HEAVY METAL ASSESSMENT OF PHOSPHOGYPSUM WASTE STOCKPILE MATERIAL FROM JORDAN

Al-Hwaiti, M.\textsuperscript{2}, V. Carney, J. F. Ranville, and P. E. Ross

Abstract: Phosphogypsum is a waste by-product of the phosphate fertilizer industry. The phosphate industry in Jordan has generated over 40 million tons of this waste material. Production continues at the rate of 3 million tons per year. The toxic heavy metal elements present in the by-product phosphogypsum and their effect on the human health and environment has prompted this study. The present study investigates potential toxic elements in phosphogypsum waste material from the Aqaba and Eshidiya fertilizer plants. Study parameters include concentrations and bioavailability of toxic elements, particle microstructure (SEM and XRD). Other variables considered include origin of deposit, age of deposit, particle size fraction and basic physico-chemical parameters. The results are used to determine the toxic element concentrations of phosphogypsum as well as to assess the impact of heavy metals that may pose a potential hazard to the human health and the environment from the two study sites.

Additional Key Words: heavy metals, distribution, phosphogypsum, bioavailability, Jordan

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Since the implementation of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) in May of 1978, many opportunities have been lost for the reforestation of surface mines in the eastern United States. Excessive compaction of spoil material in the backfilling and grading process is the biggest impediment to the establishment of productive forests as a post-mining land use. Cultural barriers that exist within the mining industry and the Federal and State regulatory authorities, contribute to the failure of reforestation efforts under the federal law over the past 26 years. Efforts are being taken to change the perception that the federal law and regulations impede effective reforestation techniques and interfere with bond release. The results of reclamation research have generated the following recommendations toward successfully establishing productive forests of reclaimed surface mines: (1.) Create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material; (2.) Loosely grade the topsoil or topsoil substitutes placed on the surface to create a non-compacted growth medium; (3.) Use native and non-competitive ground covers that are compatible with growing trees; (4.) Plant two types of trees – early succession species for wildlife and soil stability, and commercially valuable crop trees; and, (5.) Use proper tree planting techniques. Research plots have been established on a mountaintop removal operation in Pike County Kentucky for the purpose of evaluating tree performance on compacted, loose graded, ripped and excavated spoils. Loose graded spoil that is predominately grey un-weathered sandstone will be compared with loose graded spoil that is predominately brown weathered sandstone in regards to mineralogical composition, chemical and physical analysis, water infiltration characteristics, and tree performance.
HARDWOOD STOCKING AFTER FIVE YEARS ON RECLAIMED MINED LAND IN CENTRAL APPALACHIA:
A PRELIMINARY ANALYSIS¹

Ted Auch², James A. Burger, and David O. Mitchem

Abstract. Restoring mined land to native forest after surface mining could provide short- and long-term financial, environmental, and societal benefits. This study was conducted to test establishment procedures for short- and long-rotation tree species that consider (i) tree and ground cover compatibility, (ii) seeding versus hand-planting of certain short-rotation hardwood species (sycamore, green ash and tulip poplar), (iii) performance toward bond release, (iv) stocking among species and species types, and (v) the influence of spoil type, grading intensity, and site factors on tree performance. Reforestation treatments including natural invasion, direct seeding, and planting of nurse trees, softwoods and hardwoods were established on ten 2-ha recently-mined sites in Virginia, West Virginia, and Kentucky. A broad gradient in spoil type, degree of compaction, and ground cover amount occurred across the 10 sites. Natural invasion was negligible (7 trees/ha), and direct seeding of nurse and softwood species produced only 353 trees/ha. Planted softwoods (sycamore, green ash, red maple) had the highest stocking level (907-930 trees/ha), while planted hardwoods (oaks, sugar maple, white ash) survived with 783-865 trees/ha. Stocking levels of the commercially-valuable long-rotation hardwoods were significantly less than short-rotation softwoods. Stocking was influenced by groundcover competition, mine spoil density, and slope. None of the reforestation treatments were sufficiently stocked to meet state bond release criteria. Better mine soil conditions and less competitive ground covers are needed to ensure adequate stocking of native hardwoods.

Additional Key Words: hydroseeding, short-rotation softwoods, long-rotation hardwoods, reforestation, mine soil quality.

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THE EFFECT OF SOIL THICKNESS ON CROP YIELDS¹

Richard Barnhisel², James Powell, and R. Brent Gray

Abstract: Data from several reclamation projects of non-prime, non-prime cropland, and prime farmland soil research projects are summarized. As one would expect, the soil thickness of reclaimed surface mined land had a significant effect on various crop yields. The soil thickness was most important for corn, followed by grain sorghum, soybeans, wheat, and alfalfa. Soil compaction also affected crop yields, especially for corn. Since the primary standard used to determine Phase III bond release in the mid-western states is based on corn yield, several studies were conducted on the effect of both soil depth and bulk density data as controlling factors in determining corn yield. Soybeans and wheat yields are less affected by soil depth than was found for corn. Alfalfa yield was least affected by soil depth and this crop helped reduce soil compaction. Corn yields were significantly improved following five years in alfalfa production. Yield data were collected on most areas as a part of continuing activities for at least ten years. Most of the corn, soybean, and wheat yields were collected with a combine equipped with a yield monitor.

In many of these projects, subsoiling or ripping, liming, cropping practices prior to planting corn, and organic amendments to the subsoil prior to replacement of the topsoil were also variables that were evaluated as to their role in corn yield. Although these studies illustrated significant effects on corn yield, space does not allow them to be summarized here.

Additional Key Words: Phase III bond release, bulk density, soil compaction, non-prime, non-prime cropland, and prime farmland

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Abstract: Aquatic biological data have been collected from the upper Arkansas River since 1994 to monitor aquatic biological conditions in the river relative to historic mining and recent remediation activities in the California Gulch drainage. California Gulch flows directly into the Arkansas River and has historically contained elevated levels of several metals. Reclamation efforts (capping of waste rock piles, interception and treatment of adit water, etc.) have eliminated surge flows from the adits and lowered concentrations of metals entering the Arkansas River. Monitoring of brown trout populations has shown increasing trends in both density and biomass since 1994. Brown trout density and biomass were historically low downstream of California Gulch. However, trout density and biomass have been comparable or better than the reference condition upstream of California Gulch since 2002. Numbers of young-of-year brown trout have also improved. For macroinvertebrates, density, total number of taxa, number of mayfly taxa, and number of metal intolerant taxa have shown increasing trends downstream of California Gulch since 1994. The percent of total density as heptageniid mayflies is still somewhat lower than the reference sites, indicating some residual effects of California Gulch are still occurring. These data indicate reclamation efforts have improved conditions for the aquatic biota in the Arkansas River downstream of California Gulch.

Additional Key Words: metals, Colorado, Superfund Site, biological monitoring, cadmium, copper, lead, zinc
Evaluation of the TerreSIM© Model for Cover Design Analysis

R. J. Bilodeau

Abstract: In the spring of 2001, Shepherd Miller, Inc. (now MFG, Inc.) completed a closure design for a Waste Rock Storage Facility in northeastern Nevada. An ecological simulation model application, TerreSIM©, was utilized to evaluate various cover designs as part of the cover design process for the 180-acre facility. TerreSIM© is a spatially-explicit, mechanistic computer model that estimates development of the above- and below-ground plant community over time, imitates responses of ecological systems to environmental stressors, and estimates the hydrological dynamics related to ecosystem changes. TerreSIM© modeled the effect of various substrate depths and textures on the establishment of vegetation and water use by vegetation at the site. The final closure was implemented from May 2002 to Nov 2003. Lysimeters were installed in the reclaimed facility to provide a means to measure cover performance relative to the design evaluations. These lysimeters have been monitored periodically after the installation. This paper evaluates the effectiveness of using the Terrestrial Ecosystem Simulation Model (TerreSIM©) for cover design analysis, and validates the model’s projections based upon the lysimeter data.

Additional Key Words: simulation modeling, hydrology

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ATURALLY OCCURRING ACID ROCK DRAINAGE IN COLORADO’S LAKE CREEK WATERSHED\textsuperscript{1}

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\textbf{Abstract.} The Lake Creek watershed in Colorado is an excellent, unique, natural outdoor laboratory for studying naturally occurring acid rock drainage (ARD) and other hydrogeochemical processes involving metal transport and deposition. ARD originates in Peekaboo Gulch, Sayres Gulch, and Sayres Bowl Stream, headwater tributaries of Lake Creek that drain low-grade Cu-Mo hydrothermal systems associated with the Grizzly Peak Caldera, host of an Oligocene, calc-alkaline porphyry. The watershed receives no visible contribution of ARD from mining or other anthropogenic disturbances. The pH in Peekaboo Gulch, Sayres Gulch, and Sayres Bowl Stream starts in the 2.5-3.0 range, but is naturally neutralized by freshwater tributaries to Lake Creek and ultimately attains a pH of 7.7 at the confluence with the Arkansas River, 37 kilometers downstream. Dissolved concentrations of 277 mg/L Al, 498 mg/L Fe, 10 mg/L Cu, and 1,180 µg/L Zn in the acidic headwaters are naturally attenuated downstream to 0.014 mg/L, <0.05 mg/L, 0.0016 mg/L, and 1.57 µg/L, respectively, at the confluence. However, suspended Al and Fe concentrations, which can exceed their dissolved counterparts by a factor of 100 locally, tend to increase along significant stream reaches even as dissolved concentrations are decreasing, resulting in gradually increasing total metal loads over most of the watershed. Many kilometers of streambed are coated with mineral precipitates caused by the neutralization of Lake Creek from freshwater inflow along its course. In low-pH regimes high in the watershed, Al and Fe precipitates consist primarily of sulfates, but grade into oxides and hydroxides as pH increases downstream. Trace metal concentrations tend to mimic Al and Fe concentrations, probably due to adsorption onto precipitated phases of Al and Fe. Concentrations of dissolved Al, Fe, and other metals are strongly pH dependent, and the system displays the ability of Al and Fe to shift rapidly from dissolved to suspended forms depending on pH.

Additional Keywords: Arkansas River, Peekaboo Gulch, Sayres Gulch, Grizzly Peak Caldera, aluminum, iron

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USING ENZYME BIOASSAYS AS A RAPID SCREEN FOR METAL TOXICITY

E.P. Blumenstein\textsuperscript{2}, J.F. Ranville\textsuperscript{3}, L.M. Choate\textsuperscript{4}, and P.E. Ross\textsuperscript{5}

Abstract: Mine tailings piles and abandoned mine soils are often contaminated by a suite of toxic metals, which were released in the mining process. Traditionally, toxicity of such areas has been determined by numerous chemical methods including the Toxicity Characteristic Leachate Procedure (TCLP) and traditional toxicity tests using organisms such as the cladoceran \textit{Ceriodaphnia dubia}. Such tests can be expensive and time-consuming. Enzymatic bioassays may provide an easier, less costly, and more time-effective toxicity screening procedure for mine tailings and abandoned mine soil leachates. This study evaluated the commercially available MetPLATE\textsuperscript{™} enzymatic toxicity assay test kit. The MetPLATE\textsuperscript{™} assay uses a modified strain of \textit{Escherichia coli} bacteria as the test organism. Toxicity is defined by the activity of $\beta$-galactosidase enzyme which is monitored colorimetrically with a 96-well spectrophotometer. The study used water samples collected from North Fork Clear Creek, a mining influenced water (MIW) located in Colorado. A great benefit to using the MetPLATE\textsuperscript{™} assay over the TCLP is that it shows actual toxicity of a sample by taking into account the bioavailability of the toxicants rather than simply measuring the metal concentration present. Benefits of the MetPLATE\textsuperscript{™} assay over the use of \textit{C. dubia} include greatly reduced time for the testing process (~2 hours), a more continuous variable due to a greater number of organisms present in each sample (100,000+), and the elimination of need to maintain a culture of organisms at all times.

Additional Key Words: enzyme bioassay, metal contamination, mine tailings, contaminated soils, toxicity testing, MetPLATE\textsuperscript{™}

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LONG-TERM PLANT COMMUNITY DEVELOPMENT IN RESPONSE TO TOPSOIL REPLACEMENT DEPTH ON MINED LAND IN WYOMING

Cliff K. Bowen, Gerald E. Schuman and Richard A. Olson

Abstract: Effects of topsoil replacement depth on plant community development of reclaimed mined lands has been discussed for nearly three decades. Numerous research projects assessing topsoil depth effects were initiated during the 1970s. However, data collection for many of these studies was limited to 3-5 years. Plant community establishment, development, and stabilization through successional processes require considerable time. Only aboveground biomass and plant cover were reported in these short-term studies. In 2001, a research project initiated in 1977 was re-evaluated to assess the long-term effects of topsoil replacement depth (0, 20, 40 and 60 cm) on plant community development in south-central Wyoming. Percent grass cover and aboveground biomass were highest on the 40 and 60 cm topsoil depths, while forb cover was highest on the 0 and 20 cm depths. Percent bare ground was lowest on the 60 cm depth (30%) and highest on the 0 cm topsoil depth (62%). Plant species richness and diversity were significantly higher on the 0 cm topsoil depth and lowest on the 60 cm depth. Many native plant species established naturally in the abundant open space of the 0 cm topsoil replacement treatment. Variable topsoil replacement depth is a good management practice to enhance plant community diversity on reclaimed mined lands. However, placement of variable topsoil depths must consider erosion potential during the early years of reclamation. Areas of shallow topsoil should be limited to sites not prone to erosion, limited in size, and intermingled with other areas of greater topsoil replacement to ensure early stabilization and plant diversity of the reclaimed landscape.

Additional Key Words: plant species diversity, succession, species richness
Abstract. Establishment of woody vegetation on southwest mine sites poses difficult challenges. Among these are; species, timing, and planting method. This program was initiated in 1994 by building five terraces (10’ x 500’) on a north-facing spoil stockpile. 300 seedlings of seven species were planted in the spring (March 1995) and consisted of bare root and container stock. Mountain mahogany, piñon pine and ponderosa pine were solely bare root stock; while big sagebrush, fourwing saltbrush, and antelope bitterbrush were planted from both bare root and container stock. Gambel oak was planted only as containerized stock. 314 container seedlings of six species were planted in the fall (October 1995). Antelope bitterbrush was excluded. Survival was determined annually for three years and then in 2003 (year eight). Based on eight year survival, fall planting was more successful than spring planting, 47% and 8%, respectively. Spring planted bare root sagebrush, fourwing and bitterbrush were more successful than the containers, 18% and 4% respectively. However, fall planted containers of sagebrush and fourwing averaged 65%. Fall planted shrubs, and piñon pine averaged 56%. None of the spring planted trees survived. Survival of 50% or greater was reported for all fall planted species after 8 years except ponderosa pine. Both prior to interseeding and after interseeding indicated the interseeding provided no ill effects to the regeneration of the existing shrub population.
LONG-TERM EFFECTS OF COVER SOIL DEPTH ON PLANT COMMUNITY DEVELOPMENT FOR RECLAIMED MINED LANDS IN NEW MEXICO

Bruce Buchanan, Matt Owens, John Mexal, Tim Ramsey, and Brent Musslewhite

Abstract: Double wedge research plots are used to simultaneously evaluate the effects of cover soil depth and suitable spoil depth on reclamation. A double wedge was constructed and seeded in the fall of 1993 at a coal mine in northwestern New Mexico. The purpose was to determine “optimal” depths of cover soil and suitable spoil. Depth of cover soil ranged from 0 to 90 cm and depth of suitable spoil ranged from 0 to 120 cm. Sample points were established at 49 permanent locations evenly spaced throughout the plot. Vegetation sampling events were conducted in November 2003 and June of 2004 to determine vegetative cover, production, shrub density, and species diversity. Cover soil and suitable spoil depths were used to evaluate the response of cover, production, and diversity. Total cover and production increased with cover soil depth. Rabbitbrush density decreased with cover soil depth, whereas winterfat density increased with cover soil depth. The greatest species diversity occurred at cover soil depth between 25 and 65 cm. None of the vegetation parameters were affected by suitable spoil depth.

Additional Key Words: Vegetative establishment, revegetation, soil cover depth, vegetative cover, production, shrub density, species diversity, and wedge studies.

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PLANT ESTABLISHMENT ON RECLAIMED MOLYBDENUM TAILINGS, QUESTA TAILINGS FACILITY, QUESTA, NEW MEXICO

Bruce Buchanan, Matt Owens, Anne Wagner, and Ed Redente

Abstract: Molycorp, Inc. operates a molybdenum mine and associated tailings facility, near the Village of Questa, New Mexico. Neutral tailings are pumped 5.6 km from the mine to the Questa Tailings Facility where interim reclamation activities have been conducted for over 30 years. Four interim reclamation areas of the tailings facility, widely ranging in age, were evaluated for the effect of cover soil depth on plant communities. Sampling of various plant community components was conducted along random transects. The plant community components include; plant cover, shrub density, and species diversity. The evaluations suggested that depth of cover soil has little influence on the plant community components.

Additional Key Words: tailings basins revegetation, cover depth, and reclamation.

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ABSTRACT. There is increasing interest among eastern U. S. landowners and coal operators in restoring mined land to native hardwood forests. Establishing a mix of native hardwood tree species simultaneously with erosion control ground covers is difficult. The purpose of this study was to test the response of hardwood species to three levels of ground cover control using an herbicide. Treatments were control (90% ground cover), spot spray around trees (50% cover), and broadcast spray (10% cover). Survival of oak species was generally greater when spot sprayed, but survival of ash, maple, poplar and white pine was unaffected. Tree biomass of most species was greater on spot sprayed plots. Trees on broadcast sprayed plots were damaged by herbicide drift rendering this treatment less effective. Overall stocking on spot sprayed plots was 67%, which met the stocking performance standard when 700 trees/acre were planted. A Forestland Reclamation Approach, which includes ground cover management, is needed for successful native hardwood reforestation.

Additional Key Words: reforestation, herbicides, tree planting, reclamation
LOWER GREY CLOUD ISLAND FOREST PATCH: A 20 YEAR RECLAMATION MONITORING STUDY

J. B. Burley, C.A. Churchward, C.J. Burley, and W. D. Sanders

Abstract. Reclamation specialists are constantly searching for efficient and effective revegetation methods upon xeric sites. In our investigation, we created a small forest patch, densely packed with woody plants and observed the development (expansion and mortality) of individual plants and groups of plants in the patch for the last 20 years. The patch has expanded from about 0.11 acres to about 1 acre in area; while the inner core of trees has only slightly expanded from 0.08 acres to 0.10 acres in size. The collective basal area of most tree species has increased but is now spread across many individuals. The basal area growth of some of the inner individuals has nearly halted (less then 0.1 inches in dbh over 5 years). In contrast, many surviving edge trees have increased their basal area with some individuals growing more than 0.5 dbh inches per year. Box elder (Acer negundo L.) is the only species that has greatly increased in the number of individual trees (dbh ≥ 10 cm). Siouxland Eastern Cottonwood (Populus deltoides Bart. Ex Marsh. “Siouxland”) has gone extinct. Woody plant seedling recruitment continues to occur for northern red oak (Quercus rubra L.), woodbine (Pathenocissus quinquefolia (L.) Planch), riverbank grape (Vitis riparia Michx.), Eastern red cedar (Juniperus virginiana L.), grey dogwood (Cornus racemosa), Norway maple (Acer platanoides L.), green ash (Fraxinus pennsylvanica (Marsh.), and common hackberry (Celtis occidentalis L.). A small stand of Kentucky Bluegrass (Poa pratensis L.) remains in the understory of the inner core of the stand and the wood chip mulch which was applied during installation has been consumed. The full extent of the stand has become unrecognizable, as the stand has now merged with naturalized stands of sumac (Rhus sp.). Our study indicates that such an approach can achieve 100% shrubland savanna cover in 20 years, by establishing patches over 10% of the Lower Grey Cloud Island landscape. In contrast, traditional landscape treatments applied on the site have not achieved such a rapid colonization rate (p ≤ 0.01).

Additional Key Words: plant ecology, landscape ecology, landscape architecture, planting design, landscape horticulture, urban forestry, landscape planning

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COMPARISON BETWEEN OBSERVED AND MODEL PREDICTED PARTICULATE METAL TRANSPORT IN A MINING-IMPACTED STREAM (NORTH FORK CLEAR CREEK, COLORADO)  

Barbara A. Butler, James F. Ranville, and Philippe E. Ross

Abstract. Acid-mine drainage (AMD) is an important source of metals to aquatic ecosystems. Once these metals are input to oxygenated stream water of neutral pH, there may be oxidation of metal ions, precipitation of metal oxyhydroxides, and co-precipitation and/or sorption of metals. Understanding the fate and transport of these metals requires knowledge of the distribution of metals between the suspended solid and dissolved phases. Models exist for the prediction of sorption of metals to oxyhydroxides phases, primarily for hydrous iron oxide (HFO). Visual-MINTEQ now includes a database for a second hydrous oxide phase: hydrous manganese oxide (HMO), which may prove to be an important sorbent for some metals in mining-impacted systems. This paper discusses the comparison between model predicted and observed percentage particulate copper and zinc in stream water collected over a two-year study of the North Fork of Clear Creek, Colorado. It was found that the model over-estimated the percentage of particulate copper actually observed, using HFO as the sole sorbent phase, but that the comparison was within a factor of two. Inclusion of HMO for modeling of the zinc improved the prediction of percentage particulate zinc; however, results indicate that there may be another process controlling particulate zinc in the stream.

