must necessarily establish, reproduce and tolerate rootzone conditions with elevated metals. At the California Gulch NPL site near Leadville, Colorado mine wastes were released during legacy mining operations resulting in metal contamination of the floodplain and adjacent agricultural lands. Both fluvial mine tailings and contaminated irrigation water with elevated Pb and Zn were released during historic mining and redeposited near the Arkansas River resulting in acidic soil conditions and sparse vegetation cover. The barren and sparse deposits consequently were a source of metals to water resources in addition to having limited use for wildlife and agriculture. An 11-mile reach of the Upper Arkansas River was remediated during 2008-2009 using soil treatment employing lime, compost and fertilizer followed by reseeding with adapted plant species. Bioavailable metal levels were sharply reduced and soil fertility enhanced through amendment incorporation into contaminated soil materials. Vegetation monitoring demonstrates the effectiveness of remedial action while companion soil sampling shows the associated changes in soil solution chemistry. While total metal levels in the rootzone have remained essentially unchanged vegetation reestablishment has been made possible by raising the pH for control of metal mobility supplemented by the introduction of plant macronutrients through compost and fertilizer amendment.

Bio:
Stuart Jennings is a principal at Reclamation Research Group, LLC. His work emphasizes soil remediation of land affected by mining and especially the geochemical and hydrologic function required for mitigation of trace element mobility. Mr. Jennings' B.S. degree is in geology and M.S. degree in land rehabilitation; both from Montana State University where he worked as a Research Scientist and Adjunct Professor. In his work he has been responsible for development of land reclamation designs for treatment of metal-contaminated soils at several Superfund sites in EPA Region 8. Resulting innovations have been recognized by EPA and others for providing

reproducible protocols and guiding principles for *in-situ* treatment of mine waste and metal-contaminated soil. Mr. Jennings' work in the western United States, Canada and Alaska emphasizes soil bioengineering for native plant revegetation on disturbed lands, reestablishment of landscape hydrologic function, and training other practitioners, students, regulators and industry personnel.

POST-RECLAMATION SOIL PHYTOTOXICITY AND LAND MANAGEMENT AT THE ANACONDA SMELTER NPL SITE

Robert B. Rennick[1] *(presenting author)*, **Stuart Jennings**[2,A] **and Dennis Neuman**[2,B]
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Abstract:
An investigation was undertaken at the Anaconda (Montana) Smelter Site to evaluate plant and soil relationships, residual soil phytotoxicity, and remedy permanence on in-place remediated lands, based on EPA and MDEQ concerns regarding the integrity of remediated lands under uses such as livestock grazing. Although most reclaimed areas were determined to be on track to meet the compliance standard, the 2010 Five Year Review identified stressed vegetation in some areas and concluded that residual (post-remedial action) soil phytotoxicity may be the cause. The 2011 investigation evaluated: 1) results from previously conducted, independent greenhouse growth studies that used contaminated soil from the site, 2) plant community structure and soil chemistry at 27 in-place treated and 3 untreated sites, and 3) the ability of the seeded species to withstand livestock grazing. A review of data from the greenhouse studies indicated a sharp increase in phytotoxic effect (reduced biomass) with increasing metal and arsenic concentrations even at circum-neutral soil pH levels. This phytotoxic effect was measureable at low, near background, soil metal concentrations. The greenhouse work indicated that low to moderate residual metal concentrations may result in significant (20-45%) biomass reductions in lime-treated areas. Correlation analysis conducted on the 2011-collected data showed statistically significant correlations for vegetation cover and soil pH ($r = 0.445$), cover and sum of total soil metal concentrations ($r=-0.460$), and cover of noxious/undesirable plant species and total soil copper concentration ($r=0.449$). Data suggest that the sum of total soil metals greater than 1,000 mg/kg or arsenic greater than 250 mg/kg each represent acceptable parameters to predict where substantial residual phytotoxic conditions may exist. The 2011 plant community assessment indicated that redtop (*Agrostis gigantea*), a non-seeded volunteer species, was a significant contributor to total plant cover. Of the seeded species, basin wildrye (*Leymus cinereus)* performed best and had disproportionately greater cover relative to its composition in the seed mixtures. Seeded forbs generally failed to persist or were not significant plant community components and few native plant species had volunteered in the reclaimed areas. A review of the species being seeded at the site indicated their tolerance of moderate to intense grazing; proper animal stocking rates are therefore not expected to adversely affect reclaimed area integrity. In fact, moderate grazing is predicted to improve range condition. The investigation concluded that land use management plans are needed where post reclamation soil metal concentrations are predicted to cause significant plant stress and that regular monitoring of the potentially more sensitive high soil metal areas is required until it is clear that they will remain stable under long-term grazing and other uses.

Bio:
Mr. Robert Rennick serves as a Senior Land Rehabilitation Scientist for CDM Smith with a focus emphasis on soil biology and chemistry, plant species selection and land reclamation. He holds a B.S. degree in wildlife biology and an M.S. degree in range ecology from Montana State University.

Session 8: Monitoring and Treatment (cont.)

MINE WATER TREATMENT STRATEGIES RESOLUTION COPPER MINING AND THE EAGLE PROJECT

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Abstract:
Rio Tinto has two new mining projects that require two unique water treatment processes in order to meet compliance requirements.

Currently under construction is the Eagle Project, a new underground nickel and copper mine located in the Upper Peninsula of Michigan, approximately 25 miles northwest of the City of Marquette. In accordance with rigorous regulatory requirements, including Michigan's new Nonferrous Metallic Mining Regulations and its Great Lakes Initiative, the project will include an extensive water management program. Its state-of-the-art water treatment facility, which began operation in October 2011, cleans water used in mining to be equivalent to, or in many cases, better than drinking water quality. After undergoing several treatment technologies the water passes twice through a reverse osmosis system and is then treated through an evaporation/crystallization process. Then, the clean water is discharged back into the ground via rapid infiltration, at pace that works for the surrounding environment.

Located in Arizona, Resolution Copper Mining is working to develop the third largest undeveloped copper resource in the world. The project, a joint venture partnership with BHP Billiton, is currently in the pre-feasibility phase.

As part of its long-term commitment to water management, Resolution partnered with university researchers, consultants, and an irrigation district in a unique project to remove almost seven billion liters of water that have naturally accumulated in the empty mine near the project site.

Resolution constructed a water treatment facility on the site, where reclaimed water is treated with lime and soda ash using a high-density sludge process. The company also built a 27-mile pipeline that carries the treated water to central and southern Arizona, where it is used to irrigate more than 5,000 acres of farmland. An extensive sampling and analysis program tracks all monitored constituents, mainly salinity in order to meet irrigation requirements. To date the project has been highly successful. An overview of the water blending process, continual monitoring program, monitoring results, and grower relations will be presented.

Bio:
Dr. Casey McKeon is the Environmental Manager for Resolution Copper Mining in Superior, Arizona where she has been working for the past 7 years. She manages the environmental reclamation permitting and compliance for Resolution as well as their biodiversity program. She is also currently serving the past Chair of the Environmental Division of the Society of Mining and Metallurgical Engineering. She received her Ph.D. in 2003 from the University of Arizona in soil and water science where she focused on the use of native plants for a variety of reclamation and remediation projects in arid environments.

MINE DEWATERING AND WATER MANAGEMENT AT BARRICK GOLDSTRIKE MINE IN THE CARLIN TREND, NEVADA

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Abstract:
Barrick Goldstrike Mines Inc. (BGMI) operates the Betze-Post open pit and the Meikle and Rodeo underground mines. Because the majority of the ore body is located below the water table, mining at BGMI requires a significant dewatering program. BGMI has a comprehensive dewatering and water management system that experienced a peak dewatering rate of 4,400 liters per second (l/s) in the mid 1990s. Changes to the hydrologic/hydrogeologic system caused by the mine dewatering have been monitored by an extensive network of groundwater monitoring wells and surface water monitoring stations which covers about 1,550 km^2. In addition to the monitoring program, a new tool, called Interferometric Synthetic Aperture Radar (InSAR), has also been used to enhance the evaluation of changes. Finally, a groundwater flow model has been developed which successfully simulates and predicts aquifer responses in the mine area and region. The well-calibrated flow model has served as a reliable tool to develop dewatering and mining plans, and project post-closure hydrologic conditions in the region.

This presentation introduces the BGMI dewatering and water management system and the means used by BGMI to evaluate and anticipate hydrologic responses in the region. The water management and analysis system has been and continues to be an integral part of managing ongoing operations, planning and costing future activities and evaluating the long-term effects of mine water handling.

Bio:
Dr. Johnny Zhan is the Regional Manager, Hydrology for Barrick Gold of North America. Since joining Barrick in 1996, he has advanced through various positions of increasing responsibility at Barrick. He earned a doctoral degree in hydrology/hydrogeology from the University of Nevada, Reno. Prior to coming to the United States in 1993, Dr. Zhan had been a faculty member in two Chinese universities. Dr. Zhan has done extensive work on the mine dewatering and saturated/unsaturated flow and transport modeling for Barrick mines and projects covering six continents. Dr. Zhan has authored or co-authored 30 papers in professional journals or conference proceedings.

ARD REMEDIATION WITH SLAG: AN APPLICATION TO BERKELEY PITLAKE WATER

C.A. Young[1,A] *(presenting author)*, **K. Filius**[2], **E.A. Streich**[3], **D. Berg**[1] **and L.G. Twidwell**[1]
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Abstract:
Treating waste water, particularly acid rock drainage from both active and inactive mines, is critical worldwide for many reasons but usually for environmental purposes. Being part of a superfund site, the Berkeley Pitlake (BPL) in Butte, Montana may be the most famous acid-rock drainage (ARD) clean-up project in the United States. Currently, its treatment consists of a two-stage lime precipitation for processing only Horseshoe Bend Water, which is the only adit to the BPL. Research has shown that another waste product, namely slags from pyrometallurgical operations, can be substituted for lime either wholly or in part. Three locally available slags from closed smelting sites were investigated: Rhone Poulenc/Stauffer Chemical Company slag from a phosphorous plant in Ramsay, MT; ARCO/Anaconda Copper Company slag from copper operations in Anaconda, MT; and ASARCO slag from a lead blast furnace in East Helena, MT. Each slag differed in iron, silica and calcium content and therefore reacted differently to remediate BPL water. Results were analyzed and modeled using statistical analyses of experimentally designed tests and are presented in regards to pH and metal concentration as a function of amount added and particle size. Results indicate that slags can be used to either supplement or replace lime, depending on the application. Conceivably, the process could also be done *in-situ*. Aside from remediating ARD, an added socio-benefit, often referred to as dual ecosystem enhancement, is the removal of unsightly slag piles.

Bio:
Dr. Courtney Young is Department Head and Lewis S. Prater Distinguished Professor of Metallurgical and Materials Engineering at Montana Tech in Butte. He is a graduate of three premiere mineral schools. As such, he received his B.S. from Montana Tech in 1984 in mineral processing engineering, his M.S. in 1987 from Virginia Tech in minerals engineering, and in 1995 from The University of Utah in metallurgical engineering. Over the years, he has been recognized with many awards of which he is most proud of the 2009 AIME Frank F. Aplan Award, 2009 SME President's Citation, and 2012 MPD Mill Man of Distinction Award. Throughout his career, he has learned to use his processing knowledge to waste and waste water treatment. Of his 76 publications and 107 presentations, about 40% are environmental related. His successes include but are not limited to cyanide remediation, spent potliner recycling and acid-rock drainage. His work on ARD predominantly encompasses the Berkeley Pitlake which is less than 2 miles from his office and the subject of his presentation.

TEN-YEAR PERFORMANCE EVALUATION OF THE EVAPOTRANSPIRATION COVER AT BARRICK GOLDSTRIKE MINE'S AA LEACH PAD

Mike Milczarek[1,A] *(presenting author)*, **Jason Keller**[1], **Margaret Buchanan**[1], **Gary Goodrich**[2] **and Johnny Zhan**[2]
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Abstract:
Barrick Goldstrike Mine is located in north-central Nevada. The AA Leach Pad is a HDPE lined gold heap leaching facility operated from 1987 through 1999. At the end of operation the total area of the pad was approximately 224 acres and consisted of 55 million tons of run-of-mine leached ore. In 2000 and 2001 the AA Pad was reclaimed using an evapotranspiration (ET) cover designed to limit meteorological infiltration through the leach pad. The ET cover consisted of 3.5 to 5.5 feet of fine grained soil cover derived from salvaged topsoil or Tertiary-aged valley fill deposits (Carlin silt) placed over the leached ore. To monitor the ET cover's capacity to store and release precipitation water, eleven near surface (up to 8 ft below ground surface) cover performance monitoring sensor nests were installed in 2001 and three additional sensors nests were installed in 2005. Sensor nests were instrumented at various depths with water content, water pressure potential and temperature sensors, and in the 2005 sensor nests, water flux meters. Sensor nest locations were chosen to exemplify the differences in solar aspect, slope location, proximity to constructed runoff channels, and cover material types on cover performance.

Monitoring of sensor nests has continued for ten years and data indicate that the cover is performing well, limiting average annual net percolation through the pad to approximately 1.2% of precipitation. Estimated average annual net percolation from seasonal increases in AA Pad drain-down rates in response to spring melt agree with sensor nest estimates, being 1.3% of precipitation. Based upon the 10 years of data, there are clear indications of the factors contributing to the success of the AA Pad cover system. South-facing slopes were more effective at reducing percolation than east- and west-facing slopes due to their receiving more direct solar radiation. Slight differences in net percolation were observed based on slope position; however, percolation was greatest for those stations near runoff channels. Results from the AA Leach Pad cover monitoring study show generalized ET cover system performance for closure of other comparable waste facilities and offer guidance on ET cover system requirements in northern Nevada.

Bio:
Mike Milczarek has an M.S. degree in soil and water science and B.S. degrees in chemistry and environmental science. He has more than 20 years' experience in developing, implementing, and managing vadose zone hydrology and mine reclamation/closure studies. He has participated in a number of long-term ET cover performance monitoring studies at mine sites in Arizona, Nevada and Peru.

CHARACTERIZATION AND SELECTION OF WASTE ROCK BORROW MATERIAL FOR USE AS ROCK ARMOR TO REDUCE TAILING IMPOUNDMENT SIDE-SLOPE EROSION

Michael Milczarek[1,A], Jason Keller, R.G.[2] *(presenting author)*, **Tim Hawthorne, P.E.[3], Scott Rogers, R.G.[4], Robert Litle[5], Tom Klempel[6], Matt Grabau[1], Robert Rice[1] and Margaret Buchanan[1]**

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Abstract:
Stable reclaimed side-slopes in the semi-arid southwestern USA require a significant amount of rock content as precipitation events may frequently exceed 1-inch/hour. An in-situ waste rock characterization effort was designed and implemented on the San Xavier District of the Tohono O'odham Nation portion of the Mission Mine to identify favorable borrow material for use as rock armor on a tailing impoundment side-slope reclamation project. The following criteria were applied: 1) sufficient volumes of material; 2) particle size distributions with greater than 50% of the material larger than 0.5-inch particle diameter; 3) acid-base accounting showing positive net neutralization potential, and; 4) sufficient nutrient levels and minimal potentially phytotoxic elements to facilitate revegetation. In addition, a field-scale erosion test designed to simulate a 100-year, 24-hour storm event was conducted to determine the efficacy of the selected rock material and of selected ripping treatments in controlling erosion.

Based on historic mine data, seven potential rock armor borrow areas were identified. Field investigations of the different potential borrow areas consisted of sampling test pits and trenches with sample collection for physical and geochemical analyses. Particle-size distributions were determined using digital imagery and laboratory methods; pH, acid-base accounting, macro- and micro-nutrients and phytotoxic element levels were also determined to evaluate potential acid generation and suitability for revegetation.

Two generally non-acid generating and erosion resistant mine-waste rock types were found; argillite and arkose material. The arkose material is coarser than the argillite, however, the haul distance to the tailing side-slopes was significantly greater. At least 85% of the argillite and arkose samples showed non-acid generating (net neutralizing) potential. Within the potential source areas, evidence of oxidation (yellowish-red staining) was a good predictor of net acid-generating material and used as exclusion criteria. Field erosion tests conducted on argillite waste-rock material demonstrated that ripping the argillite along the contour to a depth of 24 inches was most resistant to the simulated rainfall events.

Based on these findings, the tailings side-slopes were re-graded with placement of one foot of alluvium material, followed by one foot of waste rock armor. Argillite material sources were used as rock armor on short slopes and the coarser arkose source area for slope-lengths > 300 feet.

Bio:
Jason Keller is a Senior Hydrogeologist at GeoSystems Analysis, Inc. Mr. Keller has over 10 years of experience investigating cover system performance and characterizing material hydraulic properties at mine and nuclear waste facilities. He has managed several field lysimeter test facilities used to evaluate cover system designs and has designed and implemented monitoring systems to assess the performance of full scale store and release cover systems. Mr. Keller also has extensive experience in using various unsaturated flow numerical models to predict cover system performance. He has a M.Sc. in soil science from the University of Arizona.

