Abstract. Integral to the large-scale mining in Butte, Montana, was a railroad network to service, support, and supply the mining activities. The first railroad arrived in Butte in the early 1880s, as a world-class copper industry was being established. A shortage of efficient smelter capacity led copper baron Marcus Daly to seek development of new smelting facilities 40 kilometers away in Anaconda. Ore from Butte was subsequently transported via rail to smelters in Anaconda for nearly 100 years. In the early 1980s, the Butte area was designated as a Superfund site by EPA. Residential action levels for the site set by EPA for arsenic and lead are 250 mg/kg and 1,200 mg/kg, respectively.

The purpose of the Railroad Bed Time-Critical Removal Action (RRTCRA) is to address elevated concentrations of metals associated with railroad beds within the site. Elevated concentrations of arsenic and lead in railroad beds are due to the use of mining-related waste materials for subgrade soil or ballast and/or from spillage from rail cars during transport of ore or ore concentrates. About 3/4 of the approximately 300 samples collected exceeded the arsenic action level, leaving only small segments of more than 20,000 meters of rail line untouched during this removal action. Construction was implemented in 2001 and is expected to be completed by the end of 2003.

The RRTCRA is expected to reduce human health risk in Butte and environmental risks to Silver Bow Creek. Standard construction techniques are being employed, focusing on providing barriers to waste materials for environmental separation and to reduce erosion along rail embankments, and implementing improvements to the storm water drainage system. Barriers include the use of soil covers, rock covers, and geotextile materials (e.g., cellular confinement). Storm water improvements include emplacement of a new 60-inch storm water main and other significant water routing improvements to the Butte storm water drainage system, including properly-sized ditches, culverts, and retention ponds. Soil removal and other improvements have been made to residential properties along active and inactive rail lines. Waste rock and other contaminated materials located within the 100-year floodplain were removed and a waste repository which may be part of a future dedicated development was constructed. The project is highlighted by a new historic preservation trail constructed on 7 kilometers of former rail line from the community of Rocker, passing by Montana Tech, and ending at the Kelley Mine Yard in upper Butte.

1Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation at The 9th Billings Land Reclamation Symposium, Billings, MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

Abstract: Treatment wetlands have been used for the remediation of mine drainage for nearly 20 years. However, detailed understanding of specific processes affecting water quality is needed. In this study, a 2-year-old reducing and alkalinity producing system (consisting of two vertical flow and two surface flow cells) was constructed as a pilot system to treat acid mine drainage (AMD) from an abandoned coal mine in Latimer County, Oklahoma. The vertical flow cell substrate was a 20:10:1 mixture of spent mushroom substrate, limestone and hydrated fly ash. Inflow-outflow water quality analyses demonstrated substantial metal retention in the first vertical flow cell for Al, Cd, Cu, Fe, Ni and Zn. In the second vertical flow cell, water quality changes indicated substantial Cd, Cu, Fe, Mn, Ni and Zn retention. In order to assess the fate of these sequestered metals, substrates were examined to determine the forms in which the metals were sequestered in the two vertical flow cells. Substrate cores (7.6 cm diameter by 25 cm long) were collected at nine locations and two depths in each of the two vertical flow cells. Cores were frozen upon collection. In the laboratory, cores were sequentially extracted to determine metal (Al, Ca, Cd, Cu, Fe, Mg, Mn, Ni, Pb and Zn) concentrations in six fractions (water-soluble, exchangeable, organically bound, carbonate, oxide/oxide-bound and residual e.g., sulfide). In the first vertical flow cell; Fe in the surface substrate was retained primarily as an oxide and sulfide, Al as oxide-bound and carbonate, and Mn as organically bound and as carbonate. At depth the highest concentrations of Fe were found as carbonate and sulfide whereas Al was found as carbonate, oxide-bound and sulfide. In the second vertical flow cell, Fe was found in the surface substrate as an oxide and sulfide and Mn was found organically bound and as carbonate. The lower depth substrate analysis showed Fe to be retained as a carbonate and sulfide and Mn as organically bound and as a carbonate.

Additional Key Words: ecological engineering, sequential extraction, metal sequestration

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2Denae Athay, Graduate Research Assistant, Robert W. Nairn and Keith A. Strevett, Associate Professors, School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, OK 73019.
THE USE OF A CORN GRAIN YIELD MONITOR TO EVALUATE SOIL QUALITY OF RECLAIMED PRIME FARMLAND

Richard I. Barnhisel

During the past few years, target yields for corn have been measured with a plot combine equipped with a yield monitor. The primary goal was to determine productivity for phase III bond release and provide statistical data that may be needed for this process. At the same time grain yield data was being generated that could be used to create maps. It was obvious that in some plots there were significant differences in the yields in different parts of these plots. After harvesting, areas within these plots were sampled to determine why the yields were greater or smaller. Such parameters as actual topsoil thickness as well as overall soil thickness, soil fertility, and soil density was determined. Topographic differences were also observed such as small depressions that could pond water and could possibly produce nitrogen losses, thus affecting grain yield.

Several of the above factors seemed to be responsible for yield depressions. Although it was not possible to replicate such a study, there were several trends that could be attributed to the lower yields in some plots or portions of a plot. The three most frequent attributing factors were the presence of a small depression that is believed to have caused denitrification and the presence of compacted zone and areas of thinner topsoil. Actual soil N levels were never measured but the appearance of the corn crop indicated that N was likely lower in these areas based on corn height and color of the fodder. Soil fertility did not directly seem to be affecting corn yield as in most cases adequate P and K was found and the pHs were within an acceptable range.

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Butte Reclamation Evaluation System

P.S. Blicker, M.K. Reeves, D.T. Shanight, M.W. Hills, and D.R. Neuman

Abstract. The Environmental Protection Agency (EPA) designated Montana’s Silver Bow Creek a Superfund site in 1983. By 1987 it was recognized that mine waste piles within the city of Butte, Montana posed a significant health risk to local residents and represented a major source of contamination to the Creek. The city of Butte was then added to the Silver Bow Creek Superfund site. Beginning in 1988 and continuing to date, EPA has performed response actions to address waste piles within the Butte Priority Soils Operable Unit (BPSOU). Response actions have focused on addressing mine waste “in-place”. These response actions include land reclamation techniques using coversoil caps and revegetation. The Butte Reclamation Evaluation System (BRES) was developed as an evaluation tool designed to ensure that the integrity of all reclaimed land, including soil cover caps or other forms of engineered caps covering mine-waste left-in-place, are maintained at a level that provides for the long-term protection of human health and the environment in an urban-upland setting. EPA will utilize the BRES over the long-term to assess the condition of response action sites, identify problem areas, specify corrective action, and determine long-term monitoring schedules. During the development of the BRES, stakeholder representatives (County, State, EPA, and the Potentially Responsible Party Group) worked together to establish overarching objectives, develop site assessment methodologies, provide guidance, and identify evaluation parameters. Reclamation evaluation parameters include ground cover, erosion, condition of site edges, exposed waste material, bulk soil failure or land slumps, barren areas, and gullies. This paper describes the BRES field evaluation parameters used to characterize response action sites in terms of meeting human health and environmental risk objectives and the evaluation parameter performance standards that collectively determine the appropriate corrective action.