Additional Key Words: Iron oxyhydroxides, suspended sediment, manganese oxyhydroxides, and adsorption

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MOSSES AND OTHER EARLY COLONIZERS: PIONEERS FOR REVEGETATING MINE WASTE ROCK DUMPS AND ROCK WALLS


Abstract: In the Buller Coal Field, New Zealand (41°41'S; 700–1100 m a.s.l.), the steep slopes of waste rock dumps and rock walls are difficult to revegetate using traditional techniques despite regular rainfall (6000 mm p.a.). Our goal has been to accelerate natural soil development and plant succession processes on the infertile sandstone-derived overburden. Initial trials using hydroseeding technology to apply a mixture of mosses, lichens and pioneer vascular plants achieved an average of 15% moss cover and 9.5% vascular cover within 18 months of applying the most successful treatment. This compared with 0.5% and 2.3% cover on the control plot, where no moss was applied, for moss and vascular cover respectively. Natural moss resources are limited and this would significantly limit the area that could be practically hydroseeded each year. To overcome this, a hydroseeding mixture trial was established to determine whether an effective revegetation outcome could be achieved at lower application rates on different substrates. This trial illustrated that significant moss cover can be achieved, but that there is considerable variability in cover (0.1% to 28%), depending on the aspect, rock type, slope stability, hydroseeding mixture and micro-climate. Some sub-plots suffered erosion and overall moss cover on these tended to remain unchanged. After depositing overburden, a 12-month period to allow the loose waste rock spoil to consolidate before hydroseeding is suggested. Artificial moss nurseries were also investigated as a means of increasing moss volumes to enable scaling-up for revegetation of larger areas. Results suggest that low flat covers over moss beds are more effective; being less expensive, less susceptible to wind, and promoting moss growth as well as a hooped profile alternative. The best plot in this trial yielded moss growth that was 30 times the amount of moss ‘sown’ after two years.

Additional Key Words: tailings reclamation, rock slopes, pit wall, plant establishment, hydroseeding, erosion.

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THE IMPORTANCE OF IDENTIFYING NATURAL VARIATION IN AQUATIC COMMUNITIES: THE THOMPSON CREEK MOLYBDENUM MINE EXAMPLE


Abstract: The monitoring of aquatic communities is a common way to assess impacts of human activities in a watershed. However, aquatic communities can show substantial temporal variability as the result of natural processes. A well-designed monitoring program is necessary in order to identify the difference between potential impacts and natural variation. The Thompson Creek Molybdenum Mine is located in the Thompson Creek and Squaw Creek watershed in central Idaho. The monitoring program for the mine included upstream reference sites, and the sampling of multiple organisms with quantitative techniques over many years. Fish and macroinvertebrate data have been collected for these streams upstream and downstream of the mine site since 1980, which includes the period prior to construction through operation to present. Using this long-term data set and the Idaho Department of Environmental Quality (IDEQ) Water Body Assessment Guidance Document, the natural variation at study sites upstream of any potential mining impacts was compared to the variation at study sites downstream of the mining activities. For macroinvertebrate data, the IDEQ index varied from very good to poor among the various years in Thompson and Squaw creeks. The range of variability was similar at upstream reference sites and sites downstream of the mine. This analysis points out the importance of monitoring both reference sites and potentially impacted sites for long periods of time. Changes in the macroinvertebrate community which might have been attributed to the mine were likely the result of natural variation.

Additional Key Words: temporal variability, reference sites, Idaho, fish assemblage, macroinvertebrate assemblage, biological monitoring

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FIRST YEAR SEEDLING RESPONSE TO THREE LEVELS OF SILVICULTURAL INPUT ON POST-SM CRA RECLAIMED LANDS¹

C.N. Casselman², T.R. Fox, J.A. Burger, and A.T. Jones

Abstract. Surface mined lands in the Appalachian coal producing region reclaimed after the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) have been found to have dense ground covers, compacted soil materials, and unfavorable soil chemical properties. To address these concerns three study sites, which had been reclaimed post-SMCRA, were located in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia. At each site, three species assemblages were planted across a gradient of three levels of silvicultural intensity intended to alleviate the previously mentioned problems associated with post-SMCRA mined land. Response to treatment was variable by site with the site in Virginia having the best survival and greatest growth of the three sites. Hardwood species survived better at all sites than white pine or hybrid poplar. Hardwood survival across treatments was 80 and 85% for sites in Virginia and West Virginia respectively, while only 50% in Ohio. Hybrid poplar height and diameter growth were superior to other species with the height growth of this species reaching 126.6cm in the most intensive treatment at the site in Virginia. Hybrid poplar biomass increased from 15.7g to 104.5g from the least intensive to the most intensive silvicultural treatment for the site in Nicholas County, West Virginia. Hybrid poplar’s excellent response to silvicultural treatment and adequate survival, especially at the site in Virginia, may give this species an advantage over the others tested in this experiment for reverting post-SMCRA reclaimed mined lands supporting grasses back to forests.

Additional Key Words: compaction, ground cover, fertility, reforestation, native hardwoods, white pine, hybrid poplar, reclamation

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DETERMINING SOURCES OF WATER QUALITY IMPACTS USING BIOLOGICAL MONITORING: THE MOLYCORP QUESTA MOLYBDENUM MINE EXAMPLE

J.W. Chadwick, S.P. Canton, D.J. Conklin, Jr., and L.C. Bergstedt

Abstract: Biological monitoring was initiated on the Red River in 1997 to evaluate the effects on aquatic biota of open pit mine operations and mine rock piles over nearly a 40-year period. The general public perception was that the mine has had severe effects on the aquatic biota due to the absence of robust biological populations adjacent to the mine. However, initial biological monitoring data provided evidence that the observed negative impacts to fish and benthic invertebrates in the Red River near the mine were actually caused by naturally occurring thermal scars upstream of, and within, the mine area in the Red River drainage. These data indicated the open pit mine and mine rock piles did not measurably impact the suitability of the Red River to support aquatic organisms. Continued biological monitoring has reinforced these earlier conclusions, and has shown that the aquatic biota is most likely limited by episodic summer rain storms which simultaneously add large amounts of sediment and degrade water quality in the Red River downstream of the hydrothermal scars, although groundwater appears to be a contributing factor in low baseflow periods. Fish and macroinvertebrate parameters decreased immediately downstream of the town of Red River, demonstrating that the negative impacts to the aquatic biota begin well upstream of the Molycorp Mine property. Long term biological monitoring has demonstrated the complex nature of factors structuring the aquatic biota in the Red River, and demonstrated the value of well-designed monitoring programs.

Additional Key Words: Red River, New Mexico, hydrothermal scars, aquatic communities
THE USE OF “ENHANCED” MOISTURE STORE-AND-RELEASE COVER SYSTEMS OVER REACTIVE MINE WASTE IN COLD AND WARM SEMI-ARID CLIMATES

D. Christensen and M. O’Kane

Abstract. Moisture store-and-release cover systems utilize the high evaporative demand in semi-arid and arid climates to reduce the infiltration of meteoric waters to underlying reactive mine waste. This paper describes the benefits of adding a thin, reduced hydraulic conductivity layer below the overlying non-compacted layer to “delay” the downward percolation of infiltrating moisture and enhance the overall performance of the cover system. The additional cover layer is not required to be a high quality “barrier” layer and therefore does not necessarily require a clay-rich material. For example, a compacted waste rock layer as a result of haul truck traffic on top of a dump lift could serve as the low hydraulic conductivity layer. A one-dimensional numerical modeling program was used to compare the performance of a conventional moisture store-and-release cover system and an “enhanced” moisture store-and-release cover system. The modeling program was based on actual climate conditions and measured soil properties from a cold semi-arid site in northern Canada and a warm semi-arid site in Australia. Two cover system alternatives examined at each site found a decrease in the average annual net percolation for the enhanced store-and-release cover system of approximately 4%-7% of annual precipitation compared to the conventional store-and-release cover system. Analysis of the simulations showed net percolation occurred during the spring after snow melt and following the autumn rainfall events at the northern Canadian site and after intense rainfall events during the rainy season at the Australian site. The thin, reduced hydraulic conductivity layer improved the performance of the store-and-release cover system by holding water within the cover system for an increased period of time, allowing increased actual evapotranspiration in the subsequent dry periods.

Additional Key Words: moisture storage, net percolation, numerical modeling program

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TRACKING SLUDGE DISPOSAL USING ELECTRICAL CONDUCTIVITY MAPPING

Michele M. Coleman, Karl E. Butler, Anthony Mersich and Tom A. Al

Abstract. Disposing of lime neutralization sludge from an acid mine water neutralization facility back into the acid generating waste rock could provide several benefits for reclamation of abandoned coal mines. These include: a low cost final disposal area for the sludge; reduced diffusion of oxygen into the waste rock; reduced personal liability by eliminating sludge ponds, and less disturbance of land for sludge disposal purposes. NB Coal had been depositing lime neutralization sludge from its acid mine water treatment plant back onto the waste rock at the backfilled Fire Road strip mine since 1992. Chemical investigations have identified a decrease in the mine water acidity and iron and aluminum concentrations, which may be in part due to the application of the sludge.

Electromagnetic (EM) surveys were first used over parts of the Fire Road mine in 2000 to identify subsurface accumulations of acid mine drainage (AMD). One unexpected result was the observation of anomalous electrical conductivities in an area that had previously been used for the disposal of sludge. The possibility of using electrical conductivity as a tracer to track sludge migration within the waste rock motivated NB Coal to sponsor the acquisition of an EM apparent conductivity survey over the entire backfilled pit. Results of that survey, conducted in 2004, show that distribution of electrical conductivity over the mine is highly variable. A long, linear conductivity high, located along the high wall of the mine, is attributed to pooling of mine water and higher porosities (higher water contents) in that zone. Other conductivity highs, however, are clearly associated with historical patterns of sludge application and its subsurface migration. The presence of moist, conductive sludge filling a portion (or all) of the void space in the waste rock above the water table may explain this association. If so, then apparent conductivity maps may be useful as a management tool to decide which parts of the mine site would benefit most from the application of sludge for purposes of reducing the infiltration of oxygen and production of AMD.

Additional Key Words: acid mine drainage, surface coal mining, coal mine reclamation, lime neutralization sludge, electromagnetic, resistivity, geophysics

12 Michele M. Coleman is the Environmental Coordinator, NB Coal Limited, Minto NB E4B 3V1 Canada. Karl E. Butler and Tom A. Al are Associate Professors in the Dept of Geology, University of New Brunswick, Fredericton NB E3B 5A3 Canada. Anthony Mersich is completing his final year in the undergraduate Geophysics Program at the University of Alberta, Edmonton, AB, Canada.
EFFECTS OF COVER SOIL THICKNESS ON REVEGETATION OF ACIDIC APPALACHIAN COAL REFUSE\textsuperscript{1}

W. Lee Daniels\textsuperscript{2}

\textbf{Abstract}. Appalachian coal processing wastes are typically acid forming with potential acidities in Virginia ranging from an average of 12 Mg CCE demand/1000 Mg waste up to > 50 Mg/1000 Mg where higher sulfur coal seams are cleaned. Direct seeding of these materials is further complicated by high rock fragment content, low water-holding capacity, and high summer surface soil temperatures. In Virginia, conventional revegetation protocols established by the Virginia Division of Mined Land Reclamation (DMLR) in the early 1980’s required the return of 1.2 m of soil cover over all actively permitted coal wastes. Unfortunately, most active piles at the time had no available topsoil reserves, so the only alternative was to disturb adjacent properties via blasting to generate spoil derived topsoil substitutes. Between 1982 and 1990, we investigated a number of direct seeding and reduced topsoil cover alternatives in an effort to determine the optimal combination of soil amendments and cover soil thickness for the successful revegetation of varying coal waste acidity conditions. The centerpiece of this research effort was a series of topsoil wedge experiments established over three different coal waste materials where cover soil depth was varied from 0 to 125 cm, with and without lime (15 to 25 Mg/ha) at the soil/coal waste contact. Multi-year vegetation and soil sampling results indicated that a minimum of 45 to 75 cm of cover soil was required over highly acid-forming refuse (47 Mg CCE demand/1000 Mg), with the shallower depth sufficient when a lime layer was applied at the contact zone. Over moderately acid-forming materials (15 to 35 Mg CCE /1000 Mg), as little as 25 cm of cover soil was adequate as long as lime was added to the soil/waste contact zone. Coal waste materials that are < 15 Mg CCE/1000 Mg net acid forming can be direct seeded if high P applications are coupled with heavy mulch or organic amendments, especially when the fill faces are not south-facing. These results were implemented into permit review and oversight by Virginia DMLR in the early 1990’s and over the past 15 years, a wide range of active coal waste piles have been successfully revegetated with soil covers of 50 cm or less.

\textbf{Additional Key Words}: Potential acidity, direct seeding, liming, coal waste, gob.

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Abstract: The Appalachian Regional Reforestation Initiative (ARRI) is a broad-based citizen/industry/government program working to encourage the planting of productive trees on active coal mine lands and abandoned coal mine lands. Using a combination of private and governmental resources, the program will facilitate and coordinate citizen groups, university researchers, the coal industry, corporations, the environmental community, and local, state, and federal government agencies that have and interest in creating productive forestland on reclaimed mined lands.

Forestry research conducted by various academic institutions has confirmed that highly productive forestland can be created on reclaimed mine land by using a Forestry Reclamation Approach. The Office of Surface Mining Reclamation and Enforcement (OSM) has determined that this technology can be implemented under the current federal regulations. The Forestry Reclamation Approach has five fundamental parts:

- Create a suitable rooting medium for good tree growth that is no less than four to six feet deep and comprised of topsoil, weathered sandstone, and/or the best available material.
- Loosely grade the topsoil or topsoil substitutes to create a noncompacted soil growth medium.
- Use native and noncompetitive ground covers that are compatible with growing trees.
- Plant two types of trees – early succession species for wildlife and mine soil improvement and commercially valuable crop trees.
- Use proper tree planting techniques.

Tree planting is documented throughout Appalachia in the regulatory programs in Ohio, Pennsylvania, Maryland, Kentucky, Virginia, Tennessee, and West Virginia. Although trees are being planted, the reclamation plans generally do not reflect the current technology. The mission of ARRI is to promote and encourage the use the Forestry Reclamation Approach technology in both Title IV and Title V programs of the Surface Mining Control and Reclamation Act. Part of our effort will be to provide Forestry Reclamation Approach training and to explain the multiple benefits of creating productive forestland. These multiple benefits include restoration of clean water and air resources, carbon sequestration, soil conservation, wildlife and endangered species habitat, recreational opportunities, and timber production.
Abstract. Two trenches were dug into the south Dinero mine-waste pile near Leadville, Colorado, to study the weathering of rock fragments and the mineralogic sources of metal contaminants in the surrounding wetland and Lake Fork Watershed. Water seeping from the base of the south Dinero waste-rock pile was pH 2.9, whereas leachate from a composite sample of the rock waste was pH 3.3. The waste pile was mostly devoid of vegetation, open to infiltration of precipitation, and saturated at the base because of placement in the wetland. The south mine-waste pile is composed of poorly sorted material, ranging from boulder-size to fine-grained rock fragments. The trenches showed both matrix-supported and clast-supported zones, with faint horizontal color banding, suggesting zonation of Fe oxides. Secondary minerals such as jarosite and gypsum occurred throughout the depth of the trenches. Infiltration of water and transport of dissolved material through the pile is evidenced by optically continuous secondary mineral deposits that fill or line voids. Iron-sulfate material exhibits microlaminations with shrinkage cracking and preferential dissolution of microlayers that evidence drying and wetting events. In addition to fluids, submicron-sized to very fine-grained particles such as jarosite are transported through channel ways in the pile. Rock fragments are coated with a mixture of clay, jarosite, and manganese oxides. Dissolution of minerals is a primary source of metals. Skeletal remnants of grains, outlined by Fe-oxide minerals, are common. Potassium jarosite is the most abundant jarosite phase, but Pb- and Ag-bearing jarosite are common. Grain-sized clusters of jarosite suggest that entire sulfide grains were replaced by very fine-grained jarosite crystals. The waste piles were removed from the wetland and reclaimed upslope in 2003. This was an opportunity to test methods to identify sources of acid and metals and metal transport processes within a waste pile.

A series of entrapment ponds, lined with limestone rip rap, was created where the mine waste was once situated. A flooded adit discharges low-pH metal-bearing waters into the ponds. A white (Zn, Mn)-sulfate precipitate was observed in 2003 around the edges of the most distal pond.

Key Words: mine waste, dissolution, jarosite, anglesite, microlamination, leachate

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CONCENTRATION OF ARSENIC, SELENIUM, AND OTHER TRACE ELEMENTS IN PYRITE IN APPALACHIAN COALS OF ALABAMA AND KENTUCKY

Diehl, S.F., Goldhaber, M.B., Koenig, A.E., Tuttle, M.L.W., and Ruppert, L.F.

Abstract. Coals in the Appalachian basin host pyrite that is locally enriched in trace elements, including As, Mo, Hg, and Se. Trace element enrichment in the coals is the result of migrating hydrothermal fluids generated during the late Paleozoic Allegheny orogeny. A comparison study of coal between the Black Warrior Basin in northwestern Alabama and coal in eastern Kentucky reveals differences in concentrations and mode of occurrence of these elements in host pyrite. Although pyrite occurs in similar morphologic forms in the two coal basins and in similar structures (e.g., pyrite-filled cellular structures and veins), trace element content differs as does their sequence of emplacement. The highest arsenic content in pyrite in eastern Kentucky coal occurs in cellular-filled structures (up to 1.1 wt. %), whereas the highest arsenic content in pyrite in Alabama coal occurs in pyrite-filled veins (up to 2.6 wt. %). Selenium content is highest in pyrite-filled cells (up to 670 ppm Se) in eastern Kentucky, whereas selenium content in Alabama is highest in pyrite-filled veins associated with a major fault zone (up to 590 ppm Se). Coal samples from eastern Kentucky commonly contain marcasite-filled veins, whereas marcasite is not recognized in pyrite-filled veins in Warrior Basin samples. Differences in sulfide mineralogy may reflect different fluid composition in the two regions or different timing of deformation and migration of metal-bearing fluids.

Samples from both localities show deformation structures at thin section scale; however, the coal samples from Alabama exhibit greater late-stage microfaulting and microveining. The pyrite-filled microstructures that cross-cut earlier pyrite-filled woody cell structures and clay-filled desiccation cracks are host to elevated levels of arsenic, selenium, thallium, and the potentially toxic trace metals lead and mercury. The formation of fractures and faults requires that coalification proceeded to a point where brittle failure occurred after considerable burial. Therefore, trace element enrichment is post depositional.

Characterizing the morphological occurrence of pyrite and its trace element content can contribute to a better understanding of the progression of weathering of pyrite in coals, and release of the trace elements into the environment. Dendritic pyrite, for example, has many branched projections, which offers a large surface area for reaction with fluids and oxygen, which increases its susceptibility to weathering and dissolution. Dendritic pyrite in Alabama coal contains up to 1.2 wt. % arsenic.

Additional Key Words: Black Warrior Basin; mine waste, metals; laser ablation

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Abstract. Poor soil physical condition is identified as the most limiting factor to successful row crop production on mined land in Illinois. Compacted mine soils lack a continuous macropore network to provide for water movement, aeration and root system extension. Critical to reclamation success are i) selection of the best available soil materials used in soil reconstruction and ii) reclamation methods which will minimize compaction during soil reconstruction. In Illinois, topsoil replacement has generally enhanced seedbed preparation, stand establishment, and early season growth when compared to graded spoil materials. Yield response to topsoil replacement has ranged from strongly positive to strongly negative. Excellent corn and soybean yields have been achieved when reclamation methods result in low strength soils. Total crop failures have commonly occurred when high traffic soil replacement methods result in mine soils with high soil strength.

Additional Key Words: topsoil, minesoil, prime farmland reclamation, compaction
THE ADAPTATION OF HIGH ELEVATION PLANTS TO LOW ELEVATION GROWTH¹

Richard Dunne²

Abstract. From 1999 to 2002 we gathered seed from 19 perennial species deemed critical for roadside revegetation of the Beartooth highway in Wyoming and Montana, 40 miles northeast of the east entrance to Yellowstone. Collection elevations ranged between 2,895 and 3,322 meters during mid August to early September as seed ripened. In 2001 and 2002 we transplanted 38,000 tubelings for seed production at a farm in the Big Horn Basin of Wyoming with an elevation of 1,230 meters. After four years of production the field grow-out was cancelled due to poor results. 13 species exhibited premature anthesis, which lead to poor seed production or early mortality. Nine species exhibited difficulty adapting to heavy clay soils or very sandy soils. Nine species exhibited traits rendering mechanized seed harvest impossible or prohibitively expensive. Two species were highly susceptible to predators. In all, only four species exhibited favorable attributes for commercial seed production while an additional three could be made commercially viable with further work. Twelve species were considered very unlikely for commercial availability. The successful species, *(Achillea millefolium, Penstemon procerus, Poa nevadensis, Stipa nelsonii)*, where usually minor components of the source landscape, dominated by grasses, *(Deschampsia cespitosa, Danthonia intermedia, Phleum alpinum, Poa alpina)*. Results indicate a need for a collection and trials of many populations to develop broadly adapted cultivars for high elevation mining use in North America.

Additional Key Words: native plant propagation, commercial seed production, high elevation revegetation, ecoregion seed production.

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CONTROLLING MINE DRAINAGE PROBLEMS IN MINNESOTA - ARE ALL THE WETLAND TREATMENT SYSTEMS REALLY ABOVE AVERAGE?¹

Paul Eger²
Petrina Eger

Abstract. Five surface flow wetland treatment systems were built in the 1990’s to remove copper, nickel, cobalt and zinc from mine drainage in northeastern Minnesota. All but one of the drainages were neutral, and metal concentrations ranged from around 0.02 to 10 mg/l. Nickel was the primary metal generally accounting for about 90% of the load. The one acid seep was pretreated with a peat/limestone bed prior to discharge to a surface flow wetland.

System design, maintenance and performance of the wetland systems varied. Some systems have required essentially no maintenance and have produced water that has always been in compliance, while others have required a variance to maintain compliance and have required a considerable amount of reconstruction.

All the systems included a series of berms to control the hydraulic gradient and to provide access to the wetland. Some of these berms included elaborate under drains, which were generally ineffective since only a small amount of the total flow could be transmitted. The key factor in performance was the size of the wetland. An areal nickel removal rate of about 40 mg/m² day was determined in pilot cell tests prior to wetland construction. In general, the systems that met this requirement produced the most consistent compliance with water quality standards.