PRELIMINARY DESIGN OF WATER BALANCE COVERS: A METHOD BASED ON THE ACAP DATA SET

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Abstract:
Water balance covers (often called evapotranspiration covers) are earthen final covers used for waste containment that rely on the capacity of fine-textured soils to store infiltration during wetter periods and evapotranspiration to remove the stored water during drier periods. Percolation is transmitted from the base of the cover when the water storage capacity is exceeded and under conditions of preferential flow. Percolation is controlled to an acceptable quantity by selecting a soil profile that provides sufficient available storage capacity to retain infiltration without drainage and a vegetation community with sufficient transpiration capacity to remove the stored water. The principles and important factors of *available* water storage capacity are well known and include soil hydraulic properties, layering and profile thickness. Determination of *required* storage capacity, or the quantity of water a cover must store to minimize drainage, has been less well defined. Lack of an accepted procedure to determine storage requirement has led to uncertainty by both design engineers and regulatory analysts with occasional inadequate performance and excessive design (and cost).

A procedure for estimating cover storage requirements is now available based on data from the U.S. EPA's Alternative Cover Assessment Program (ACAP). The ACAP data, from a nation-wide network of large instrumented drainage lysimeters, show that precipitation and potential evapotranspiration data can be employed to calculate both the threshold and quantity of water accumulation in a water balance cover. The environmental diversity and multi-year span of the ACAP data set support widespread application of this method. Use of numerical models for preliminary design necessitates decisions regarding input parameters regarding all aspects of climate, soil and plant parameters. The uncertainty inherent in modeled estimates is avoided through use of this method.

Bio:
Dr. William Albright is Research Hydrogeologist at the Desert Research Institute of the Nevada System of Higher Education. He has more than 30 years of research experience in environmental science. His research interests have included topics in waste containment, near-surface water balance, arid lands soil physics, regional air pollution, atmospheric chemistry and weather modification. Dr. Albright is principal investigator for EPA's Alternative Cover Assessment Program (ACAP). His book – Water Balance Covers for Waste Containment: Principles and Practice – co-authored with Dr. Craig Benson and Dr. Jody Waugh is available from the American Society of Civil Engineers.

Session 10: Metals and Metalloids

THE INCREASING IMPORTANCE OF BIOMONITORING DATA TO INTERPRET CHANGING RISK ESTIMATES FOR LEGACY MINING COMMUNITIES

Rosalind Schoof, Ph.D.[1] *(presenting author)*, **Terry Moore, Ph.D.**[2], **Cord Harris, Ph.D.**[3] **and Dina Johnson**[1]
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Abstract:
Lead and arsenic are commonly identified as risk drivers at legacy mine sites. Nationally, several movements are underway to reassess elements of lead and arsenic risk assessment. Lower toxicological benchmarks for lead and arsenic and altered assumptions for exposure parameters may impact human health risk estimates at these sites while actual exposures to people will be unchanged. Understanding the factors affecting site-related lead and arsenic exposures by people living, working, and visiting these legacy mine sites is critical to a meaningful interpretation of site-specific risk estimates and evaluation of the protectiveness of existing or proposed remedies. Risk assessments that incorporate site-specific exposure information alone will not address this need. Biomonitoring studies can contribute to a multiple lines of evidence approach to critically assess and validate theoretical predicted risks. Biomonitoring data from large legacy mine sites will become more important to augment the interpretation of changing risk estimates and can help guide consequential risk management decisions for all legacy mining communities into the future.

For the purposes of this presentation, legacy mine sites are defined as sites that are no longer actively in production, but where a long history of mining-related operations may have impacted the surrounding area. Within the State of Montana, active remedial investigation of several large legacy mine sites has been underway for more than two decades. During the 1990s comprehensive exposure and biomonitoring studies for several of these sites provided valuable input during the conduct of health risk assessments and subsequent remediation projects. Using case examples from these and other more recently evaluated sites, this presentation will summarize key site-specific risk assessment issues relevant to former mining and smelter sites identified in these earlier studies,

describe remaining uncertainties surrounding the predicted site-related exposures, and discuss the possible role of new biomonitoring programs to complement interpretation of theoretical lead and arsenic risk estimates and to provide data for assessing remedy protectiveness at legacy mine sites.

Bio:

Dr. Rosalind Schoof is Principal at ENVIRON International Corporation. She is a board certified toxicologist and a Fellow of the Academy of Toxicological Sciences. She has served on numerous peer review panels and committees for U.S. agencies, Canadian ministries and the National Academy of Sciences. She is currently serving on the Washington Department of Ecology Model Toxics Control Act Science Panel and is on the editorial board of Human and Ecological Risk Assessment. Dr. Schoof is an internationally-recognized expert on health risk assessment of arsenic, lead and other metals, with a focus on mining and mineral processing sites. She has directed research on the bioavailability of metals from soil and on dietary exposures to arsenic and metals. A particular research interest and the subject of her presentation, is consideration of biomonitoring studies as a line of evidence supporting site-specific exposure assessment at mine and smelter sites.

LONG-TERM MONITORING AND METAL BIOACCUMULATION MODELING PROVIDE IMPORTANT FEEDBACK RELATED TO REMEDIATION IN THE CLARK FORK RIVER, MT

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Abstract:

A mining legacy of more than a century has left the Clark Fork River (CFR) in western Montana heavily contaminated by a suite of heavy metals, especially copper. The CFR became part of a large Superfund complex in 1989. As remediation progresses, there is an expectation that reduced copper loadings to the river will result in lower copper exposures and improved conditions for aquatic life. Tracking changes over large spatial and temporal scales can be aided by long-term monitoring programs, providing critical site-specific feedback that can relate back to remediation activities. As part of a USGS water quality monitoring program, bed sediment and aquatic insects have been collected annually since 1992 to evaluate spatiotemporal trends of metals, especially as they relate to metal bioaccumulation. Resident aquatic insects such as the caddisfly *Hydropsyche* (O: Trichoptera) are useful bioindicators because they integrate metals from the surrounding environment and are representative of bioavailable metal. However, unless physiological processes governing metal bioaccumulation are understood, interpretations related to biological response to changing exposure conditions are limited. Laboratory experiments and biodynamic modeling can help explain bioaccumulation, allowing us to 1) quantify the relative importance of dissolved versus dietary exposure; 2) identify the time period of exposure represented by tissue concentrations; and 3) determine exposure scenarios necessary to reach reference values.

Physiological rate constants for copper accumulation and loss in *Hydropsyche* were determined using enriched stable isotope tracers. When combined with site-specific geochemical field conditions and incorporated into a biodynamic model, we were able to validate our model parameters and predict copper bioaccumulation in the species. Results show that *Hydropsyche* has a fast copper uptake and loss rate, which has important implications for any monitoring program. For example, under constant exposure conditions, this species can reach steady state in less than 30 days. If copper exposure is removed, *Hydropsyche* can eliminate up to 25% of its copper body burden per day. The

model also revealed that dietary copper influx is ~3-fold higher than dissolved influx, indicating that copper uptake from food is the primary route of exposure for this species. Indeed, if the dietary component is excluded from the model, dissolved exposure under-predicts *Hydropsyche* copper concentrations by ~70%. This model provides a mechanistic understanding of copper accumulation in *Hydropsyche*, allowing us to predict how tissue concentrations will change with declining copper exposures, and thus provides a useful tool for the decision-making process.

Bio:
Dr. Michelle Hornberger is a research scientist at the USGS, National Research Program, in Menlo Park, California. Her current research focuses on understanding how environmental and physiological factors influence metal accumulation in freshwater biomonitors. Dr. Hornberger also works on an EPA funded monitoring program with the USGS Montana Water Science Center. Her 2009 *Ecological Applications* paper on the Clark Fork River, a Superfund site in western Montana, identifies linkages between remediation activities and spatiotemporal metal trends in sediment and biomonitors. Dr. Hornberger has also conducted research on San Francisco Bay, including sediment core studies which examine the historical trends of metals pre and post-industrialization. She is the San Francisco Bay Toxics Program Coordinator and is a member of the Hard Rock Mining Toxics Program group. Dr. Hornberger received her B.A. in environmental studies and geology from University of California Santa Barbara, an M.S. in marine science from Moss Landing Marine Laboratory and her Ph.D. in ecology from University of California Davis.

EVALUATING THE BIOAVAILABILITY, BIOACCESSIBILITY, MINERALOGY, AND SPECIATION OF ARSENIC IN MINE WASTE AND SOILS, EMPIRE MINE LOW-SULFIDE GOLD-QUARTZ VEIN DEPOSIT, NEVADA COUNTY, CALIFORNIA

C.N. Alpers[1] *(presenting author),* **V.L. Mitchell**[2]**, N.T. Basta**[3]**, S.W. Casteel**[4]**, A.L. Foster**[5]**, A.E. Blum**[6]**, C.S. Kim**[7]**, P. Myers**[2]**, T.L. Burlak**[8] **and L. Hammersley**[8]
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Abstract:
Arsenic (As), a known carcinogen, is a contaminant of concern at many inactive and abandoned gold mines. In the Mother Lode region of California, low-sulfide gold-quartz vein deposits are a source of As in mine waste and of elevated natural baseline concentrations in unmined areas, leading to potential human exposure to As through ingestion and inhalation pathways. Soils in the Mother Lode region are relatively high in hydrous Fe oxides, which bind As strongly and may reduce its bioavailability. The goal of a multi-disciplinary study funded by the U.S. Environmental Protection Agency's Brownfields Program is to develop cost-effective tools for evaluating As bioavailability in mine wastes and soils with regard to the ingestion pathway. For this study, 25 samples of mine waste and (or) soil were collected in and near the Empire Mine State Historic Park in Nevada County, California. After screening to < 0.25 mm, total As in the samples ranged from 15 to 12,100 milligrams per kilogram (mg/kg), with a median of 1,240 mg/kg.

Bioaccessible As, measured using *in vitro* methods simulating conditions in the human stomach and small intestine, ranged from 1.4% to 11% in the 25 samples. Relative bioavailability (RBA), measured using *in vivo* methods in juvenile swine comparing the mine waste to highly soluble sodium arsenate, ranged from 4.0% to 23% in 6 samples. The five-step sequential extraction procedure of Wenzel et al. (2001, *Analytica Chimica Acta* 436: 309–323) was applied to the 25 samples. The first two fractions (F1, 0.05 M ammonium sulfate; F2, 0.05 M ammonium phosphate) liberated sorbed As; the sum of F1+F2 concentrations was less than the *in vitro* test results for all samples. The third fraction (F3, 0.2 M oxalate at pH 3) liberated As associated with amorphous and poorly crystalline oxides of iron (Fe) and aluminum (Al). The sum of F1+F2+F3 concentrations was consistently higher than results from both *in vitro* and *in vivo* tests, suggesting that some As associated with amorphous and poorly crystalline Fe and Al oxides is neither bioavailable nor bioaccessible.

Arsenic mineralogy and geochemical speciation are being evaluated by using a variety of microbeam and synchrotron-based spectroscopic methods, including electron microprobe, Quantitative Evaluation of Minerals by SCANning electron microscopy (QEMSCAN), x-ray diffraction (XRD), x-ray fluorescence (XRF), micro-XRF, Extended X-ray Absorption Fine Structure (EXAFS), and X-ray Absorption Near Edge Structure (XANES). Results indicate that As is associated with the primary sulfide minerals arsenopyrite (41 to 43 wt. % As) and arsenian pyrite (0 to 5 wt. % As), and secondary weathering products, including hydrous Fe oxides (ferrihydrite and goethite, 0 to 18 wt. % As), hydrous Fe arsenate (scorodite and related phases, more than 20 wt. % As), and unidentified Ca-Fe-arsenate minerals that may contribute disproportionately to the RBA.

Results of sieving of the mine wastes and soils into 11 size fractions and analyzing each fraction by inductively coupled plasma – mass spectrometry (ICP-MS) after acid digestion indicate that most samples feature an inverse relationship between particle size and As concentration; finer-grained particles that are more prone to airborne and waterborne transport contain As concentrations as much as 10 times greater than the those in corresponding bulk samples. The detailed characterization of As mineralogy and speciation in gold-mine wastes and soils from the Empire Mine area in this study may help regulatory agencies to develop cost-effective methods for estimating As bioavailability that are predictive of results from *in vivo* testing.

Bio:
Dr. Charlie Alpers has an undergraduate degree in geology from Harvard University (1980) and a Ph.D. in geology from U.C. Berkeley (1986). For the past twenty years he has been a Research Chemist with the U.S. Geological Survey California Water Science Center in Sacramento, California, where his work has focused on environmental problems related to abandoned mine lands. His past work includes research on acid mine drainage and sulfate minerals from copper mines including Iron Mountain and Penn Mine, California. He currently leads several investigations of mercury contamination and bioaccumulation associated with past mining of gold and mercury in the Coast Ranges, and the Sierra Nevada, California, and is collaborating on a study of arsenic bioavailability and bioaccessibility at the Empire Mine Historic State Park in the Sierra Nevada.

Session 11: Rare Earth Elements

RARE EARTH ELEMENTS: A REVIEW OF PRODUCTION, PROCESSING, RECYCLING, AND ASSOCIATED ENVIRONMENTAL ISSSUES

Robert Weber, M.S.[1] *(presenting author)*, **David Reisman**[2], **James Cunningham**[3,A], **Scott A. Guthrie**[3,B], **Coleen Northeim**[3,C] **and Susan Wolf**[3,D]

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Abstract:
Rare Earth Elements (REEs) are a group of chemical elements including the Lanthanides (elements 57-71 on the periodic table). Scandium and Yttrium also are occasionally included. REEs are vital to applications in clean energy, information and defense sectors. Historically, the United States supplied most of the world's demand. However, over the past 20 plus years, China has been supplying over 95 percent of the world's demand. With increasing uncertainties regarding supplies and increased demand, the United States is challenged to rapidly develop its own REE mineral resources. With this sense of urgency to develop the domestic supply, there is increased focus on locating and mining domestic mineral reserves and developing robust recycling processes. The environmental aspects are not well understood, but information is being rapidly collected in this emerging area. A leading effort to collect such information was organized by EPA's Office of Research and Development. The report "Rare Earth Elements: A Review of Production, Processing, Recycling, and Associated Environmental Risks" will serve as a technical information resource to policy makers and other stakeholders who are concerned with the potential environmental effects and impacts that can be identified across the REE supply chain. The presentation will highlight the key aspects of the report, including specifically addressing the importance and potential environmental impacts of REEs.

Bio:
Robert J. Weber is a Physical Scientist (Superfund and Technology Liaison - STL) with the U.S. Environmental Protection Agency (EPA), Office of Research and Development (ORD), Office of Science Policy (OSP). He is stationed in EPA Region 7 and provides and facilitates technical support and assistance on hazardous waste sites/issues and facilitates access to ORD and other national technical resources for EPA regional staff including Superfund remedial project managers, on-scene coordinators, and RCRA corrective action officers. Mr. Weber also leads and assists with hazardous-waste-related technical transfer and training and facilitates research communications, coordination and implementation. Before serving as an STL, Mr. Weber was an RPM in EPA Region 7 managing several large-scale National Priorities List (NPL) sites with remedial and removal components. Prior

to EPA, Mr. Weber was employed by a state government environmental agency as a unit manager and project manager working on multi-media hazardous and solid waste and spill response sites. Prior to the state agency, Mr. Weber worked as a project geologist for an environmental engineering and consulting company working on environmental investigation and remediation sites across the United States. He has received several awards including an EPA National Notable Achievement Award and is an author on several hazardous-waste-related publications. Mr. Weber earned a B.S. in geology from the University of Kansas, Lawrence and an M.S. in geology from Kansas State University, Manhattan.

GEOLOGIC AND ENVIRONMENTAL CHARACTERISTICS OF RARE EARTH ELEMENT DEPOSIT TYPES FOUND IN THE UNITED STATES

Robert R. Seal, II[1,A] *(presenting author),* **Philip L. Verplanck[2,B], Bradley S. Van Gosen[2,C] and Andrew E. Grosz[1,D]**
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Abstract:
Based on current knowledge, the potential for significant future mining for rare earth elements (REE) in the United States appears to be limited to a few geologically distinct deposit types. Two deposit types likely produce REE as a primary commodity are carbonatites and alkaline intrusion-related deposits. Carbonatites consist of greater than 50 percent carbonate minerals, such as calcite, dolomite and ankerite. Mountain Pass (California), Elk Creek (Nebraska), and Bear Lodge Mountains (NE Wyoming) are examples of carbonatite REE deposits. At Mountain Pass, the main ore mineral is bastnasite [$(Ce,La)(CO_3)F$], which constitutes roughly 10 to 15 percent of the ore, and is associated with 65 percent dolomite and calcite, 20 to 25 percent barite, and minor accessory minerals, which include galena and pyrite. Generally, the alkaline intrusion-related deposits are either associated with layered complexes or with dikes and veins associated with multi-phase alkaline intrusions. Bokan Mountain (SE Alaska) is an example of an alkaline intrusion-related deposit. Alkaline-intrusion-related deposits have a more diverse group of ore minerals including fluorcarbonates, oxides, silicates and phosphates. The mineralization can include minor calcite and sulfides. The acid-generating potential of carbonatites and alkaline intrusion-related deposits is low due to the dominance of carbonate minerals in carbonatite deposits, the presence of feldspars and minor calcite within the alkaline intrusion deposits, and only minor quantities of potentially acid generating sulfides. Both of these deposit types are produced by igneous and hydrothermal processes that enrich the high-field strength, incompatible elements, which tend to be excluded from common rock-forming minerals. Thus, elements such as Y, Nb, Zr, Hf, W, Ti, Ta, Sc, Th and U tend to be associated with these REE deposits. Most of these elements, with the exception of U, have low solubility in water at the near-neutral pH values that is expected around these deposits. Thus, the greatest environmental challenges associated with these types of REE deposit are related to enrichments in Th and U; however, their mineralogical hosts tend to be fairly unreactive in the environment. Uranium can be recovered as a byproduct to mitigate environmental effects. Thorium remains a waste-stream product that requires management in the absence of progress towards the development of thorium-based nuclear reactors in the United States. Two deposit types which could produce REE as a byproduct are heavy mineral sand deposits (placers) and phosphorite deposits. Heavy mineral sands are found in the eastern coastal plain of Virginia, North Carolina, South

Carolina, Georgia, and Florida, and in alluvial deposits in Idaho. The heavy mineral sands deposits of the eastern coastal plain typically contain between 2 and 10 percent heavy minerals. They are currently mined primarily for their zircon and ilmenite contents. Monazite [$(Ce,La,Nd,Th)PO_4$] typically constitutes less than 15 percent of the heavy mineral fraction, but is currently not separated due to environmental concerns related to thorium. Monazite typically contains greater than 60 percent REE oxides. The phosphorite deposits, such as those found in Florida, North Carolina, Idaho, Montana, and Utah, are less well understood. The total concentration of Y and REE in these deposits is less than 1 percent; Y and REE are currently part of the waste stream at these phosphate mines. No attempt has been made to recover these commodities. Uranium is an environmentally significant trace element associated with these phosphate deposits.