Additional Key Words: revegetation, assessment.

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CHEMICAL ANALYSIS OF CORES OBTAINED FROM A VERTICAL FLOW POND

Fred J. Brenner, Ed Nowacki, Shaun Busler, and Charles D. Cooper

Abstract: The vertical flow pond at Jennings Environmental Education Center, Butler County, PA, was constructed in 1997. After five years of operation, the system continued to produce alkalinity and remove iron and aluminum, but the flow rate through the system has continuous declined. To determine the type and pattern of chemical distribution throughout the system, 9 cores were obtained and analyzed for iron, manganese, aluminum, silica, sulfate, calcium and trace metal concentrations. Iron precipitates accumulated in the upper 7-10 cm of the spent mushroom compost and limestone mixture with the majority of aluminum precipitate accumulation occurring between 10 and 20 cm below the surface of the media. Although there was sufficient CaCO₃ in the substrate to continue to provide alkaline addition, the accumulation of metals in the upper 10 cm of the substrate has reduced the permeability of the substrate.

Additional Key Words: iron, aluminum, silica, spent mushroom compost, limestone, permeability

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COMPARISON OF BACTERIA POPULATIONS WITH METAL AND SULFATE CONCENTRATIONS IN A SCALE MODEL VERTICAL FLOW POND

Fred J. Brenner, Shaun Busler, Kim Kosick, Corrie Gardner, and Carol Tippie

Abstract: The pattern of alkaline addition, metal removal and sulfate reduction was analyzed in a model of a vertical flow pond (VFP) aerobic wetland system that was a scale model of the system constructed at the Jennings Environmental Education Center. Samples were obtained from four locations in the VFP and at three locations from the aerobic wetland. Acidity removal occurred in the upper 60 cm of the substrate resulting in a net alkaline discharge. The system was effective in iron and aluminum removal. Iron and manganese concentrations were inversely correlated with iron and manganese bacteria populations. Sulfate concentrations did not vary significantly throughout the VFP, and with sulfate concentrations was correlated with anaerobic sulfate bacteria. A core was obtained from the VFP and the metal and sulfate concentrations compared with concentrations in the water samples. Alkaline addition appeared to be a result of limestone dissolution with little if any contribution from sulfate reduction. However, bacteriological activity is an important but little understood mechanism involved in the function of aerobic and anaerobic passive treatment systems.

Key Words: passive treatment, bacteria, iron, manganese, aluminum and sulfate reduction

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2 Fred J. Brenner is Professor of Biology, Grove City College, 100 Campus Drive, Grove City, PA 16127, Kimberly D. Kosick, Shaun Busler, Corrie A. Gardner, and Carol Tippie were senior biology majors at Grove City College, 100 Campus Drive, Grove City, PA 16127.
USE OF GRASSLAND AVIAN COMMUNITIES TO MONITOR RECLAMATION SUCCESS ON SURFACE MINE LANDS

Shawn M. Rummel and Fred J. Brenner

Abstract. Grassland songbird communities have been on a steady decline for many years throughout their range. Recently, however, it has been discovered that several species of grassland birds are nesting on reclaimed surface mines. The use of surface mines by these species have been shown to be correlated with the size of the grassland, along with habitat characteristics and the dispersal of these habitats upon the landscape. The current paper provides a mechanism to use the structure and composition of avian communities to assess the initial and long term sustainability grassland habitats on reclaimed mined lands. The use of feeding guilds and biotic indices along with species composition and bird density provide a means to rapidly assess the sustainability of these systems. The authors provide several suggestions to enhance the number and diversity of bird species along with other wildlife using grasslands on reclaimed surface mines.

Key Words: Grasslands, bird communities, monitoring
INTEGRATION OF SURFACE WATER MANAGEMENT WITH MITIGATION OF GROUND WATER IMPACTS AT A PROPOSED PHOSPHATE MINE OVERBURDEN FACILITY\textsuperscript{1}

Brian W. Buck\textsuperscript{2} and Bruce Winegar

Abstract
Environmental impact evaluation of proposed phosphate mine overburden fills at the J.R. Simplot Smoky Canyon Mine, in Southeastern Idaho indicated that leaching of the overburden by infiltrating precipitation could potentially contaminate local ground water with selenium. The Idaho Department of Environmental Quality (IDEQ) required that ground water impacts be reasonably localized to the immediate mine vicinity. A number of best management practices (BMPs) were incorporated into the design of the overburden fills to reduce potential surface water and ground water impacts, but ground water quality impacts were still predicted to extend off site in the long term (100 years). A number of alternatives were then evaluated to reduce the infiltration of precipitation into the overburden through use of low permeability covers. These were rejected for cost and engineering feasibility reasons. Use of modified infiltration trench technology for storm water management at the periphery of the proposed overburden fills was then evaluated for recharge of runoff into the local ground water. Both the State and the EPA already approve this technology as a storm water management BMP. Ground water impact modeling showed that incorporation of runoff recharge areas into the margins of the overburden fills would be effective in containing the area of ground water impacts to the immediate mine vicinity. This design was eventually approved by the IDEQ, EPA, and the Federal land management agencies and has potential applicability in similar hydrogeologic situations at other mining operations.

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\textsuperscript{2}Brian W. Buck Geological Engineer, Vice President, JBR Environmental Consultants, Inc., Sandy, UT Bruce Winegar Senior Environmental Manager, J. R. Simplot Company Corporate Regulatory Affairs, Pocatello, ID
Abstract. Reclamation of a quarry used to produce sandstone aggregate and clay near Boulder, Colorado was undertaken in 1995 without the benefit of salvaged topsoil. Subsoil was generated from remaining clay (weathered Lykins formation shale). Top layer growth medium was created using filter fines from a City of Boulder water treatment plant. These filter fine materials were sediment load accompanying the water passing from a high mountain watershed down a steel pipeline to the treatment plant. Silt and coarser size particles had been separated by filtration; clay particles were precipitated using alum. The resulting “filter fines” had the appearance of topsoil with occasional aggregations of alum. Planting in this material in late 1994 was accomplished by broadcast and mulched with bonded fiber matrix or hydromulch. Plentiful rain in Spring 1995 resulted in a very strong cover of the sown native grasses (mainly thickspike wheatgrass and western wheatgrass, *Elymus lanceolatus* and *E. smithii*). Bonded fiber matrix mulch accompanied the stands with initial highest plant cover. Over time the hydromulched areas with lower initial cover values were possessed of the greater species density, as less competitive native species were able to slowly establish in the absence of heavy grass competition.