Additional Key Words: copper, nickel, cobalt, zinc, surface flow wetlands

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RECLAIMING COARSE TACONITE TAILINGS – IS IT ALL JUST BS?
(BIOSOLIDS)\textsuperscript{1}

Paul Eger\textsuperscript{2}

Abstract. Establishing acceptable vegetation on the coarse fraction of taconite tailings has been a major problem for Minnesota’s mining industry. Reclamation rules require that percent cover must equal 90\% after three to five years (depending on slope and aspect), and vegetation must be self-sustaining after ten years. Despite repeated application of seed and fertilizer, less than 10\% of the coarse tailings areas have met standards. Typical cover on coarse tailings, even after five years, has ranged from about 30 to 50\%.

The addition of organic amendments, such as municipal solid waste compost, peat and yard waste compost, can significantly improve vegetative cover and additions of about 20 dry ton/acre have produced vegetation that has met reclamation standards. However, availability and cost of these amendments has limited their use. Biosolids, due to their high nitrogen content and concern for water quality impacts are applied at much lower rates. An application that supplies about 100 lbs N/acre improved vegetation, but a second application was required to meet standards.

This study was designed to determine if there was an optimum biosolids application that would produce vegetation that would meet reclamation standards without impacting water quality. In the spring of 2002, six two acre plots of coarse taconite tailings were treated with anaerobically digested biosolids that would supply 100, 200 and 400 lbs N/acre. Paper mill residue was added to two of the plots to tie up excess nitrogen. A series of small bins (each about 3 feet by 9 feet) were built to examine the water quality impacts associated with the use of these amendments.

After two years, percent cover on all of the amended bins was at least 2 times greater than the cover produced by standard mineland reclamation and all plots with biosolids application of at least 200N had cover in excess of 75\%. Nitrate concentrations in all plots, except the control, periodically exceeded the nitrate standard of 10 mg/L. Adding paper mill residue reduced the nitrate concentrations by about 50\%. Based on both vegetation and water quality, a biosolids application equivalent to 200 lbs N /acre appears to be an optimum rate.

Additional Key Words: copper, nickel, cobalt, zinc, surface flow wetlands

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DEMONSTRATION OF MODULAR SULFATE REDUCING BIOREACTORS IN THE UPPER CLEAR CREEK WATERSHED

Linda Figueroa\textsuperscript{2}, Marek Zaluski\textsuperscript{3}, Judith L. Bolis\textsuperscript{2}, Andrew Miller\textsuperscript{2}, Daphne Place\textsuperscript{2}, and Alison Ruhs\textsuperscript{2}

Abstract: Advances in understanding critical components of sulfate reducing systems in recent years has allowed for the development of a better sulfate reducing bioreactor (SRB) system that considers the issues of sustainability of sulfate reducing activity, flow distribution, maintenance and placement at remote sites. Remote sites with low flow mine seeps or drainages number in the thousands in Colorado alone. SRB systems are ideal for remote sites with low flow and heavy metals such as zinc, copper, cadmium and lead at near neutral pH. SRB based systems for high acidity and metals are prohibitively large for most remote sites. In these situations, a much smaller required area can be achieved by using a two stage approach where an alkalinity generating system is used first to reduce acidity and the SRB based system is applied second for heavy metal removal.

The Upper Clear Creek Watershed in Clear Creek County Colorado has been selected for demonstration of a modular SRB design developed by MSE, Inc. A modular bioreactor system will facilitate installation and maintenance at remote sites. The bioreactor system is modular in the sense of the reaction vessel (maximum diameter of 8 ft) and includes replaceable cartridges of organic substrate (5-gallon volume in a mesh bag). Four reactors will be constructed with a mix of substrates consisting of corn stover and walnut shells to evaluate SRB systems. The design includes an impermeable cover on the bioreactor to minimize oxygen intrusion and facilitate insulation from cold temperatures. Two vertical sampling ports per reactor will be installed for quarterly sampling of the various substrates. In addition to liquid phase analyses for metals and pH, solid phase samples will be collected. Analyses will include evaluation of microbial activity and organic matter consumption. Bioreactor design, including port design will be presented.

Additional Key Words: mine drainage, organic substrates, Upper Clear Creek Watershed

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THE ACIDIC LIGNITE PIT-LAKES OF GERMANY-MICROCOSM EXPERIMENTS ON ACIDITY REMOVAL THROUGH CONTROLLED EUTROPHICATION

A. Fyson and B. Nixdorf

Abstract: Pit lakes in the Lausitz lignite mining district of Germany are diverse in size and morphometry. Many are extremely acidic with pH ≤ 3 and high in iron concentrations. Productivity in most of the mining lakes is generally low and they support only simple food webs; a few of the acidic lakes, with high nutrient concentrations, are highly productive. State planners hope to develop the lake region for recreation. To that end, various methods are being investigated to remove acidity from the lake waters. The microcosm experiment described here employs controlled eutrophication to enhance element cycling and sediment-bound alkalinity generating processes.

Sixty litre microcosms with water and sediment from Lake Grünewalde (pH 3.0, Fe 14 mg L\(^{-1}\), acidity (KB\(_{8.3}\)) 2 mmol L\(^{-1}\) and phosphorus 4 µg L\(^{-1}\)) were set up under laboratory conditions. Addition of nutrients (organic carbon and phosphorus) led to dramatic increases in primary production associated with blooms of green algae (Chlamydomonas sp.) and diatoms (Eunotia exigua) but no substantial removal of acidity. Generation of temporary anaerobic conditions through addition of potatoes led to removal of 85 % of acidity, all detectable dissolved iron, and an increase in pH from 3 to 7. These conditions were maintained with this treatment for the remainder of the 8 month observation period following removal of iron and protons from the water column.

Additional Key Words: aquatic chemistry, acid mine drainage, ecology, primary productivity, algal biodiversity

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TRACKING SALT AND SODIUM BUILD UP DUE TO IRRIGATION WITH COALBED NATURAL GAS PRODUCT WATER: SOIL SOLUTION LYSIMETER AND SOIL SATURATED PASTE EXTRACT STUDIES

Girisha K. Ganjegunte, George F. Vance and Lyle A. King

Abstract: Irrigation with coalbed natural gas (CBNG) co-produced water is a popular management option used by many gas companies operating in northwestern Powder River Basin (PRB), Wyoming. Depending upon local conditions and production rates, a CBNG well may be productive for 2 to 20 years, with an average lifespan of 7 years. At present there are over 20,000 CBNG wells permitted or drilled in the PRB region and it is estimated that another 50,000 to 100,000 new wells will be drilled in the future. The total CBNG water production in the PRB is expected to peak at about 47,000 ha-m in 2006 and the cumulative CBNG-water production during the period 2002-2017 is estimated to be 366,000 ha-m. CBNG water is dominated by sodium (Na\(^+\)) and bicarbonate (HCO\(_3^-\)) ions and the average discharge of a single CBNG well ranges from <1 to 100 liter per minute, with pH ranging from 6.8 to 9.0, electrical conductivities (EC) from 0.4 to 4 dS/m, Na adsorption ratio (SAR) from a low of 5 to an extreme high of 70 and total dissolved solids (TDS) concentrations from 270 to 2720 mg/L. Application of poorer quality CBNG water can have significant impacts on soil physical and chemical properties. Changes in soil chemistry due to land application of CBNG waters were investigated using lysimeters installed at depths of 15, 30, and 60 cm. Soil solutions collected during June to August 2004 from soil solution lysimeters were analyzed for EC and SAR. Soil solution chemistry data were compared with EC and SAR data from saturated paste extracts of CBNG irrigated soil samples collected at the same depth. Preliminary data indicate the build up of salts and Na in the upper horizons of irrigated fields. The EC values of lysimeter soil solution samples were greater than those of saturated paste. However, SAR of lysimeter soil solution and saturated paste extracts were comparable. The results of this study will be useful to understand potential changes in soil properties due to land application of CBNG waters and to develop possible mitigating criteria for reclaiming impacted PRB ecosystems.

Additional Key Words: Lysimeters, soil saturated paste, CBNG water, irrigation, electrical conductivity, sodium adsorption ratio, Powder River Basin (PRB), Wyoming

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SUSTAINABLE DEVELOPMENT IN APPALACHIA – A NEW WAY OF LOOKING AT MOUNTAINTOP MINING

J. Steven Gardner and Paul Sainato

Abstract. Mountaintop Mining in Appalachia has been challenged in recent years by continuous reinterpretation of environmental regulations for this long accepted mining practice. Effective planning, permitting and reclamation results in a “Higher and Better Land Use”. Mountaintop mining creates opportunities for development and can be called a value-added process. This analysis of mountaintop mining and Post Mining Land Uses attempts to set out a conceptual framework for establishing increased land values. Mountaintop mining epitomizes the concept of Sustainable Development within the borders of the United States in a region that truly needs new development opportunities.

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ENVIRONMENTAL ANALYSES OF HOT MIX ASPHALT MADE WITH MINING WASTE MATERIALS\textsuperscript{1}

C. F. Gause, R.W. Nairn and M. Zaman\textsuperscript{2}

\textbf{Abstract.} Beneficial reuse of mining residuals may represent a cost-effective and environmental responsible option in land reclamation. At the Tar Creek Superfund Site of northeastern Oklahoma, approximately 75 million tons of unvegetated mining waste materials (known as chat) litter the surface in large piles. Chat is primarily composed of chert, dolomite and calcite, and contains elevated concentrations of metals, particularly lead (Pb), zinc (Zn), and cadmium (Cd). Metals concentrations are particularly elevated in the finer (<0.425 mm) size fractions. At the present time, many county roads in the mining district are graded with raw or pile run chat gravel, raising substantial air and water quality concerns. However, chat also possesses certain properties indicative of high quality aggregates, e.g., hardness and angularity. Therefore, this laboratory study was designed to examine the mechanical and environmental properties of asphalt products which maximize the amount of raw (not size-fractionated) chat. Mix designs containing 80\% and 50\% raw chat, for surface and base mix designs, respectively, were found to meet mechanical criteria of the Oklahoma Department of Transportation. Detailed results are presented in a companion poster. In addition, raw chat, size-fractionated chat, asphalt products and residues created by simulated asphalt weathering were subjected to Toxicity Characteristic Leaching Procedure (EPA method 1311) and total metals analyses (EPA method 6010). Pb wipe tests (HUD method) were conducted as well. The results of these environmental analyses indicate that incorporation of raw chat into hot mix asphalt presents a beneficial reuse of this contaminated material. Concentrations in both weathered surface and base mix designs were below EPA action levels for Pb in soil and water. TCLP regulatory limits for Pb (5.0 mg/L) were not exceeded by either design. Longer-term, field-scale examinations of similar mix designs are planned through construction and monitoring of a pavement test section.

Additional Key Words: Chat asphalt, chat pavement, mining reclamation, Tar Creek Superfund Site

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ANALYSIS OF MULTI-TEMPORAL GEOSPATIAL DATA SETS TO ASSESS THE LANDSCAPE EFFECTS OF SURFACE MINING

Dean B. Gesch

Abstract. Geospatial data sets, especially digital elevation data, have proven useful for characterizing and analyzing land surface conditions. Digital elevation models are routinely used for describing the morphology of the land surface in terms of slope gradient and aspect. Additionally, the elevation data are useful for deriving parameters that describe the local drainage conditions such as watersheds and stream channels. When the element of time is added to the analysis through the use of multi-temporal topographic data, the effects of changes to the physical shape of the land surface may be studied. Such is the case with analysis of historical (pre-mining) and recent (post-mining) topographic and other geospatial data sets, including land cover maps derived from remote sensing. Nationwide geospatial data sets now exist with the required spatial and temporal resolution that allow for assessment of the effects of surface mining operations. Changes to the local landscape morphology are readily identified, and the effects to the surface drainage features are quantifiable, such as changes to local relief and drainage pattern and the total length of affected streams. Additionally, the visual impact of the movement of rock and soil materials may be assessed through viewshed analysis. Examples in both Appalachian and Western coalfields show the usefulness of analyzing detailed historical and recent geospatial data sets to better map and describe the effects of surface mining.

Additional Key Words: geospatial data, digital elevation model, change detection, multi-temporal analysis, surface hydrology.

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LINKING PHYSICAL AND SOCIAL SYSTEMS FOR IMPROVING DISTURBED-LAND RECLAMATION

J.J. Griffith and T. J. Toy

Abstract: Land disturbance is already recognized as detrimental to ecological settings. Yet we need to better understand and model how degradation events – natural or human-caused – contribute to the evolution of environmental management and affect relations of society in general. To this purpose we have developed a physical-social conceptual model that explains linkages between physical and social systems for a wide range of severe ecological events. Many models already exist representing the physical aspects of degradation such as changes to soils, hydrology, and vegetation. But most of these are incomplete because they ignore or minimize the importance of social-system components. The new and comprehensive model presented here corrects this deficiency by linking the physical and social systems by means of causal loops, the principal tool of systemic thinking. Causal loops express how tendencies of influence operate among the variables of a given system, resulting in either dynamics of reinforcement or reestablishment of stability. According to the model, a disturbance sufficient to overcome system resiliency sets either or both of the physical or social system in motion. Once actuated, the affected systems manifest movement in three possible ways and time frames: 1) by accelerated reactions in the short term, 2) by a natural and not necessarily human-assisted recuperation in the long term (if we are willing to wait long enough), and 3) through an intermediary compensating feedback mechanism that operates in the medium term and connects the other two phases. We argue that interventions at the compensating feedback-mechanism level may be more effective than trying to strategically resolve chaotic situations in the short term or confront stubborn system inertia in the long-term. A single causal loop diagram summarizes the Physical-Social Model, and we redefine key concepts of degradation, recuperation and restoration with reference to this diagram.

Additional Key Words: severely disturbed land reclamation, conceptual modeling, systemic thinking, feedback theory

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OVERCOMING ACCESS ISSUES AT A REMOTE PASSIVE TREATMENT SITE NEAR LAKE SHASTA, CA 1

By James Gusek, 2 Brad Shipley, 3 and Donald Lindsay 4

Abstract. Constructing bench scale and pilot scale sulfate reducing bioreactors (SRBRs) at abandoned mine sites can become routine until the site is accessible only by boat. The Golinsky site is a small underground copper mine complex consisting of abandoned mine workings and remnants of smelter operations located on a steep hillside above Little Backbone Creek, a tributary to Lake Shasta. The mine pool (impounded behind bulkheads) is typical acid rock drainage with a pH of 2.5 to 4 containing heavy metals including iron, aluminum, copper, zinc, cadmium, and manganese. The US Forest Service committed to a bench and pilot scale testing program to demonstrate that the SRBR technology would work at the remote site and reduce metal loading on Lake Shasta. However, accessing the site requires a three-mile boat trip across the lake and a two-mile hike along a narrow abandoned railroad grade from the beach head to the mine. The windows of construction access were controlled by the weather but also by changing lake levels. Bench and pilot SRBR test systems were constructed in 2004.

For the pilot system, all the materials (about 45 tons) and construction equipment were hauled across Lake Shasta in a WWII vintage landing craft. Efficiently off-loading this quantity of material was a challenge that was met with an innovative cable tramway system strung between the landing craft and a shore-based tower consisting of two large pine trees. Implementing the amphibious “assault” on “D-Day” with just one landing craft was complicated enough; indeed, the experience invoked a greater respect for the Allied soldiers and commanders in Normandy almost 60 years to the day earlier.

Additional Keywords: acid rock drainage, heavy metals, sulfate reducing bioreactors acid mine drainage

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WHERE DOES THE RECOVERY OF METAL RESOURCES FROM PASSIVE TREATMENT SYSTEMS FIT IN SUSTAINABLE DEVELOPMENT INITIATIVES ASSOCIATED WITH LARGE MINING PROJECTS?  

James Gusek,2 and Karen Clarke-Whistler3

Test Passive treatment systems for dealing with acid mine drainage/acid rock drainage (ARD) have been shown to be more economical than hydrated lime or similar neutralizing reagent methods. However, little effort has been focused on the beneficial use of precipitated metals in these systems. The metals are usually retained in passive systems as oxides, carbonates, or sulfides – probably forming a mineral suite similar to the deposit mined. Recovery of mineral resources retained in the passive systems will probably not be as profitable as the mine itself, primarily because of the typically slow kinetics of the process. However, a market for the minerals does exist; e.g., iron oxide recovered from passive systems associated with coal mines is being recovered and processed for paint pigment and similar uses. A similar effort may be possible for the recovery of sulfides or carbonates from sulfate reducing bioreactors, an alternative passive technology.

This passive treatment situation is an obvious opportunity for sustainable development at mines, whether currently operating or approaching closure. In many instances, some amount of ARD will result no matter what prevention measures are implemented. In many cases, treatment of ARD will be required in perpetuity, along with its long-term O & M responsibilities. Developing a sustainable cottage industry of metal recovery from these systems may effectively transfer these responsibilities to a local company. Opportunities for a metal recovery business may actually transform the treatment system liability cost into an asset. Benefits include enhancement of a given mining property’s profitability and increased community acceptance of the operation because it will result in sustainable employment. The mine plan may even be altered to enhance the profitability of the metal recovery effort by selective placement of wastes containing desirable metals (e.g., leaching of copper waste dumps). The question is, what does the mining industry need to do to integrate this concept into its sustainable development initiatives?

Additional Keywords: recycling, metals, beneficial uses, sulfate reducing bioreactors


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COMPARISON OF MINE WASTE ASSESSMENT METHODS AT THE RATTLER MINE SITE, VIRGINIA CANYON, COLORADO

Philip L. Hageman\(^2\), Kathleen S. Smith\(^2\), Thomas R. Wildeman\(^3\), and James F. Ranville\(^3\)

**Abstract.** In a joint project, the mine waste-piles at the Rattler Mine near Idaho Springs, Colorado, were sampled and analyzed by scientists from the U.S. Geological Survey (USGS) and the Colorado School of Mines (CSM). Separate sample collection, sample leaching, and leachate analyses were performed by both groups and the results were compared. For the study, both groups used the USGS sampling procedure and the USGS Field Leach Test (FLT). The leachates generated from these tests were analyzed for a suite of elements using ICP-AES (CSM) and ICP-MS (USGS). Leachate geochemical fingerprints produced by the two groups for composites collected from the same mine waste showed good agreement. In another set of tests, CSM collected another set of Rattler mine waste composite samples using the USGS sampling procedure. This set of composite samples was leached using the Colorado Division of Minerals and Geology (CDMG) leach test, and a modified Toxicity Characteristic Leaching Procedure (TCLP) leach test. Leachate geochemical fingerprints produced using these tests showed a variation of more than a factor of two from the geochemical fingerprints produced using the USGS FLT leach test. We have concluded that the variation in the results is due to the different parameters of the leaching tests and not due to the sampling or analytical methods.

Additional Key Words: mine wastes, contaminated soils and sediments, toxicity testing, leachate tests

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HYDROLOGIC CHARACTERIZATION OF A LARGE UNDERGROUND MINE POOL IN CENTRAL PENNSYLVANIA

Jay W. Hawkins², Eric F. Perry, and Mike Dunn

Abstract: Major proposed changes in drainage control from a large underground mine pool required a detailed assessment of the hydrology, geochemistry, and impacts on the receiving streams. Proposed changes entail relocation of the withdrawal and treatment facilities to an adjoining, but separate watershed and increasing the pumping rate by 35%.

Fifteen major and numerous smaller mines in two coal seams comprise the mine pool system. Degree of interconnection between mines ranges from horizontal and vertical seepage through natural fractures, subsidence-induced fractures, and coal cleat to open pass-throughs, slopes, and shafts. Water levels of several mines rise and fall in a mirrored fashion with only a few meters of head difference. An adjacent mine pool with 59.7 meters of head and an intact barrier ranging from 9.4 to 457 meters thick contributes at least 28% to the discharge rate. Mine storage capacity (5.38 billion liters) equates to a porosity of about 11%, a significant reduction from the original extraction volume of 63%. Mean ground water yield of the complex is 28 million liters per day. Recharge rate of 0.41 liters per minute per hectare is less than expected due to the thick overburden over much of the mine complex. The mine complex responds sharply to large precipitation events and large-volume pumping due to the relatively low storage volume and large aerial extent of the mine complex. Water levels respond to large precipitation events within three days and rises exceeding one meter have been recorded. Conversely, current maximum pumping at 35.6 million liters per day will draw the pool down an average of 0.09 meters per day. The proposed pumping of 37.9 million liters per day will, over the long term, exceed ground-water recharge and will dewater large portions of the mine complex. This will adversely impact the water quality, may induce additional subsidence, and could dewater some domestic water wells. Addition of water from an adjacent mine would allow the discharge of 37.9 million liters per day.

Additional Key Words: mine water storage, dewatering, barrier seepage.

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DETERMINING HYDRAULIC CONDUCTIVITIES IN A VERTICAL FLOW SYSTEM

Rachel Hutchinson and Robert W. Nairn

Abstract: Vertical flow systems (VFS) are a type of passive treatment unit process in which acid mine drainage (AMD) flows vertically through layers of organic matter and limestone. Located in the coal belt of eastern Oklahoma, the Red Oak VFS was constructed to address AMD exiting an abandoned underground coal mine. The passive treatment system consists of five cells, alternating between surface flow (cells 1, 3, and 5) and vertical flow (cells 2 and 4) designs. The VFS included an approximately 0.6-m limestone drainage layer containing a network of pipe overlain by approximately 1-m of composted horse manure mixed with limestone. Design surface water elevations were approximately 1-m above the organic matter surface. In spring 2004, cell 4 appeared to be experiencing hydraulic conductivity problems as outflow discharge rates decreased and water levels increased, based on measured flows and staff-gauge readings, respectively. It was hypothesized that accumulated solids (either sulfides or degraded organic material) were causing clogging in the substrate. This investigation was conducted to evaluate these possible hydraulic conductivity problems. A well point screened throughout the substrate layer and water column and containing a pressure transducer was installed. A series of field dropping head permeameter tests was conducted to determine hydraulic conductivity. Although vertical flow cells have been shown to result in substantial water quality improvement, concerns about the long-term physical viability of these systems warrants further investigation.