Bio:
Dr. Bob Seal is a Research Geologist at the USGS in Reston, Virginia. His research focuses on the environmental geochemistry of mining. This work has led to a number of interactions with a variety of state and federal agencies, including EPA at a number of abandoned mine Superfund sites, especially in Region 1. He has authored or co-authored over 100 publications and he is currently an associate editor for *Applied Geochemistry*. Dr. Seal received his B.S. from Virginia Tech, his M.S. from Queen's University in Canada, and his Ph.D. from the University of Michigan – all in geological sciences.

RESEARCH INITIATIVES IN RECYCLING AND SUBSTITUTES OF RARE EARTH ELEMENTS

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Abstract:
To help meet world demand of rare earth elements, in addition to developing new sources, there is significant activity in improving recycling of REE containing materials. Increasing recycling would reduce the environmental impacts of mining while also significantly lowering world demand. Currently, very few products that contain REEs are recycled at the end of their life-times. Additionally, reuse of manufacturing losses also present potential opportunities for reducing the demand of REEs. However, increasing recycling and reuse will require research into new processes. More efficient and effective processes, combined with well-designed policies, will help make recycling economically viable over time.

In addition to recycling, another strategy for reducing consumption of REEs is developing substitutes at the element, component and system levels. There are efforts underway at academic, industrial and government research facilities developing alternatives for REEs – most focused on applications in magnets for motors and wind turbines. Other clean energy technologies – such as phosphors for lightings – also are receiving similar attention. While investments have been made in the area, mostly by the Department of Energy, there are still significant challenges to face. In addition to R&D initiatives, there are significant activities in the federal government towards ensuring a stable supply chain of rare earth elements and other critical materials. These efforts are being coordinated through an inter-agency process to address issues throughout the supply chain.

Bio:
Dr. Mike McKittrick is a Chemical Engineer with the National Center for Environmental Research in the Office of Research and Development at the EPA. In this role, he is working to develop extramural research programs related to rare earth elements and other critical materials. He also works in the area of nanomaterials – managing research grants to universities exploring the fate and transport of nanomaterials in the environment. Prior to EPA, Dr. McKittrick was at the University at Buffalo as an assistant professor, focusing on developing energy efficient catalytic materials for pollutant degradations. Most recently, he was one of the authors of the Department of Energy's 2011 Critical Material Strategy. Dr. McKittrick has a B.S. in chemical engineering and chemistry from Virginia Commonwealth University and a Ph.D. in chemical engineering from Georgia Institute of Technology.

Session 12: Sustainability / Life Cycle

HARDROCK MINING WITHIN A SUSTAINABLE DEVELOPMENT CONTEXT

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Abstract:
Historical closure of hardrock mines has a checkered past with some mines leaving a legacy of water contamination from Acid Rock Drainage (ARD). The International Network for Acid Prevention (INAP), a network of international mining companies was formed to prevent and mitigate ARD by expanding research, technology and information transfer and the promotion of the ideals of ARD prevention and sustainable mine development.

Recently, INAP has published the GARD Guide, a web-based, best-practices guide for the prevention of ARD. In this guide, decades of research and experience in mining sulfide ore bodies is compiled resulting in substantial and valuable technical information on ARD characterization, prediction, drainage treatment, monitoring, prevention and mitigation.

In this presentation, we will focus on the issues and approaches found in the GARD Guide to develop a proactive ARD management program that engages, informs and collaborates with stakeholders to insure that the plan meets the expectations and objectives of all. Stakeholders' engagement is enhanced and credibility gained as mining companies develop an integrated and responsible approach that accounts for short- and long-term environmental, social and economic issues, and emphasizes the importance of clean and available water for current and future generations. Examples of effective ARD prevention will be presented within a sustainable development context.

Bio:
Dr. Terrence D. Chatwin is Technical Manager of the International Network for Acid Prevention (INAP), a network of international mining companies, whose objective is to prevent and mitigate acid rock drainage (ARD) and mine in a sustainable manner. In this position, he has overseen the preparation and publication of the GARD Guide (www.gardguide.com), a best practices guide for the prevention of ARD. He is also project manager of several collaborative research and information transfer activities funded by INAP. INAP sponsors ICARD, the international Conference on Acid Rock Drainage, which will be held in Ottawa, on May 20-26, 2012. Previously, Dr. Chatwin was the Director of the Utah Engineering Experiment Station. He was recently presented the SME Environmental Division Distinguished Service Award. He has numerous publications and presentations on various process and remediation technologies. Dr. Chatwin has a Ph.D. in metallurgy from the University of Utah and a B.S. in mechanical engineering from the Massachusetts Institute of Technology.

PREDICTING AND MANAGING WASTE IMPACTS THROUGH A HOLISTIC AND LIFE-OF-MINE GEOMET APPLICATION

Karin Olson Hoal[1,A] *(presenting author),* **John Jackson[1], David Mulligan[2] and Mansour Edraki[2]**
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Abstract:
The mining industry's obligation to produce the materials necessary for society while protecting the quality of water, air, land and human health presents an increasingly challenging path to low-impact mining, particularly when faced with lower-grade and more inaccessible deposits and higher operating and energy costs. Nevertheless, mining companies are driving the reconciliation of extraction with sustainable practices by using the tools at hand in new ways. This presentation looks at operational state-of-the art approaches to integrated extraction, beneficiation and mineral processing for effective prediction of environmental and economic impacts. The life-of-mine progression, from exploration through to reclamation, contains a few steps that are repeated at different stages of a project by different departments. By integrating these steps in a geomet framework, projects become more effective and less risky, and the added knowledge helps to better predict process and environmental outcomes. Among the steps most relevant to the geomet framework are sampling, materials characterization, modeling, and decision making for value optimization.

Materials characterization is a means of describing and quantifying material attributes that are relevant for different stages of the process. As a whole, it entails geology, mineralogy, alteration, texture, chemistry, geophysics, blasting efficiency, hardness, crushability, grindability, floatability, recovery, leachability, acid-neutralization potential, permeability, rheology and other characteristics. At different stages, materials are typically sampled and characterized for the process at hand, without consideration for sample representivity or for impact of the results on other phases of the project. In the geomet scenario, front-end characterization of carefully sampled materials provides understanding of the orebody and its environs that is relevant to the beneficiation, processing, recovery, and waste impact issues downstream. This is because the downstream tested responses of the materials are primarily determined by the original chemical and textural makeup of the ore and gangue minerals. This applies for beneficiated materials as well as for the nonearthen products of

mineral processing. Quantitative evaluation of materials and modeling of important parameters (such as sulphur deportment, deleterious elements, acid neutralization mineralogy) provides operators and managers with necessary information relating to the materials being mined, processed and disposed of. This allows for effective knowledge-based decision making, and for the ability to predict and plan by reducing the uncertainties and unknowns and therefore the risks and potential impacts of the project.

Bio:
Dr. Karin Olson Hoal is a Senior Consultant with JKTech, Pty Ltd and Research Professor at Colorado School of Mines. Her area of specialization includes integrating ore body characterization and variability information into mining, processing, extraction and waste operations for reduced risk and uncertainty and improved project value. Dr. Olson Hoal has previously worked for mining and exploration companies and service providers as well as university and government affiliations, principally in the field of diamonds. She has a B.S. in geology from St. Lawrence University, an M.S. in geology from McGill University, and a Ph.D. in geology from the University of Massachusetts, and was a Postdoctoral Fellow at the University of Cape Town.

LIFE CYCLE ASSESSMENT ANALYSIS FOR ACTIVE AND PASSIVE ACID MINE DRAINAGE TREATMENT OPTIONS FOR THE STOCKTON COAL MINE, NEW ZEALAND

Tyler Hengen[1], Maria Squillace[1], Aisling O'Sullivan[2], F.A. Crombie[3] and James Stone[1,A] *(presenting author)*
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Abstract:
The majority of acid mine drainage (AMD)-impacted streams in New Zealand are located on the West Coast of the South Island within estuarine coal formations. Carbonaceous mudstones and coal containing abundant sulfide results in acidity, Fe and sulfate released during pyrite oxidation, while Al leaches from the ubiquitous micaceous and feldspathic-rich rocks, in itself generating additional metal acidity. The primary metals associated with AMD include Fe and Al, which account for over 98% of metal contributions. While current AMD discharges are effectively mitigated through lime-dosing or passive treatment, historical AMD has drastically impaired the local ecology. The purpose of this study was to determine the life cycle assessment (LCA) environmental impacts for various passive and active treatment approaches adopted for the neutralization of AMD at the Stockton Coal Mine site, approximately 35 km north of Westport. LCAs provide an indication of the true sustainability of an AMD treatment system through a 'cradle to grave' assessment approach. No financial aspects are incorporated in the LCA but in practice a cost benefit analysis would be considered in parallel.

The LCA was completed following International Organization for Standardization, ISO (e.g., ISO 14040:2006 and ISO 14044:2006) using a functional unit of kg acidity removed. Five treatment scenarios were assessed including both active and passive approaches: (1) mussel shell bioreactor with virgin mined materials, (2) mussel shell bioreactor using recycled substrate materials, (3) passive treatment using limestone aggregate, (4) lime-dosing treatment utilizing ultra-fine limestone (UFL),

and (5) mussel shell "leaching beds." Preliminary design flows and unit operations considered were based upon existing and proposed site treatment operations, with all design considerations based upon a 16.9 year design life. Alternatives were evaluated based upon LCA midpoint and endpoint categories for the functional unit and design life. Midpoint impact categories included climate change (kg CO_2 eq.), terrestrial acidification (kg SO_2 eq.), freshwater eutrophication (kg P eq.), marine eutrophication (kg N eq.), and terrestrial ecotoxicity (kg 1,4-DB eq.), while endpoint included climate change impacts to human health impact (Disability Adjusted Life Years) and ecosystems (species.yr), and fossil fuel depletion ($). Preliminary results from the ongoing evaluations will be presented that highlight differences between type of treatment strategy employed for AMD mitigation.

Bio:
Dr. James Stone is an Associate Professor of Environmental Engineering at the South Dakota School of Mines and Technology. His research interests include contaminant fate and transport from historical mining-impacted areas, and life cycle assessment modeling. He has over 25 publications on these topics. Dr. Stone received his B.S. and M.S. in environmental engineering from Virginia Tech, and his Ph.D. in environmental engineering from Penn State.

Presentation Abstracts and Speaker Bios

Thursday, April 5, 2012

BLUE LEDGE MINE SUFERFUND SITE REMOVAL ACTION, ROGUE RIVER-SISKIYOU NATIONAL FOREST

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Abstract:
The U.S. Forest Service successfully completed a $15 million non-time-critical removal action at the Blue Ledge Mine superfund site in the fall of 2011. The abandoned mine is situated on patented land in remote, rugged mountains just south of the Oregon-California border. With over two miles of underground workings on 10 levels, it was one of the largest mines in mineral-rich SW Oregon and northern California from 1902 through the 1920s, with intermittent development continuing through the 1940s. The mine is a massive sulfides deposit that was primarily developed for copper and zinc, but also yielded gold, silver and lead. High grade ore was hand sorted and sent to the smelter in Tacoma, Washington. Miners dumped over 150,000 tons of sulfides-rich waste rock on the extremely steep mountain slopes located below 13 adits. Four distinct waste rock piles covered more than 12 acres. The waste rock piles became the source of highly toxic metal-rich acid mine drainage (AMD) that discharged 500,000 gallons per day into drainages at peak flow during spring runoff. For over 100 years the AMD destroyed virtually all aquatic life in the four miles of Joe Creek that passes directly below the waste rock piles.

The two-season long removal action focused on AMD source control by excavating over 66,500 cubic yards of waste rock from the steep slopes and hauling it to a sealed repository. The repository was constructed about 1.5 miles from the mine. Poor access, steep cliffs, rock fall, and extremely hazardous conditions presented substantial challenges to the contractor. Cleanup standards required waste rock removal down to background metals concentrations in the soil, or within ½" of bedrock, whichever came first. The contractor chose to use up to three spider excavators to climb up the 38^0-45^0 waste rock piles to excavate the waste rock from the top down, until the pile could be reached by conventional excavators and dozers. As many as 23 laborers in rock climbing gear/ropes followed closely behind the spider excavators. Laborers used picks, shovels and brooms to clear waste rock down to bedrock. Handheld X-ray fluorescence equipment was used to field verify cleanup success, followed by laboratory confirmation. Five off-highway 35-ton articulated dump trucks hauled over 5,000 loads of waste rock down steep access roads, with some constructed at 30% grades. Helicopters ferried a mini excavator, 30,000 pounds of reclamation materials, and 20,000 pounds of steel for 10 bat gates custom constructed at the adit portals.

Reclamation included placing clean topsoil on the more gentle slopes, planting 10,000 native shrubs and trees grown for the project, riprap lining 1,800' of drainage channel banks, installing 600 square yards of slope stabilization mesh, and placing native grass seed and mulch on about 20 acres of disturbed ground. Approximately 1,300' of log wattles and 2,600' of straw wattles were installed on the steep slopes where clean soil remained following waste rock removal. All disturbed soils were covered with straw, hydromulch, bark mulch, slash or riprap. Nine innovative basins were constructed in the drainages below the waste rock piles to treat eroded residual waste rock sediment,

metals and low pH runoff. Effectiveness monitoring and site maintenance is scheduled through the spring 2015, after which EPA will take over the site.

The successful public lands cleanup was funded with $12.5 million from the American Recovery and Reinvestment Act, and $2.5 million from a CERCLA cost-recovery claim negotiated between the Department of Justice and ASARCO. URS from Portland, Oregon provided the removal design. The general contractor was Engineering/Remediation Resources Group located in Martinez, California. The earthworks subcontractor was Granite Construction from Sacramento, California. As many as sixty on-site workers and engineering support staff benefited from working on the project. Twenty-three workers were newly hired. More than $4 million was spent in the economically depressed local counties.

Bio:
Pete Jones is an On-Scene Coordinator for the U.S. Forest Service, Pacific Northwest Region. For the last four years he has been the CERCLA program manager responsible for the investigation, analysis, and cleanup of abandoned mines throughout the state of Oregon and northernmost portions of California. Prior to his current position, he worked for 27 years as a geotechnical engineer and engineering geologist on the Rogue River-Siskiyou National Forest. He was responsible for environmental remediation, slope stability analysis, road and pavement design, groundwater studies, safety of dams, and construction management. Prior to his Forest Service career Mr. Jones worked throughout the western United States as an exploration geologist for Homestake Mining Company. He received his B.S. in geology from Southern Oregon University, and his M.S. in geological engineering from the University of Nevada, Reno.

MANAGING MINE SLIMES - JACK WAITE MINE REMEDIAL ACTION

Todd Bragdon[1] *(presenting author)*, **Bill Adams[2], Brandon Ball[3], Rod Zion[4], Jeff Johnson[5] and Rich Hamlin[6]**
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[6]Project Superintendent, Conti Federal Services, Inc.

Abstract:
This presentation will summarize the complexities and solutions for reclamation of an abandoned mine site under the Superfund program. The U.S. Environmental Protection Agency, Army Corps of Engineers, and Forest Service are reclaiming the abandoned Jack Waite Mine in the Coeur d'Alene Basin, Idaho, under an interagency agreement with funding provided by the American Recovery and Reinvestment Act and other sources. In May 2011, the remedial action (RA) contractor mobilized to the site to begin construction. Several challenging field conditions were encountered and were managed using a project team approach requiring participation of the owner, owner's representative, engineer and contractor. The project illustrates the benefits of design flexibility and cooperative teamwork in achieving effective and efficient mine remediation.

Tailings Slimes: During removal of Tailings Pile 2 (TP2), tailings slimes were encountered. This waste material, generated during the mill flotation process, is very fine-grained and has high water content (soft clay). Although the slimes were identified during the pre-design investigation, the

extent of this material was unknown. Approximately 6,000 cubic yards of the material was encountered and could not be hauled to the on-site repository because it would liquefy during transport. Several field activities were successfully implemented to facilitate removal, including dewatering and addition of Portland cement.