Additional Key Words: Steep slope reclamation; bonded fiber matrix, filter fines

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2David L. Buckner, Senior Plant Ecologist, ESCO Associates Inc., Boulder, CO 80308. Lynn Riedel, Plant Ecologist, City of Boulder Open Space and Mountain Parks Department, Boulder, CO 80303.
Abstract. Faced with the need to pass judgment on the vegetational adequacy of surface coal mine reclamation, all interested parties are well advised to take heed of the evidence provided by monitoring, suggesting that processes by which native ecosystems came to be are complex beyond original “plant-a-garden” reclamation techniques and regulations. Over the past 30 years, techniques have evolved considerably toward the end of producing vegetation more closely compliant with requirements for plant cover, forage production, woody plant density, and species diversity. This evolution has been driven by the need to balance plant competition between the major species involved in provision of cover and production (mostly grasses) with the usually much more weakly competitive woody plants and native forbs. Environments in which most surface coal mine revegetation passes through its infancy can only be described as ideal for herbaceous species and grasses in particular. Homogenized topography with even depths of agriculturally suitable soil offers what can only be termed a grass vision of heaven. In recent years a significant number of mines have undertaken to render conditions of reclamation landscapes less perfect for grasses in order to effect a balance of lifeforms more compatible with bond release goals. These trials may result in a shortening of the period of development needed to reach desired lifeform balances. On older reclamation, however, the favored balance is out of reach until stresses to the dominant grasses allow the establishment of forbs and significant shrub / tree cover. This will probably occur over a period much longer than a ten-year liability period or even the 20+ years that some revegetation has already been in place. Over the long term, conditions of climate and human management, among other variables, will change, perhaps disadvantaging the “ruling” grasses. It is posited that the species composition / balance of pre-mining plant communities to a large degree reflects the cumulative effects (a “developmental ecology”) of stresses and readjustments between plant lifeforms and species. Evaluation of the adequacy of some older revegetation efforts necessitates consideration of the question of whether low levels of woody plant density and forb abundance represent an adequately established potential for development of more shrubby and species –diverse vegetation in the longer term.

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2David L. Buckner, Senior Plant Ecologist, ESCO Associates Inc., Boulder, CO 80308.
WHITE PINE GROWTH AND YIELD ON A MINED SITE IN VIRGINIA: RESPONSE TO THINNING AND PRUNING

J. A. Burger\(^2\), W. E. Auch, R. G. Oderwald, and M. Eisenbies

**Abstract.** Owners of reclaimed mined land are interested in the feasibility and benefits of re-establishing forests for a variety of products and ecosystem services. We reported the projected rotation-age volume yields and timber value for a thinned and pruned white pine stand growing on mined land in Wise County, Virginia. Tree growth from age 17 to 23 increased significantly in response to thinning. The mean annual increment (MAI) of the unthinned stand was 13 m\(^3\)ha\(^{-1}\)yr\(^{-1}\), compared to 20 m\(^3\)ha\(^{-1}\)yr\(^{-1}\) for the thinned stand; this amounted to a 62% increase in the rate of growth due to thinning. Projected to age 30, the age at which the stand will be harvested, stand volume will be 404 m\(^3\)ha\(^{-1}\) versus 306 m\(^3\)ha\(^{-1}\) for the thinned versus unthinned, respectively. Thinned harvest volume of crop trees will be 25% greater than that of crop trees in stands left unthinned. The sawtimber value based on current prices is $2211 ha\(^{-1}\) versus $1689 ha\(^{-1}\) for the thinned versus unthinned stands, respectively. This amounts to a 31% increase in the value of the thinned stand. Depending on current markets, pruning trees up to 5 m can bring a 17% stumpage premium. The results of this study show that thinning and pruning are viable options and good investments, provided that the tree stand has adequate mine soil resources for rapid growth.

Additional Key Words: reclamation, forest site quality, reforestation, mine soil quality

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Abstract. Reclamation specialists are interested in assessing the landscape potential for many organisms through the use of wildlife habitat models to minimize the impacts of mining operations during the life of the mine. In this study, ten United States Fish and Wildlife Service habitat models (tree squirrels \textit{[Sciurus} sp.], downy woodpecker \textit{[Dendrocopus pubescens]}, black-capped chickadee \textit{[Parus atricapillus]}, Eastern cottontail \textit{[Sylvilagus floridanus]}, snapping turtle \textit{[Chelydra serpentina]}, great blue heron \textit{[Ardea herodias]}, Western grebe \textit{[Aechmophorus occidentalis]}, red-winged blackbird \textit{[Agelaius phoeniceus]}, belted kingfisher \textit{[Ceryle alcyon]}, and American coot \textit{[Fulica americana]}) were examined in a model validation experiment across ten cover types (76-100% canopy, 51-75% canopy, 26-50% canopy, grassland/urban savanna, exposed substrate, saplings, seedlings, shallow water/mudflats, water deeper than 2', and river) at the Rigden Mine near Fort Collins, Colorado for one year during 1989 through 1990. In addition, a second experiment tested for differences across the ten habitat models during carefully managed progressive mining operations by applying the predictive models for the management years 1975 (pre-mine), 1977, 1979, 1981, 1986, 1996, and 2036 (post-mining). The analysis revealed that the habitat scores significantly (p<0.05) predicted actual observed habitat use, but only explained 32 percent of the variance. There were no significant differences in the habitat quality across the pre-mine, mine operations, and post-mine landscapes. This study suggests that there is still much work to be conducted to refine predictive wildlife habitat models, but that there is great potential for mining operations to minimize the impacts to wildlife during the life of the mine.
REVEGETATION OF MINING WASTE USING ORGANIC AMENDMENTS AND EVALUATING THE POTENTIAL FOR CREATING ATTRACTIVE NUISANCE FOR WILDLIFE

D. Byrne-Kelly, J. Cornish, R. Gordon, and I. Licis

Abstract: The project was performed under the Mine Waste Technology Program, which is funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement. (IAG No. DW89938513-01-0 and DOE Contract No. DE-AC22-96EW 96405)

The objectives of this project are to demonstrate that use of organic amendments enhances the establishment and growth of grass on lead mill tailings and evaluates the affect of those amendments on plant uptake of metals. Two sources of compost and an organic fertilizer derived from municipal sewage treatment plant sludge were incorporated into two types of tailings near Desloge, Missouri, and the replicated plots were planted with grass. Both types of tailings (fine-textured floatation tailings at the Big River Mine Tailings site (BRMTS) and coarse-textured gravity separation tailings at the Leadwood Chat Tailings site (LCTS)) contain elevated concentrations of Pb, Zn, and Cd. This project was evaluated for three growing seasons (2000, 2001, and 2002).

At the end of each growing season, vegetative cover and biomass production were quantified, and tailings and vegetation samples were obtained and analyzed. In addition, at the end of the third growing season, core samples were collected in designated plots to evaluate compost incorporation and root penetration and to perform microbiological characterization, which will be presented in a future report. Also, precipitation data was compiled for each growing season.

Vegetation evaluations and analyses of plant tissues and tailings materials indicate differences among amendment types and application rates are environmentally significant. In general, compost has been very effective in establishing and maintaining adequate vegetation cover and biomass production under reduced precipitation conditions. This is due to in part to improved soil structure, water holding capacity, and soil nutrient content. Compost also reduced plant uptake of metals two to three fold compared to those observed in the controls.