Additional Key Words: Acid Mine Drainage, Vertical Flow Wetlands, Hydraulic Conductivity, Passive System Treatment, Metal Removal, Groundwater Flow

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AMERICAN CHESTNUT AS A FUTURE RESOURCE TO ENHANCE MINE RECLAMATION PRODUCTIVITY

Douglass F. Jacobs

Abstract. Mine reclamation sites can be difficult to reforest, and trees that successfully establish on these sites are often comprised of relatively undesirable species. American chestnut (Castanea dentata) once dominated the forests throughout much of the coal-producing region in Appalachia. However, the exotic fungus Cryphonectria parasitica was discovered in 1904 and within several decades, the blight killed nearly every tree throughout the range. A dedicated breeding program sponsored by The American Chestnut Foundation has made tremendous progress toward producing a blight-resistant variety of American chestnut by hybridizing with the blight-resistant Chinese chestnut (Castanea mollissima). It is expected that a blight-resistant hybrid chestnut tree (~94% American chestnut) will be available for reintroduction within the next decade, providing a new species option for reclamation programs. Due to continued presence of the fungus throughout eastern forests, few studies have examined American chestnut growth performance in plantations. However, a recent study on a blight-free site in Wisconsin reported exceptional growth capacity of chestnut relative to co-occurring hardwood species. Sufficient evidence also exists to suggest that American chestnut may tolerate many of the stressful physical and chemical soil characteristics typical of mine reclamation sites. Rapid growth, adaptability to a wide range of environmental conditions, good timber quality, and exceptional wildlife properties make American chestnut a highly desirable potential species for future reclamation programs.

Additional Key Words: Castanea dentata, plantation establishment, site tolerance, competitive interactions, juvenile growth performance
DEVELOPMENT OF A FOREST SITE QUALITY CLASSIFICATION MODEL FOR MINE SOILS IN THE APPALACHIAN COALFIELD REGION\textsuperscript{19}

Andy T. Jones\textsuperscript{20}, John M. Galbraith, and James A. Burger

\textbf{Abstract}. The Appalachian coalfields occur largely under rugged mountains covered by native hardwood forests. These forests, soils, and bedrock are removed by the surface mining process. Surface mines are not typically reclaimed to a managed forest land-use, but are often seeded with non-native grasses and legumes, or with pines, black locust, and shrubs for unmanaged forest land. Surface mining and reclamation techniques since the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) create highly compacted mine soils with high coarse fragment content, low organic matter, and high pH, which inhibits native forest reestablishment. The purpose of this study was to develop a forest site quality classification model to advise landowners on the production potential and feasibility of reforesting their mined lands with white pine (\textit{Pinus strobus} L.). Ten selected physical, chemical, and site properties were assessed and a model was developed using variables that were the most highly correlated with the growth of 10- to 18-year-old white pines established on post-SMCRA surface-mined sites. A model with soil pH, texture, density, and rooting depth variables yielded a coefficient of determination of 0.71. Sufficiency curves were used in a productivity index (PI) model to classify reclaimed surface-mined land into one of five forest site quality classes (FSQC). A site index (SI\textsubscript{50} = dominant tree height at age 50) for white pine was estimated for each class, and this measure of productivity may be used to aid in management decisions regarding reforestation of surface mines in the Appalachian coalfields.

Additional Key Words: forest productivity, reclamation, reforestation, site quality, productivity index.

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MINE WASTE TECHNOLOGY PROGRAM: HISTORICAL PERSPECTIVES, CURRENT HIGHLIGHTS, FUTURE OPPORTUNITIES

Helen Joyce, Diana Bless, and Gene Ashby

Abstract. For the past 13 years, the Mine Waste Technology Program (MWTP) has been operated by MSE with administrative assistance from the Department of Energy (DOE)’s Western Environmental Technology Office (WETO) and technical direction from EPA’s National Risk Management Research Laboratory (EPA-NRMRL). A portion of the MWTP funding has been used to perform Field Demonstrations of innovative technologies with the potential to address mine waste issues. This paper will highlight current and past MWTP successes and discuss important lessons learned.

Over 70 distinct projects have been completed or are currently being performed by MSE and Montana Tech of the University of Montana. Some issues addressed by these projects include: sustainability; acid drainage/water treatment; trace/heavy metal removal; remote locations; source control; pit lakes; and heap detoxification/closure. Other projects are focused on prediction, characterization, and modeling.

Within the past year, new MWTP management personnel have been assigned at MSE, EPA-NRMRL, and Montana Tech of the University of Montana providing an opportunity for positive evolution of the MWTP. Future strategies for MWTP success will also be presented.

Additional Key Words: acid drainage, water treatment, sustainability, source control, pit lakes, remote locations, selenium, arsenic

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USING SPREADSHEETS TO PREDICT STREAM SALINITIES IN THE YAMPA RIVER BASIN COAL FIELDS, NORTHWESTERN COLORADO

Tom Kaldenbach

Abstract: Spreadsheets were used for predicting stream salinities in the Yampa River watershed. The concentration of total dissolved solids (TDS) represents salinity. The spreadsheets calculate TDS at 22 locations by summing the flow-weighted TDS values upstream from each point. The flow-weighted TDS values were compiled from publicly available monitoring data and from predicted future mining inputs. This spreadsheet method provides only a rough prediction of TDS concentrations because it does not precisely account for non-mining sources like irrigation and municipal runoff. Also, significant error is introduced by the differences in sampling times between locations. Spreadsheets were developed for eight different scenarios with various combinations of moisture conditions (precipitation), season (flow), and pumping of underground mine water to the surface. Calculated TDS values were posted on a GIS map of the watershed for visualizing mining impacts along stream segments. The eight scenarios for the spreadsheets predict the largest percentage increase in TDS occurs when there is uncontrolled mine pumping in a relatively dry year during low seasonal stream flow.

Additional Key Words: aquatic chemistry, cumulative hydrologic impact assessment, GIS hydrologic model, mass balance, mine drainage, mine pollution, numerical model, solute transport, salt loading stream model, spreadsheet hydrologic model

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THE CHEMISTRY OF CONVENTIONAL AND ALTERNATIVE TREATMENT SYSTEMS FOR THE NEUTRALIZATION OF ACID MINE DRAINAGE

Margarete Kalin, Andrew Fyson and William N. Wheeler

Abstract. The objective of this paper is to review the chemical processes which drive the performance of both conventional and passive treatment systems for Acid Mine Drainage and to compare the two. Several decades of research have improved the performance of both yet neither provides an environmentally acceptable, sustainable solution to the problem, which is still a major financial liability of the mining industry. A review of the literature and an examination of the underlying chemical reactions of both approaches suggests that the greatest potential for improvements lies with passive ecological systems. Future research areas are suggested.

Additional Key Words: acid mine drainage, acid rock drainage, passive treatment, lime treatment, ecological engineering.

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THE TOXICITY OF BINARY METAL MIXTURES TO *CERIODAPHNIA DUBIA* IN MINING INFLUENCED WATERS\(^1\)

Kathryn Kangas\(^2\), Jessica Ayers\(^2\), James F Ranville\(^3\), and Philippe Ross\(^2\)

**Abstract.** Revisions to current EPA regulations for surface waters containing metals, such as mining influenced waters (MIW), are under consideration. It is proposed to substitute a calculation using the Biotic Ligand Model (BLM) for the current hardness-based criteria. This approach may more accurately account for the influence of varying surface water chemistry on metal toxicity. Although the revision may be a great improvement from the traditional toxicity determination, metals are only considered individually. Most effluents from mining disturbed lands contain multiple toxic metals. Currently the approach used in this situation is to assume that metal toxicity is additive. There are reasons to believe that not all metals form additive combinations. The biotic ligand model was used to determine the LC\(_{50}\) values for copper, cadmium, nickel, and zinc individually for *Ceriodaphnia dubia* in a MIW. Binary-metal acute toxicity tests on *C. dubia* using the four metals were then conducted. Both the BLM calculations and the experiments were performed using stream water collected upstream of a mining-impacted reach of North Fork Clear Creek, Colorado. Experiments were performed in order to determine if additivity was occurring. In fact, antagonistic (less than additive) effects were seen for most binary combinations. Results indicate that, for the metal combinations tested, the proposed BLM-based regulations could be sufficiently protective if non-additive effects are accounted for in describing the toxicity of metal mixtures.

Additional Key Words: metal contamination, mining influenced waters, toxicity testing

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USE OF COAL BED NATURAL GAS (CBNG) WATERS: SOIL AND PLANT RESPONSES

L.A. King, G.F. Vance and G.K. Ganjegunte

Abstract. With about 20,000 coal bed natural gas (CBNG) wells currently permitted or drilled in the Powder River Basin (PRB) of Montana and Wyoming and projections of more than 50,000 future wells, CBNG water production in the PRB over the next 15 years will exceed 366,000 ha-m. Therefore, proper CBNG product water utilization is warranted. Land application using conventional center-pivot and side-roll irrigation systems is a common strategy for managing saline-sodic waters derived from CBNG production within the PRB. Various soil and plant impacts resulting from 1 to 4 years of saline-sodic water (EC = 1.8 to 4.0 dS m\(^{-1}\); SAR =15 to 38) applications were examined during the 2003 and 2004 field seasons on 6 (2003) to 8 (2004) study sites representing native range grasslands, seeded grass hayfields and alfalfa hayfields. Because soil and plant types, water application rates and water and soil treatment strategies were variable across study sites, parameters measured from each treated (irrigated) site were compared directly to those from representative control (non-irrigated) sites. Soil chemical and physical parameters including pH, EC, SAR, texture, bulk density, surface infiltration rate and Darcy flux rates were measured at various depth intervals to 120 cm. Multiple year applications of saline-sodic water produced consistent trends of increased soil EC and SAR values at depths to 30 cm, reduced surface infiltration rates and reduced Darcy flux rates to 120 cm. Significant (P=0.05) differences in EC, SAR, infiltration rates and Darcy flux (P=0.10) were determined at most sites. Up to 4 years of saline-sodic water applications significantly (P=0.05) increased native perennial grass biomass production and cover on treated vs. control sites. However, overall species evenness was reduced. Biological effects were variable and complex, reflecting site specific conditions and management strategies.

Additional Key Words: coalbed methane, saline-sodic water; land application; sodium adsorption ratio; soil chemical, physical and biological properties; Powder River Basin; vegetation diversity.

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SALINE-SODIC WATER IMPACTS TO SOILS AND VEGETATION

L.A. King¹, G.F. Vance², and G.K. Ganjegunte²

Abstract: Saline-sodic waters derived from coalbed methane (CBM) gas production are being applied to rangelands and production agricultural lands within the Powder River Basin (PRB) of Montana and Wyoming. Impacts from 1 to 4 years of irrigation with saline-sodic waters (EC’s = 1.8 to 4.0 dS m⁻¹; SAR =15 to 38) to soil and vegetation were examined on study sites with variable soils, vegetation communities, and water management strategies. Soil chemical and physical parameters (pH, EC, SAR, texture, bulk density, water infiltration rate and Darcy flux rate) from treated (irrigated) sites were compared with those of representative control (non-irrigated) sites at 6 depth intervals to 120 cm. Saline-sodic water applications significantly (P=0.05) increased soil EC values at depths to 60 cm and SAR values to 30 cm. Infiltration rates and Darcy flux were significantly (P=0.10) reduced on treated vs. control sites. Saline-sodic water applications significantly increased both above-ground biomass production and canopy cover of perennial grasses compared to controls on all study sites. Up to 4 years application of CBM waters has significantly altered soil chemical/physical properties, soil water flow dynamics and native vegetation communities, resulting in significant considerations for reclamation potential of these lands.

Additional Key Words: coalbed natural gas, coalbed methane, infiltration rates, hydraulic conductivity, land application.

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PROBLEMS WITH MANGANESE AND MAGNESIUM IN HOT ACIDITY TITRATIONS

C.S. Kirby and B. Means

Abstract: Standard Method “Hot Acidity” titrations to an endpoint of pH 8.2 or 8.3 are commonly employed to evaluate the contributions of hydrogen ions and hydrolyzable metals to the acidity of mine drainage. These titrations employ steps (addition of hydrogen peroxide, sulfuric acid, boiling followed by cooling) to improve the reproducibility of the methods. Coal mine drainage from the bituminous coal fields of Western Pennsylvania commonly contains concentrations of Fe, Al, and Mn in excess of 20 mg/L and Ca and Mg in excess of 100 mg/L. High concentrations of Mn and Mg in solutions can create difficulties in the interpretation of the values estimated for acidity.

We performed Hot Acidity titrations on mine drainage solutions with a wide range of chemical compositions. The pH and measured Hot Acidity were recorded, and filtered aliquots were analyzed for metals and sulfate at several stages of each titration (raw water, after cooling, and at pH intervals up to the endpoint). Calculated acidities were also computed for each stage based on pH and dissolved metal concentrations. Hot and calculated net acidity results showed poor agreement for some waters. Mn removal after Hot Acidity titration ranged from 0 to 96%, thus the reliability of the Hot Acidity to account for Mn acidity is not clear. Up to 27% of Ca+Mg decreases were not explained by dilution, thus Ca and Mg apparently contributed acidity. Up to 80% of SO$_4^{2-}$ decreases were not explained by accounting for dilution and H$_2$SO$_4$ addition. Both of these phenomena are contrary to predictions based on geochemical computer modeling, and both can impact treatment planning and costs.

Additional Key Words: calculated and measured acidity.


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RECLAMATION OF WASTE ROCK STOCKPILES UTILIZING PAPER MILL RESIDUALS AT CLIFFS MICHIGAN MINING COMPANY

Allan E. Koski

Abstract: Two of the largest industries in northern Michigan, pulp and paper manufacturing and iron mining, formed a mutually beneficial partnership and collaborative research program to utilize paper mill residuals for waste rock stockpile reclamation. Historically, the majority of the paper industry’s residuals have been disposed of in landfills. The beneficial use of paper mill residuals for mine reclamation provides an environmentally sound recycling solution for the solids generated at northern Michigan paper mills and eliminates the need to strip additional overburden (glacial till) for final mine reclamation. Residuals offer a cost-effective source of organics and nutrients necessary for successful reclamation and waste rock stockpiles offer an economical and environmentally sound solution for disposal of residuals. The goal is to successfully pioneer technical development of paper mill residuals to accomplish vegetation of steep waste rock stockpile slopes and benches to establish a self-sustaining plant community that meets final reclamation requirements. Of the various types of iron mining wastes, rock stockpiles pose the greatest reclamation challenge. Success depends on incorporating sufficient organic matter into the rock stockpiles to produce a growth medium that can sustain vegetation without the need of overburden. This is an ongoing research program that is evolutionary in nature with numerous field trials, greenhouse studies, data collection and monitoring over multiple growing seasons. The program is a combination of innovative ideas and accepted reclamation practices that is proving to be a beneficial and economic approach to paper mill residual management and mine reclamation that will eventually lead from research to standardized reclamation procedures. The observations in this paper are from the first field season.

Additional Key Words: land application, beneficial use, mill residuals, WTP residuals, solid waste management, paper sludge, land spreading

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POND REHABILITATION AND ESTABLISHMENT OF A SITE-BASED ENVIRONMENTAL EDUCATION CURRICULUM

Allan E. Koski

Abstract: A pond rehabilitation and environmental educational project were proposed by Cliffs Michigan Mining Company (CMMC) and approved by the Michigan Department of Environmental Quality (MDEQ) and the United States Environmental Protection Agency (USEPA) as partial fulfillment of conditions for a stream mitigation permit. The goals of the project were the rehabilitation of a pond on a tributary of a local trout stream, enhancement of public access and appreciation, and the initiation of a site-based environmental education curriculum dealing with aquatic and riparian ecosystems. CMMC undertook a suite of actions to rehabilitate the freshwater pond created by an underground mining operation in 1912 and make accessible to local schools the aquatic and riparian ecosystems of the pond. The rehabilitated pond and riparian zone also provides an accessible natural area available to citizens of the nearby town for such activities as hiking, biking, walking, fishing and nature study. The project was a partnership with the local governmental unit and local school districts. Vegetative enhancement included the planting of native shrubs and wildflowers along with showy herbaceous plants in the pond, on the riparian fringe and the surrounding area. A signed interpretive trail was designed and developed around the pond. Local schools built and installed picnic tables, benches and a kiosk. CMMC developed pond lesson plans and a teaching kit tied to the Michigan Curriculum Framework and hosted a workshop for teachers from nine local schools. Classes regularly utilize the pond during the school year by conducting environmental studies. Nesting boxes, wildflower gardens, bat houses, frog deformity surveys and water quality studies are a few of the activities that have been conducted at the pond.

Additional Key Words: streams, stream mitigation, and environmental education

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CO-OPERATIVE PARTNERSHIP AND INNOVATION IN THE PLANNING AND EXECUTION OF THE DECOMMISSIONING OF THE MT MCCLURE GOLD PROJECT

Harley Lacy\textsuperscript{2} and Mike Slight\textsuperscript{2}

Abstract. The standards achieved in the closure of the Mt McClure Gold Mine in Western Australia (W.A.) in 2004, was recognized with a Golden Gecko Award for Environmental Excellence, the highest environmental award available in W.A.. The project was also awarded the Newmont Australia Award for Environment as “the best environmental project in 2004” across the Australian operations.

The key to the successful closure of Mt McClure was the genuine and dynamic partnerships, which were developed and nurtured primarily by the Newmont-McClure management team, with a vision to create the best possible closure outcome “effectively a closure with pride”. Newmont engaged and worked closely with leading consultants, researchers and contractors in earth moving, plant demolition, tailings closure design, land rehabilitation, environmental monitoring and feral animal control to achieve the closure of Mt McClure.

Mining at Mt McClure commenced in 1991, and was then operated by four different companies before it came under the control of Newmont Australia.

Significant challenges for the closure project, included.
\begin{itemize}
  \item No closure and rehabilitation plan, and little waste characterisation data.
  \item Little progressive rehabilitation had been completed to the standards set by the site licence conditions and commitments.
  \item Existing rehabilitation works had generally failed or was inadequate.
  \item Lack of cash flow, necessitating the injection of significant capital.
  \item No feral animal management, leading to significant vegetation damage.
  \item Lack of an appropriate environmental monitoring regime.
  \item A processing plant that had degenerated to having no resale value.
  \item A general lack of competency in the earthmoving contracting sector with regard to rehabilitation earthworks, and a prevailing contractor attitude that rehabilitation works were not core business.
  \item No process of verification of the works carried out, to assure regulators and other stakeholders of the quality and consistency of performance.
\end{itemize}

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PRODUCTIVITY OF RECLAIMED SOIL AT THE RED HILLS LIGNITE MINE IN ACKERMAN, MS

David J. Lang, George Hawkey, and Benson Chow

Abstract: The Red Hills Lignite Mine (RHM) is located on the eastern edge of the Wilcox geological formation. The soils within the mine area are generally eroded with an average topsoil depth of 18 cm. In the absence of sufficient topsoil, mining regulations allow that appropriate subsoil or overburden can be used as a topsoil substitute if its soil fertility and vegetative productivity is demonstrated to be equal to or superior to existing soils. This study compared productivity of two native soils (Oaklimiter and Smithdale/Sweatman (SS)) with oxidized (OX) and unoxidized (UNOX) overburden. Oaklimiter is considered prime farmland (PR) by the NRCS and serves as the benchmark for comparison of productivity of potential substitute soils. The PR, SS, and SS soils were placed over oxidized overburden to a depth of 30 cm in 6 x 15 m plots replicated 3 times. UOX topsoil substitute was placed over 1.2 m of UOX overburden in similar plots. Soil pH was 5-5.5 for SS, PR, and OX; pH of UOX was 7.5. Wheat (*Triticum aestivum*) was planted in November 2002 followed by common bermudagrass (*Cynodon dactylon*). Fertilizer was applied to supply 76 kg N/ha for wheat production 67 to 76 kg N/ha after each harvest for bermudagrass production. Wheat grain yield was 1844 kg/ha growing in SS soil, 2333 kg/ha in OX substitute soil, 2301 kg/ha in PR soil, and 2778 kg/ha growing in UOX overburden. Yield of bermudagrass growing in UOX was 2656 kg/ha and was considerably less than bermudagrass growing in OX (6434 kg/ha), SS (6478 kg/ha) and PR (8192 kg/ha) in 2003. During 2004, bermudagrass yield was statistically similar for all soils and ranged from 11,480 to 12,768 kg/ha. The UOX soil substitute was not satisfactory as a potential soil substitute due to its low bermudagrass yield and its high soil pH would be unsuitable for loblolly pine (*Pinus taeda*) growth. The OX soil substitute was 79% as productive as PR soil in 2003 and 110% as productive in 2004. OX soil substitute exceeded the productivity of the native SS soil in terms of wheat grain yield in 2003 and bermudagrass production during both 2003 and 2004.

Additional Key Words: Topsoil substitute, overburden, strip mine

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INNOVATIVE TECHNOLOGY APPLICATIONS TO MINE RECLAMATION USING NEUTRALIZED RED MUD AND RECYCLED SOIL MANUFACTURING TECHNOLOGIES1

Charles R. Lee, Norman K. Murray, Phil N. Baldwin, Jr. and Michael D. Farrall2

Abstract: Red mud is the fine-grained residue remaining after the NaOH extraction of aluminum from bauxite using the Bayer process. For each 5 tons of bauxite refined approximately 3 tons of waste spent bauxite is also produced. This residual material possesses a naturally high pH of about 13. This red mud can be processed into a number of neutralizing products for use to solve environmental problems with acid or toxic metal contamination. Neutralite Technologies, Inc. (NTI) processes the red mud by neutralizing the pH from 13 to 8.6 using a propriety blend of reagents to produce NeutraTreat-NRM™ that has retained its pH buffering ability of 2.5 – 7.5 moles of acid/kg of NRM. Its trace metal trapping capacity is greater than 1,000 milliequivalents of metal/kg and it possesses a high capacity to trap and bind phosphates and arsenates. The qualities of NeutraTreat-NRM™ include exceptional ability to neutralize acidic water and soil and absorb toxic heavy metals, phosphates and arsenates. Uses of NeutraTreat-NRM™ include cleansing acidic heavy metal laden toxic mine water, permanent solution to treating acidic heavy metal laden mine tailings and waste rock, treating acid rock drainage (ARD) and acid mine drainage (AMD) mine sites, capping former mine sites, treating phosphate from phosphate mining activity, treatment of acidic soil, revegetation and erosion control as well as being a solution to countless other environmental problems. Recycled Soil Manufacturing Technology blends artificial topsoil from waste residuals such as dredged material, cellulose, biosolids and liming materials such as processed red mud and has been applied to a 35 acre abandoned acid coal mine site to form the Vintondale, PA AMD & ART recreation/education park.