Additional Waste Volumes: The design featured innovative and cost-effective approaches, including the use of light detection and ranging (LiDAR) aerial surveying and three-dimensional computer-aided design and drafting (CADD 3D) to provide accurate estimates of cut/fill volumes of mine waste areas. In addition, the EPA Technology Innovation Office program was accessed to provide expertise in state-of-the-art x-ray fluorescence (XRF) technology to guide identification and cleanup of metals-impacted soil and sediment. During RA construction, however, waste volume estimates were exceeded at the TP2 and Mill areas. Fortunately, flexibility in the contract and in the design of the on-site repositories enabled the team to handle additional contingency volumes.

Insufficient Gradation Characterization: Volumetric estimates for available on-site restoration material (e.g., growth media, oversize rock) were also developed using LiDAR and CADD 3D tools. Test pits were completed to provide information including depth of material and soil gradation data. During construction, however, the overall gradation of the borrow material contained significantly more oversize material than had been estimated. This excess posed several challenges, including identifying adequate stockpile areas in mountainous terrain and determining on-site use of the generated material.

Tailing Pile 3 (TP3) Toe Drain: During consolidation of waste to the TP3 repository, a seep was observed near the downgradient end of the repository embankment toe. Construction of the low-permeability cover anchor trench across the seep could have led to buildup of pore pressure within the consolidated waste material. A revised design of the anchor trench was completed to allow for drainage through the toe anchor trench; the revision was expedited to reduce delays in construction.

Bio:

Todd Bragdon is a project manager and senior engineer with 18 years of engineering experience in project management, environmental investigation and remediation. Mr. Bragdon is a project manager on mine reclamation environmental assessment and cleanup projects for various private and government clients, including U.S. Environmental Protection Agency (EPA) remedial contracts in Regions 6, 8 and 10. His responsibilities include managing projects that evaluate and select efficient and cost-effective remedial technologies, pilot-testing design and implementation, and designing, permitting, and providing construction oversight support for various remedial actions. Mr. Bragdon has a B.S. in civil engineering from the University of Colorado (1992) and an M.S. in civil/environmental engineering from the University of Cincinnati (1997).

SCREENING AND CLEANUP PROCEDURES FOR LIBBY AMPHIBOLE CONTAMINATED PROPERTY IN LIBBY, MT

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Abstract:
The Libby Asbestos Superfund Site is an especially large and complex site in which Libby Amphibole (LA) asbestos is prevalent throughout the town and surrounding areas. The source of this contamination was from historic vermiculite mining and processing activities. Mine waste and vermiculite was used throughout the town for many purposes including as fill material, a soil amendment, home insulation and road base. Since 2000, over 1,600 property cleanups have been conducted, resulting in the removal of over 940,000 cubic yards of contaminated soil. This presentation will discuss the methods developed for this project to effectively and efficiently screen properties for asbestos and how property cleanups are being conducted.

Bio:
Mike Cirian received a civil engineering technology degree in 1981 from Metro Tech Community College, Nebraska. He worked for American Smelting and Refinery Co. (ASARCO) in Omaha, Nebraska from 1981 through 1987 and served in the U.S. Navy Reserves from 1987 through 1994. Mr. Cirian received a B.S. degree in civil engineering in 1991 from the University of Nebraska. He worked for the U.S. Army Corps of Engineers from 1991 through 2005. He worked in environmental design until he received his professional engineer license in February 1997. Then he went into construction management where he was in charge of all aspects of environmental work for the Badger Area Office for the Corps of Engineers. He spent 50 days on the Columbia Shuttle Recovery Mission in 2003. When he arrived he was given the role of an EPA Division Supervisor, was promoted to Chief of Logistics/Planning, and before he left was promoted to Deputy Incident Commander. Mr. Cirian volunteered and spent 6 months as chief of engineering and construction in Mosul, Iraq for Operation Iraqi Freedom. The North District program consisted of large and diversified support for civilian reconstruction and military construction projects budgeted at over $3 billion within the northern third of Iraq. He received the Superior Civilian Service Award for Meritorious Service during Protracted Combat Operations in Support of Iraqi Freedom. In July of 2005, Mr. Cirian was hired by the U.S. Environmental Protection Agency to be the On-Site Remedial Project Manager (RPM) for the Libby Superfund Project where he still continues to manage the on-site planning, removal and remedial actions. He received Superfund's "Excellence in Community Involvement Award Remedial Project Manager of the Year 2009."

Session 14: Opportunities for Re-Use and Site Management

WHAT IS ENVIRONMENTAL STEWARDSHIP AND HOW CAN IT BE PROFITABLE IN THE MINING INDUSTRY?

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Abstract:
The rising price of precious metals has breathed new life into the mining industry and as a result, new mines are emerging and idle or abandoned mines are being reactivated. The cost and effort of planning and incorporating environmental stewardship principles and best management practices into mine operations can be a tough pill to swallow and the standards are ill defined. However, if environmental stewardship principles and best management practices are not effectively considered, the staggering cost for fighting opponent lawsuits and mitigating environmental damage can be a major blow to profits of even the most successful mining companies. This discussion presents some perspectives on the current state of the practice regarding responsible environmental stewardship in the mining industry. Some ideas are presented that promote a different paradigm for mine operations planning that emphasizes the implementation of environmental stewardship principles through state-of-the-practice and cost effective environmental controls and best management practices at the early stages of mine planning and operations. These controls and practices, when focused on the goal of environmental stewardship, may require higher upfront costs for engineering and capital improvements but the return on investment comes in the form of lower back-end closure costs, reduced long-term environmental liability, and better public image. These benefits in turn result in lower closure/post closure financial assurance bonds, better corporate image with the public, more cooperative working relationships with environmental regulators, and higher profit margins, among other key benefits.

This presentation will discuss some of the proactive environmental controls that can be incorporated into mine planning and presents case histories that illustrate the benefits of the new paradigm, including life-cycle cost savings that can be realized. Proactive environmental controls that will be discussed include:

- Properly designed containment facilities for tailing ponds, surface impoundments, heap leach pads, evaporation ponds and waste rock piles.
- Appropriately designed groundwater and surface water monitoring systems around process, operations and waste management areas.
- Surface water/stormwater controls incorporating best management practices.
- Forward planning strategies to manage and maximize water resource assets at mine sites.

Case studies will be presented that show the high cost of closure as a result of minimal environmental controls in contrast with cases that show life-cycle cost savings as a result of proactive environmental controls.

Bio:
Randy Brandt has over 25 years experience in hydrogeology with special emphasis on environmental and hazardous waste issues. He is adept at developing creative and cost effective remediation strategies to meet objectives of project stakeholders, including responsible parties, regulatory agencies and the public. He has particular experience with devising strategies to integrate site remediation with land development activities, supporting an end-state vision which emphasizes reduced overall life-cycle cost and liability exposure. Mr. Brandt has provided strategic consultation and technical direction for sites falling under the jurisdiction of the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Clean Water Act (CWA), National Environmental Policy Act (NEPA) and numerous state environmental programs in California, Washington and Oregon. He has provided consulting services at hard rock and aggregate mines, oil refineries, military installations (active and closed) and chemical manufacturing plants. Mr. Brandt has B.S. degrees in geology and oceanography from Humboldt State University, Arcata, California.

ABANDONED MINE RECLAMATION PLANNING AT FRENCH GULCH, BRECKENRIDGE, CO AND THE LAUNCHING OF A NEW BOOKLET SERIES AND LEGACY SITE WEB-PORTAL

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Abstract:
This presentation discusses the conceptual plan for French Gulch, an application of landscape revitalization on a former mining site where ecological design and planning, redevelopment, and environmental clean-up are being integrated. The various aspects of the conceptual planning process and plan that includes the completion of the affordable housing community, wetlands and stream reclamation, passive water treatment technologies, recreation uses and planning. The application of the 3D simulations used to communicate the plan is also discussed. The culmination of the conceptual plan and the process involving community input and stakeholder negotiation will be candidly discussed.

The French Gulch reclamation project has a long history of community interest and involvement. Stakeholders formed a common vision to address environmental issues associated with the legacy site, provide affordable housing, and create backcountry recreational opportunities. From this vision, a number of projects were initiated in French Gulch, including development of an affordable housing community, construction of a treatment system to collect and treat mine drainage, and recreational use planning for open space lands purchased by local government. These projects were proceeding successfully, but were developed in isolation of each other, leading to a disjointed community landscape. To promote improved planning within French Gulch, local government,

citizens and the U.S. Environmental Protection Agency worked with Alan Berger and P-REX, Project for Reclamation Excellence at the Massachusetts Institute of Technology (www.theprex.net) to develop a conceptual plan to better integrate existing and future projects and remediate French Gulch.

The dissemination and extension of this work has most recently been funded by Tiffany and Co. Foundation. This presentation will launch a new publication series and the first booklet documenting the French Gulch reclamation planning process will be distributed to the audience free-of-charge. The presenters will also describe a new reclamation web-portal being designed through MIT for any community to find out more about legacy site reclamation design issues or stakeholder process initiations.

Bios:
Alan Berger is Tenured Associate Professor of Urban Design and Landscape Architecture at Massachusetts Institute of Technology where he teaches courses open to the entire student body. He is founding director of P-REX (www.theprex.net), a research practice focusing on the design and reuse of waste landscapes and environmental systems worldwide. His work emphasizes the link between our consumption of natural resources, and the waste and destruction of landscape, to help us better understand how to proceed with redesigning around our wasteful lifestyles for more intelligent outcomes. He coined the term "Systemic Design" to describe the reintegration of disvalued landscapes into our urbanized territories and regional ecologies. In addition to his award winning books *Drosscape: Wasting Land in Urban America* and *Reclaiming the American West*, his other books include *Designing the Reclaimed Landscape*, *Nansha Coastal City: Landscape and Urbanism in the Pearl River Delta (with Margaret Crawford)*. His most recently published books are *Systemic Design Can Change the World* and *Landscape + Urbanism Around the Bay of Mumbai (with Rahul Mehrotra)*. Prior to MIT he was Associate Professor of Landscape Architecture at Harvard-GSD, 2002-2008. He is a Prince Charitable Trusts Fellow of The American Academy in Rome.

For the past 18 years, Victor Ketellapper has worked as a Superfund Program Project Manager for the U.S. Environmental Protection Agency in Denver, Colorado. Currently, he leads the Libby Asbestos Superfund Site. While with EPA, he has been a leader of the development of policies and guidance concerning the revitalization of abandoned mine sites. Mr. Ketellapper is a registered professional engineer in Colorado and has bachelor's degrees in economics (University of California) and geology (California State University) and a master's degree in environmental engineering (University of Colorado).

RECYCLING AND UTILIZATION OF MINE TAILINGS AS CONSTRUCTION MATERIAL THROUGH GEOPOLYMERIZATION

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Abstract:
Each year millions of tons of mine tailings are generated by the hardrock mining industry. Storage of these tailings occupies large areas of land and leads to high monetary, environmental and ecological costs. On the other hand, considerable amounts of materials are used in highway and building construction and there is a shortage of construction materials in many parts of the United States. If mine tailings are recycled and used as construction material, the land required for disposal

impoundments will be saved, the related monetary and environmental costs will be avoided, and the demand for natural materials that would need quarrying will be reduced. All these will contribute significantly to sustainable development. To use mine tailings as construction material, they need to be stabilized. Research has been conducted on stabilization of mine tailings using ordinary Portland cement (OPC); but this technique has a number of limitations, including low acid resistance, poor immobilization of contaminants, and high energy usage and greenhouse emissions. This may be one of the reasons why, even today, only a very small percentage of mine tailings are recycled.

We have been conducting research on stabilization of mine tailings using a recent innovative technology called "geopolymerization" so that they can be used as construction material in a cost-effective and environmentally-friendly way. Geopolymerization involves a chemical reaction between solid aluminosilicate oxides and an alkali metal solution at ambient or slightly elevated temperatures, yielding an amorphous to semi-crystalline polymeric material called geopolymer. Geopolymer not only provides performance comparable to OPC in many applications, but has additional advantages, including rapid development of mechanical strength, acid resistance, excellent adherence to aggregates, immobilization of toxic and hazardous materials, and significantly reduced energy usage and greenhouse emissions. Since mine tailings contain a significant fraction of silica and alumina components, they can be geopolymerized and then used as construction material. We use an innovative multi-scale and multi-disciplinary approach in the investigation, consisting of systematic macro-scale and micro/nano-scale experimentation and unique numerical simulations. We will present the results obtained so far, including the macro-scale strength, micro/nano-scale structure, chemical composition and leaching behavior of mine tailings geopolymer created at different conditions. The results indicate that mine tailings can be used to produce geopolymer construction material for different applications.

Bio:
Dr. Lianyang Zhang is an assistant professor in Civil Engineering at the University of Arizona, with over 15 years of professional experience in academia and consulting. He has been the manager, PI, CO-PI and/or main investigator of different projects involving waste recycling and utilization, contamination remediation, ground improvement, landfill facilities, new construction material and sustainable development. He has published over 60 technical papers and is the author of two books. Dr. Zhang is an Associate Editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering and serves on the Editorial Boards of the Frontier of Architecture and Civil Engineering and the International Journal of Geosciences. He also serves on the ASCE Geoenvironmental Engineering and Rock Mechanics Committees, and the Board of the International Association for Computer Methods and Advances in Geomechanics. Dr. Zhang has an M.S. in civil and environmental engineering and a Ph.D. in geotechnical engineering, both from MIT.

ECONOMIC RECOVERY OF ZINC FROM MINING INFLUENCED WATER

Kathleen Whysner[1] *(presenting author)*, **Elliot Petri[2], Linda Figueroa[3], Michael Holmes[4] and Wendy Naugle[5]**
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Abstract:
Metals removed from mining influenced water (MIW) typically end up in landfills. The metals contained in MIW represent potential resources that unfortunately end up in uneconomically retrievable forms. The key to cost effective recovery of metals is that the processes used to treat the MIW must create metal forms amenable to beneficial use. We targeted zinc as our example to examine the economic recovery of metals from MIW. Two potential uses for recovered zinc were considered: zinc smelting and zinc fertilizer. A key requirement for material to be used as feed for smelting is a zinc content greater than 50%. This requires a relatively pure form of zinc, which can be met with a zinc sulfide precipitate that contains minor amounts of co-precipitates. Industrial and by-product materials are currently used in the manufacture of zinc fertilizers. The manufacture of zinc micronutrient fertilizers from MIW has potential but more information is needed on the feedstock forms needed for the wide variety of zinc fertilizers used in agriculture. This presentation will cover chemical forms amenable to economical beneficial use, the analysis of two contrasting MIW treatment systems as benchmarks for zinc recovery potential, and requirements for the production of feedstock for zinc fertilizers.

Bio:
Kathleen M. Whysner is currently completing her master's degree in the Department of Civil and Environmental Engineering at the Colorado School of Mines. She has a B.A. in environment and development from McGill University in Montreal, Canada where she engaged in research on open pit mining in Latin America. As part of this research she interned for the Centro de Incidencia Ambiental (CIAM) in Panama, exploring the Impacts of Canadian mining exploration there, specifically related to the Cerro Colorado copper project. She is supervised at CSM by Dr. Linda Figueroa, Ph.D., P.E, for her research on the economic recovery of zinc from mining-influenced water.

USING MINE SCARRED LANDS FOR FUTURE RENEWABLE ENERGY PROJECTS

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Abstract:
Addressing America's future energy needs and lessening our dependence on foreign energy will require site for thousands of megawatts of renewable energy. The U.S. Environmental Protection Agency believes that the approximately 490,000 contaminated or formerly contaminated properties in the United States would serve as excellent locations for many of these future renewable energy projects. Many of these properties are mining sites, and EPA has been promoting these types of properties to renewable energy developers as part of its RePowering America's Lands initiative. To further this effort, the EPA Region 8 office has worked with the State of Colorado to build a 35 kilowatt (kW) hydroelectric plant at the Summitville Mine in southwest, Colorado. It has also erected meteorological towers at the Anaconda Smelter and Gilt Edge Superfund sites in Montana and South Dakota respectively. The towers are collecting wind data that will be offered to potential wind farm developers. In addition, EPA Region 8 is working with a local developer to install a 500 kW, community-owned solar array on the 40 acre Templeton Gap landfill in Colorado Springs, Colorado. The solar array is being constructed in response to a request for proposals from Colorado Springs Utility (CSU), and is expected to be one of four community solar gardens built in 2012 as part of CSU's pilot community solar program. Since this will be the first *community owned* array constructed on a contaminated property in the United States, the parties have agreed to use this project to collect and publish data on the cost of ballasted PV arrays compared to traditional driven-pile-anchored arrays. In addition, the parties will conduct research on the effectiveness of integrating low-cost storm water controls into the array as a way to substantially decrease the amount of precipitation that could enter a landfill and potentially become contaminated ground water, and to protect against future erosion problems. EPA has been contacted by numerous community groups expressing interest in constructing community-owned solar arrays on mine scarred lands in Colorado. EPA expects that the popularity of the community solar concept will drive construction of many such projects on Colorado mine lands.