Key words: vegetation, organic amendments, tailings, and compost, and bioavailability
RECLAMATION AND BOND RELEASE AT THE CARBON NO. 2 MINE IN NEW MEXICO: A NATIONALLY RECOGNIZED SUCCESS

David L. Clark, Frank J. Mraz, and Diane M. Thomas

Abstract. In early February, 2002, the New Mexico Mining and Minerals Division (MMD) nominated Carbon Coal Company (Carbon) for a National Award from the Office of Surface Mining Reclamation and Enforcement (OSM) for outstanding overall performance in meeting and exceeding the goals of the Surface Mining Control and Reclamation Act of 1977. Specifically, the MMD considered the reclamation completed at the Carbon No. 2 Mine to be exemplary in terms of enhancement of the permit area’s hydrologic balance and its capability to support the postmine land use. The mining and reclamation completed by Carbon reduced the risk of flash flooding in the southern part of the City of Gallup from routine to nil. The postmine livestock carrying capacity of the reclamation was more than double the premine capacity. The potential long-term benefit to other western coal mining operations resulting from Carbon’s pioneering application of New Mexico’s “Hydrologic Window” regulation also merited recognition. Carbon applied for final (Phase III) bond release for Carbon No. 2 Mine in December of 2001. The MMD approved final bond release and terminated jurisdiction over the mine permit area in late March, 2002. OSM recognized Carbon’s reclamation efforts with a National Award at the September 2002 awards ceremony in Washington, D.C.

Additional Key Words: recreation, revegetation, success criteria, wildlife habitat

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Abstract. The chemical composition of nine abandoned mine water discharges at the Tar Creek Superfund Site were examined in 2001-2002 and compared to data collected in the mid-1980s. The site is a portion of the abandoned Tri-State Lead and Zinc Mining District of Oklahoma, Kansas and Missouri. In the initial water quality study conducted in 1983-1986, mine waters were characterized as having low to circumneutral pH and elevated metal concentrations. Fe, Zn and alkalinity concentrations ranged from 140-1836 mg/L, 47-200 mg/L, and 0-560 mg/L as CaCO$_3$ eq., respectively, and pH values ranged from 3.0-6.1. During the summers of 2001 and 2002, sampling of nine previously studied discharges was conducted. Data were compared with 1980s data to help characterize suspected changes in mine water chemistry. In situ parameters included pH, temperature, conductivity, dissolved oxygen, alkalinity, and turbidity. Samples were collected and analyzed for Fe, Zn, Cd, Pb, Ni, Mn, Cu, Ca, Mg, SO$_4^{2-}$, NO$_3^-$, NO$_2^-$, PO$_4^{3-}$, Cl$, F^-$, NH$_4^+$, K$, Na^+$, and Li$^+$ concentrations. In 2001-2002, mine waters were found to have circumneutral pH and exhibit substantial alkalinity with elevated Fe, Zn, Pb and Cd concentrations. Water quality ranges for data collected 2001-2002 were 51-197 mg/L for Fe, 4-11 mg/L for Zn and 124-414 mg/L CaCO$_3$ eq. for alkalinity. The range in pH values was 5.8-6.2. In general, most water quality data showed very little change when compared with data from the 1980s study. However, metal contaminant concentrations changed substantially with average decreases in Fe, Zn, and Mn of 74%, 91%, and 74%, respectively. Changes in mine water chemistry are presumed to have occurred due to filling of mine voids with water, which altered the amount of oxygen available at exposed sulfide surfaces, thus decreasing rates of contaminant production. Prior surface water diversions characteristically deemed as having little impact on mine drainage discharge or receiving streams quality, may have substantially modified mine pool hydrology, thus resulting in a general improvement in water quality. The current mine drainage chemical composition lends itself to implementation of passive treatment systems for effective metal removal.

Additional Key Words: lead, zinc, mine drainage, Tar Creek Superfund Site

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UPTAKE OF ARSENIC BY NATIVE PLANTS GROWING ON GOLD TAILINGS IN WESTERN AUSTRALIAN RANGELANDS

J. Costello, H. Lacy, Z. Rengel, D. Jasper, and M. Quaghebeur

Abstract. The natural concentration of arsenic in soils may range from 1-40 mg/kg, whereas soils overlying sulphide ore deposits in Western Australia may contain several hundred mg arsenic per kg. The greater concentration of arsenic exists within the orebodies and their immediate surrounds, and values in the thousands of mg/kg are often recorded. As a result, high arsenic levels are often found in gold tailings milled from these orebodies. Environmental considerations require that local native species are established on tailings storage facilities (TSF). Uptake of arsenic by these plants is a concern, but there is little information available to allow the potential risks to be assessed in an Australian context.

A glasshouse experiment was conducted using arsenic–rich gold tailings as the growth medium. The aim was to determine if native plants accumulate arsenic, and their growth response in the tailings. A complementary field survey assessed accumulation of metals in native plant species growing on historic and more recent TSF’s in the Western Australian rangelands. In the glasshouse experiment, survival and growth of native species was far greater on low-arsenic material than on the arsenic-rich tailings. All the plants that survived in the tailings took up arsenic with concentrations ranging from 6 to 66 mg/kg, depending on plant species and the level of phosphorus application.

In the field, there were substantial interspecific differences in the concentration of arsenic in leaf material, for plants growing in arsenic-rich materials. For example, Atriplex species accumulated relatively little arsenic, even at high soil concentrations. By contrast, another chenopod, Maireana pyramidata, appeared to consistently take up larger quantities. Species of other genera appeared to fall in a range between these two. In preliminary comparisons of washed and unwashed Atriplex plants, it appeared that considerable quantities of arsenic may be also found on leaf surfaces. If confirmed, then arsenic that wildlife may ingest by eating leaves and shoots may be 50% greater than measured in this survey.

In 2 out of 14 species grown in the glasshouse experiment in these arsenic-rich gold tailings, arsenic concentrations exceeded the ANZECC maximum tolerable dietary intake level for livestock (50 mg inorganic arsenic per kg of diet). In the field study, arsenic in leaf material of Maireana pyramidata also exceeded the toxicity limit. Eight out of 14 species grown in the glasshouse experiment, and plants from two genera sampled in the field, contained in excess of 20 mg/kg of arsenic.

Additional Key Words: mining, revegetation.

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NATIVE MYCORRHIZAL FUNGI WITH ASPEN ON SMELTER-IMPACTED SITES IN THE NORTHERN ROCKY MOUNTAINS: OCCURRENCE AND POTENTIAL USE IN RECLAMATION

Cathy L. Cripps

Abstract: Aspen (*Populus tremuloides*) is an early successional tree that has naturally colonized large tracts of land near functioning and defunct smelter sites in the northern Rocky Mountains. This is evidenced by extensive aspen stands on the East Ridge of Butte (MT), behind the smelter stack at Anaconda (MT), near the (removed) smelter in Kellogg (ID), and downwind of the Trail, B. C. smelter (Canada). Aspen is able to colonize these areas due to mutualistic relationships with mycorrhizal fungi which increase phosphorus uptake, and ameliorate soil conditions such as low pH, high heavy metals, low fertility, and drought. Mycorrhizal fungi have been used to establish various trees on coal spoils and mine sites in eastern U.S., Ohio, and Utah, but use of aspen has not been examined. Typically a commercial fungal inoculum is added to trees, but inherent problems are: spread of exotic fungi, and use of expensive generic fungi which are not site/host specific. One solution is use of native fungi adapted to a particular tree species, soil type, and climatic region. This research is initiating investigation of the use of native mycorrhizal fungi to enhance aspen establishment on smelter-impacted sites. Thirty species of native fungi are reported on these sites, half of which grew under laboratory conditions. A few grew well enough to warrant further interest as inoculum, including: *Laccaria proxima*, *Tricholoma flavovirens*, *Tricholoma populinum*, *Scleroderma cepa*, and *Paxillus vernalis*. Inoculum is presently being developed for use in greenhouse and field studies with aspen. Potential for heavy metal immobilization and uptake are discussed.