Additional Key Words: Neutralizing Acid Soils, AMD treatment, AMD restoration

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PRELIMINARY STATUS REPORT ON MOLYCORP GOATHILL NORTH TRENCHES, QUESTA, NEW MEXICO


Abstract: Rarely do rock pile characterization methods allow for examination and sampling of the undisturbed interior of large rock piles in-situ. The regrading of the Goathill North (GHN) rock pile at the Molycorp Questa mine, New Mexico provided a unique opportunity to examine and sample the undisturbed, interior of a large rock pile through the construction of trenches cut into the rock pile as earth-moving progressed. Weekly during the regrading of the GHN rock pile, contractors excavated a trench to allow for sampling of rock pile material. Trenches typically had four benches, which were 1.5 m wide and did not exceed 1.2 m in height, to give an overall slope of 1.4 horizontal to 1.0 vertical within the trench. Each trench extended for a length sufficient to explore site conditions, maintain the regraded 2:1 slope, and ensure personnel safety.

Once excavated, trench walls and benches were surveyed using a differential global positioning system. For every trench, maps and logs of each bench were created to describe the different “mine soil” units, including the thickness, dip and extent of the units. Units were defined based on color, grain size, stratigraphic position, and other physical properties that could be determined in the field. Units were correlated between benches and to both sides of each trench, and several units were correlated downward through the series of successively excavated trenches.

The field sampling crew began sampling within each of the identified units after the unit boundaries were identified and mapped. The following in situ measurements were taken along either the horizontal or vertical surfaces of each exposed bench and along the base of the trench: sand cone (density), tensiometer (matric suction), gravimetric moisture content, grain size, infiltration, and nuclear gauge measurements (density, moisture content). Gravimetric water content samples were collected at the locations selected for the measurement of matric suction and infiltration tests. Samples were collected from each defined unit for geochemical, geotechnical (including shear box tests, slake durability tests), biological, and electron microprobe analyses. Channel sampling for pyrite reserve modeling was performed in short 1.5-m long horizontal slots using a rock hammer to chip material to be placed into a sample bag. Additional material from selected layers was collected for potential weathering-cell tests in the future. Typically, paste pH increases with distance from the outer, oxidized zone (west) towards the interior, unoxidized zone (east) of the GHN rock pile.

Additional Key Words: mineral weathering, acid drainage, characterization of rock piles, stability

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RATE OF MANGANESE REMOVAL IN LIMESTONE BED SYSTEMS¹

Brent Means and Arthur W. Rose²

Abstract: Manganese removal by limestone beds, as pioneered by Vail and colleagues ("Pyrolusite Systems") can be effective for passively removing Mn from acid mine drainage. This paper reports rates of removal and sizing concepts based on data from eight Mn removal beds.

A representative chemical reaction for Mn removal is

\[ \text{Mn}^{2+} + 0.5\text{O}_2 + \text{H}_2\text{O} = \text{MnO}_2 + 2\text{H}^+ \]  

(1)

Laboratory studies indicate that Mn removal is catalyzed by bacteria and by Mn oxide surfaces, and that at constant pH and oxygen saturation, the rate of Mn removal from solution can be expressed as

\[ \frac{d[\text{Mn}]}{dt} = k [\text{Mn}][\text{MnO}_2] \]  

(2)

where \([\text{Mn}]\) is the concentration of Mn, \([\text{MnO}_2]\) is the surface area of Mn oxide (including the effect of bacteria), \(k\) is a rate constant and \(t\) is time. Integration of the resulting simplified equation gives the relation

\[ \log \left( \frac{[\text{Mn}]}{[\text{Mn}_0]} \right) = -k_1 St/2.3 \]  

(3)

where \(\text{Mn}_0\) is the influent Mn concentration (time 0), \(S\) is the surface area of Mn precipitation and \(k_1\) is a rate constant including effects of bacteria and surfaces. Based on equation (1), the rate may also be proportional to \((\text{O}_2)^{0.5}\) and \((\text{H}^+)^{-2}\).

The Mn vs. retention time data for six of the field sites closely fit a rate constant \((k_1)\) of \(10^{-3.35}\) hr\(^{-1}\)(m\(^3\)/m\(^3\))\(^{-1}\) where \(S\) (m\(^3\)/m\(^3\)) is the surface area of limestone per cubic meter of bed. Retention time is estimated assuming 50% porosity. Two sites show faster Mn removal. An effect of pH may be present but is not large since the field data show that the limestone buffers pH to between 6.5 and 7.5. A dissolved O\(_2\) effect is undoubtedly present but cannot be resolved with the available data. The influent water should be well aerated and open to the atmosphere. Also, Fe and Al must be essentially lacking in the influent or the bed will plug with Fe or Al precipitate.

The following equation can be used to size beds for manganese removal:

\[ A(\text{m}^2) = -0.276Q \log \left( \frac{[\text{Mn}]}{[\text{Mn}_0]} \right) / (k_1SD) \]  

(4)

where \(A\) is the bed area, \(Q\) is the flow rate (L/min) and \(D\) is the depth (thickness, m) of the bed.

Additional Key Words: Acid mine drainage, passive treatment.

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USE OF PERFORMANCE STANDARDS AND ADAPTIVE MANAGEMENT TO GUIDE REMEDIATION AT THE BUNKER HILL SITE, IDAHO

D. L. Mengel and T. A. White

Abstract. Adaptive management follows a general model of study, prescribe, monitor, and refine management approaches. The original Record of Decision concerning remediation activities at the smelter-affected Bunker Hill site in northern Idaho contained little guidance on how to evaluate the success of remediation. Therefore, the Bunker Hill project team convened a series of three workshops in 1998 and 1999 to develop remediation guidance statements including goals, objectives, and performance standards. Project purpose and goals defined broadly based visions for the project. Objectives identified specific approaches to achieving the purpose and goals, assuming all work would be conducted under the umbrella of adaptive management. Performance standards were developed for each objective to measure its success. Owing to significant uncertainty regarding performance of site soils at varying levels of plant cover, performance standards were considered interim until monitoring could measure parameters of site performance. Site remediation activities are now essentially complete and monitoring has been ongoing since 1998. An interagency project team workshop was convened in 2004 to evaluate site performance and to validate or invalidate the ability of the interim performance standards (IPSs) to clearly reflect the project’s objectives. Based on the workshop and site performance, proposed final performance standards (FPSs) were developed at the workshop. This paper presents the evolution of the performance standards and how monitoring results were used to validate or modify those standards. The role and importance of goal setting and their evolution in remediation projects are presented in the context of actual project performance.

Additional Key Words: monitoring, smelter-affected soils, restoration goals, restoration objectives, remediation planning

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THE AFFECT OF TAILINGS CHARACTERISTICS ON MINE RECLAMATION AND CLOSURE

M. Milczarek, T.M. Yao, T.L. Thompson

Abstract: Mine tailing properties are so different from other types of mine waste that the reclamation design, criteria for reclamation success and post-closure monitoring require a very different approach from the standard methods used for waste rock and heap leach material. Research has shown that although tailings can be directly revegetated under some conditions, tailings alone are typically a poor growth media due to lack of structure, poor moisture retention characteristics, and lack of fertility and microbiota. Nonetheless, when cover material is used, unless the tailings are highly acidic, plant roots will propagate into the tailings and reduce deep percolation, effectively acting as an evapotranspirative cover. Evidence also suggests that limited oxygen ingress occurs into finer grained tailings and long-term acid generation may be limited to the near surface. These same high moisture retention characteristics can mean that tailings drainage will occur for centuries, depending on the size and construction methods of the impoundment. All of these factors require careful consideration during closure and reclamation design.

Tailings can generally be classified into three textural types corresponding to location within the impoundment: coarse- to fine-grained sands at the dams, sandy silts in perimeter mixed zones, and silt (slimes) in the decant area. The latter two types comprise the majority of tailings. Coarse- to fine-grained sands have poor moisture retention and limited plant available water holding capacity. Silts and sandy silts have high moisture retention but limited permeability, which can reduce infiltration and impede root penetration. Although a number of studies have shown that the addition of organic matter to tailings (such as biosolids and green waste) improves textural properties and fertility, the long-term effects of amendments may be limited. Moreover, for sandy tailings at the impoundment slope areas, limited water availability and high erosion rates make revegetation virtually impossible.

The addition of nominal (one foot or less) amounts of growth media significantly affects the revegetation of non-acid tailings. Primary root growth occurs in the growth media, but rooting extends at depth into the tailings in order to extract moisture during dry periods. Indeed, high moisture retention in the sandy silts and slimes can result in vigorous growth of deep-rooted trees and shrubs after reclamation. Even with thick covers where the roots do not extend into the tailings, the moisture retained in tailings can be wicked via evapotranspirative demand during dry periods.

Continued
The high moisture retention characteristics of most tailings also results in extremely long drainage periods. Model simulations of tailings drainage indicate that the bulk of the tailings solution drains from the dam and mixed zones within a relatively short period of time, but that extremely low rates of drainage occurs from the slimes area for a sustained period. Tailings consolidation due to overburden pressure will increase the rate of drainage, however, many impoundments larger than hundreds of acres may take decades for the majority of drainage to occur and centuries, to completely drain.

The implications of tailings characteristics for reclamation design are: 1) Non-acid tailings can be revegetated with nominal cover and/or amendments; 2) Revegetated tailings/cover systems can serve as highly efficient evapotranspirative covers; 3) Acid tailings can be covered, however, wicking of tailings solution into the cover may occur; 4) Long-term tailings drainage can take decades or more.

Long-term issues needing further study include the relationship between tailings consolidation and long-term drainage rates from tailings impoundments and the long-term effects of salinity on vegetation in both non-acid tailings and covered acid tailing.
OXIC LIMESTONE DRAINS FOR METAL MINE DRAINAGES\textsuperscript{1}

Andrew Miller\textsuperscript{2}, Linda Figueroa\textsuperscript{2}, and Judith L. Bolis\textsuperscript{2}

\textbf{Abstract:} Separation of neutralization function and toxic metal removal can significantly reduce overall size of passive treatment systems. Many acid-metal mine drainages are oxic and neutralization strategies must work with this fact. The use of oxic limestone drains for acidic water has challenges. Some designs have failed to meet design goals due to armoring, loss of hydraulic retention time, short-circuiting from solids dissolution and solids buildup. However, appropriate design, operation and maintenance features can overcome challenges. This paper will present an examination of how to improve design guidelines to minimize armoring, loss of hydraulic retention time, short-circuiting from solids dissolution and solids buildup. In addition, results of the successful neutralization and metals removal using bench-scale oxic dolomitic limestone will be presented.

Additional Key Words: design guidelines, passive treatment systems

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CHARACTERIZATION AND LEACH TEST ASSESSMENT AT THE TIP TOP MINE, A MARGINALLY IMPACTED SITE\textsuperscript{1}

Jessica Moehle\textsuperscript{2}, Stephanie Fox\textsuperscript{2}, James Ranville\textsuperscript{2}, Thomas Wildeman\textsuperscript{2}, and Philippe Ross\textsuperscript{3}

\textbf{Abstract:} The Tip Top Mine in Gamble Gulch, Colorado is a high mountain site where the stream above the mine is pristine and below the influx of acid rock drainage, the aquatic ecosystem appears to be impacted. An aquatic toxicity assessment study was carried out to determine the impact of contaminants on the stream and to test the leaching methods and simple toxicity tests that have been developed at the Colorado School of Mines. All tests show that the stream water above the adit inflow is pristine. However, the stream below shows concentrations of Al, Cu and Zn that are slightly above acute aquatic toxicity limits. Leaching tests on stream sediment samples taken below the adit entrance show concentrations of contaminants that are on the borderline of being toxic. Physical and chemical assessments of the mine waste piles on the site show that they are not impairing the immediate vicinity or the stream. It appears that the cause of any aquatic toxicity is the adit water entering the gulch or the heavy oxyhydroxide precipitates lining the streambed below the mine site.

\textbf{Additional Key Words:} metal contamination, mine wastes, contaminated soils and sediments, toxicity testing

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Abstract. Due to poor water quality in the initial backfill well constructed in 1981 at the Caballo Mine, the Wyoming Department of Environmental Quality, Land Quality Division required that the mine drill more backfill wells in the small area surrounding the initial well. The water quality results from these wells led to a number of landmark studies on backfill water quality and the behavior of selenium, nitrogen, and organic carbon in backfill waters. Although it was thought at the time that these water quality results would be typical for the Powder River Basin (PRB), the benefit of experience with other backfill wells in the PRB and a review of the history of the backfill surrounding these original backfill wells, indicates that the high total dissolved solids (TDS), selenium, and nitrogen concentrations observed in the early backfill area are not typical of backfill wells at Caballo. These high concentrations are a product of the backfill material used near the wells and their location. Selenium and nitrogen concentrations in the backfill waters are now very low in the initial backfill area. Moreover, the water quality in the initial backfill area and other resaturated or partially-resaturated backfill areas at Caballo is also similar to or better than premining water quality in the area surrounding these wells. Moderate amounts of selenium have been detected in more recently constructed wells at Caballo, but selenium concentrations have decreased to below the detection limit or are expected to rapidly decline as more saturated and reducing conditions develop.

Additional Key Words: Backfill, Alluvium, Geochemistry, Selenium, Nitrogen, Wetlands

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WEATHERING CHARACTERISTICS OF SALINE AND SODIC MINESOILS IN THE SOUTHWESTERN UNITED STATES

B.D. Musslewhite, T. H. Brown, G. W. Wendt, and C. Johnston

Abstract: Relationships between electrical conductivity (EC) and sodium adsorption ratio (SAR) in reconstructed soils at surface coal mining operations are poorly documented in the literature. Research has focused primarily on agricultural and range soils. Chemical and physical properties of reconstructed soils are unique and quite different from natural soils formed over hundreds of years through pedogenic processes. These differences largely occur because relatively unweathered overburden is exposed during mining processes and subsequently used as a lower root-zone medium (minesoil) during soil reconstruction. Some of these materials are classified as sodic and therefore are considered unsuitable rooting media for establishment of native vegetation. Weatherable minerals (i.e., pyrite, calcite, gypsum, and other geologic substrates) present in minesoils can effectively remediate or mitigate an elevated SAR condition by maintaining EC levels in the soil solution to promote clay particle stability and by providing sources of exchangeable calcium and magnesium. Coversoil (e.g., topsoil) enhances remediation through physical and chemical buffering between sodic root-zone material and the reconstructed soil surface. A laboratory core-study was used to evaluate weathering potential of 10 minesoil materials from three mining operations in the Southwestern United States. Cores were prepared with 15 cm of coversoil over 30 cm of minesoil and subjected to simulated precipitation. Chemical evaluations of weathered materials show significant reductions in EC and SAR and overall improvement of minesoil quality. Chemistry of drainage water from three coversoils shows these materials behave as a chemical buffer above the underlying sodic materials. Coversoils provide a source of calcium and other electrolytes that promote physical stability and enhance remediation of sodic minesoil materials.

Additional Key Words: Sodium adsorption ratio, salinity, minesoils, root-zone material, and weathering

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CURRENT AND PLANNED REMEDIATION DEMONSTRATION PROJECTS OF THE OKLAHOMA PLAN FOR TAR CREEK

R.W. Nairn, M.J. Calvey, and T.L. Landers

Abstract: The Tar Creek Superfund Site is a portion of the abandoned lead and zinc mining area known as the Tri-State Mining District (OK, KS and MO) and includes approximately 104 km² of disturbed land surface and contaminated water resources in northeastern Oklahoma. Underground mining from the 1890s through the 1960s degraded over 1000 surface ha, and left nearly 500 km of tunnels, 165 million tons of processed mine waste materials (chat), 300 ha of tailings impoundments and over 2600 shafts and boreholes. The site was listed on the National Priorities List (NPL) in 1983 and received a Hazard Ranking System score of 58.15. Initial remediation efforts in the 1980s focused on addressing surface and ground water quality. In 1993, an Indian Health Service study demonstrated that 35% of children had blood lead levels above thresholds dangerous to human health. Since 1995, the focus has been excavation and replacement of contaminated residential soils. In 2004, the University of Oklahoma (OU) and Oklahoma Department of Environmental Quality (ODEQ) began a series of related projects to demonstrate applicable technologies and establish a longer-term remediation and restoration process. The site was divided into five “perimeter” areas where initial projects would be focused and a single core area, based loosely on watershed and community boundaries. OU is leading projects on i) construction and evaluation of a passive treatment system to address contaminated mine drainage, ii) establishment and assessment of a test road section incorporating chat into asphalt pavement and iii) remediation and restoration monitoring in support of all projects, including collection of water quality, hydrology, air quality, soil ,chat, fine tailings and meteorological data. ODEQ projects include i) mine hazard attenuation (i.e., closing open shafts and boreholes), ii) chat utilization as fill and in pavement, iii) land reclamation to productive use and iv) stream restoration. Initial projects are anticipated to be completed in 3-5 years.

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Abstract. The Keating Tailings site is located in Broadwater County, Montana on land administered by the Bureau of Land Management. These low pH (4 standard units) wastes resulting from historic gold and copper mining operations contain phytotoxic levels of several metals and are generally devoid of vegetation. With an estimated volume of 110,100 m$^3$, these tailings represent unacceptable risk to the environment and human health. The objective of conducting a phytostabilization study at the Keating Tailings Site was to provide BLM managers and decision makers with site specific information and data relating to the implementation, and effectiveness of phytostabilization so that it may be applied to other similar acid metalliferous mine tailings sites administered by the Bureau. To achieve this management objective, replicated experimental plots were implemented using soil amendments, lime and organic matter, designed to ameliorate the plant inhibiting chemical characteristics of the tailings. The plots were seeded with a mix of indigenous native plant species. Vegetation performance of plants grown in the amended or phytostabilized tailings was compared to results for plants seeded into tailings that were not amended, and performance of plants seeded in an adjacent off-site, but non-impacted area. Response variables evaluated in the first growing season, 2004, included emergence and establishment, density, and canopy cover. Concentrations of metals in vegetation were evaluated in terms of plant sufficiency/excess, and in terms of maximum allowable dietary levels for cattle. Changes in soil rootzone pH, conductivity, and soluble metal concentrations before and after treatment were also determined.

Additional Key Words: phytoxicity, mine wastes, environmental risk, reclamation

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DEVELOPING ECOLOGICAL COMPLETION CRITERIA TO MEASURE THE SUCCESS OF FOREST AND WOODLAND ESTABLISHMENT ON REHABILITATED MINES IN AUSTRALIA

O.G. Nichols¹, C. Grant and L.C. Bell

Abstract. Over the last 20 years, mining companies throughout Australia have increasingly adopted an objective of establishing sustainable native ecosystems following mining. A significant area of risk associated with mine closure is the question of completion criteria for native ecosystem rehabilitation – what standards will regulators and the community accept as part of an overall mine closure plan, which if met, will result in lease relinquishment? Two examples from mines located in forest and woodland habitat in different parts of Australia illustrate how companies have adopted an innovative approach to the development of ecological completion criteria.

Alcoa World Alumina Australia mines bauxite in the jarrah forest of south-western Australia. Shallow mining (~4 m) occurs in isolated pods averaging 10 ha in size. The overall objective of rehabilitation is ‘to restore a self-sustaining jarrah forest ecosystem, planned to enhance or maintain water, timber, recreation and conservation values’. Completion criteria were developed after extensive liaison with stakeholders. The criteria are assessed at five different stages, ranging from planning (prior to mining) to late (10-15 years). More than 25 years of research data enabled Alcoa to set criteria that include a range of biodiversity and ecosystem function measures.

Wesfarmers Curragh Mine in central Queensland is located in a woodland environment. The open-cut coal mine produces large spoil areas that are reshaped and planted to an open woodland/grassland community. A recent study recommended completion criteria which state (in part) that ‘The objective of rehabilitation following mining at Curragh is to establish a stable, self-sustaining native ecosystem that fulfils designated land uses including protection of water resources and nature conservation, and which…is similar in composition and function to that occurring in representative unmined reference sites’. Compared to those of Alcoa, the Curragh criteria reflect differences in the pre-mining environment, climate, and the mining operation.

This paper describes the similar approach used to develop completion criteria at the two mines, and illustrates how the issue is being addressed in Australia.

Additional Key Words: succession, reference site, rehabilitation monitoring.

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ACID ROCK DRAINAGE PREVENTION AND TREATMENT WITH THIOCYANATE AND PHOSPHATE-CONTAINING MATERIALS

G.J. Olson², T.R. Clark and T.I. Mudder

Abstract. Stopping the weathering of sulfide minerals causing acid rock drainage (ARD) involves control of both biological and chemical oxidation processes. We are developing a technology for ARD prevention and control that combines thiocyanate and phosphate treatments of sulfidic materials. The technology extends to overburden, tailings, waste rock, and spent heap leach ore. Thiocyanate at low concentrations is a strong and selective inhibitor of microbial iron oxidation. This curtails severe ARD that lessens the effectiveness of phosphate in precipitating Fe and Al phosphates. Combined phosphate and thiocyanate treatment has been tested on sulfidic waste materials at kg scale in laboratory humidity cell and column leach tests and at 600 ton scale in field trials. Sources of phosphate tested include phosphate rock, commercial agricultural phosphates such as dicalcium phosphate, and waste material from phosphate beneficiation. Thiocyanate treatment of waste rock reduced ARD 50% or more compared to untreated material. Low dosages of phosphate materials combined with thiocyanate treatment reduced ARD beyond that achieved with thiocyanate alone. This treatment, especially if combined with an effective waste and water management strategy, offers a promising approach to source control of ARD in both newly and previously mined waste materials.