Bio:
Tim Rehder currently serves as renewable energy on contaminated lands coordinator for EPA's Denver office, as well as a primary contact for green building issues. Previous EPA assignments include serving on the design team for the new EPA office building located at 1595 Wynkoop Street, overseeing the Department of Energy's $9 billion cleanup of the Rocky Flats nuclear weapons facility, and managing the cleanup of the Denver Radium Site. Mr. Rehder earned a M.S. degree from Southern Methodist University and is a LEED Accredited Professional.

BRAZIL MILLSITE: BROWNFIELD TO BRIGHTFIELD RENEWABLE ENERGY ENGINEERING DESIGN PROJECT

Ed Rapp, P.E.[1] and Diane Kielty[2]
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Abstract:
The Brazil Millsite is a reclaimed mine tailing area in Clear Creek County covering 3+ acres which is under a 15 year management agreement held by the Clear Creek Watershed Foundation (CCWF). Clear Creek County, property owner, has authorized CCWF access to manage the property for the purpose of research, education, and demonstration of mill tailings pond reclamation Best Management Practices. CCWF, in collaboration with the U.S. EPA (EPA), Colorado School of Mines (CSM), and Clear Creek Power (CCP), is evaluating re-use options on the Brazil Millsite, specifically renewable energy generation potential. An electrical distribution line runs directly through the property. CCP has been collecting wind data in the county for the past five years and is sharing the data for this location in accordance with a non-disclosure agreement. The site is also being evaluated for solar power generation potential.

The central elements to the evaluation are: How might entities in Clear Creek County make highest and best use of this property as a distributed renewable energy source? Considerations include:

- technical feasibility
- financial feasibility
- capability of local governments to provide services
- capacity of service delivery systems and public utilities (such as road capacity, wastewater treatment, emergency services, water availability, etc.)
- changes in tax revenues or total property tax burden
- effect on quality or quantity of recreational opportunities and experience
- compliance with applicable land use plans
- risk from natural hazards
- air quality
- surface water and groundwater quality
- wetlands and riparian areas
- terrestrial and aquatic animal life and habitat
- terrestrial plant life and habitat
- critical wildlife habitat
- soils and geologic conditions
- visual quality
- releases of hazardous materials
- paleontological, historic or archeological resources

The project deliverable will be a detailed engineering design of potential renewable energy technology applications on the site to include, but not limited to: layout, foundations, capacity, distribution tie-in, support infrastructure and cost estimates. The final document will be formatted

to conform with the County's 1041 regulatory requirements and as such, will demonstrate that conducting the required environmental studies is not onerous.

Bio:
Edward G. Rapp, P.E., is a long-time Clear Creek Watershed resident and advocate of sustainable futures. He has been the Clear Creek Watershed Foundation's President since its incorporation in 1997. Mr. Rapp is former Comptroller and Director of Resources at the U.S. Army Corps of Engineers and has nearly 50 years of worldwide engineering management experience. He is a retired Adjunct Associate Professor from the Colorado School of Mines and a retired Clear Creek County Commissioner, has engineering degrees from the Colorado School of Mines and Missouri School of Mines, and is a graduate and Senior Fellow of the Industrial College of the Armed Forces. Mr. Rapp is an avid outdoor enthusiast who especially enjoys fishing and hunting.

Diane Kielty has over 20 years of experience in business operations, project development, strategic planning and facility management in both the private and public sectors. As President of Lange Golf, Ms. Kielty directed the development and implementation of long and short-range business objectives, warehouse administration, policies, purchasing and budgets. She served as senior management oversight of facility product production and procedures and as liaison to assembly facility, vendor and key customer accounts. As a consultant with the Clear Creek Watershed Foundation, she is leading their Distributed Renewable Energy Initiative. She coordinated the discussions, public hearings, consensus building and presentation materials resulting in the formal rezoning of Clear Creek County for large scale renewable energy as a use by right. Ms. Kielty was recently awarded the Outstanding Performance Award, Clear Creek Watershed Person of the Year. She has a B.A. degree from Slippery Rock University of Pennsylvania.

Poster Session I
Abstracts

<u>Tuesday, April 3, 2012</u>

PCBS AND MINES

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Polychlorinated biphenyls (PCBs) are highly stable toxic organic compounds that remain a persistent environmental threat for decades. The molecules, once valued for chemical stability and fire resistance, made their first industrial debut in 1929, being manufactured and processed primarily for use as insulating fluids and dielectrics in electrical equipment. In 1979, the U.S. EPA issued final regulations banning the manufacture of PCBs and phasing out unenclosed PCB uses based on bioaccumulation and toxicity data. However, many major uses such as dielectrics in transformers, capacitors, and fluorescent light ballasts were authorized for the useful life of the equipment. Many PCB-containing pieces of electrical equipment remain in use and in abandoned surface and deep mining operations, worldwide, releasing PCBs into ground water and eventually to the ocean where they bioconcentrate in phytoplankton, the basis of the ocean food chain and producer of about 50 percent of the atmospheric oxygen. This presentation addresses five arenas of PCBs: environmental hazards, identification information, hidden sources to look for, potential liabilities, and what to do when you find PCBs.

LOSING OUR NATION'S MINING HERITAGE – A NEW PERSPECTIVE

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Throughout our nation's history mining and minerals have been a core ingredient responsible for continued economic growth and prosperity that have made the United States a world leader. For decades the production of minerals has been going overseas, greatly increasing our import dependency on essential minerals and materials. Today, coupled with the decline in producing industrial minerals, is the continued decay and destruction of our majestic historic mining sites. As these sites become lost forever, towns and communities are spending large revenues planning and building tourist attractions to provide needed revenue. Ironically, if preserved, these historic sites would provide needed revenues from tourism, as well as an understanding and appreciation of the importance of mining and minerals to the continued prosperity of our nation.

Regardless of the many legal, social and technical controversies, the dismantling and destruction of our historic mining past and loss of these sites from neglect and regulations remain a tragedy. We must learn from their stories, gain economic advantage from their historical value, and chart a mining and minerals future for our nation.

Travel with the author on a photo tour highlighting some of the historic mining sites throughout the mining districts of Colorado. The presentation will focus on a brief history and current status of two sites where an alternative approach of preserving, not restoring, the buildings would not only help prevent losing our mining and minerals legacy, but also would provide needed economic advantages. The sites are the dismantling of the Black Cloud Mine in Leadville, Colorado, and the decaying ruins of the Ghost Town of Summitville, Colorado.

LIDAR AND MULTISPECTRAL STUDIES OF LEGACY MINING-DISTURBED LAKE SUPERIOR COASTAL ENVIRONMENTS

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Due to its high spatial resolution and excellent water penetration, coastal light detection and ranging (LiDAR) coupled with multi-spectral imaging (MSS) has great promise for resolving shoreline features in relatively clear waters. Previous investigations in Lake Superior documented a metal-rich 'halo' around the Keweenaw Peninsula, related to past copper mining practices. Grand Traverse Bay on the Keweenaw Peninsula provides an excellent Great Lakes example of global mine discharges into coastal environments. For over a century, waste rock migrating from shoreline tailings piles has moved along extensive stretches of coast, damming stream outlets, intercepting wetlands and recreational beaches, suppressing benthic invertebrate communities, and threatening critical fish breeding grounds. In the bay, the magnitude of the wastes dumped literally 'reset the shoreline' and provided an intriguing field experiment in coastal erosion and spreading environmental effects. Employing a combination of historic aerial photography and LiDAR, we estimate the time course and mass of tailings eroded into the bay and the amount of copper that contributed to the metal-rich halo. We also quantify underwater tailings spread across benthic substrates by using MSS imagery on spectral reflectance differences between tailings and natural sediment types, plus a depth-correction algorithm (Lyzenga Method). Concerns about stamp sand migration from the Gay pile, aided by preliminary LiDAR and MSS imagery, spurred the U.S. Army Corps of Engineers (USACE) Detroit District Office, in February 2011, to approve a U.S. $8-9 million Keweenaw Stamp Sands Ecosystem Restoration Plan for Grand Traverse Bay.

ARSENIC DISTRIBUTION IN SEDIMENT AND PORE WATERS OF THE HISTORICAL MINING-IMPACTED BELLE FOURCHE AND CHEYENNE RIVER FLOODPLAINS, SOUTH DAKOTA

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Mineral extraction and waste disposal conducted in and near the town of Lead in western South Dakota, directly discharged spent gold mine tailings into Whitewood Creek from 1876 until 1977. Physical and chemical processes have resulted in substantial transport and deposition of arsenic-enriched materials within Whitewood Creek, the Belle Fourche and Cheyenne Rivers, and Lake Oahe (post 1958). Previous research has shown that historical sediment arsenic concentrations within the impacted floodplains range from greater than 10,000 micrograms per gram (μg/g) near the mouth of Whitewood Creek to greater than 400 μg/g in the Cheyenne River near Lake Oahe. Geochemical arsenic interactions within sediment and pore waters were investigated to determine physical, chemical, and biological processes that may influence arsenic transport from active floodplain sediments. Sediment pore-water dialysis chambers (peepers) were deployed near the Belle Fourche and Cheyenne Rivers during a 2-week sampling period and their contents were analyzed for select trace element concentration to determine temporal and seasonal influences associated with sediment redox geochemistry. In parallel, sediment cores were collected adjacent to the peepers and analyzed for mineralogy, trace element concentration, redox characteristics associated with trace element binding affinities, and aerobic and anaerobic microbial substrate utilization efficiencies. At the Belle Fourche sampling site, sediment pore-water arsenic concentrations exceeded 2,500 micrograms per liter (μg/L), whereas the associated sediment arsenic concentrations (≤ 1,010 μg/g) and minimal microbial substrate utilization profiles suggest elevated pore-water arsenic exists due to abiotic geochemical processes. Pore-water arsenic concentrations were lower at the Cheyenne River site (350 μg/L) compared to the Belle Fourche River site. However, elevated microbial activities were observed indicating that, under the specific biogeochemical conditions, microbial-mediated arsenic dissolution processes were effective, even under low sediment arsenic concentrations (≤ 130 μg/g). This presentation will summarize the key research findings from ongoing field work and laboratory analyses within the mining-impacted Belle Fourche and Cheyenne River alluvial systems.

DIETARY BIOAVAILABILITY OF CU BOUND TO SYNTHETIC HYDROUS FERRIC OXIDES

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Previous studies provided evidence that under conditions encountered in nature the consumption of metal-contaminated periphyton is an important exposure route of cadmium and copper (Cu) to freshwater benthic grazers, which include species known to be highly sensitive to metals. However, the complexity of natural diets imposes uncertainties on predictions of dietary metal uptake and its potential toxicity. For example, the metal burden measured in periphyton samples certainly includes various inorganic particles, including metal-bearing iron (Fe) and aluminum oxide colloids, entrained in the periphyton matrix. Ingestion of these particles may contribute to dietary metal uptake if metals bound to them are biologically available. While previous studies indicated that metals bound to sediment particles can be solubilzed during digestion by some marine invertebrate deposit-feeders, little information exists for freshwater species. In this study, the bioavailability of Cu sorbed to hydrous ferric oxides (HFO) was assessed by quantifying its assimilation in the freshwater gastropod *Lymnaea stagnalis*. HFO was synthesized, labeled with ^{65}Cu to achieve a Cu/Fe ratio comparable to that in naturally formed HFO, and then aged. The labeled colloids were mixed with a food source (the diatom *Nitzschia palea*) to represent colloids entrained in periphyton. *L. stagnalis* was 'pulse-fed' for 4 hours on the contaminated diet and assimilation efficiency was determined from the mass balance of ^{65}Cu retained in the soft tissues of the snail and the ^{65}Cu egested as feces during a depuration period (1-3 days). Results indicated that defecation of unassimilated ^{65}Cu was largely completed within the first day of depuration. The assimilation efficiency was 71% (i.e., 71% of ingested Cu was retained in soft tissues) with no significant loss of assimilated Cu over the next two days. In a separate experiment, in which diatoms were spiked with Cu-HFO to vary the dietary Cu concentration (yielding concentrations from 215 to 815 nmol/g), assimilation efficiency was constant at 72%. This suggests that increasing concentrations of Cu-HFO did not perturb digestion and uptake of Cu in *L. stagnalis*. Furthermore, ingestion rates did not vary among treatments indicating that levels of Cu (and Fe) contamination in the food source did not affect feeding behavior. Thus, rates of Cu influx were proportionate to Cu concentrations of the diet. Presently, we are investigating the form of bioavailable Cu. Given their high metal-binding capacity, HFOs potentially represent a source of dietary Cu to benthic grazers, especially where there is active formation, aggregation, and settling of these particles onto benthic substrates.

BURLINGTON MINE VOLUNTARY CLEAN-UP: AN ECOLOGICAL APPROACH TO HISTORIC MINE SITE REMEDIATION

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This paper describes the remediation of the Burlington Mine, Boulder County, Colorado under a Voluntary Clean-Up (VCUP) action. The VCUP design integrated several innovative techniques that resulted in exceeding basic requirements, met multiple project goals, and accommodated the abundant physical constraints and challenges of remediating a high-altitude mine site.

The VCUP remediation goals integrated an ecologically-based approach to create a self-sustaining local system that would:

- improve water quality in down gradient receiving streams by reducing surface and ground water interaction with waste rock;
- limit potential for future subsidence; and
- reduce onsite safety hazards and liability.

Located in the eastern Rocky Mountain foothills, this mine produced fluorspar from 1920 to 1973. Prior to the VCUP action, the vacant mine property was dominated by an unvegetated slope covered by a large, acidic waste rock pile, with unprotected mine adit and shaft openings, and numerous subsidence features. An intermittent creek crossed the waste rock, capturing and conducting surface water drainage from the waste rock downstream to confluence with James Creek.

Project objectives included moving mine waste rock out of contact with a local drainage and mine pond; consolidating, stabilizing, covering, and revegetating mine waste rock piles and open cut; plugging, filling, and revegetating subsidence features; diverting surface and ground water from drainage, around the surface subsidence features; and managing surface water from the entire mine site to reduce its potential from entering the reclaimed area, underground mine workings, and the mine pond. All objectives were accomplished.

The presentation will review details of the remediation action and presents monitoring results against remediation goals and objectives seven years after completion of the VCUP action.

CERCLA REMOVAL ACTION AT THE RAINY MINE, WASHINGTON

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Millennium Science and Engineering, Inc. (MSE) was commissioned by the U.S. Forest Service to complete a CERCLA Removal Action (remediation and closure) at the Rainy Mine (Site), a remote location in the Washington Cascade Mountain Range approximately 20 miles northwest of North Bend, Washington. The site receives approximately 120 inches of precipitation annually, and the final three miles of access road were all but completely washed out and culverts were plugged. In addition, a bridge on the county road leading to the site required replacement to accept the weight of heavy equipment loads required for site work. The main portion of the site consists of a short adit with a buried portal, a 110-ft. deep shaft with a collapsed collar, and 2,400 cubic yards (cy) of acid-producing waste rock within which was buried the burned and collapsed flotation mill structure. A 100-ft. exploration adit with acidic waste rock is located 900 ft. upstream of the shaft and former millsite. Runoff from the site discharges directly to Quartz Creek, which then discharges to the Taylor River then the North Fork Snoqualmie River and the Snoqualmie River to discharge to Possession sound near Everett, Washington. All are popular recreation reaches and sources of water. Seeps from the site exceeded various human health and ecological criteria for total recoverable arsenic, cadmium, chromium, copper and zinc. Waste rock exceeded various human health and ecological criteria for silver, arsenic, copper, lead, antimony, selenium and vanadium.

A repository site which had received no prior characterization had been selected on a ridge top approximately one mile from the mine. Although the Engineering Evaluation/Cost Assessment (EE/CA) was completed in 2007, mobilization did not occur until after Labor Day 2011, because of delays to complete impact studies for the marbled murrelett followed by elevated fire hazard. The rainy season began shortly after mobilization. Significant road reconstruction required excavation and transport of 3,000 cy of gravel by a 25 ton capacity articulated truck from a lowland source four miles from the site. 900 cy was required to fill a washed out bridge and ravine near the mine. Eleven culverts were cleaned or replaced, and countless water bars were constructed with rainfall causing constant maintenance. Several road sections required use of geogrid and geotextile fabric, because of deep mud. The repository was logged for sale and all stumps were shredded in a large grinder to generate mulch for use during site reclamation. Colluvium and outwash at the repository was excavated up to 10 feet to bedrock; groundwater flow at this interface required collection by draintile and diversion to an infiltration basin to divert it from the waste rock. The shaft and adit had been opened, and as much waste rock as possible placed in both as a repository. The shaft should have held approximately 250 cy, but actually held approximately 1,200 cy. The buried mill structure was not expected and required approximately 700 cy to dispose. 1,800 cy of waste rock was excavated from the site, placed in the repository and covered with an 80 mil thick high friction HDPE cap. This was covered with two feet of soil then one foot of shredded wood. Recovered salmonberry plants were planted at a five-foot spacing. Construction runoff was collected in infiltration/settlement basins. All metal debris was transported to a local landfill; the site was regraded and covered with clean soil and debris. The final half mile of access road was fully reclaimed and made impassable with the remainder of the road left intact for in-holder access. Significantly more gravel was required to repair the road than anticipated in the EE/CA as was more waste rock removed due to the unknown presence of the buried mill structure.

ASSESSING THE EFFECTIVENESS OF HARDROCK MINE REGULATION, RECLAMATION AND FINANCIAL ASSURANCES: WHAT IS THE "BOTTOM LINE"?