Key words: ectomycorrhizal fungi, *Populus tremuloides*, smelters, heavy metals

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CHEMICAL AND PHYSICAL PROPERTIES OF MINERAL SANDS MINE SOILS IN SOUTHEASTERN VIRGINIA

W. L. Daniels, Z. W. Orndorff, and P.D. Schroeder

Abstract. Significant areas of prime farmland in the upper Coastal Plain of Virginia and North Carolina will be disturbed by heavy mineral sands (Ti/Zr-bearing ilmenite, rutile, zircon) mining over the next 20 years. The physical and chemical properties of mine soils that result from the mining and reclamation process were studied in a replicated small plot experimental setting between 1994 and 1997 and in detailed transects over a succession of eight mining pits reclaimed between 1997 and 2002. Separation of sandy tailings from silt+clay slimes in dewatering pits leads to significant differences in soil texture, seasonal wetness and bearing capacity across the reclamation surfaces. Plant growth in sandy tailings areas is directly limited by low water holding capacity while that in finer textured zones is limited by the massive and laminated nature of the slimes. Compaction of the surface and subsurface also limits rooting in non-sandy reclaimed areas. Freshly deposited materials tend to be very low in pH (< 5.2) and in plant-available nutrients due to the highly weathered nature of the original deposit and the mineral separation processes employed. Native topsoil on-site is very high in heavy mineral content, and is therefore subject to being processed rather than saved for reclamation. An array of reclamation protocols have been implemented at the site including heavy liming and P application, deep ripping, and the utilization of biosolids to improve post-mining productivity. Revegetation of eight mining pits produced between 1997 and 2002 was positively affected by the utilization of topsoil, and extremes in surface texture limited revegetation where topsoils were not employed. Issues associated with differential settlement as the fills dewater over time, and the possibility of P leaching in areas of pure sandy tailings warrant further study.

Additional Key Words: Reclamation, titanium mining, tailings, slimes, biosolids, tillage, soil strength, soil fertility, soil acidity.

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2W. Lee Daniels, Professor, Zenah Orndorff, Post-doctoral Research Associate, and Phil Schroeder, former Graduate Research Assistant, Dept. of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, VA, 24061-0404.
HORIZONTAL FLOW LIMESTONE BED (HFLB): AN EFFECTIVE AND VALUABLE PASSIVE TREATMENT SYSTEM COMPONENT FOR MANGANESE REMOVAL AND ALKALINITY GENERATION

Clifford F. Denholm, Timothy P. Danehy, Margaret H. Dunn, Shaun L. Busler

Abstract. Horizontal Flow Limestone Beds (HFLBs) are extremely useful and effective passive treatment system components that not only generate alkalinity, but also promote manganese removal. Generally, this component is placed at the end of a passive system in order to give the final effluent discharge an alkalinity boost and to remove additional metals. This component appears to be particularly effective in removing manganese. Although the manganese removal mechanism is not clearly understood at this time, processes such as auto-catalyzation and bacterial activity are suspected in addition to other related environmental conditions such as dissolved oxygen and dissolved iron concentrations. There does appear to be a lag time following the installation of the HFLB component when manganese removal is minimal, but after several months the removal rates increase. In some instances, up to 30 mg/L of manganese have been removed by this component and in some cases final effluent discharges with a pH of 7.5 or less possess less than 1 mg/L of dissolved manganese. Whether the lag time is due to the establishment of manganese-oxidizing bacteria and/or algal populations or due to the development of auto-catalytic processes or both, future research efforts should focus on a better understanding of these mechanisms and their role in passively treating acid mine drainage.

Additional Keywords: Passive Treatment Systems, Manganese, Horizontal Flow Limestone Bed

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SLAPPM TEST: AN EASY METHOD FOR A SIMPLE LIMESTONE ALKALINITY PRODUCTION PREDICTION AND MONITORING TEST FOR VERTICAL FLOW POND TYPE SYSTEMS

Clifford F. Denholm\textsuperscript{2}, Margaret H. Dunn, Timothy P. Danehy, Shaun L. Busler

\textbf{Abstract}. Limestone is one of the principal materials utilized in passive systems to treat acid mine drainage due to its relatively large percentage of calcium carbonate (CaCO\textsubscript{3}) content. When the limestone is placed in contact with acidic water it dissolves into ionic “species”, neutralizing acids and raising the pH in order to hydrolyze and precipitate metals. Since chemical and physical properties can vary greatly among different mine discharges as well as different kinds of limestone, it is highly recommended to perform a test to predict the alkalinity generation of the particular water to be treated with the specific stone to be used before designing the passive system. Although the “cubitaner” test has been proven to be a very useful indicator for the alkalinity generation of an anoxic limestone drain its results are somewhat limited for other types of systems and purposes. Through the use of a Simple Limestone Alkalinity Production Prediction and Monitoring (SLAPPM) Test, not only could the amount of alkalinity production and acid neutralization be roughly predicted per hour for an individual vertical flow pond type system, but the data can be plotted similar to a regression analysis curve and utilized to determine how well a system is functioning over time and to what degree or amount of effective contact time with the limestone is occurring within the system.

\textbf{Additional Keywords}: vertical flow ponds, passive treatment system, alkalinity production, limestone dissolution

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TRACE-METAL SOURCES AND THEIR RELEASE FROM MINE WASTES: EXAMPLES FROM HUMIDITY CELL TESTS OF HARD-ROCK MINE WASTE AND FROM WARRIOR BASIN COAL


Abstract. To assess the potential impact of metal and acid contamination from mine-waste piles, it is important to identify the mineralogic source of trace metals and their mode of occurrence. Microscopic analysis of mine-waste samples from both hard-rock and coalmine waste samples demonstrate a microstructural control, as well as mineralogic control, on the source and release of trace metals into local water systems. The samples discussed herein show multiple periods of sulfide mineralization with varying concentrations of trace metals.

In the first case study, two proprietary hard-rock mine-waste samples exposed to a series of humidity cell tests (which simulate intense chemical weathering conditions) generated acid and released trace metals. Some trace elements of interest were: arsenic (45-120 ppm), copper (60-320 ppm), and zinc (30-2,500 ppm). Untested and humidity cell-exposed samples were studied by X-ray diffraction, scanning electron microscope with energy dispersive X-ray (SEM/EDX), and electron microprobe analysis. Studies of one sample set revealed arsenic-bearing pyrite in early iron- and magnesium-rich carbonate-filled microveins, and iron-, copper-, arsenic-, antimony-bearing sulfides in later crosscutting silica-filled microveins. Post humidity cell tests indicated that the carbonate minerals were removed by leaching in the humidity cells, exposing pyrite to oxidative conditions. However, sulfides in the silica-filled veins were more protected. Therefore, the trace metals contained in the sulfides within the silica-filled microveins may be released to the surface and (or) ground water system more slowly over a greater time period.