Additional Key Words: biooxidation, sulfide oxidation, source control of ARD

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PROPERTIES AND CLASSIFICATION OF MINERAL SANDS MINE SOILS IN SOUTHEASTERN VIRGINIA

Z.W. Orndorff, W.L. Daniels, and J.M. Galbraith

Abstract. Significant areas of prime farmland in the upper Coastal Plain of Virginia have been disturbed by heavy mineral sands (Ti/Zr-bearing ilmenite, rutile, zircon) mining over the past 7 years. Previous work has shown that separation of sandy particles (tailings) from finer particles (slimes) in dewatering pits leads to significant lateral variability in the soils. The objectives of this study were 1) to characterize the chemical, morphological and physical properties of these mine soils and 2) to classify these soils. Thirteen soil profiles, ranging in age from 2 to 6 years, were described and sampled to 2 m. Samples were analyzed for particle size distribution, pH, exchangeable bases, exchangeable acidity, extractable Al, and organic matter (OM). The plow layers, which in most cases included topsoil, fertilizer, lime, and biosolids additions during reclamation, ranged from 10 to 24 cm in depth. These horizons were typically loamy sands and sandy loams with OM ranging from 0.2 to 1.5% and pH ranging from 5.6 to 8.0. Subsurface horizons were typically sands, loamy sands, sandy loams, sandy clay loams, and clays with lower pH, (< 5.5) low OM (< 0.5%), and low plant-available nutrients. Some profiles were relatively consistent in the subsurface, or changed only gradually with depth. Others contained adjacent dissimilar layers with abrupt horizons in between, such as alternating sands and clays. Several profiles contained dissimilar materials within a horizon, expressed as banded materials or as clayey fragments within a sandy matrix. Many profiles exhibited overturned stratification that we refer to as “convoluted banding” and may prove to be a diagnostic feature of some mineral sand mine soils. Heavy compaction was indicated in most profiles by the presence of densic layers in both loamy and clayey materials. The thirteen profiles were classified according to Soil Taxonomy into 4 subgroups, including one Fluventic Dystrudept, two Typic Udifluvents, three Typic Quartzipsamments, and seven Typic Udorthents.

Additional Key Words: Densic horizon, slimes, soil profiles, reclamation, titanium, tailings

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SHRUB BASE UNIT PRODUCTION SAMPLING TECHNIQUE

Matt Owens, Bruce Buchanan, Brent Musslewhite, and Tim Ramsey

Abstract: Production sampling of large shrubs can be a time consuming activity. The time spent sampling production can be decreased, by utilizing a base unit sampling method technique. This method estimates the shrub production based on a daily base unit. Prior to sampling, base units of individual shrub species are clipped and carried throughout the days sampling. Shrub production is estimated by approximating how many individual species base units are present within each production sampling plot. Throughout the day various base unit estimations are clipped to establish a linear regression to assign values for the remaining production values. A trial of this technique on 196 production sampling plots indicated this method is a viable method to estimate shrub production.

Additional Key Words: Revegetation, shrub production, and sampling techniques

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RESULTS OF INTERSEEDING ON EXISTING SHRUB POPULATIONS, LA PLATA MINE, NEW MEXICO

Matt Owens, Bruce Buchanan, Tim Ramsey, and Brent Musslewhite

Abstract: Interseeding of perennial grasses and shrubs was conducted to re-establish a sustaining vegetative cover on a reclaimed stockpile located on the La Plata Mine in northern New Mexico. Periods of low precipitation had led to marginal revegetation results on the McDermott Dump Stockpile. Shrub establishment had occurred on portions of the stockpile; however the herbaceous layer had not established a sustainable community. Rather than reseed the entire area, and destroy the established shrub community, it was determined to interseed additional herbaceous species. This was accomplished by entering the seeded areas applying additional seed. The seed was applied using standard revegetation practices. Concerns regarding the additional traffic in these areas affecting the regeneration of the established shrubs proved to be unwarranted. Shrub establishment both prior to interseeding and after interseeding indicated the interseeding provided no ill effects to the regeneration of the existing shrub population.

Additional Key Words: Revegetation, seeding techniques

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ASSESSING VISUAL PREFERENCE FOR AGGREGATE PIT REHABILITATION DESIGNS USING COMPUTER ANIMATED LANDSCAPE MODELS

Eli Paddle  
George Antoniuk  
Robert Corry

Abstract. The most common concern expressed by the public regarding aggregate mining is the negative aesthetic impact the activity has upon the scenic quality of the landscape. It is important that rehabilitation efforts restore scenic quality as well as function to the post-mining landscape. To this end the Management of Abandoned Aggregate Properties (MAAP) Program rehabilitates ten to twenty-fives sites in Ontario annually, based upon the criteria of safety, aesthetic, ecological and economic concerns. This study assesses the public’s visual preference for different aggregate property naturalization designs. To investigate this relationship, computer-modeled rehabilitation designs of an aggregate property were developed using landscape modeling software to simulate three-dimensional development over a fifteen year time period. Respondent groups evaluated how natural, rehabilitated, attractive they perceived the simulations to be and assigned a rank order to the eight design strategies from best to worst. Design alternatives are shown to improve the perception of aggregate rehabilitation efforts over the current methods being commonly employed by MAAP.

Additional Key words: gravel pit, reclamation, visual simulation.

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HIGH ALTITUDE REVEGETATION EXPERIMENTS ON THE
BEARTOOTH PLATEAU PARK COUNTY, MONTANA AND PARK
COUNTY, WYOMING

Liz Payson, Richard Trenholme, and Jennifer Corwin

Abstract. ERO Resources Corporation (ERO) is conducting revegetation tests on the Beartooth Plateau to assist Federal Highway Administration (FHWA) in identifying techniques that maximize opportunities for successful revegetation along high altitude portions of U.S. Highway 212, the Beartooth Highway. A portion of the Beartooth Highway that travels through alpine and subalpine areas is proposed for reconstruction by FHWA. ERO and FHWA have conducted revegetation experiments since 1999 to identify the most successful revegetation techniques for revegetating alpine areas. This paper presents the findings of the fourth year of annual monitoring of one of the revegetation experiments.

In September 1999, ERO placed revegetation tests plots in an existing gravel borrow area along the Beartooth Highway. The variables tested were soil salvaging, seeding rates, soil amendments, and reapplication of Kiwi Power™ or inorganic fertilizer. Native seed was collected on Beartooth Plateau and used for direct seeding of the revegetation test plots.

Results from this study will assist mining, oil and gas, and utility companies, highway departments, and other land management agencies in revegetating high altitude disturbances to meet requirements of various state, local, and federal permits. The 2003 monitoring indicated that of all the variables tested, topsoil placement appeared to have the most beneficial effect on vegetation cover. Fertilizer reapplication, seeding rate, and organic material application did not have statistically significant effects on vegetation cover.

Additional Key Words: alpine revegetation, native plant restoration, highway revegetation, soil amendments, seeding rates, topsoil.

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COMPARISON OF INOCULA APPLIED IN THE REMEDIATION OF ACID MINE DRAINAGE BY SULFATE REDUCTION

L.P. Pereyra, R. Hanson, S. Hiibel, A. Pruden and K.F. Reardon

Abstract: Sulfate-reducing permeable reactive zones (PRZs), such as anaerobic wetlands, sulfate-reducing bioreactors, and permeable reactive barriers, are an attractive means of passively treating mining influenced waters contaminated with heavy metals. While the low cost and maintenance requirements are significant advantages of PRZs, the lack of clear design criteria is a disadvantage. It is not known why some systems will function for long periods of time without need for intervention, while others fail or do not recover well when exposed to stresses such as winter weather or other changes in conditions. This study explores the role of microorganisms in PRZs and the potential to use selected inocula to improve performance with respect to start-up time, sulfate-reducing activity level, and activity retention time. We have compared these attributes using various inocula, including: dairy manure, anaerobic digester sludge, acclimated column inoculum, and inoculum collected from two sulfate-reducing bioreactors operated in the field (Luttrell and Peerless Jenny King). Our results demonstrate that there are clear differences between the inocula and that the Luttrell bioreactor inoculum performs the best in terms of start-up time and overall activity. Sulfate concentrations, metal concentrations, and pH were measured in the aqueous phase to evaluate the ability of the different inocula to remediate acid mine drainage (AMD). In subsequent studies, DNA-based methods that profile the microbial community will be used to determine what kinds of microorganisms are present and to quantify key functional groups, including sulfate reducers, methanogens, and cellulose degraders. The ultimate goal will be to transfer these results to the field by developing the capability to intelligently design inocula for site-specific concerns.

Additional Key Words: microbiology, acid mine drainage, sulfate-reduction, permeable reactive zones, bioremediation


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WATER QUALITY TRENDS IN A FLOODED 35 YEAR OLD MINE-POOL

Eric F. Perry, Jay W. Hawkins, Mike Dunn, Robert S. Evans, and John K. Felbinger

Abstract: Thirty five years of water quality data from a pumped, mostly flooded, mine-pool were examined for trends in mine drainage parameters. At the start of pumping in 1970, the Lancashire 15 mine-pool discharged acidic water with average iron (Fe) concentration exceeding 900 mg/L. Average sulfate (SO₄) concentration was about 3700 mg/L. After 14 years of pumping about 21 mine-pool volumes, Fe and SO₄ were about 20% of their initial concentrations. Alkalinity had increased from less than 50 to about 120 mg/L, and pH was about 6.0. In 1986, an overlying mine complex closed and flooded. Its’ waters have low concentrations of Fe and SO₄, and are hydraulically connected to the Lancashire 15 mine-pool. The combined mine-pool waters reduced Fe by about 50% in Lancashire 15. Since 1986, Fe and SO₄ concentrations have continued a slow, irregular decline at the rate of 1 to 2 mg/L/yr for Fe and about 10 to 15 mg/L/yr for SO₄. Short term fluctuations due to seasonal and pump rate variations occur, but long term concentration trends can be described with curvilinear models.

The Lancashire 15 discharge is sodium-sulfate (Na-SO₄) type water. Geochemical calculations show that cation exchange of calcium (Ca) for Na is a feasible explanation for the observed water composition. Mixing calculations show that mine-pool composition can be explained by cation exchange; continuing dissolution of iron and sulfur bearing minerals, iron oxyhydroxide formation and about 80% of recharge as leakage from adjacent and overlying mines, and 20% recharge from unmined strata.

The Lancashire 15 mine-pool quality has improved significantly since closure and flooding. After leaching an estimated 55 pool volumes, Fe concentrations are about 5% of original values, and the waters are net alkaline. Continued mineral dissolution, and inefficient leaching due to dispersion and short circuiting, are likely responsible for current water quality conditions.

Additional Key Words: acid mine drainage, mineral solubility, pyrite, Eh

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Abstract. Microorganisms within passive reactive zones (e.g. wetlands, SR bioreactors, PRB’s, etc.) utilize organic substrates, such as wood, in the process of reducing sulfate and immobilizing the metals from mine drainage. The rate and extent of substrate utilization controls the performance and longevity of the passive treatment system. This paper evaluates alterations in substrate composition for four reactive mixtures, over time. The alterations are determined using a method adapted from a sequential extraction technique used to determine carbohydrate and lignin composition in agricultural products. Tracking substrate alterations in this way can be used as a tool for substrate selection as well as evaluation of substrate performance over time. The data collected by tracking organic substrate alterations from pre-operational to post-operational conditions for the four bioreactors can be tied with performance data to better understand the function of the bioreactors. Analysis of the data shows that using total carbon to predict the longevity of passive treatment systems is not enough because the carbon must be in a form that is bioavailable to the microbial community. Analysis also shows that using cellulose to lignin ratios may be useful in the substrate selection process. Tracking substrate alterations over time also allow for the estimation and prediction of substrate utilization that can be correlated with sulfate reduction rates. Applicability of tracking substrate alterations over time is not limited to lab scale bioreactors. It can be used to analyze both spatial and temporal samples for within any passive treatment system to provide valuable insight for the planning and monitoring of passive reactive treatment zones. It can show if the proposed reactive mixture contains carbon in the forms that can be used by the microorganisms. It can also show why a system may be reducing sulfate at a lower than expected rate. Finally, it can help manage the sustainability of the passive treatment system by showing when and if the reactive mixture needs to be refreshed.

Additional Key Words: reactive mixture, sulfate reducing bacteria, substrate utilization
MICROBIAL CHARACTERIZATION OF SULFATE-REDUCING COLUMNS REMEDIATING ACID MINE DRAINAGE

Amy Pruden, HyunSuk Hong, Laura Y. Inman, Miranda V. Logan, Carmen Sans, Dianne Ahmann, Linda A. Figueroa, and Kenneth F. Reardon

Abstract. Sulfate-reducing permeable reactive zones (PRZs) are a promising approach for passively remediating mine drainage. PRZs may be applied effectively in the field in anaerobic wetlands, sulfate-reducing bioreactors, or permeable reactive barriers. However, maintenance difficulties, such as variation of sulfate-reducing activity, are not well understood. To solve these problems, a better understanding of microbial communities in PRZs is essential. DNA based techniques provide a powerful means of characterizing microbial composition of PRZs. In this study, we developed a suite of methods specific to PRZ communities and analyzed samples from columns simulating PRZs that were operated at the Colorado School of Mines. Our objective was to determine the differences in microbial community structure between highly active columns, columns with reduced activity, inactive columns, and columns operated for over one year. Denaturing gel gradient electrophoresis (DGGE) and single stranded conformation polymorphism (SSCP) were performed to compare the microbial community structures of the columns with different activity levels and operation times. Sequencing results from DGGE and SSCP suggested that gram positive microorganisms belonging to the Clostridium group were dominant in all columns. This group includes cellulose degraders, fermenters, and sulfate reducers: all critical to PRZ function. In order to target sulfate-reducing groups directly, quantitative real-time PCR (Q-PCR) methods were developed for three genera: Desulfobacterium, Desulfotomaculum, and Desulfovibrio. Quantification of all three groups demonstrated that a decline in sulfate-reducing activity does not necessarily indicate a decline in SRB populations, suggesting that previous steps in the PRZ functional pathway would be wiser targets for improving performance. The methods developed in this study will be useful as diagnostic tools for PRZs in the field and may assist in developing optimized PRZ inocula.

Additional Key Words: microbiology, acid mine drainage, sulfate reduction, permeable reactive zones, passive treatment


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Abstract: No attempt has ever been made to track the long term progress of reforested mine sites in Indiana following reclamation bond release. The purpose of this survey was to determine how well reforested mine sites in Indiana were performing in terms of values and services normally ascribed to native forest and what their future potential might be. Black locust (*Robinia pseudoacacia*) was the most abundant species on 68% of the surveyed sites and accounted for 45% of all tallied trees and shrubs across all sites. Many black locust stands are currently experiencing decline and dieback caused, in part, by the locust borer. Forty percent of stands approached unmined planted tree height growth rates, while only 27% approached stem diameter growth rates of stands on unmined sites. Most reclaimed mine sites had measured site quality indices below the poorer quality sites in the region’s native forests. Overall stocking in the establishment phase of stand development appeared adequate for future commercial timber production on many of the study sites. However, the dominance of black locust stocking in many stands limits their future viability for timber production. Tall fescue and sericia lespedeza along with naturally occurring goldenrod were the most common ground covers in surveyed tree plantings. With few exceptions the reclaimed mine sites in this study show very low levels of productivity for forest products and carbon sequestration relative to native forests of this region, even though stocking levels appeared to be adequate. This suggests that the current bond performance measurement of 450 trees/acre bears little relevance to long term forest productivity. The results of this survey should serve as a baseline to determine the extent to which recent and future changes in reclamation methods improve reforestation success while meeting the other mandates of Indiana’s mining regulatory program.

Additional Key Words: reforestation, forestry, tree stocking, forest productivity, tree growth, carbon sequestration

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LONG-TERM PLANT COMMUNITY DEVELOPMENT ON TOPSOIL TREATMENTS OVERLYING A PHYTOTOXIC GROWTH MEDIUM

E. F. Redente and R. S. Sydnor

Abstract. The application of topsoil over phytotoxic mine waste materials is often the most effective method of establishing and maintaining plant communities during reclamation. However, long-term data on the effectiveness of topsoil cover treatments, as well as on treatments used to enhance vegetation establishment on soil covers, are lacking. Therefore, we evaluated long-term plant community development on study plots in which 60 cm of retorted oil shale was covered by various depths of topsoil. Each plot was drill seeded with one of three seed mixtures (native, introduced, and combination of native and introduced species), and fertilized with one of three rates of nitrogen (N) and phosphorus (P) following plot construction in 1977. Data collected in 1997 showed that native species were as productive as introduced species on deeper topsoil depths and on the control. Also, relative plant species composition and plant species richness continued to be greatly influenced by seed mixture treatments. Seeded plots for all three seed mixtures were dominated by a subset of the species originally seeded, and native seed mixture plots were more species rich than introduced seed mixture plots. Finally, the one-time application of N and P was no longer influencing aboveground biomass.

Additional Key Words: seed mixtures, fertilization, soil depth, succession, native species, introduced species, species diversity.

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ABANDONED MINE SAFETY REMEDIATION: CLOSING THE HOLES IN NEVADA

Christopher Ross, PhD.

Abstract: Nevada has an estimated 300,000 abandoned mine land (AML) features, of which about 50,000 represent significant risks to public safety. Almost every year there are injuries or deaths related to AML sites, from causes ranging from falls and collapses to drownings, asphyxiations, and motor vehicle accidents. The BLM Nevada State Director has established a goal of securing or eliminating such hazards near population and recreation centers, and other areas of high public use. A GIS project was developed to locate, analyze, and prioritize hazards. A programmatic Environmental Assessment was developed to expedite NEPA compliance.

Extensive clearances for land and mining claim status, bats and other wildlife, protected plants, and cultural resources are required prior to backfilling. Spreadsheets track clearances and resources. The State of Nevada AML program includes inventory and fencing by Nevada Division of Minerals staff, summer interns and volunteers from prospecting organizations and Eagle Scouts, as well as public education (Stay Out and Stay Alive), all of which are integral to the remediation process.

An innovative cooperative effort to do clearances and actual dirtwork for permanent closures includes representatives from the Nevada Division of Minerals, the Nevada Mining Association, the Nevada Natural Heritage Program, Nevada Department of Wildlife, Bat Conservation International, heavy equipment dealers, individual active mines, trucking companies, and others. This team works closely with a minimum of formality to rapidly clear and close dangerous sites. Over 80 backfills were done last year. Options for temporary and permanent mitigation, including gating, will be discussed. Obstacles and the means to overcome them will be presented, with specific lessons learned. Emerging future hazard issues related to pit lakes will be brought forward. Additional Key Words: Safety, hazard, backfill, NEPA, wildlife

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A STUDY OF ZINC METAL TOXICITY ON THE CELLULOLYTIC BACTERIA IN ANAEROBIC PASSIVE TREATMENT SYSTEMS

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\textbf{Abstract.} The effective use of anaerobic passive treatment systems (APTS), such as sulfate-reducing bioreactors, to treat acid mine drainage will help to mitigate water contamination from mines located in remote areas as well as cut current treatment costs. One draw back to these systems has been the inhibition of sulfate reduction with high concentrations of metals. APTS contain a complex microbial ecosystem, and metal toxicity could be indirectly affecting sulfate-reduction by inhibiting other important microbes. If microbes such as the cellulolytic - fermenting bacteria are inhibited from producing viable substrate for the sulfate-reducing bacteria, then the rate of sulfate reduction over time in APTS will ultimately decline.

We examined the toxic effect of zinc, a common metal found in acid mine drainage, on a pure culture of \textit{Cellulomonas flavigena}, a cellulolytic - fermenting bacteria. Serum bottles containing \textit{C. flavigena}, at two protein concentrations of 250 and 500 mg/L, were exposed to initial zinc concentrations of 0, 20, and 40 mg/L and monitored over a 9 hour period. The extent of inhibition on \textit{C. flavigena} activity correlated best ($r^2=0.93$) with the mass ratio of zinc uptake to cell protein. Final zinc concentrations ranged from 0.9 to 2.2 mg/L. Zinc uptake was operationally defined as the total zinc removed from solution and includes sorption and internalization. Initial and final dissolved zinc concentration did not correlate well with extent of inhibition. In the presence of higher biomass the relative rate of glucose utilization was 20 to 50\% higher in the presence of zinc than at lower biomass concentration. The concurrent internalization of metals with sorption and precipitation processes can produce inhibition in the presence of low metal concentration. Thus low effluent metal concentration may not be indicative of the extent of inhibition experienced by the microbes. The inhibitory effect of metals on cellulolytic - fermenting bacteria is an important aspect to consider when establishing the limitations of sulfate reducing biozones.

\textbf{Additional Key Words:} water treatment, sulfate reducing bioreactor

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USING AIRBORNE GEOPHYSICS TO IMPROVE THE MANAGEMENT OF PRODUCED WATER FROM COAL BED NATURAL GAS EXTRACTION IN THE POWDER RIVER BASIN

James Sams, Brian Lipinski, Richard Hammack, Garret Veloski, Terry Ackman and Bill Harbert

The Powder River Basin (PRB) of Wyoming and Montana has seen a boom in drilling for coalbed natural gas (CBNG), the natural gas contained in coal seams. Large quantities of water are coproduced during the extraction process. The water is currently managed by land application (irrigation), returned to shallow groundwater aquifers via infiltration basins, directly discharged to ephemeral or perennial streams, or injected into the deep subsurface via injection wells. At present, there are over 28,000 CBNG wells permitted or drilled in the PRB and it is estimated that another 50,000 to 100,000 new wells will be drilled in the future. Produced water management is a major challenge to the oil and gas industry as well as federal and state regulators.