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One challenge facing federal agencies regulating hardrock mine reclamation is the assessment of the effectiveness of hardrock mine regulation. To the extent that current mine regulation is adequately protecting the environment then continued implementation of existing programs and regulatory tools is indicated; if not, then programmatic reassessments are in order. Anecdotal information provides individual case studies but does not objectively assess the overall programmatic effectiveness of mine regulation. The question that must be asked is: "What data most correctly assesses the effectiveness of hardrock mine regulatory programs?"

The most fundamental measure of successful industrial regulation is the extent to which mine regulation prevents the need for taxpayer dollars to be used to fund closure, reclamation and compliance. The most comprehensive database of sites requiring the use of taxpayer dollars is the CERCLA National Priorities List ("NPL"). The presentation will review: (1) the extent to which mining and beneficiation sites ("Sites") have been included on the CERCLA NPL; (2) the vintage of such sites; (3) the general nature of mine regulation in each of the major relevant time periods; (4) draw conclusions based upon the effectiveness of mine regulation in each relevant time period; and,

(5) then based upon such evaluations make recommendations regard current programmatic needs for mine regulation.

The presentation will also evaluate certain data regarding mine facility compliance with relevant water quality standards.

Innovative Technology and Techniques

INTEGRATED RESOURCE ASSESSMENTS: A FRAMEWORK TO CONSIDER THE POTENTIAL CONSEQUENCES OF MINERAL RESOURCE DEVELOPMENT

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The U.S. Geological Survey (USGS) is developing a framework for integrated mineral and energy resource assessments that links quantitative assessments of the probable amount, location, and extent of resources with quantitative estimates of potential consequences associated with resource development. These consequences are broad and may include local and regional impacts to the quality of water, land, and air, and to the health of biota, as well as social and land-use issues related to resource development. An integrated resource assessment is the foundation that allows stakeholders to make informed decisions about resource development. We will focus on a mineral resource application of an integrated assessment tool developed by a working group within the John Wesley Powell Center for Analysis and Synthesis at the USGS.

As currently envisioned, the first step is to identify questions of interest (or areas of concern) of the stakeholders with respect to mineral resource development. Next, permissive tracts (areas having a potential for resource discovery) for specific deposit types are identified in the area of interest. Then, data layers of ambient conditions, such as geology/lithology, soil type, topography, water quality of streams and groundwater aquifers, climatology, land use and ownership, population density, and previously identified sensitive (or endangered) biota, habitat, or landscape, are examined in light of the permissive tracts and of the issues or questions of concern. Potential development of the mineral resource is then considered. Numerous variables that may influence environmental and social impacts of mineral resource development, including deposit type; hydrothermal alteration; natural weathering of the deposit; climate and precipitation; choice of mining, milling, and processing methods; water needs and usage; and proximity to population centers, are evaluated.

The assessment involves developing metrics that incorporate, weight, and consider uncertainty of critical variables, such as changes in water quality (pH, metal concentrations), amount of degraded habitat, mortality of sensitive biota, or impacts to views upon development of an ore deposit. These metrics then can be compared both within and between permissive tracts in a given area to provide the necessary information for decisions by stakeholders. For example, although development of a porphyry type deposit may have a large areal footprint and probable impacts to water, land, air, and biological resources, its development in a remote area will result in different impacts than its development near a population center. Similarly, development of an ore deposit using underground techniques will result in different impacts than development using open-pit methods. Additional examples will be provided to illustrate a framework for completing an integrated mineral resource assessment.

MINING WASTE TREATMENT TECHNOLOGY SELECTION: A WEB BASED APPROACH FOR REMEDIATING MINE SITES

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Historic mining practices and the lack of mineland reclamation have led to sites with significant environmental and human health issues. Typical remedial solutions are often lengthy and expensive, and are unacceptable to the mining community, the regulatory community and to the public. 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 approval process for better, more cost-effective, environmental technologies. Funding comes from the Departments of Defense and Energy, as well as the U.S. Environmental Protection Agency and is used to support teams to address state environmental priorities. The ITRC mine waste team was formed to address mining issues 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). The guidance contains decision trees, technology overviews, case studies and regulatory challenges. The mine waste team has collected 59 case studies on the treatment of mining-influenced water and solid mining waste. The decision trees, through a series of questions, guide users to a set of treatment technologies that may be applicable to their particular situation. Each technology is described and includes applicability, advantages, limitations, performance, stakeholder concerns, regulatory considerations and lessons learned. The technology overviews include information to help users decide how well the technology may fit their particular site and remedial/reclamation goals.

A MULTI-PHASED APPROACH FOR DEEP TUNNEL DETECTION AT A GOLD MINE REMEDIATION SITE

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Multi-phase surface and crosshole geophysical investigations, including time-domain dipole-dipole resistivity and frequency domain Mise-a-la-Masse (MALM) surveys, were conducted on the Captain Jack Project, an EPA Superfund remediation site, located near the town of Ward, Colorado. The project area consists of an abandoned gold mine comprised of the Big Five Tunnel, the Dew Drop Tunnel and the Niwot Crosscut. Access into the mine workings is from the Big Five Portal, but extends only approximately 900 feet before a collapse prevents further exploration into the tunnels. Historic data suggests that the Big Five tunnel follows the NE-SW mineralized trend for more than 2,000 feet, before intersecting the Niwot crosscut which connects the Big Five to the Columbia vein to the North. The Dew Drop Tunnel is up-dip of the Big Five, following the same mineralized structure.

The objectives of the first phase of the geophysical program (June 2011) was to characterize the geology of the host rock and the mineralized fault zone, as well as to determine the location of the tunnel system, if possible. Time-domain resistivity results indicated a high resistivity background with lower resistivity fluid conduits, but were unable to image deep enough to detect the mine tunnel. The MALM was used as a reconnaissance survey, with large distances between the lines covering the overall trend of the Big Five and Dew Drop tunnels. However, MALM data showed potential to optimize the placement of drill holes meant to intersect the geologic structure associated with the mine, or intersect the tunnel itself.

The second phase of the surface geophysics (August 2011) consisted of more MALM acquisition on the western end of the project, filling in gaps and areas of interest from the previous work. By combining data from both phases an interpretation of the location of the Big Five tunnel and Niwot intersection was made. This interpretation correlates well with historical renderings. Using the mine tunnel as a transmitting electrode it appears the MALM survey technique was able to image its approximate position 2,000 ft into the mountain side, at depths of up to 500 ft. The effectiveness of using the tunnels as electrical transmitters may be dependent on seasonal variations in water levels. Given good seasonal conditions and continuity of cultural features (e.g., rails) and water, the MALM '*in-tunnel electrode*' techniques can be used as a tool for tunnel location.

Multiple drill locations were chosen based off of the MALM results. The first two holes were less than 30 ft apart and failed to intersect the tunnel; thus, crosshole ERT was acquired between the borings. Based on the crosshole ERT results, a third boring was drilled on the ERT anomaly and intersected the tunnel. It was determined the initial borehole missed the tunnel by less than 5 feet laterally.

A second location was drilled further along the fault trend. The tunnel was expected to be at a depth of approximately 450 ft. During drilling a large void was encountered at approximately 350 feet, and

extended several hundred feet downward. This boring was likely drilled into a previously unknown shaft or winze system.

Best Management Practices to Achieve Remediation Objectives

LABORATORY AND GREENHOUSE EVALUATION OF THE EFFECTS OF ENHANCED OXIDATION AND VARIOUS AMENDMENTS ON SEDIMENT CHEMICAL PROPERTIES, PLANT GROWTH, AND PLANT TISSUE METALS CONCENTRATIONS

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Milltown Reservoir, near Missoula, MT, accumulated contaminated sediments, milling tailings, and other organic-rich sediments for over 100 years. These sediments were excavated in 2009 and deposited with other mineral processing wastes at Opportunity Ponds, near Anaconda, Montana. The excavated Milltown materials were placed in a 24" layer over existing waste. Initial attempts at direct vegetation of sediments over 2-3 years were largely unsuccessful. Characterization of the materials indicated that they had near neutral pH, but crusted heavily, were moderately saline, and had significant water soluble concentrations of nitrates and metals (especially Mn and Zn).

A series of laboratory and greenhouse studies were conducted to determine the best strategy for improving the sediment to support vegetation. Mineralogical characterization of the materials showed a mixed mineralogy characteristic of the basin, but also containing sulfides (Fe, Cu and Zn), gypsum, and a number of weatherable silicate phases. Enhanced weathering reactors showed that oxidation and weathering of sulfides was occurring, but the pH was buffered near neutrality by reactive silicate minerals (carbonate minerals were absent). Initial greenhouse studies illustrated that plant rooting was severely inhibited in the Milltown materials and resulted in inability to extend into a sufficient soil volume for sustainable nutrient and water uptake.

Greenhouse studies were then conducted to identify soil amendments and treatments that improve the ability of plants to root into these materials. Treatments included: wetting/drying cycles, addition of organic matter, zero-valent Fe, lime kiln dust (LKD), and sediment washing. Sediments were amended, placed in shallow plastic trays, and tilled and wetted daily for a period of 28 days while monitoring water soluble chemistry. The treated sediments were then used as a growth medium for barley, redtop and annual ryegrass. After 40 days, shoot and root dry weights and rooting depth were determined, and shoots were acid digested and analyzed for ICP metals. The successful treatments from this study were incorporated into another greenhouse study, where amended and layered soil treatments simulating field treatments were grown for 100 days.

Components of simulated field treatments included a local calcareous cover soil, LKD, local organic matter sources, and three grass species (smooth brome, Great Basin wild rye, and thickspike wheatgrass). Plants were measured for: shoot height, mass and metals concentration; root depth and mass; and water uptake. LKD and added organic matter increased depth of rooting into sediment. Water-extractable sediment Mn and Zn were reduced to very low levels by LKD addition. Metals concentrations in aboveground plant tissues for all treatments were below ranges considered phytotoxic. Treating sediment with LKD and coversoiling with a local calcareous borrow source appears to offer the best opportunity for successful revegetation.

HOW OSM/VISTA VOLUNTEERS FACILITATE STAKEHOLDER INPUT AND COLLABORATION

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The Western Hardrock Watershed Team (WHWT) is a coalition of community/watershed improvement groups confronting the inherited environmental and social challenges that affect rural communities in the mining belt of the American West. WHWT places OSM/VISTA volunteers with watershed improvement groups across Colorado and New Mexico. WHWT currently has 24 OSM/VISTAs serving Hardrock mining communities.

The Kerber Creek Restoration Project (KCRP) is an award-winning collaboration of 16 federal, state and local agencies, non-profit groups and more than 20 local landowners dedicated to the restoration of the Kerber Creek watershed from historic mining impacts. With the help of three OSM/VISTAs since 2008, stakeholders along Kerber Creek have gradually come to pool their resources, time, and land to a watershed-wide approach restoring the Creek.

The Coalition for the Upper South Platte (CUSP), a sponsor site for OSM/VISTAs since 2009, has a current OSM/VISTA working in Victor, CO, the heart of Colorado's Cripple Creek Mining District, on community revitalization and stakeholder collaborations to revive the city of Victor. Drawing on the input from stakeholders representing several viewpoints, Victor is generating a truly collaborative approach to restoring watersheds and communities.

Together these groups will talk about the successes, resources, and lessons learned of their respective projects and how OSM/VISTA Volunteers were the cornerstone in each rural stakeholder collaboration. They will touch on the following points:

- Requisite legwork before a successful stakeholder collaboration can occur
- Guidelines to follow to facilitate stakeholder collaborations
- Recruiting stakeholders and landowners and getting them invested in solving a common problem
- Successes and lessons learned
- How to use an OSM/VISTA for your rural community's environmental clean-up, generating stakeholder facilitation, and moving people out of poverty.

DEVELOPMENT OF AQUATIC-MINING ECOSYSTEM MODELS USING COMPUTATIONAL INTELLIGENCE

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We evaluate the efficacy of a machine-learning paradigm to simultaneously model aquatic-mining ecosystem variables at sites along a mining gradient. A self-organized map (SOM) is trained using water-quality data from sample sites of 1st-3rd order catchments in central Colorado (55,000 km^2). Pattern analysis of component planes revealed previously known and unknown aquatic-mining ecosystem relations. Crossvalidation of water chemistry and toxicity; sediment chemistry and toxicity; invertebrate taxon numbers, community abundance and richness metrics; and site conditions including no hydrothermal alteration and unmined, hydrothermal alteration and unmined, and hydrothermal alteration and mined revealed the SOM to be unbiased with varying amounts of nonlinear site uncertainty. Application of the Davies–Bouldin criteria following k-means clustering of SOM neurons identified conceptual models for future research and empirical model development.

CONNECTIVITY MAPPING AMONG VARIABLES IN A MINING-AQUATIC ECOSYSTEM

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We evaluate the applicability of auto-contractive mapping to identify connections among variables characterizing natural-weathering and mining-induced metal loading into aquatic ecosystems. This new artificial adaptive data-mining approach is based on unsupervised training by field data sampled at 1st-3rd order catchment sites in central Colorado (about 55,000 km^2). Connectivity is evaluated and compared to projections of component planes derived using the self-organizing map technique. The combined analysis is used to formulate parsimonious models comprising system variables from multiple categories: geologic, sediment chemistry, water chemistry, aqueous field parameters, toxicity, risk quotients; and macroinvertebrate taxon counts and related community abundance, dominance, richness and tolerance metrics.

Poster Session II Abstracts

Wednesday, April 4, 2012

WATER-QUALITY AND STREAMFLOW TIME TRENDS, UPPER CLEAR CREEK WATERSHED (COLORADO) – SYSTEMATIC LONG-TERM MONITORING FULFILLS A RANGE OF INFORMATION NEEDS

See abstract on page 41.

A REMOTE HIGH-ALTITUDE PILOT TREATMENT SYSTEM FOR MINING-IMPACTED WATERS

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Mining Influenced Water (MIW) from a high-altitude historic metals mine Superfund site in Gunnison County, Colorado is impacted with heavy metals and exhibits acidic conditions. These waters discharge into the local watershed that feeds the town water supply. The remote location of the site and cold weather extremes make construction and sustained operation of traditional water treatment systems almost impossible; the mine is located in a remote mountainous area at 11,000 feet above sea level with annual snowfall ranges between 400-700 inches. Operator-intensive mechanized treatment systems are not feasible during winter months when there is little-to-no vehicle access to this area. A treatment system in this area has to be nearly self-sufficient in order to produce an effective remedy at this site.

A mostly-passive pilot treatment system (PTS) consisting of a biochemical reactor (BCR) and an aerobic polishing cell (APC), was installed as part of a treatability study to evaluate an innovative technology in this unique environment. The system was developed to test whether a PTS, that uses less energy and has only intermittent need for operations personnel, can work effectively at high altitudes in extreme cold conditions. As of May 2011, this system is known to be the only PTS over 11,000 feet. The system uses a solar-powered battery that pumps water a short distance into the BCR, but most of the water movement through both treatment phases relies on gravity and natural hydraulic gradients. The PTS is also equipped with a remote monitoring system that is powered by both battery and solar equipment. Remote monitoring consists of telemetry units that transmit field data to a satellite, which transmits the data, in real time, to a website. The BCR consists of a geomebrane-lined cell and filled with a buffered organic substrate that provides an organic carbon source for microbial population and promotes biological reduction of sulfate to sulfide and subsequent removal of metals in the BCR as metal sulfides precipitate. Treated effluent from the BCR flows directly into the APC, a polyethylene lined aeration channel designed to increase

dissolved oxygen and manganese removal, as well as reduce effluent toxicity prior to discharge into a nearby tributary.

Water quality analyses from system startup in 2008 were compared from the three phases of treatment: the mine effluent water upstream of the BCR, the treated BCR effluent upstream of the APC, and the APC effluent. Primary metal contaminants include cadmium, copper, lead and zinc. Iron and manganese are also evaluated as part of the pilot PTS, although the BCR is not intended to remove manganese. Analyses include the total and dissolved metals and other indicator parameters such as sulfate, sulfide, biochemical oxygen demand, pH, temperature, dissolved oxygen and oxidation-reduction potential. The BCR component exhibited a removal efficiency of greater than 99% for cadmium, copper, lead and zinc. While the BCR demonstrated no significant removal of manganese an overall average manganese removal efficiency of 82.0% indicates significant manganese removal within the APC. Water quality indicator monitoring also demonstrates the efficacy of the PTS. Measured field parameters such as the oxidation-reduction potential in BCR influent and effluent show that reducing conditions exist in the BCR. Decreased dissolved oxygen in the BCR component and increased dissolved oxygen in the APC component also support the positive system performance conclusions.

In summary, the results of operating and maintaining the PTS has demonstrated that the system is a viable technology and is effective and consistent in treating highly-acidic and metal-impacted waters in remote, high-altitude, and extreme cold conditions. The information from the problems encountered during the pilot tests over the past four years can be used in the future design and construction of a full-scale system that effectively treats mining-impacted waters and is resilient to the challenges of operating in a remote mountain ecosystem.