In the second case study, trace metal-rich pyrite-bearing coals from the Warrior Basin, Alabama were analyzed. Arsenic-bearing pyrite was observed in a late-stage pyrite phase in microfaults and microveins that crosscut earlier arsenic-

Additional Key Words: jarosite, copper, zinc, microanalysis

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CONTAMINANT MIGRATION FROM ACIDIC-METALLIFEROUS TAILINGS INTO AN IN-SITU LIME AMENDED ROOT ZONE DURING A SEVEN YEAR PERIOD

D. J. Dollhopf*, and J. D. Goering

Abstract. Concern exists that acidic (pH 2.2), metalliferous (Cu, Fe, Zn) and As laden tailings treated in-situ with lime will in time become chemically unsuitable for plant growth. Specifically, acidity and metals from untreated tailings may migrate upward into the lime amended tailings via mechanisms associated with mass flow of water or diffusion. In spring 1995, a demonstration area was constructed where the 0-60 cm tailings zone, having a clay loam texture, was amended with a combination of CaCO₃ and CaO to facilitate contaminant precipitation from solution and a pH suitable for plant growth (pH 7.0-8.0). No water table was present within 6 m of the reclaimed surface. During the subsequent seven year period, the semiarid site supported grass production consisting of several wheat grass species and wildrye. Following sampling in 6 mm depth increments in replicated test pits, it was determined that after seven years as much as 7 cm of the amended zone nearest the acidic tailings had acidified (pH 4.0-4.5). Similarly, the specific conductance in this acidified zone increased significantly (9.8-12.3 dS/m) compared to that in amended tailings nearer to the surface (2.4-3.0 dS/m). Neither As, Cu, Fe nor Zn were present at significantly greater concentrations in the acidified zone, indicating these elements did not migrate from acidic tailings into the lime amended zone. It was not known whether acidification of the lime amended zone nearest the tailing was at equilibrium or not, suggesting additional acidification of the amended zone in the future was possible. These results indicate acidic-metalliferous tailings treated with in-situ liming methodologies should account for upward migration of acidity during the design process.


**Douglas J. Dollhopf, Professor, and John D. Goering, Geologist, Reclamation Research Unit, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman 59717.
RISEING ECOREGION MYTHS IN FEDERAL REVEGETATION POLICY

Richard Dunne

Abstract. A new revegetation goal, to maintain genetic diversity within the same species, may threaten future reclamation success. Advocates of “ecoregion” seed origins, restrictive seed transfer zones, and localized seed production are strongly influencing federal policy. The creation of generalized rules without scientific validation politicizes and undermines efforts to improve revegetation results. Local ecotype preferences are often based upon faulty assumptions about evolution, genetics, modeling and seed production realities. Federal contracting to grow locally collected seed in local seed production fields, without testing the fitness of selections, is flawed because local ecotypes are not inherently superior to broadly adapted cultivars. This program underestimates the difficulty of developing new species for seed production and by-passes research facilities which are designed to scientifically evaluate native species and to select improved cultivars. By creating an expensive and failure prone seed production system, we face the prospect of rising seed costs, limited supplies and diminished revegetation success. Imposition of such federal requirements on the mining industry will jeopardize our ability to chose the best seed. The war against weeds is being lost because local native species cannot repel many invasive species. By using our funding to protect local ecotypes, we risk losing entire ecosystems for lack of natives able to successfully compete with weeds. Research into improving native seed has decreased while the need for improved cultivars has increased. We cannot afford to waste money on an inadequate model of ecoregion seed production. We must accelerate research on improving key natives.

Keys words: ecoregion, seed transfer zones, ecotype, cultivar

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FROM DRAGLINE TO FISHING LINE – DEVELOPING A WILDLIFE MANAGEMENT AREA AND FISHERY AT A LARGE SURFACE COAL MINE IN THE SEMIARID WEST\textsuperscript{1}

Joe D. Friedlander\textsuperscript{2}

**Abstract.** In the late 1990’s, a reclamation plan was developed to create a lake and wildlife management area on reclaimed land at The Coteau Properties Company’s Freedom Mine in west-central North Dakota. Although final highwall or pit lakes at surface mines are not uncommon in the East, this was one of the first attempts to create a recreational lake and fishery in the semiarid West. Local demand for more public recreation areas and favorable physical site conditions provided an impetus for lake and recreation area development. A final highwall pit was planned for the area that normally would have been completely backfilled. In this case the final highwall pit adjoined abandoned orphan spoils where coal had been removed more than 30 years ago. East Antelope Creek, an intermittent creek flowing in response to heavy rainfall and spring snowmelt, ran nearby. The proposed lake was designed to accommodate flows from the diverted creek, taking about 5% of the entire projected annual yield from the 9,500 acre contributing watershed. The 45 acre lake has a linear configuration, a few hundred feet across and about a mile long. Its depth ranges from eight to 20 feet. It has been stocked with largemouth bass and bluegills. Along with the lake, reclaimed native grasslands, wetlands, shrubby plantings and old orphan spoils comprise the entire wildlife management area of 637 acres. This was donated to the North Dakota Game and Fish Department and will be managed for public hunting and fishing.

Many challenges were encountered when planning for the lake and surrounding wildlife management area. This project entailed a land use change to recreation and significant revisions in post-mine hydrology and topography. Starting in early 1998, Coteau submitted applications for numerous permits and approvals from several local, state and federal agencies. A large amount of time was spent answering questions from regulatory authorities. Coteau had to demonstrate that steeper slopes and shorelines would be stable, adequate water quantity and quality was available for a fishery, the inlet and outlets were properly designed, creek diversion did not cause a net loss of wetlands, downstream surface and groundwater impacts were minimal, public access was readily available, and that the North Dakota Game and Fish Department was willing and able to take over long-term operation and maintenance after bond release.

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SURFACE MINING AND RECLAMATION OF ABANDONED UNDERGROUND MINES

N. M. Frisbee

Abstract. Within the area that is now the Jewett Mine, there were several acres of abandoned underground lignite mines. Texas Coal Mining Regulations (Section 12.367) (Railroad Commission of Texas, 1997) prohibit surface coal mining activities within 152 meter (500 feet) of an abandoned underground mine unless jointly approved by the Railroad Commission of Texas and the Mine Safety and Health Administration. No reliable method could be found to define the extent of the underground mines, therefore the 152 meter buffer zone could not be defined. Once it was decided to surface mine the underground mines, Northwestern Resources Co. contacted and received joint approval from the regulatory agencies to mine through the abandoned underground mines and recover the remaining reserves.

Mobile equipment was used in the shallower overburden and a Marion 8200 dragline was used in the deeper overburden to uncover the lignite reserves remaining in the abandoned underground mines. A backhoe and front-end loader were used to clean the sediment out of the collapsed tunnels and mine the lignite.