The purpose of this study was to evaluate the use of airborne electromagnetic (AEM) methods for the large-scale mapping of vadose zone properties. The base maps derived from the AEM data show the location of conductive anomalies within the vadose zone. These conductive anomalies have been identified as conditions related to soil properties, geologic features, saturated areas, and seepage zones. In the PRB, the data can be used to identify suitable locations for constructing impoundments in areas that avoid highly conductive soils where infiltrating water may leach salts through the vadose zone and into shallow aquifers. Hydrologic changes within the vadose zone were evaluated by completing an AEM survey in 2003 and 2004 over two coincident spatial areas. The data were analyzed to determine statistical relationships between the data sets, in particular data outliers which may represent areas of significant change between each year. The outliers plot in areas of CBNG development. These areas may have been altered between 2003 and 2004 through land disturbance or the construction of water management systems such as impoundments. Ultimately, it is hoped that the information from these surveys will identify cost effective treatment or disposal options for produced water that address both production and environmental issues.

Additional Key Words: electromagnetic conductivity, vadose zone mapping, conductive anomalies, leaking impoundments

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2Jim Sams, Hydrologist/GIS Analyst, 3Brian Lipinski, Hydrologist, 4Richard Hammack, Geochemist, 5Garret Veloski, Chemist and 6Terry Ackman, Mining Engineer, U. S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA 15236. 7Bill Harbert, Chair, Department of Geology and Planetary Sciences, University of Pittsburgh, Pittsburgh, PA.
ONGOING EVALUATION OF EFFECTS FROM VARIABLE TOPSOIL DEPTHS AT A COAL MINE IN NORTHEASTERN WYOMING\textsuperscript{1}

Brenda K. Schladweiler, George F. Vance, David L. Legg, and Scott Belden\textsuperscript{2}

**Abstract.** After passage of the Surface Coal Mine Reclamation Act in 1977, studies on mine reclaimed areas in the late 1970’s and early 1980’s evaluated varying topsoil depths over unsuitable backfill on vegetation productivity and cover. In recent years, several of those earlier studies have been revisited to provide long-term results on vegetation productivity, cover and diversity. A more recent study developed in 1999 was conducted to evaluate variable topsoil depth on soil and vegetation factors at the North Antelope/Rochelle Mine (NARM). Backfill at this location did not exhibit unsuitable plant growth parameters, based on Wyoming Department of Environmental Quality (WDEQ) guidelines. The formal study evaluated vegetation parameters such as cover, production and diversity, and soil differences in pH, electrical conductivity (EC), and sodium adsorption ratio (SAR) between three treatment depths, i.e., 15, 30 and 56 cm. Reclaimed and two native vegetation reference areas were sampled three times during the 2000-2002 growing seasons. At the end of the 2002 monitoring, results were mixed. After that time, the reclaimed area only continued to be part of the ongoing vegetation monitoring program at NARM. Five years of continuous monitoring (2000-2004) were statistically analyzed to determine significant trends between topsoil depth treatments, as the seeded areas matured. No significant differences were found between treatments for two measures of cover and three measures of species richness. Although no significant differences were found between treatments for shrub density, positive increasing trends in the more shallow treatments are evident.

Additional Key Words: vegetation cover, shrub density, plant diversity, topsoil treatment depth.

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THERMAL CAMERA IMAGING OF ROCK PILES AT THE QUESTA MOLYBDENUM MINE, QUESTA, NEW MEXICO

Heather R. Shannon, John M. Sigda, Remke L. Van Dam, Jan M. H. Hendrickx, and Virginia T. McLemore

Abstract. Between 1969 and 1981 open pit methods were used to recover the molybdenum ore producing some 317.5 million metric tons of mined rock from the Questa molybdenum mine, which went into nine rock piles. The mine is located in the Sangre de Cristo Mountains of Taos County in northern New Mexico. As part of a multi-disciplinary study to determine the effects of weathering on the long-term stability of the rock piles, we are searching for areas where weathering is occurring within the rock piles. Pyrite oxidation is a weathering process that typically generates large amounts of heat, making it a good candidate for detection by infrared thermography. We conducted surveys of surface temperatures on two rock piles during February and May 2004 using the FLIR SC 3000 infrared thermal camera.

Thermal imaging of the rock piles revealed at one rock pile, a “heat vent” of roughly 40 m by 30 m that had the same maximum temperature of 18°C during February and May 2004. The maximum temperature of this heat vent was much larger than the ambient temperature in February (0-2°C) and May (4-6°C). During the February survey, the heat vent had little or no snow cover and appeared to be very wet, whereas the area surrounding the heat vent was snow-covered and frozen at the same time. The heat vent is likely the result of pyrite oxidation within the rock pile. Thermal imaging results from a second rock pile indicate that it is less likely to have a heat vent because the differences between the ambient and maximum surface temperature were much less significant. The small temperature difference could be explained by spatial variations in emissivity from local variations in rock thermal properties or moisture content or by a relatively small heat flux out of the rock pile.


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INFLUENCE OF PHYSICAL, CHEMICAL, AND BIOLOGICAL MINE SOIL PROPERTIES ON WHITE OAK SEEDLING GROWTH

J. M. Showalter, J. A. Burger, C. E. Zipper, and J. M. Galbraith

Abstract. Landowners in the Appalachian region are becoming increasingly interested in restoring the native hardwood forest on mined land after reclamation. Trees are usually planted in topsoil substitutes consisting of blasted rock strata from the geologic profile. Reforestation attempts using native hardwoods have often been unsuccessful due to the highly variable nature of the physical, chemical, and biological properties of mine spoils. The purpose of this study was to determine which mine soil properties most influence white oak seedling growth, and to test whether or not these properties are adequately reflected in a preliminary mine soil classification model. Seventy-two 3-yr-old white oak trees were randomly selected across a reclaimed site in southwestern Virginia that varied greatly in spoil type and site properties. Tree height was measured and soil samples were taken to a 40 cm depth at the base of each tree and analyzed for physical, chemical, and biological properties hypothesized to influence tree growth. Tree height and biomass, which ranged from 15 to 125 cm, and 0.24 to 190.03 g, respectively, were regressed against mine soil and site properties. Potassium, size of microbial populations, extractable nitrogen, pH, soil texture, aspect, and phosphorous accounted for over 52% of the variability in tree growth. This study indicates that white oaks are most successful growing on east-facing aspects, in slightly-acidic, sandy loam textured, fertile mine soils that are conducive to soil microbial activity. These results suggest that sandstone rock types with suitable chemical properties should be selected for topsoil rock types when native hardwood restoration is the desired post-mining land use.

Additional Key words: Site index, microbial biomass, native hardwoods

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INFLUENCE OF RECLAMATION MANAGEMENT PRACTICES ON SOIL BULK DENSITY AND INFILTRATION RATES ON SURFACE COAL MINE LANDS IN WYOMING

Gyami Shrestha, Peter. D. Stahl and Lachlan Ingram

Abstract. A study was conducted to examine the impacts of land reclamation and management practices on the saturated infiltration rates ($K_s$) and bulk densities (BD) of soils in reclaimed surface coal mines of Wyoming. The use of direct-hauled topsoil vs. stockpiled topsoil, hay mulch vs. stubble mulch, grazing vs. no-grazing, and standard seed mixes (grass seeding) vs. shrub mosaic seed mixes as surface coal mineland reclamation practices were studied in five coal mines of the Powder River Basin, the Green River Coal Region and the Hanna Coal Field in Wyoming. Results from the reclaimed sites with the above listed management practices were compared to each other and with representative soils from adjacent native undisturbed sites. In all the study sites, native undisturbed soils had the lowest BD and the highest $K_s$ compared to reclaimed soils. At Jim Bridger mine, results indicated no differences in BD and $K_s$ between stockpiled and directly hauled soils. At the Belle Ayre mine, there was no significant difference in $K_s$ between reclaimed soils and native undisturbed soil. At Seminioe mine, reclaimed stubble mulched soil had greater $K_s$ (9.208 mm/min) than native undisturbed soil $K_s$ (6.042 mm/min). At Jacob’s Ranch, ungrazed soils had greater $K_s$ (6.958 mm/min) than grazed soils $K_s$ (3.350 mm/min) and native undisturbed soils (3.833 mm/min). BD at 0-5 cm for grazed soils was also greater (1.462 g/cm$^3$) than for ungrazed soils (1.255 g/cm$^3$). Native undisturbed soils had the lowest BD (1.116 g/cm$^3$) averaged over all depths. Although native undisturbed BDs were generally lower, their $K_s$ were not always greater. These results suggest that removal and manipulation of soil during mining accompanied by heavy machinery traffic over reapplied topsoil during reclamation may cause some degree of soil compaction relative to undisturbed sites. However, it can be concluded that land reclamation and management measures taken during and after mining may help to improve infiltration rates.

Additional Key Words: mine land reclamation, compaction, saturated infiltration

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DEMONSTRATION OF A PULSED LIMESTONE BED PROCESS FOR THE TREATMENT OF ACID MINE DRAINAGE AT THE ARGO TUNNEL SITE, IDAHO SPRINGS, COLORADO1

P. L. Sibrell2, T. R. Wildeman, M. Frienmuth, M. Chambers and D. Bless

Abstract: Pulsed limestone bed treatment is a new technology for the processing of acid mine drainage that utilizes limestone in fluidized bed reactors for an economical method of neutralizing acidity, adding alkalinity, and removing metal contaminants from mining impacted waters. The technology was developed by the U.S. Geological Survey, at the Leetown Science Center in Kearneysville, West Virginia. Previous demonstrations of this technology have taken place at coal mining sites in the Appalachian region. In this demonstration project, funded by the Mine Waste Technology Program of EPA, the Pulsed Limestone Bed (PLB) technology is being demonstrated at the Argo Tunnel Water Treatment Facility, which currently treats metal mining impacted waters flowing into Clear Creek. A 230 liter per minute pilot treatment system was installed in a moving van trailer and transported to the site in summer of 2004. Untreated water at the Argo site typically contains about 600 mg/L acidity (as CaCO₃), due to the presence of hydrolysable metals including iron, aluminum, copper, zinc and manganese. Shakedown tests of the system were conducted by project cooperators from the Colorado School of Mines, and demonstrated an increase in pH from 3.0 to 7.0, nearly complete removal of iron and aluminum and an effluent alkalinity of about 100 mg/L as CaCO₃. Post-treatment of the process effluent was required for removal of Mn and Zn, but test results indicated a decrease in reagent costs, as well as decreased sludge volume, due to the replacement of lime or sodium hydroxide by limestone as the neutralization agent. Complete process testing is scheduled for summer 2005.

Additional Key Words: remediation, fluidized bed reactor, pilot plant, portable treatment system, metal removal and sludge volume

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RECLAMATION OF PRIME FARMLAND AFTER SURFACE MINING FOR COAL AND FARMLAND PROTECTION POLICY ACT

H. Raymond Sinclair, Jr.

Abstract: Reclamation of prime farmland (RPF) after surface mining for coal and farmland protection policy act (FPPA) have a similar function, but the approach to achieve the same purpose is different. The similarity of RPF and FPPA is to reduce the loss of prime farmland and other important farmlands. The reclamation of prime farmland after surface mining for coal allows the disturbance of prime farmland, which is only one of the four categories of important farmland. After disturbance, prime farmland is reclaimed to its original productivity. FPPA’s purpose is to limit the acreage of prime farmland as well as unique farmland, and farmland of statewide and local importance from being converted from agricultural uses to non-agricultural uses. FPPA uses easements, mitigation, and federal programs to maintain the farmland base. The soil properties of important farmlands are similar for RPF and FPPA. This paper discusses the soil and programmatic relationship of RPF and FPPA.

Additional Key Words: farmland, grandfathering, historically, easement, mitigation.

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CHARACTERIZATION OF RECLAIMED SOILS IN SOUTHWESTERN INDIANA AFTER SURFACE MINING FOR COAL, PART II.\textsuperscript{1}

H. R. Sinclair, Jr., K. M. McWilliams, C. A. Seybold, R. B. Grossman, S. L. Baird, and T. G. Reinsch.\textsuperscript{2}

\textbf{Abstract:} The study is the second part of an earlier paper to document some physical soil properties and morphological characteristics of soils reclaimed after surface mining for coal in southwestern Indiana. All sites except Daviess 001 were reclaimed using scraper placement. Daviess 001 used shovel-truck placement during reclamation. All the soils were fine-silty Alfisols before they were disturbed for mining. The reclaimed soils classify as either fine-silty or loamy Udarents. Four of the undisturbed soils had fragipans and aquic or oxyaquic conditions, which are indicated, in their classification. All reclaimed soils were reclaimed using prime farmland rules and regulations developed by the State Regulatory Authority as set forth in the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). Both the bulk density and soil strength indicate that these reclaimed soils are shallower to a root restrictive soil layer than the premined soils. Gravimetric water content and bulk density explains 73 percent of the variation in soil strength. The restrictive layers in these reclaimed soils reduce the available water capacity to the extent that crop yields are reduced as compared to the premined soils. The reclamation of the soils in this study ranged from 6 to 17 years before present. These soils have been in cropland or hayland during this period of time.

Additional Key Words: Land Capability-Classification, penetrometer, water retention difference (WRD), proof of productivity, Code of Federal Regulations.

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PERFORMANCE OF 116 PASSIVE TREATMENT SYSTEMS FOR ACID MINE DRAINAGE

Jeff Skousen and Paul Ziemkiewicz

Abstract. State and federal reclamation programs, mining operators, and citizen-based watershed organizations have constructed hundreds of passive systems in the eastern United States over the past 20 years to provide reliable, low cost, low maintenance mine water treatment in remote locations. In 2000, we evaluated 116 systems comprised of eight system types in eight states. We revisited 14 of these sites in 2004 to confirm results from the earlier study. Each system was monitored for influent and effluent flow, pH, net acidity, and metal concentrations. Performance was normalized among types by calculating acid load removed, and also by converting construction cost, projected service life, and metric tonnes of acid load treated into cost per tonne of acid treated. Of the 116 systems, 105 reduced acid load (90%). Average acid load reductions were 0.8 t/yr for Ponds; about 9 t/yr for open limestone channels (OLC), anaerobic wetlands (AnW), aerobic wetlands (AeW), and vertical flow wetlands (VFW); 76 t/yr for slag leach beds (SLB), and about 15 t/yr for limestone leach beds (LSB) and anoxic limestone drains (ALD). Average removal rates ranged from 18 to 2,334 g/day/t for the limestone systems, and 1.7 to 87 g/m²/day for the Ponds and wetlands. Average costs for acid removal varied from $36/t/yr for SLB to $1,468/t/yr for Ponds. The 2004 data showed slightly greater removal efficiencies for two Ponds, two VFWs, and one LSB. Large declines in removal were found for one AnW, two VFWs, one ALD, and one OLC. Two OLCs greatly increased efficiency. Most passive systems were effective for >5 yrs, yet there was wide variation in performance within each system type.

Additional Key words: acidity; acid load; aerobic wetlands; anaerobic wetlands; anoxic limestone drains; limestone leach beds; open limestone channels; Ponds, slag leach beds; successive alkalinity producing systems; vertical flow wetlands.

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USE OF THE BIOTIC LIGAND MODEL TO PREDICT METAL TOXICITY TO AQUATIC BIOTA IN AREAS OF DIFFERING GEOLOGY

Kathleen S. Smith

Abstract. This work evaluates the use of the biotic ligand model (BLM), an aquatic toxicity model, to predict toxic effects of metals on aquatic biota in areas underlain by different rock types. The chemical composition of water, soil, and sediment is largely derived from the composition of the underlying rock. Geologic source materials control key attributes of water chemistry that affect metal toxicity to aquatic biota, including: 1) potentially toxic elements, 2) alkalinity, 3) total dissolved solids, and 4) soluble major elements, such as Ca and Mg, which contribute to water hardness. Miller (2002) compiled chemical data for water samples collected in watersheds underlain by ten different rock types, and in a mineralized area in western Colorado. He found that each rock type has a unique range of water chemistry. In this study, the ten rock types were grouped into two general categories, igneous and sedimentary. Water collected in watersheds underlain by sedimentary rock has higher mean pH, alkalinity, and calcium concentrations than water collected in watersheds underlain by igneous rock. Water collected in the mineralized area had elevated concentrations of calcium and sulfate in addition to other chemical constituents. Miller’s water-chemistry data were used in the BLM (computer program) to determine copper and zinc toxicity to Daphnia magna. Modeling results show that waters from watersheds underlain by different rock types have characteristic ranges of predicted LC$_{50}$ values (a measurement of aquatic toxicity) for copper and zinc, with watersheds underlain by igneous rock having lower predicted LC$_{50}$ values than watersheds underlain by sedimentary rock. Lower predicted LC$_{50}$ values suggest that aquatic biota in watersheds underlain by igneous rock may be more vulnerable to copper and zinc inputs than aquatic biota in watersheds underlain by sedimentary rock. For both copper and zinc, there is a trend of increasing predicted LC$_{50}$ values with increasing dissolved organic carbon (DOC) concentrations. Predicted copper LC$_{50}$ values are extremely sensitive to DOC concentrations, whereas alkalinity appears to have an influence on zinc toxicity at alkalinities in excess of about 100 mg/L CaCO$_3$. These findings show promise for coupling the BLM (computer program) with measured water-chemistry data to predict metal toxicity to aquatic biota in different geologic settings and under different scenarios. This approach may ultimately be a useful tool for mine-site planning, mitigation and remediation strategies, and ecological risk assessment.

Additional Key Words: bioavailability, toxicological testing, copper, zinc, Daphnia magna, ecological risk assessment, water chemistry

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BASELINE LABORATORY STUDIES OF SPHALERITE (ZnS) DISSOLUTION: EFFECTS ON AQUEOUS METAL CONCENTRATIONS AND SOLUBILIZATION RATES

Mark R. Stanton

Abstract. The geochemical behavior of sphalerite (ZnS) under conditions where acid drainage is generated is well-documented. However, the rates of solubilization of major and trace metals, and their subsequent geochemical pathways after release from sphalerite, have been less well-studied. These rates and pathways are key to understanding how metal-mining wastes and acid rock/acid mine drainage (ARD/AMD) evolve, and are critical components in assessing and predicting water quality in the vicinity of a reactive mine waste. Although pyrite (FeS₂) weathering usually dominates aqueous chemistry under acidic conditions, in metal-mining waste where pyrite is low in abundance or metals content, dissolution of ore minerals like ZnS might contribute significant amounts of dissolved metals to effluent waters.

Experimental leaching of sphalerite in acid chloride solution releases several major and trace elements into the aqueous phase. The concentrations produced depend on the original geochemical composition of the ZnS and gangue material, and the rate at which the mineral dissolves (a function of grain size/surface area). A fine-grained, high-iron sphalerite (12.1 wt. %) leached at pH 2-3 (25° C) produces dissolved iron and zinc concentrations approaching 50 and 180 mg/L, respectively, within one week of reaction. Copper and lead measure 3 g/L and 250 g/L, respectively, by the end of the week-long run. At higher pH (>4) using the fine-grained sample, longer reaction times (≤2 months) are needed before metal concentrations reach levels similar to those at low pH (<4).

At pH 4.0, coarse-grained, high-iron sphalerite produces much lower metal concentrations compared to the fine-grained sample, even after several months of reaction. Dissolved iron and zinc are about 400 and 6 times lower, respectively, compared to leachate from the fine-grained sample. Nonetheless, after 8 months of continuous reaction, the texture and color of the original coarse-grained crystalline sphalerite strongly resembled a ZnS-rich mine waste that had been weathering in the subsurface (3 meters) of a waste pile for more than 70 years.

Low-iron sphalerite (0.2 wt. %) produces Zn concentrations similar to the high-iron sample at pH 2.0 but lower Zn concentrations at pH 4.0. At both pH values, aqueous iron is about 100 times lower than the high-iron sample. Other metals (Cu, Pb, etc.) show a range of concentrations that depend on their original abundance in the solid and their solubilities in the solutions.

These data indicate sphalerite can act as a major source of metals when low-pH weathering of mineralized waste rock occurs. The results reinforce previously-established concepts that remediation of mine-related sites should take into account the potential metal contribution of non-pyritic minerals such as sphalerite, including the mineralogy, composition, and grain size of the mine waste, as well as oxidation-reduction and pH conditions, and hydrology and geochemistry of the site.

Additional Key Words: acid drainage, aqueous chemistry, sulfide minerals, mine wastes

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USE OF OZONE TO REMEDIATE MANGANESE FROM COAL MINE DRAINAGE WATERS¹

Susan J. Tewalt², Motoaki Sato², Frank T. Dulong², Sandra G. Neuzil², Allan Kolker² and Kristin O. Dennen²

Abstract. Manganese is an aesthetically undesirable metallic element that is difficult to remove from mine drainage that has acidic to neutral pH. In spite of the thermodynamic prediction that oxygen in the atmosphere or in solution should oxidize dissolved manganese (Mn²⁺) to an oxide or a hydroxide, this does not happen in acidic aqueous solutions. The capability of ozone to oxidize and precipitate manganese as an oxide was proven in bench-scale experiments at U.S. Geological Survey (USGS) labs, and the process was granted U.S. patent no. 6,485,696. Ozone (O₃) oxidizes Mn²⁺ to MnO₂ (Mn⁴⁺) as follows:

\[ 3\text{Mn}^{2+} + \text{O}_3 + 3\text{H}_2\text{O} = 3\text{MnO}_2 + 6\text{H}^+ \] (Gibbs free energy \(\Delta G = -38.985\) kcal at 1⁰ C; Roine, 1999).

In order to test the method in the field, the USGS installed a pilot-scale treatment facility at the Little Toby Creek Treatment Plant in Elk County, PA, which is a limestone-based acid mine drainage treatment plant run by the Pennsylvania Department of Environmental Protection. The manganese treatment system was commissioned in March 2004. Ten pairs of mine drainage water samples, collected prior to and following ozone treatment, were analyzed for manganese and trace metals. In addition to Mn, the treatment should also precipitate as oxides or hydroxides: iron, nickel, cobalt, lead, silver, palladium, bismuth and thallium, if present. Dissolved manganese concentrations in the treated effluent were lowered by about 98 percent, iron by 99 percent, cobalt by 78 percent, and nickel by 8 percent. Measurements of Eh-pH values in the water samples subjected to ozone treatment demonstrate a shift from the Mn²⁺ field into the manganese dioxide (Mn⁴⁺) stability field.