ELECTRO-CATALYTIC FLUX TECHNOLOGY FOR TREATMENT OF MINING WASTE WATER

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This paper describes a new treatment process for mining wastewater processing using electro-catalytic flux (EC) technology. The EC technology uses charged sacrificial anodes that generate ion-producing materials during operation that destabilize and remove waterborne contaminants and kill bacteria and viruses. Several prototype systems of various sizes are described and their performance reviewed. Results were measured in pounds of pollutants removed versus electrical dose in Watts. Optimal performance resulted in a 90% reduction in BOD, a 99% reduction in E-Coli, a 95% reduction in nitrates/nitrites and a 95% reduction in total phosphate and a 99% reduction in suspended solids. The key variables for successful treatment at the atomic and molecular levels were voltage, amperage, hydraulic retention time and electrode material in combination to provide electrical charge densities on the electrodes and electrical potential between the electrodes to produce the desired EC reaction. EC treatment of polluted waters has shown to be effective in breaking both ionic and covalent molecular bonds in substances often difficult to treat by

conventional biological means (nitrates and phosphates), in neutralizing negatively charged colloidal solids and suspended particles (separation) and for the precipitation of heavy metals (silver, zinc, nickel, etc.). Test results are shown for treatment of municipal wastewater, heavy metals removal, treatment of mining fluid-mud and treatment of frac-fluid used in underground pressure mining for oil and gas. Cost assessment for treatment of wastewater using the EC system as compared to traditional treatment methods was measured to be as much as 10 times less costly. The technology is scalable to treat high volume applications as well as smaller mining wastewater streams. The EC system is flexible in design and can be tuned to specific application by modification of the specially designed electrode cartridges that are positioned parallel to the direction of flow in the treatment unit. The design of the selective electrode materials and electrode spacing includes integrating the system's operating variables into an individual design, which is then applied for the removal of a specific contaminant or a combination of contaminants that are present at specific concentrations within an aqueous stream for a specific application. The cells may be single or plural in parallel or series arrays.

USE OF HYPER-SPECTRAL REMOTE SENSING SYSTEMS FOR MONITORING MINING OPERATIONS

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This study demonstrates the effectiveness of hyper-spectral remote sensing systems to monitor various aspects of mining operations, such as contaminant movement through leaching and/or wastewater discharge, unauthorized deforestation, improper sediment ponds, unauthorized open pits and extension of mine boundaries. Both point and non-point contaminant sources from mining operations can be identified and monitored using hyper-spectral remote sensing techniques so early corrective action can be taken to prevent or minimize harmful environmental impacts. By tracking these operational changes using hyper-spectral remote sensing can be very beneficial in establishing cleanup and contaminant management plans on a regional or watershed basis. Contaminant quality collection protocol for ground observations has its limitation because of poor accessibility to the sites and wide geographic areas of coverage. This remote sensing technology can provide field validation at mine sites and in some cases may replace conventional ground-based methods of contaminant and environmental data collection and analysis. Spectral signatures from the hyper-spectral sensor data were compared to spectral signature in spectral libraries develop by the U.S. Geological Survey and other organizations to determine what contaminants and mineral compounds were present on the ground through image analysis over the mining areas of interest. Images are analyzed using several algorithms integrated into the Environmental Visualization software such as Partial Un-mixing, Minimum Noise Fraction Transformation, and Spectral Angle Mapper. Spectral angle mapper was the principal method used in this study. The method will complement other airborne or satellite remote sensing technologies being developed to locate the origin of point and non-point sources of pollutants that may be originating from mining operations. Mine operators as well as federal, state, and local agencies, need accurate information for identifying contaminants, permitted mine boundaries with periodic revisions that apply to the sites, impaired water bodies for

prioritizing response actions, and developing long term restoration and management plans. This study shows a baseline approach that would allow mine operators and public agencies to update the basic operational status of mining as they pertain to boundaries, waste piles, and contaminant movement through drainage or leachate identification over a wide area, using satellite or airborne remote sensing systems to perform change detection and trend analysis on a continuing basis.

METAL AND ARSENIC LEVELS IN DRINKING WATER AT TWO MONTANA SUPERFUND SITES

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Analyses of the concentrations of arsenic, cadmium, and lead in potable waters collected from domestic wells, springs, and creeks were conducted within the Clark Fork River Operable Unit and within the Basin Watershed Operable Unit. These Operable Units are parts of the Clark Fork River Basin Superfund Site and the Basin Mining Area Superfund Site, respectively. Both NPL Sites are located in western Montana. These sites were named to the Superfund list as a result of uncontrolled releases of contaminants from hard rock mine, mill and smelter activities. The purpose of these sampling and analyses efforts was to quantify the levels of these elements in drinking water sources on private lands and to assess any human health risks from the ingestion of water. Arsenic has been identified as a human health risk at both of these sites. Surface soil concentrations of this element greater than 150 mg/kg for residential yard soils represent an unacceptable risk at the Clark Fork River Site. A residential surface soil human health risk concentration has not been established for the Basin Creek Site. Concentrations of arsenic as well as cadmium and lead were determined in waters used by residents for drinking and other household uses. Samples were collected from wells, natural springs and creeks. Results are presented and are compared to EPA's Maximum Contaminant Levels and Montana's Numeric Water Quality Standards.

CONSTRUCTED WETLAND TREATMENT SYSTEMS FOR MINE DRAINAGE – CAN THEY REALLY PROVIDE GREEN AND SUSTAINABLE SOLUTIONS?

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The use of wetlands to treat mine drainage has become increasingly common, particularly as more information is available on their operation and construction. They offer the promise of a green and sustainable solution, but how long will they really work?

Treatment lifetime depends on the types of processes that provide the majority of the metal removal. In aerobic systems (overland flow wetlands), trace metals can effectively be removed from neutral mine drainage by reactions with organic material in the substrate. Over 90% of the copper and nickel have been removed in aerobic systems treating mine drainage in Minnesota. The primary

removal processes in these systems include adsorption, ion exchange and complexation. These processes are finite since they depend on the existence of suitable removal sites. Removal will cease unless new removal sites are generated.

Two wetlands in northeastern Minnesota have effectively been treating mine drainage for almost 20 years and are believed to be the oldest wetlands treating metal mine drainage in the United States. Estimates of removal lifetimes based on laboratory and field data suggest that the treatment capacity of these systems could exceed a hundred years. At one of the wetlands, the annual production of new removal sites has been estimated to be equal to the annual metal input. As a result, metal removal should theoretically continue indefinitely resulting in a green and sustainable solution.

ASSESSING BIOREMEDIATION OF ACID MINE DRAINAGE IN COAL MINING SITES USING A PREDICTIVE NEURAL NETWORK-BASED DECISION SUPPORT SYSTEM (NNDSS)

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In this study, an Artificial Neural Network (ANN) was developed as a predictive tool for identifying optimal remediation conditions for groundwater contaminants that include selected metals found at coal mining sites. The ANN was developed from previous field data obtained from a bioremediation project at an abandoned mine at Cane Creek in Alabama, and from a coal pile run off at a Department of Energy's site in Aiken, South Carolina. The evaluative parameters included pH, redox, nutrients, bacterial strain (MRS-1), and type of microbial growth process (aerobic, anaerobic or sequential aerobic-anaerobic conditions). Using the conditions predicted by the Neural Networks, significant levels of As, Pb, and Se were precipitated and removed over eight days in remediation assays containing 10 mg/L of each metal in cultures that include MRS-1. The results showed 85%, 100%, and 87% reductions of As, Pb, and Se, respectively. The results from these ANN-driven assays are significant. It provides a roadmap for reducing the technical risks and uncertainties in clean-up programs. Continuous success in these efforts will require strong and responsive research that provides a decision support system for long-term restoration efforts.

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DO JAROSITE MINERALS GENERATE ACID IN LEGACY MINING WASTES?

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Jarosite-group minerals commonly form as weathering products from sulfide-bearing materials and are associated with acid-generating mining wastes and acid-sulfate soils. The role of jarosite minerals as potential sources of acid generation in legacy mining wastes is a controversial subject. Jarosite can generate acid by dissolution according to the following reaction:

$$KFe_3(SO_4)_2(OH)_6 \rightarrow 3FeO(OH) + K^+ + 2SO_4^{2-} + 3H^+$$

Published solubility constants for jarosite minerals range over several orders of magnitude, and both chemical composition and particle size are recognized as important factors in determining the solubility of jarosite minerals. A complicating factor is that natural jarosite crystals cannot be individually studied due to their small size (generally <2 μm, often <0.5 μm). It has been common practice to use synthetically prepared jarosite minerals of known composition to determine the solubility and acid-generating potential of naturally occurring jarosite minerals.

We conducted a detailed study of the chemical and mineralogical characteristics of 23 natural jarosite minerals from diverse environments (Desborough et al., 2010), and of several synthetically prepared jarosite minerals. Findings from these studies indicate that: (1) freshly formed natural jarosite minerals may contain an acid-generating component that is selectively dissolved, leaving behind more stable, remnant jarosite minerals; (2) most natural remnant K- and Na-jarosite minerals are stoichiometric and relatively stable in the surficial environment; (3) there is little evidence for significant substitution (>5 mol%) of hydronium in the structure of most natural remnant K- and Na-jarosite minerals (which would contribute to acid generation upon weathering); and (4) synthetically prepared low-temperature jarosite minerals generally are not stoichiometric and are less stable than their counterpart natural remnant jarosite minerals. Therefore, the practice of using synthetically prepared jarosite minerals as proxies for natural jarosite minerals can lead to erroneous assumptions. This is because the synthetically prepared minerals have structural deficiencies and substitutions (which lead to instability) whereas the remnant natural minerals have minimal deficiencies and substitutions. It is likely that most jarosite minerals found in legacy mining wastes are relatively stable, and that these jarosite minerals make only a limited contribution to acid generation in legacy mining wastes. However, freshly formed natural jarosite minerals may generate significant acidity due to selective dissolution of relatively unstable components. Other potential contributors of acid, such as soluble salts, could be responsible for acid generation in the acidic environments where remnant jarosite minerals are found.

Desborough, G.A., Smith, K.S., Lowers, H.A., Swayze, G.A., Hammarstrom, J.M., Diehl, S.F., Leinz, R.W., and Driscoll, R.L. (2010) Mineralogical and chemical characteristics of some natural jarosites: *Geochim. Cosmochim. Acta*, v. 74, p. 1041-1056.

REMEDIATION CASE STUDY AND VEGETATION MONITORING RESULTS FOR FLUVIAL DEPOSITS AND IRRIGATED MOUNTAIN MEADOWS AT THE CALIFORNIA GULCH NPL SITE

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Historic mining in Leadville, Colorado resulted in releases of tailings and water with high metal concentrations via California Gulch to the Upper Arkansas River and associated irrigation ditches, resulting in unvegetated mine waste deposits in the floodplain, and agricultural lands with areas of reduced or no productivity. Over the years, mine tailings continued to erode and re-deposit along the Upper Arkansas River, creating a 9-mile stretch containing barren fluvial deposits, many with eroding streambanks and coated with metal salts that washed into the river during storms. During an EPA Removal Action, the fluvial deposits were characterized and 40 acres were treated with various combinations of biosolid pellets, biosolid compost, cow manure compost, limestone, and sugar beet lime. During a subsequent Remedial Action, the remaining fluvial deposits were treated using lessons learned from the Removal Action and from the Clark Fork River Basin Superfund sites in Montana. Eroding streambanks containing mine wastes were protected with deformable stabilization techniques and are now stabilized by native plants and minimally intrusive engineering materials. Additionally, ranchland that had been contaminated by irrigation water containing particulate mine wastes and high levels of dissolved metal contaminants were characterized and treated. Performance criteria were developed to measure the success of remediation. Soil criteria include post-treatment soil characteristics including pH, lime requirement, organic carbon and electric conductivity. Vegetation criteria include seedling density (1st year measure only), cover, species richness, biomass, and evidence of reproduction. Irrigated meadows criteria were developed from the results of pre-remediation sampling in impacted and unimpacted meadows, and fluvial deposits criteria were based on the characteristics of the demonstration areas 5 to 7 years after treatment and riparian reference areas. Treated areas were also monitored for erosion, bare areas and weeds. The remedy has been monitored for three years. Monitoring results indicate establishment of a successful vegetation cover. As a result of treatment, cattle graze on land that was barren for more than 80 years and a recreation area with trails, river access, and fishing areas now operates on remediated fluvial tailings deposits.

SOLUTE-TRANSPORT MODELING TO ASSIST UNDERSTANDING OF THE POTENTIAL EFFECTS OF REMEDIATION, IMPLEMENTATION OF TOTAL MAXIMUM DAILY LOADS, AND PRE-MINING CONDITIONS

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Reactive solute-transport models help identify processes affecting trace metal transport and transformation in streams, but are particularly useful in streams affected by drainage from historical mine operations. The reactive solute-transport models OTIS (One dimensional Transport with Inflow and Storage) and OTEQ (One dimensional Transport with EQuilibrium chemistry) are calibrated using detailed stream chemistry and discharge data collected during mass-loading studies. Model calibration quantifies the hydrologic and geochemical conditions that control ambient stream chemistry and thus, improves understanding of processes that affect transport and transformation of trace metals and acidity in the stream. For example, the mass-loading results and subsequent modeling illustrate the relative importance and locations of loading to the stream from distinct sources (generally surface water) and diffuse sources (generally groundwater) as well as the magnitude of natural attenuation in the stream. Once calibrated, the models can be used to simulate (1) potential changes in stream chemistry resulting from removal of the largest sources of contamination to the stream, (2) potential differences in stream chemistry resulting from implementation of different combinations of remedial actions, and, sometimes, (3) pre-mining conditions. The latter application relies on the existence of sufficient information to assign pre-mining conditions to certain model inputs in areas where mining has already occurred. But, this application can also be used to illustrate ambient loading and natural attenuation processes (pre-mining conditions) where new mining activity is being planned.

Simulations of potential changes in stream chemistry resulting from removal of large loading sources and implementation of different combinations of remedial actions were accomplished for Cement Creek, in southwestern Colorado. This information was contrasted to the Total Maximum Daily Load (TMDL) for Cement Creek to illustrate information added by reactive-transport modeling. Reactive-transport simulations indicated less improvement to instream zinc concentrations resulting from TMDL implementation (14 percent reduction) than did the TMDL (53-63 percent reduction). These differences arise because the TMDL used a strict mass-loading approach, whereas the simulations incorporated the effects of chemical reactions, natural attenuation, and downstream transport. Simulation of pre-mining conditions for Red Mountain Creek in southwestern Colorado indicated that pH values, though less acidic than post-mining conditions, were still acidic (simulated pH values were between 4 and 5.5). Thus, removal of mine-related acid and metal loading to the stream may not cause complete recovery of the stream ecosystem. These examples illustrate how application of solute-transport modeling provides information that can assist choices of remedial actions in streams affected by historical mine operations. These examples also illustrate how these techniques can help provide baseline information (pre-mining conditions) concerning the locations and magnitude of loading and natural attenuation in watersheds where future mining is planned.

ESTABLISHING SITE-SPECIFIC BACKGROUND FOR ABANDONED MINED LANDS ON A WATERSHED SCALE

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Abandoned mine lands (AMLs) typically contain by-products of mining and milling operations that present potential risks to human health and ecological receptors. In the case of metal mine sites; risk assessment is often complicated by the presence of naturally elevated background concentrations of the same metals that are present in the waste materials. Since it is not practical to cleanup to below background levels, different approaches have been formulated to define natural background concentrations (i.e., of geologic origin). For some sites it is also important to identify local or anthropogenic background, i.e., due to human activities unrelated to releases from the source of the mining wastes. Washington's Model Toxics Control Act (MTCA) regulations prescribe a means of calculating natural background concentrations, including specification of minimum sample size, statistical analysis procedures, and methods of handling analytical results that are below the method detection limit or practical quantitation limit. However, alternate statistical procedures are also available under MTCA.

This paper describes a case study in the Monte Cristo Mining Area (MCMA), a predominantly gold mining district in the Cascade Mountains, east of Everett, Washington. The area was mined extensively in the 1890s and smaller scale mining continued into the twentieth century. Today there are more than 50 reported abandoned mines and prospects scattered across three watersheds (Weden Creek, Glacier Creek and Seventy-six Gulch) that together make up the headwaters of the South Fork of the Sauk River (SFSR). The MCMA is remote; it is located within the Mt. Baker-Snoqualmie National Forest in an area that currently has no road access. The severe access constraints reduce the potential for non-mining industrial activities to increase local background concentrations. In addition, the remoteness of the sites dramatically increases potential cleanup costs. It is important to accurately determine natural background soil concentrations of metals, because background is likely a significant threshold for establishing cleanup levels.

Background soil samples were collected along with samples of mine waste rock in the summer of 2011 over a period of four weeks camping in the National Forest and traveling to sample locations by foot. Twenty background samples were collected from each of the three watersheds that are the headwaters of the SFSR. Analytical results were compared to assess whether background concentrations should be pooled for all three watersheds or evaluated separately for each watershed. Results were also compared to screening criteria for protection of ecological receptors to determine whether pooling background data for the three watersheds affects cleanup decisions. This presentation will describe the sampling methodology, analytical results and statistical analyses.

CONTROLLING ADIT DISCHARGE AT THE UPPER TENMILE CREEK SUPERFUND SITE, RIMINI, MONTANA

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This poster will summarize the adit discharge source control program that EPA has developed for abandoned mines within the Upper Tenmile Creek Mining Area Superfund site. The site encompasses approximately 150 abandoned mines, some of which have degraded surface water quality of Tenmile Creek and its tributaries. The Upper Tenmile Creek watershed is a partial source of the City of Helena, Montana's municipal water supply. Reclamation conducted on the larger mine sites has reduced erosion from waste rock piles to nearby streams. Reclamation has not addressed the approximately 37 adits that discharge acid mine drainage (AMD) and may impact surface water.