Northwestern has made artifacts and information recovered during the archeological mitigation work and mining available to the community. Landowners will no longer have to be concerned about the dangers of open shafts and sinkholes. The reclamation of the abandoned underground mines was achieved without using funds from the Federal Abandoned Mine Land (AML) Program. The Federal AML tax was collected on all of the lignite tons recovered from the abandoned underground mines and will contribute to the reclamation of other abandoned mine lands. Northwestern Resources Co. is continually working to provide a low cost fuel source to Reliant Energy and in the process has been able to transform severely damaged abandoned mine lands into productive pastureland.

Additional Key Words: Texas lignite, Calvert Bluff, Wilcox Group, claypan, Post Oak Savannah, historical mine, archeology, topsoil substitution.

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Abstract. Due to increasing environmental pressure, the state of West Virginia has proposed legislative changes for acceptable post-mining land use for surface mined lands. Current legislation in West Virginia has emphasized the development of commercial forestry as the only post-mining land use on mountaintop surface mines that seek an AOC variance. In the spring of 2001, a research study was initiated in north central West Virginia to examine the establishment and sustainability of commercial hardwood forests on reclaimed surface mine land. Research involved the planting of commercial hardwood species [red oak (*Quercus rubra* L.), black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.)] into north- and south-facing aspects, ripped and unripped minesoils, mowed and unmowed groundcover, and direct seeded and 1-0 planted seedlings. First year results were reported last year, which showed extremely high survival for planted trees (>95% for all species). Black cherry and red oak seedlings were damaged by rodents toward the end of the first growing season (2001). Results after the second growing season showed that all planted species experienced additional mortality (survival varied between 80 to 99%). Differences in tree survival among treatments became significant by the end of the second growing season. Higher tree survival was found in ripped plots (88%) vs. unripped plots (75%) and in unmowed plots (85%) vs. mowed plots (79%) in 2002. These differences in survival during the second year were most pronounced on south-facing aspects. Tree establishment from planted seeds increased during the second growing season (2002) for some species, but declined for others. During the first year, 31% of black walnut seeds germinated and established, and this number increased to 40% as additional seedlings emerged the second year. During the first year, 30% of red oak seeds germinated, but survival was only 6% after the second growing season. It appears that red oak seedlings (from seed) could not compete with the groundcover. Mortality of seeded oaks was greater in the unripped and mowed plots. The other species (black cherry, white ash, and yellow-poplar) exhibited very low germination and establishment from seeds (4%, 1%, and 0% respectively).

Additional Key Words: black cherry, black walnut, red oak, reforestation, tree planting, tree seeds, tree seedlings, white ash, yellow-poplar.

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THE EFFECT OF ORGANIC MULCHES ON CRUSTING, INFILTRATION AND SALINITY IN THE revegetation of a saline-sodic coal mine spoil from central Queensland, Australia

A.H. Grigg, G.J. Sheridan, A.B. Pearce, and D.R. Mulligan

Abstract. Dumping of saline-sodic clay spoil materials at the surface during open-cut coal mining in central Queensland, Australia, poses significant challenges for revegetation, particularly where suitable capping media are not available. Infiltration is low and surface crusting can be severe, limiting seedling emergence and the entry of water into the soil profile and subsequent leaching of salts from the root-zone. High salinities in themselves further limit the availability of water to plants.

We examined the role of two different organic mulch amendments (sawdust and straw), either surface-applied or incorporated, in improving plant establishment on a saline-sodic spoil under the subtropical climate in central Queensland. Laboratory studies indicated that application of a surface mulch cover improved infiltration, increased surface soil moisture, and reduced surface crust strength. However, under field conditions downward migration of salts out of the root-zone was limited, with consequent negative impacts on overall revegetation success. Recommendations are made on revegetation strategies for saline-sodic spoils in the region.

Additional keywords: reclamation, salinity, crusting, straw, sawdust.

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2Andrew H. Grigg is Research Fellow, Gary J. Sheridan was Research Assistant, Andrew B. Pearce was Research Scholar, and David R. Mulligan is Director, Centre for Mined Land Rehabilitation, The University of Queensland, St Lucia QLD 4072 Australia.
OSM SERVICE SHARES TECHNOLOGY NATIONWIDE

Louis Hamm, Kyle Bohnenstiehl, and Billie Clark Jr.

Abstract. The U.S. Office of Surface Mining’s Technical Innovation, and Professional Services (TIPS) is a service developed by an innovative group of employees at the Office of Surface Mining. In cooperation with State and Tribal regulatory and reclamation agencies, as well as Office of Surface Mining offices nationwide, TIPS provides the latest off-the-shelf scientific and engineering software and hardware tools for Federal, State, and Tribal experts to do their job faster and more efficiently. Since its inception in 1988, it has expanded to serve 700 desktops at 96 locations nationwide.

The tools provided consist of off-the-shelf software and technology used commonly for scientific and engineering applications by the Mining Industry. With the Industry regulators at the State and Federal level using the very same tools, exchange of information is facilitated and the regulatory and reclamation processes are expedited. Through a system of license sharing TIPS is able to provide expensive software to 700 desktops nationwide at the cost of only a few licenses. By making the technology tools available to more people directly at their desktop, usage has grown from 56 licenses in use each business day in 2001 to more than 85 licenses used each business day in 2002. TIPS also provides full, no-cost training to its customers at three training centers in Pittsburgh, PA; Alton, IL; and Denver, CO.

Additional Key Words: Remote sensing, site planning, environmental design, site inventory, site analysis, GPS, GIS, photogrammetry, aerial photography, satellite imagery, LIDAR.

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DEVELOPMENT OF A RIPARIAN EVALUATION SYSTEM (RIPES) FOR THE CLARK FORK RIVER SUPERFUND SITE

Paul L. Hansen, Dennis R. Neuman, Stuart R. Jennings, and William H. Thompson

Abstract. Montana’s Clark Fork River is an EPA Superfund site due to human and environmental risks resulting from the fluvial deposition of acid metalliferous mining wastes along 120 miles of River’s corridor. Cleanup strategies include removal of some wastes, in-place treatment of other wastes, and stream-bank stabilization. A Riparian Evaluation System (RipES) has been developed as a data predicated decision tool designed to identify and categorize polygons based on landscape stability and plant community dysfunction within the Clark Fork River Operable Unit. The system contains the following elements: definitions for three types of stream-bank polygons, and descriptions of other polygons with varying levels of contamination caused vegetation community dysfunction; a numerical component with associated threshold scores that segregate stream-bank polygons into different categories, and threshold scores that distinguish the severity of dysfunction of the vegetation community; a process for identification of data gaps and information required to complete remedial designs for each polygon; and identification of modifying factors that may affect the selection of remedial action(s) for specific lands. The numerical portion of the system is based upon the Land Reclamation Evaluation System (LRES) developed for the Anaconda Smelter NPL Site (EPA 1998, CDM and RRU 1999, and ARCO 2000), and the Riparian and Wetland Health Assessment protocols (Hansen and others 2000), which are used extensively in the western United States and Canada. In the future, the system may be used to establish performance standards, evaluate land reclamation designs, post-action effectiveness evaluations, and monitoring and maintenance programs in reclaimed areas. The RipES tool is currently being evaluated for applicability to other sites in western USA.