Additional Key Words: acid mine drainage, water treatment, manganese

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NEAR SURFACE GEOPHYSICS FOR THE STRUCTURAL ANALYSIS OF A MINE ROCK PILE, NORTHERN NEW MEXICO

Remke L. Van Dam, Luiza A. Gutierrez, Virginia T. McLemore, G. Ward Wilson, Jan M.H. Hendrickx, and Bruce M. Walker

Abstract. Recent concerns regarding the rock pile stability of a mine in northern New Mexico have lead to the instigation of a multi-disciplinary research program to investigate the pile characteristics and behavior. Geophysical techniques and 7 trenches were used to assess the internal structure of the material for the Goathill North rock pile. Electromagnetic (EM) induction and ground penetrating radar (GPR) methods were used to measure the spatial variability in electrical conductivity and to image the internal structures of the rock pile, respectively. Seven trenches were excavated for analysis of the stratigraphy.

The measurements show the characteristics of the top 5 to 8 meters of the rock pile. The electrical conductivities varied typically around 6 mS/m, but on the southwestern part of the rock pile anomalously high values up to 30 mS/m were found. These high values can be explained by a different texture, mineralogy or pore-water composition, or a higher water content. In this area the penetration depth of the GPR waves is significantly reduced and the reflection configuration is dominated by sub-horizontal reflections. In general, the GPR results have a character of reflectors whose dip directions and angles (maximum 30 degrees) reflect the rock-pile deposition. The trench data show excellent overlap with the GPR survey.

Additional key words: stratigraphy, geophysics, ground penetrating radar, electromagnetic induction, Questa molybdenum mine

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RELATING SOIL PROPERTIES TO NATIVE PLANT ESTABLISHMENT ALONG WEST VIRGINIA HIGHWAYS

Christina Venable and Jeff Skousen

Abstract: The West Virginia Division of Highways is required to develop seeding mixtures comprised of native plants for revegetation of newly constructed highway corridors. The challenges faced when revegetating highway corridors are similar to those of reclaiming mine lands. Similar processes such as blasting and backfilling result in a compacted, rocky soil that often contains acidic materials. Non-native species are generally seeded with high fertilizer rates to assure revegetation success. However, these aggressive species prohibit the establishment of desirable native species. When using native species, soil properties are an important aspect of the revegetation process of these disturbed areas. The chemical properties of soils can be manipulated, however the physical properties are more difficult to influence without great expense. This study evaluated the use of native plants for revegetation along roadsides and the soil factors influencing this reclamation. Soil properties of six West Virginia sites (Baker, Hazleton, Parkersburg, Buckhannon, Elkins, and Weston) were evaluated on the basis of bulk density, pH, electrical conductivity, texture, water holding capacity, cation exchange capacity, extractable bases, and various elemental analyses. Younger soils had less profile development as well as higher bulk densities, increased rock fragments, and decreased water holding capacities than older sites. Older sites with more vegetation had higher amounts of organic carbon in the soil, which translated into improved soil conditions and water holding capacity. Soil pH did not significantly influence native species establishment on these sites. The Elkins site had slightly saline soils as determined by electrical conductivity, which related to a decreased amount of vegetation on this site. Sites with higher amounts of vegetation correlated to soils with lower bulk densities, higher CEC and water holding capacities, and ample nutrients.

Additional Key Words: Native plants, soil properties, disturbed soils, revegetation.

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2Christina Venable, Graduate Research Assistant, and Jeff Skousen, Professor of Soils and Reclamation Specialist, Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV 26506.
PLACEMENT OF COAL COMBUSTION BY-PRODUCTS AT SURFACE MINING CONTROL AND RECLAMTION ACT (SMCRA) MINES: A SHORT HISTORY OF OSM TECHNICAL EFFORTS AND RESPONSES TO ENVIRONMENTAL CONCERNS

Kimery C. Vories

Abstract. The use and disposal of Coal Combustion By-Products (CCBs) (i.e. fly ash, bottom ash, flue gas desulfurization material, and fluidized bed combustion material) at coalmines has become an area of intense interest, research, activity, and controversy during the last decade. Beginning in May of 1994, the Office of Surface Mining (OSM) has taken an active role in encouraging and promoting technological advances, research, and technology transfer related to the use and disposal of those material residues remaining after the combustion of coal to produce electric power. Currently, approximately 2 percent of the CCBs that are produced in the U.S. are placed back at about 2 percent of the mines sites where they originated. Research indicates that the placement of these materials on the mine site usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards. Beneficial uses include: (1) a seal to contain acid forming materials and prevent the formation of acid mine drainage; (2) an agricultural supplement to create productive artificial soils on abandoned mine lands where native soils are not available; (3) a flowable fill that seals and stabilizes abandoned underground mines to prevent subsidence and the production of acid mine drainage; (4) a construction material for dams or other earth like materials where such materials are needed as a compact and durable base; and (5) a non-toxic, earthlike fill material for final pits and within the spoil area. Concerning CCB placement at coal mines, some environmental groups believe, based on historic problems experienced at some power plants, that the use of these materials at coal mines places an unacceptable risk on public health and environmental quality. This paper will attempt to provide a response to criticism that SMCRA programs are not adequate to protect public health and the environment when CCBs are placed at a SMCRA permitted mine.

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FIRST YEAR TRANSPLANT RESPONSE ON CONSTRUCTED TEST PLOTS, QUESTA MINE, QUESTA, NEW MEXICO

Anne Wagner, Matt Owens, Bruce Buchanan, and Ed Redente

Abstract: Molycorp, Inc. has initiated a test plot program to evaluate the potential cover and planting treatments for reclamation of its Questa Mine rock piles. The Questa Mine is located near the Village of Questa in Taos County, New Mexico at an elevation of approximately 8,000 feet. The test plot program consisted of constructing multiple test plots of sloped plots (3:1 and 2:1 slopes) and flat gradient plots. This poster and discussion will focus on the first year transplant response observed on the 2:1 slope test plots. Each test plot was constructed with three cover treatments (no cover, 1-ft, and 3-ft of cover material) over the existing rock pile material. The cover material used was neutral material, less than 8 inches, excavated from an existing rock pile. The test plots received treatments of either forest soil mycorrhizal inoculant or no inoculant. Each test plot was hydroseeded, hydro-mulched, and planted with transplanted tree and shrub seedlings. The transplanted seedlings were broken into three categories; nurse species, crop species, and shrub species. The nurse species planted are fast establishing, short lived species which will shade and protect the crop species. The crop species consist of multiple conifer species which represent the post mining land use plant community. The shrub species will provide understory growth and a wildlife food source. Two transplant seedling treatments were planted on each of the test plots. These seedling treatments included maintaining a constant planting rate for both the crop and shrub species while planting the nurse species at two different planting rates. First year transplant survival studies were undertaken to determine the stocking rates of each test plot and to identify any initial observations regarding the applied treatments.

Additional Key Words: Revegetation, reforestation, high altitude reclamation, transplant establishment, soil amendments, inoculant and cover depth

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Abstract. Reclamation monitoring and evaluation require examining spatial areas within a coal mine over time to assess the results of reclamation. Global Positioning System (GPS) tools allow inspectors to gather the needed data and relate that data to mine and reclamation plans. A Trimble GeoXT is used by the Land Quality Division (LQD) to monitor the reclamation effort at the North Antelope Rochelle Mine (NARM) in Wyoming. The mine permit covers 27,187 acres, including a disturbed area of 11,105 acres. Coal production during the last annual report was 82,167,516 tons.

During monthly inspections, selected requirements for Area and Incremental Bond Releases are being monitored. According to Wyoming Department of Environmental Quality Coal Rules and Regulations, the Wyoming Coal Program has two types of bonds: an Area Bond and an Incremental Bond. The Area Bond is the cost required to achieve rough backfilling (the area is backfilled, graded, and ready for topsoiling). The Wyoming Coal Program allows some Area Bond release via the Annual Report (AR) or with information supplied through a regraded spoil program. The Incremental Bond involves the approval of the specific packages concerning the release of Phase 1 (topsoil applied), Phase 2 partial release (vegetation established) and Phase 3, full release. The GPS technique is used in the field to evaluate criteria for Area Bond and all phases of incremental release requirements. The criteria include:

- extent (acreage) of area bond release areas and slopes
- topsoil depth application
- wildlife features habitats
- restoration of creek channels
- erosional stability

The GPS dictionary was established for the bond release purposes. The data dictionary includes a list of fields with attribute choices for data entry. Similar fields and attributes are built for Geographical Information System (GIS) geodatabase established for NARM.

Upon returning to the office, the GPS field results are processed using the Trimble GPS Pathfinder Office program and Microsoft ActiveSync. Files are spatially corrected to improve the accuracy of the data and then the files are exported into ESRI shapefiles. A map using ArcMap is then produced and attached to the field inspection report.

The GPS field data are also processed as a part of the GIS geodatabase established for NARM. The basic framework for the GIS geodatabase was LQD Guideline No. 20 “Bond Release Procedures for Coal Mining Operations” (2003). This framework resulted in creating data layers (e.g. permit topography, area bond release application, post-mine streams, topsoil verification points, wildlife feature, tree restoration, slope line, erosion) and associated data types (point, line or polygon) and attributes (e.g. reclamation status, date of data collection). The GPS field data incorporated into the GIS geodatabase helps to track the bond release requirements for reclamation and bond release purposes.

Using the GPS technique in conjunction with GIS is improving the LQD inspector’s ability to assess reclamation adequacy and track features required for bond release.

Additional Key Words: bond release, ArcMap, GIS.

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USING RAW CHAT IN HOT MIX ASPHALT FOR PAVEMENT APPLICATIONS1

N. M. Wasiuddin, W. B. Hamid, M. M. Zaman, R. Nairn and T. Landers2

Abstract. Over 35 million cubic meters of chat, a waste material of lead and zinc mining, are presently stockpiled at the Tar Creek Superfund Site. Currently, Oklahoma Department of Transportation (ODOT) uses up to 20% washed chat in hot mix asphalt (HMA). This paper presents the results of an experimental study to maximize raw chat in HMA, designed in accordance with the Superpave mix design methodology. Raw chat was combined with locally available limestone aggregates. Bench scale laboratory tests pertaining to engineering properties were conducted on aggregates. Trial blends were prepared by varying percentages of raw chat, and volumetric analyses were carried out for each blend so as to achieve a 4% air void content. The Superpave volumetric requirements, namely voids in mineral aggregates (VMA) and voids filled with asphalt (VFA) at 4% air void, were achieved satisfactorily in all the mix designs attempted. Chat-asphalt mixes also did well in performance tests, namely moisture susceptibility and APA rut. All specimens exhibited a much higher tensile strength ratio (above 0.9) than that required (minimum of 0.8) in moisture sensitivity tests. These mixes also performed well (<2 mm (0.08 in)) in APA rut tests (maximum of 4 mm (0.16 in) is allowed).

Additional Key Words: Superpave, voids in mineral aggregates, voids filled with asphalt

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2Nazimuddin M. Wasiuddin, Doctoral Student, Wamiq B. Hamid, Former Graduate Student, Musharraf M. Zaman, Professor, Robert Nairn, Associate Professor, School of Civil Engineering and Environmental Science, and Thomas Landers, Associate Dean for Research, College of Engineering, University of Oklahoma, Norman, Oklahoma 73019.
Abstract. Semi-passive treatment was used at two mine sites in Pennsylvania. At the first site, located in Schuylkill County, mine drainage flowing at approximately 2600 L/min (700 gpm) and containing 5 - 10 mg/L of iron was treated using the influent water to power a dry chemical feed system (using lime) and a four-cell wetland (0.40 ha = 1 acre). Prior to lime addition, pH remained virtually unchanged and iron was not significantly removed with typical iron removal being about 1 mg/L or less. After the addition of pebble lime (CaO) using an Aquafix™ system, the pH of the mine water increased from approximately 5 to between 7 and 8. Total iron concentrations were lowered to less than 0.5 mg/L at the effluent. Iron removal rates within the first wetland cell were less than 1 gd⁻¹m⁻² without lime addition and ranged between 6 and 11 gd⁻¹m⁻² with lime addition. This system used a split of the influent water to turn a water wheel that is geared to a screw feeder located at the bottom of a hopper containing the lime. Lime was added at a rate of about 75 kg/day (165 lb/day). A wireless remote monitoring system was installed at this site to monitor the addition of lime by tracking the speed of the water wheel and posting this information to a web site on a daily basis. In addition, selected individuals were notified by phone when the lime bin was nearly empty. The second site is located in Butler County. Influent water at this site is pH 2.7 and contains 117 mg/L iron, 46 mg/L aluminum, 65 mg/L manganese and 780 mg/L of acidity (as Ca CO₃). Water flows at approximately 120 L/min (32 gpm). Treatment with pebble lime will begin shortly and the results will be discussed in the poster. For both semi-passive treatment sites, cost estimates, maintenance requirements and lessons learned will be presented.

Additional Key Words: lime, water powered devices, water wheel, wetlands, iron removal

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THE EFFECTS OF SOIL DEPTH AND OTHER SOIL CHARACTERISTICS ON PLANT COMMUNITY DEVELOPMENT IN NORTH DAKOTA

A.F. Wick, S.D. Merrill, T.J. Toy, J. Hendrickson and M.A. Liebig

Abstract: Revegetation of mined lands in North Dakota is challenging because of the poor physiochemical properties of the spoil material as well as the semi-arid climate. Topsoil and subsoil replacement is a successful method used to establish productive and diverse plant communities. Previous studies conducted by Merrill et al. (1998) and Power et al. (1981) determined adequate soil depth for optimal vegetation productivity during six years of study on soil wedges in Zap and Stanton, ND. Re-sampling of these sites in 2003 documented long-term effects of soil depth and other soil characteristics on plant community development. Results of the 2003 study differed from results of past studies. At the Zap, ND Double Soil Wedge (ZSW) in 2003, the highest vegetation production occurred on 40 to 120 cm of total soil depth and the highest species diversity occurred on the alfalfa (Medicago sativa) vegetation plots with 0 to 40 cm of total soil depth. In the previous study, the highest production occurred on 51 to 110 cm of total soil depth. At the Stanton, ND Soil Wedge (SSW) in 2003, the highest production occurred on 65 to 120 cm of total soil depth. In the previous study, the highest production occurred on 92 to 132 cm of total soil depth. Changes through time in soil characteristics at the ZSW and SSW sites were similar. Electrical conductivity (EC) was lower in 2003 compared to 1979 and increased with depth in 2003. pH was higher in 2003 compared to 1979 and also increased with depth in 2003. There was a weak correlation between total soil depth and plant community development after 30 years of establishment compared to a strong correlation observed after six years of vegetation establishment in the previous studies.

Additional Key Words: soil wedge, production, cover, diversity, electrical conductivity, pH, North Dakota

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RECLAIMING A GOLD MINE

Raymond K. Will

Abstract: An open-pit gold mine in the Mother-Lode mining region of the Sierras was essentially closed according to an accepted mine closure plan. However, because one element of the plan was not completed, due to technical disagreements, the entire mine site is now being re-examined, conceptually resulting, in revisions to the closure plans for the entire site. Elements of the mine include open-pits, a pit lake, waste rock piles, tailings pile, and a site wide surface water drainage system. Concerns to be re-addressed include: off site migration of dissolved metals in groundwater, stormwater sediment transport, revised criteria for side slope gradients of waste rock piles, disposition of pit lakes, and other complex issues.

Additional Key Words: mine drainage, water treatment

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RESULTS OF INNOVATIVE CONTRACTING AND RECLAMATION METHODS USED FOR THE FONDAYAW CANYON MINE CLOSURE PROJECT, FALLON, NEVADA

H. Tom Williams, Elizabeth A. Duvall, and Henry H. Sauer

Abstract: This presentation provides an overview of the contracting and implementation processes used to close and reclaim the inactive Fondaway Canyon Mine. The closure and reclamation of the Fondaway Canyon Mine is now considered the “standard of reclamation” by the BLM in Nevada. The mine is located approximately 40 miles northeast of Fallon, Nevada on the western flank of the Stillwater Mountain Range. The site is subject to mining claims held by EPEC Minerals Company–Nevada, a subsidiary of El Paso Corporation, and has been inactive for over 10 years. The project was a medium-scale open-cut and underground gold and silver mining operation, with a heap leach pad and Merrill-Crow recovery plant. Golder’s scope was to identify current methods for the closure of all facilities, negotiate appropriate changes to the existing reclamation plan and permit, develop construction level designs, conduct a bidding process, and oversee the implementation of the reclamation plan. Golder developed innovative reclamation and erosion and sediment control methodologies for each mine disturbance feature, but they also developed an innovative incentive based contract to be used to align the Contractor’s goals with the owner’s in the hopes of achieving a better and less costly end product. This paper documents and analyzes the effectiveness of the approach taken for completion of the project. The project was nominated for an excellence in reclamation award by the State of Nevada, Department of Environmental Protection.

Additional Key Words: Heap leach facility, draindown, solutions, incentive based contract

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Abstract: The Development of Acid/Heavy-Metal Tolerant Germplasm Project began in 1995 to assemble and evaluate native indigenous plant material from areas heavily impacted by historic mining and smelting activities in western Montana. The Deer Lodge Valley Conservation District, in cooperation with the USDA-NRCS Bridger Plant Materials Center, has managed this project with grant monies from state and federal agencies responsible for the remediation and cleanup of the EPA’s Upper Clark Fork River Basin Superfund Site. Seven field studies have compared more than 500 local and non-local seed and plant collections in approximately 1,900 plots. Site preparation has consisted of deep plowing to dilute surface contamination or amending soils with lime and deep plowing to raise pH levels. The Woody Comparative Evaluation Planting, established in 2000, contains 19 accessions of seven native shrub and tree species. Top performers of the indigenous ecotypes are common snowberry, ponderosa pine, silver buffaloberry, wax currant, and Woods’ rose. At the deep-plowed and lime-amended site on Stuckey Ridge, 87 accessions of grasses, forbs, and shrubs, including two mixes each of indigenous and non-indigenous material, were planted in 2003. Superior performing indigenous species include basin wildrye, bluebunch wheatgrass, big bluegrass, slender wheatgrass, western wheatgrass, and silverleaf phacelia. Since the project’s inception, three plants were selected for pre-varietal release to the commercial seed industry: Selected class of Washoe Germplasm basin wildrye and Prospectors Germplasm common snowberry, and Source Identified class of Old Works Germplasm fuzzytongue penstemon. Certified seed production fields of Washoe and Old Works have been established in Montana, Idaho, and Washington.
INfiltration through a mine-waste dump and transport of metals to a nearby stream, clear creek county, colorado

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Abstract. Results of geophysical surveys, tracer studies, and synoptic sampling of the Waldorf mine site in Clear Creek County, Colorado, were used to evaluate the infiltration of adit water through a mine-waste dump to nearby Leavenworth Creek both before and after remediation in 2002. The common objective of these integrated studies was to evaluate metal transport from several mining-affected areas: notably the mine adit, mine-waste dump and adjacent wetland, and mill-tailings sediment. Trout are unable to survive in Leavenworth Creek downstream from the mine site because concentrations of copper and zinc exceed hardness-corrected acute and chronic standards for aquatic wildlife. Trout do survive in beaver ponds off of the main channel of the creek, which suggests that remediation to reduce metal loads might promote trout recovery in an 8-km reach downstream from the mine. Remediation in 2002 by rerouting of the adit around the waste dump was intended to improve water quality, but no discernable difference could be detected 1 year later. This study illustrates the need to develop a broad-based understanding of metal transport for an entire mine site in order to effectively improve stream quality.

Before the remediation in 2002, a NaCl tracer was used to measure the infiltration rate of adit water moving through the dump. The tracer was detected in seepage at the base of the dump in less than 24 hours, providing a maximum flow rate of 90 m/day. Flume measurements of braided surface channels flowing over the dump indicated that 43 percent of the adit discharge infiltrated the dump. Constituents that behaved conservatively in this system (Ca, Mg and Sr) helped to characterize different sources of water and the degree of mixing. Ground-water ages, determined by chlorofluorocarbon (CFCs) analysis, were 25 years for the adit and 15 years for the adjacent wetland area. Electromagnetic (EM) and direct current (DC) resistivity surveys conducted before and after remediation between 2002 and 2004 were used to map physical properties of the mine-waste dump, including preferential flowpaths of water moving through the mine-waste dump and contaminated wetland.

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Metal loading from several mining-affected inflows to Leavenworth Creek was determined from a LiBr tracer-injection study in 2002 and synoptic water-quality sampling of the stream and tributary inflows in 2003. Water chemistry of selected constituents such as Ca and Sr that behave conservatively in this system were used to (a) distinguish among different sources of mining-affected water, including the adit, mine-waste dump, and mill tailings; and (b) to quantify the relative contribution from each of these sources to a 930-m stream reach. Water-chemistry sampling and discharge measurements were repeated at selected sites in 2003 to compare zinc and copper loads before and after remediation.

Rerouting of adit water in 2002 was intended to improve water quality; however, the pre-remediation sampling results indicate that the dump was actually a net sink for most metals, including copper and zinc. This was not known until after remediation. Zinc and copper concentrations in adit water decreased after traveling across the dump and, in some cases, after traveling through the dump. The metals are thought to have sorbed onto manganese-oxide precipitates. The wetland area did not appear to have a significant effect on zinc concentrations, although the pH generally decreased between the waste dump and the wetland area.

Lastly, these studies indicate that the adit/waste-dump/wetland area is not necessarily the largest source of metal loading to the stream. Repeated sampling in different years indicates that metal loading from the adit/waste-dump/wetland area and from the leaching of the dispersed mill tailings are approximately equal. In the first year (before remediation) the tailings were the largest source, and in the second year (after remediation) the adit/waste-dump/wetland area was the larger source of zinc and copper in the creek. Contact of adit water with the dump material before remediation did not significantly affect the load(s) of either copper or zinc in adit water flowing to Leavenworth Creek. One year later, any changes that may have resulted from rerouting the adit flow were masked by higher adit discharge resulting from a larger snowpack.