The poster will specify the status of the 4-phase adit discharge source control program, which is in the second year of implementation at the Upper Tenmile Creek Mining Area Superfund site. In addition, the poster will describe key project milestones and will identify the types of scientists, engineers, mining experts, and regulatory specialists that execute this type of adit discharge source control program.

USING TIME-SERIES TRIPOD LIDAR TO QUANTIFY THE ERODED VOLUME OF MERCURY-CONTAMINATED SEDIMENT FROM A HISTORICAL GOLD MINING SITE IN CALIFORNIA

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The U.S. Geological Survey (USGS), in cooperation with the Bureau of Land Management (BLM), has utilized high-resolution ground-based Tripod LiDAR (Light Detection And Ranging [T-LiDAR]), also known as terrestrial laser scanning (TLS), to quantify the volume of mercury-contaminated sediment eroded from a stream cut-bank along Deer Creek in the Sierra Nevada 3 km west of Nevada City, California. T-LiDAR laser scanners can collect sub-centimeter, three-dimensional images of complex surfaces that cannot be mapped with traditional surveying techniques.

The eroded sediment contains mercury contamination from upstream historical hardrock and placer gold mines. The average mercury concentration in fine-grained sediment (less than 0.063 mm diameter) is 320 micrograms per kilogram (µg/kg, or parts per billion). Detailed laboratory characterization of the grain-size distribution in cut-bank sediments (especially the proportion of particles less than 0.063 mm in diameter) will facilitate estimation of the total mass of mercury added to Deer Creek by stream bank erosion documented with T-LiDAR during the winter of 2010–2011.

The cut-bank study site was approximately 51-m long and 8-m high, covering an approximate area of 408 square meters (m^2). Three-dimensional differencing of three time-series measurements of the eroding cut-bank yields a preliminary volume estimate of 163.4 cubic meters (m^3) of contaminated sediment mobilized by Deer Creek during the winter of 2010–2011. From early December 2010 to late January 2011, the cut-bank eroded horizontally 0.6 to 0.8 m at the water level. This erosion was primarily caused by a high-flow event on December 23, 2010, that resulted in approximately 29.8 m^3 of material being eroded from the cut-bank and transported by Deer Creek. A more significant discharge event occurred during late March 2011. This event caused an additional 0.9 to 1.2 m of horizontal bank retreat along a greater length of the cut-bank. During this second event, approximately 133.6 m^3 of material were eroded from the cut-bank and transported downstream by Deer Creek.

Time-series terrestrial laser scanning (T-LiDAR) has proven to be an effective tool to quantify volumetric changes of a complex eroding surface at sub-centimeter resolution. Volume estimates from T-LiDAR coupled with laboratory determination of mercury concentration and grain-size distribution will allow for the quantification of mercury loads from a discrete eroding bank. In consultation with other federal, state, and local agencies, as well as other interested parties, the information will be used to assist the BLM with prioritization of future remediation activities related to abandoned mines and mine wastes within the Deer Creek watershed.

CHARACTERIZATION OF MERCURY AND METHYLMERCURY CONTAMINATION IN STREAM AND POND ENVIRONMENTS AND PROVENANCE OF MINE WASTE FROM HISTORICAL GOLD MINING IN THE SIERRA NEVADA, CALIFORNIA

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The extensive use of elemental mercury (Hg) to enhance gold recovery during the late 19th and early 20th centuries resulted in widespread Hg contamination along the western slope of California's Sierra Nevada. Although Hg was used in conjunction with both hardrock (lode) and gravel (placer) gold mining operations, historical records indicate that significantly more Hg was used and lost to the environment from placer gold mining activities, including hydraulic mining, river mining, drift mining, and dredging, compared with Hg losses from hardrock stamp mills and associated retorts. To identify Hg "hot spots" as remediation targets in the Bear River and Yuba River watersheds (NW Sierra Nevada), the U.S. Geological Survey (USGS) has worked in cooperation with other federal, state, and local agencies on regional and detailed studies since 1999.

Samples of water, sediment, fish, frogs, and insects from more than 200 abandoned gold mine sites and receiving waters were analyzed for total Hg and methylmercury (MeHg), a toxic, organic form of Hg that readily bioaccumulates. Based on results of this effort, the State of California issued fish-consumption advisories for several lakes and stream reaches in the Sierra Nevada. In addition, since

2000, three remediation projects have been executed by federal agencies at abandoned gold mines in the Bear River watershed, resulting in removal or isolation of Hg-contaminated sediment. In 2000, the Polar Star mine tunnel, a 150-meter-long sluice tunnel in the Dutch Flat mining district, was remediated by the U.S. Environmental Protection Agency. In 2003, the U.S. Forest Service remediated a Hg-contaminated tunnel at the Sailor Flat mine. The Bureau of Land Management (BLM), in 2006, completed remediation of the Boston mine tunnel, a 130-meter-long sluice tunnel in the Red Dog mining district.

The mineralogy and geochemistry of bed sediment in rivers and reservoirs downstream of historical mining sources can be used to "fingerprint" sources of contamination. Mine waste (debris) from hydraulic mining tends to have abundant quartz and kaolinite and little feldspar because of intense chemical weathering prior to gravel deposition (approximately 50 million years ago, during the Early Tertiary). In contrast, mine waste from hardrock sources tends to have abundant feldspar and elevated concentrations of trace metals including antimony, arsenic, bismuth and lead. The USGS is using mineralogy and geochemistry of three discrete size fractions of sediment (less than 0.063 mm, 0.063 to 0.25 mm, and 0.25 to 1.0 mm) to determine the provenance of mixed mine waste at two sites in the Sierra Nevada: 1) at the confluence of Humbug Creek and the South Yuba River, where the proportion of hydraulic mining debris has been quantified, and 2) in Deer Creek, near Nevada City, California, where the relative proportions of hydraulic mining debris and hardrock mine waste are being determined. At both sites, methylmercury concentrations in water, sediment, fish (primarily brown trout and largemouth bass), and predatory invertebrates (larval dragonflies, craneflies, damselflies, mayflies, stoneflies and Dobsonflies; and adult water striders) are being monitored to assess temporal and spatial variability in stream environments, both upstream and downstream of suspected mercury sources. Results from these investigations will be used by the BLM to determine whether removal or stabilization of Hg-contaminated sediment may be needed at these sites.

Modern Mining Applications

BIOMINING METAL OPTIMIZATION AND THE ROLE OF THERMOACIDOPHILES

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There is growing interest in approaches that combine cost-efficient ore processing with reductions in the release of toxic byproducts. We describe a platform technology for improving bioleaching of base and precious metals based on functional microbial genomics. The new technology derives from the development of genetic systems for thermophilic biomining microbes that offers multiple new features for bioming improvement. Examples include strategies to reduce release of toxic metals, to accelerate metal leaching, to overcome water-related constraints, and to mitigate biotoxic shear arising from high pulp loading. An overview of the genetic systems is provided along with specific examples associated with chalcopyrite leaching. The specialized genetic systems produce unique cell lines expressing designed traits that can be sorted and matched for optimal application. Functional genomics offers new solutions to old problems.

MERCURY BIOACCESSIBILITY ASSOCIATED WITH CALCINE WASTE IN MCDERMITT, NEVADA

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The Cordero/McDermitt Mine, located in the Opalite mining district (Humboldt County, NV), is the largest historical producer of Hg (mercury) in Nevada, having produced about 10,000,000 kg of Hg, between 1933-1989. More than 1,000,000 cubic meters of Hg retort waste (calcines) are associated with this site, some of which has been used as bed paving material for a school playground in the nearby town of McDermitt, and for a number of roads and driveways on the adjacent Paiute Shoshone Indian Reservation.

During 2010, the U.S. EPA conducted a removal assessment at the Cordero Mine Site in response to regulatory concern over the potential adverse impacts to human health due to Hg exposure (e.g., via ingestion or inhalation of fine particles). This initial assessment indicated that total Hg exceeded the U.S. EPA Region IX Regional Screening Level (RSL) for residential soil (23 mg/kg) in surface samples collected at the playground and reservation, and exceeded the RSL for industrial soil (310 mg/kg) in surface samples collected at the McDermitt, Nevada roadway study area and the Cordero Mine site.

As a follow-up to the 2010 assessment, U.S. EPA in collaboration with researchers from USGS and Ecology and Environment, Inc., conducted additional sampling of surface soils from the mine site, playground, reservation and other locations around the town of McDermitt during 2011. These samples were sieved to 250 micron size fraction in the field, and subsequently subjected to multiple analytical assessments of Hg-speciation. Total-Hg analysis was performed in the field, using a portable x-ray fluorescence (XRF) unit, and in the laboratory using hot acid digestion with cold-vapor atomic fluorescence (CVAFS) quantification. In addition, the following suite of quantitative approaches were applied to arrive at some consensus regarding the likely levels of 'bioaccessable' Hg they contained: a) tin-reducible Hg(II) ('reactive'-Hg, HgR) quantification; b) 5-step sequential extraction; c) simulated gastro-intestinal extraction; and d) extended X-ray absorption fine structure (EXAFS) spectroscopy.

While data are still being examined, the following preliminary findings for the 2011 study can be reported: a) field XRF total-Hg concentrations for all sites ranged from 39–193 mg/kg (median=118 mg/kg, n=23), which were slightly higher than the THg concentrations assessed via CVAFS (range=15–199 mg/kg, median=80 mg/kg, n=23); b) HgR concentrations were a small percentage (range=0.09–0.66%, median=0.20%) of total-Hg concentrations across all sites; c) for a sub-set of 12 samples, the 5-step sequential extraction resulted in the following breakdown by fraction (F#, as % of total-Hg; mean ± std. error): F1 / DI-water extractable = 0.28±0.12%, F2 / pH=2 extractable 1.48±0.79%, F3 / 1N KOH extractable = 0.81±0.29%, F4 / 12N HNO_3 extractable = 21.4±1.8%, F5 / conc. HCl/HNO_3 extractable = 76.0±1.9%; d) EXAFS analysis indicates that samples from the Cordero Mine site contain equal proportions of cinnabar (α-HgS) and metacinnabar (β-HgS) (35% of total-Hg each, as molar %), and an undetectable amount of mercuric oxide (HgO), with the balance (30%) as undefined Hg. By contrast, the playground soil contains 40% α-HgS, 20% β-HgS, and 10% HgO, with the balance (30%) undefined. A synthesis of these results as well as those from the simulated gastro-intestinal extraction experiments will be presented.

Restoration

INNOVATIVE IN-SITU REMEDIATION AND RE-VEGETATION OF MINE TAILINGS

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California Gulch Operable Unit 11 (OU 11) is located in Lake County, Colorado, starting at the confluence of the Arkansas River approximately 3 miles south of Leadville and extending 11 miles south. Historical mining wastes including cadmium, copper, lead, manganese, and zinc were carried downriver via California Gulch and deposited adjacent to the upper Arkansas River. The increased acidity and metals contamination in soil impacted by mine waste had stressed or killed vegetation and soil organisms in the riparian zone. Some of the wastes were transported from the river via irrigation ditches to agricultural properties. The result was unvegetated mine wastes within the floodplain, including stream banks subject to erosion, and agricultural pastures with areas of reduced or denuded vegetation. In 2008 and 2009, the U.S. EPA Region 8 RAC 2 awarded Pacific Western Technologies, Ltd. (PWT) a contract to manage the remedial action at OU 11, and Frontier Environmental Services, Inc. (FESI) was subcontracted to implement the remedy. The remedy was designed by URS Operating Services, Inc. (URS) and Reclamation Research Group, LLC. The remediation method was innovative in both design and implementation.

The remedy involved in-situ remediation (including soil amendments and revegetation) of irrigated meadows and fluvial deposits, and stabilization of stream bank areas. The remedial design was unique in that it made use of sugar beet pulp lime (calcium carbonate), a locally obtained byproduct of sugar beet processing. Over 13,000 tons of “waste” sugar beet pulp were recycled into the soil amendments as an effective buffer for highly acidic soil.

The remedial design required blending the soil amendments at 6- to 12- inch depths into the irrigated meadows and at 6- to 36- inch depths into the floodplain deposits containing fluvial gravel and cobble. FESI developed an innovative approach for treatment of the fluvial deposits, in particular, by adapting an ALLU® soil processor to blend the soil amendments in separate stages. The ALLU® excavator attachment uses hydraulically-driven rotational flights equipped with hammers that are conventionally used for crushing and screening of natural bedding materials for pipeline projects. The adaptation of this equipment for in-situ treatment proved efficient and technically effective in thoroughly blending the amendments, consistently meeting design specifications for pH tolerance and organic carbon content. The screening capability of the soil processor was also useful for culling large volumes of gravel and dense cobble encountered in the treatment areas at production rates that supported the remediation schedule.

During 2008 and 2009, in-situ remediation and revegetation was completed on the designed 150 acres of irrigated meadows and 20 acres of fluvial deposits. In addition to over 13,000 tons (550 semi truckloads) of sugar beet pulp, the remedy included transportation and application of 45,000 cubic yards (1,100 semi truckloads) of compost, and 12 tons of fertilizer. In addition, approximately 3,000 linear feet of eroded stream banks were reconstructed by installing rock stabilization structures and were revegetated with native plants. In 2011, several previously untreated stream banks were restored with the construction of wood toe, soil lifts, and gradient weir structures that promote fish habitat and reduce bank erosion.

Access to treatment areas within the floodplain required construction of 15,000 linear feet of temporary roads that were designed and constructed by FESI to support delivery of the soil amendments and prevent damage to both the underlying floodplain and adjacent uncontaminated areas. The temporary roads were constructed using geosynthetic fabric and screened rock materials. Several temporary road segments were reclaimed and reseeded in 2011.

Challenges to the project included variable weather conditions and cold temperatures at approximately 9,500 feet elevation, transportation and management of the soil amendments, high winds, flooding from spring runoff, and high water table conditions in the floodplain. PWT and FESI took advantage of dry weather in late fall and occasionally in early winter seasons to screen materials and construct temporary access roads to achieve scheduling requirements. As of summer, 2011, EPA continues to perform assessments of vegetation established in the 170 acres of treated areas. Controlled livestock grazing has been reestablished within several irrigated meadows areas, and elk herds thrive within re-vegetated fluvial deposits. California Gulch OU 11 features a 3.5 mile stretch of the Arkansas River within the Hayden Ranch area that is increasingly attracting anglers on Colorado Parks and Wildlife lands.

INFLUENCE OF PHYTOSTABILIZATION ON BACTERIAL BIOMASS AND NITROGEN CYCLING ACTIVITIES IN ACIDIC METALLIFEROUS MINE TAILINGS

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From 1904 to 1969 the Iron King Mine near Dewey-Humboldt, Arizona, was mined for lead, gold, silver, zinc and copper. Highly acidic mine tailings resulted and contain elevated levels of arsenic, lead, and sulfates which contribute to local human and environmental health hazards. In September 2008, this site was listed as a federal Superfund site and feasibility studies to minimize wind and water dispersion of the tailings have ensued. Field and greenhouse trials have been initiated to examine the potential of using composted cattle manure and its associated microbial community to promote phytostabilization. 'Phytostabilization' is the use of native drought- and metal-tolerant plant species to stabilize the tailings and reduce the bioavailability of heavy metals in situ.

The objective of this research is to quantify temporal changes in the microbial biomass and nitrogen cycling potential of rhizosphere-influenced soil bacterial communities during the revegetation of mine tailings. Using highly instrumented mesocosms (1 m in diameter), a 27-month greenhouse study is being performed involving 4 triplicate treatments: (1) Iron King mine tailings only, (2) mine tailings mixed with 15% w/w compost, (3 and 4) mine tailings mixed with 15% compost and seeded with either *Atriplex lentiformis* (quailbush) or *Buchloe dactyloides* (buffalo grass), both native plant species. Sample cores are being collected every 3 months and processed for quantitative PCR (q-PCR) and quantitative reverse transcription PCR (qRT-PCR). The associated primer sets target the 16S-rRNA gene to measure bacterial biomass, the *nifH* gene to measure N-fixation, and the *amoA* gene to measure nitrification. It is anticipated that these parameters can serve as indicators of soil health and be used to assess our remediation strategy.

Results show that DNA and RNA can be successfully extracted and analyzed from amended tailings, whereas difficulties arise with unamended tailings due to low quantities of genetic material and high levels of inhibitors. Over time, the abundance and expression of all genes was marked by inter- and intra-treatment variation. Key findings show that the establishment of buffalo grass and quailbush helped prevent the loss of bacterial biomass at 3 months as compared to the unplanted compost treatment. Expression of the 16S-rRNA gene fluctuated in the buffalo grass treatment but increased over time in the compost and quailbush treatments. Regardless of the treatment, 16S-rRNA gene expression was higher at 9 months than at the start of the experiment. Although *amoA* and *nifH* genes appeared to increase to detectable and quantifiable levels by 9 months in most of the planted treatments, no detectable expression of these genes occurred.

This study offers a better understanding of the relationships between plant establishment, microbial presence, and microbial activity which may be integral for successful phytostabilization on mine tailings. Soil health indicators such as microbial biomass and nitrogen cycling potential can help us better assess mine sites in order to determine phytostabilization potential and success over extended periods of time.

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