Additional Key Words: Superfund reclamation, mine wastes, risk reduction

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Abstract. The North Antelope/Rochelle Mine Complex is located in the Eastern Powder River Basin between the towns of Gillette to the north and Douglas to the south. Elevations in the permit area range between about 4600 and 5000 feet above mean sea level. Porcupine Creek dominates the present morphology of the permit area. The entire drainage basin of Porcupine Creek is an erosional landscape with stream channels often gullied to the point where active flood plains are limited in extent. Porcupine Creek is classified as ephemeral, flowing only in response to snowmelt and rainfall in the watershed. The area receives approximately twelve inches of annual precipitation while annual potential evapotranspiration is twenty-five to thirty inches.

Following mining, the North Antelope Rochelle Mine Complex was required to restore the function of Porcupine Creek. The goals of the project were to create a creek structure and hydrology that will recharge local ground water, establish a maximum amount of wetland and riparian habitat that sustains hardy emergent and submergent obligate wetland vegetation, develop an alternating, stepped pool/riffle design and sinuous channel to simulate pre-mine conditions, and to stabilize streambanks that may erode during bank-full flows.

Porcupine Creek valley was reclaimed to follow a sinuous path within the permit area. The valley is designed to hold the 100-year flood and to be topographically suitable for flood irrigation agricultural activities. During the pre-mining surface water hydrologic studies, it was discovered that three levels of flow capacity are reflected in the pre-mining cross section of the existing Porcupine Creek channel and flood plain. The pre-mining discharges were identified as 35 cubic feet per second, 700 cfs and 6000 cfs, corresponding to the active; low flow channels and the flood plain. To encourage future agricultural activities and to discourage flood erosion of the surfaces, the low flow and flood plain channel are designed to have a large width/depth ratio. The active channel is expected to be sub-irrigated and the low flow channel should naturally flood irrigate.

Additional Key Words: wetland, riparian, sub-irrigated, alluvium, obligate wetland species, erosion, water quality, self-sustaining
CHARACTERIZATION AND DESIGN OF THE OLD DOMINION REMEDIAL ACTION PLAN

A. J. Hardy, N. R. Lindstrom, E. L. Bingham, W. A. Fuller, and R. C. Krohn

Abstract: The Old Dominion Mine in Arizona’s Globe-Miami mining district includes three tailings piles, one slag pile, and numerous waste rock dumps. The mine waste materials were generated from different operations between 1881 and 1931. The Old Dominion Remedial Action Plan (RAP) is an innovative program developed for remediating the impacts of historic mining activities on portions of the Old Dominion property in the Upper Pinal Creek drainage. Agency oversight is jointly provided by the U.S. Environmental Protection Agency and the Arizona Department of Environmental Quality. The goal of the remediation is to stabilize the mine waste materials, mitigating impact to groundwater and surface water to the maximum extent possible. The RAP was recently approved by the agencies and provides for physical and chemical stability of the mine waste materials. Considerations in the design included the high acid generating nature of the tailings and waste rock and the existing erosional and structural instability of the piles. Further, the site is subject to high intensity flows from stormwater runoff during the summer monsoon season and is located adjacent to an active railroad and a well-traveled state highway. Site characterization has included extensive static testing to determine the acid generating potential of the tailings and waste rock and detailed stability modeling. As a result, remedial measures include a 75-cm thick evapotranspirative soil cover and a 100,000 m³ rock buttress for stabilization of critical tailings slopes. Additional components of the RAP design include concrete cutoff walls and a complex network of lined diversion channels. This paper describes the results of the 8-year design and approval process.

Additional Key Words: Reclamation, Tailings, Source Control, Mine Site Closure, Site Characterization.

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SEASONAL CHANGES IN THE CHARACTERISTICS OF SUSPENDED SEDIMENT METAL TRANSPORT IN A MINING-IMPACTED STREAM

Barbara B. Harvey, James F. Ranville, and Philippe E. Ross

Abstract. An important source of metals to aquatic ecosystems is acidic, metal-rich effluents from active or abandoned mining sites. Natural processes and remedial activities both lead to the neutralization of acidity, which results in the removal of dissolved metals from the water column. This process produces sediment deposits and suspended particles having high metal concentrations. The amount and characteristics of metal-contaminated sediments and stream water, collected from a high-gradient stream reach (North Fork, Clear Creek) located in the Front Range of Colorado, were studied. Deposited sediments and suspended particulate material are dominated by very fine-grained (colloids and fine silts) iron oxyhydroxide precipitates that contain high levels of copper and zinc. Sediments of this type are susceptible to in-situ formation, re-dissolution, and aggregation/disaggregation processes. These fine-grained sediments are suspected to be the key to metal transport, fate, and toxicity in this system. We examined seasonal variations in the following: 1) water column dissolved and suspended metal concentrations, 2) relative size distributions of suspended and bed sediments, and 3) acid-soluble metal content in coatings from streambed rocks. Metals were found to be temporarily stored in loose flocculated sediments, which accumulated in periods of low flow. Significant metal transport occurred as these sediments were re-suspended during high-flow hydrologic events, including spring snowmelt and a localized summer rainstorm.

Additional Key Words: Acid mine drainage, AMD, colloids, iron oxyhydroxide.

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Modeling Sulfate-Reducing Permeable Reactive Barriers
For Treatment of Acid Mine Drainage

Paulo S. Hemsi2, Charles D. Shackelford, and Linda A. Figueroa

Abstract. The performance of sulfate-reducing permeable reactive barriers (PRB) used for the treatment of acid-mine drainage is critically affected by kinetics of cellulose decomposition and substrate production, as well as by kinetics of sulfate reduction and methanogenesis. When biofilm models are considered, the rate of substrate diffusion into the biofilm also affects performance. In this regard, results from an algorithm adapted to simulate the kinetics of the processes occurring in the PRB environment for the purpose of design and evaluation of PRBs are presented. The processes considered include solid organic-matter decomposition, glucose fermentation to acetate (the microbial substrate), sulfate reduction, precipitation of heavy metals as insoluble sulfides, and methanogenesis. Knowledge of the composition of the reactive mixture within the PRB is a pre-requisite for modeling cellulose degradation, especially in terms of parameter estimation. Preliminary modeling results for batch (no-flow) conditions reveal issues of practical importance in the design of sulfate-reducing permeable reactive barriers, such as restrictions in PRB performance due to slow kinetics of cellulose decomposition, and due to competition between sulfate reducers and methanogens for acetate.

Key Words: sulfate reduction, ground water, remediation, bioremediation.

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Abstract. Wildfires, combined with extended drought, have impacted millions of acres of forest and grazing lands in the West. Over the past 3 years, more than 272,000 wildfires occurred on 18.5 million acres across the United States. In the aftermath of such fire seasons, important questions arise: (1) should intense burns be seeded, and with what species and what methods, (2) will soil and water resources be protected and invasive species suppressed at reasonable costs, and (3) will seeded species impact timber regeneration and understory plant community composition? Similar questions have been raised in treating forestland disturbed by timber harvest. In 1974, the USDA Natural Resources Conservation Service (NRCS) began investigating these issues. Eventually, three field evaluation plantings (FEP's) representing four different forest environments were established on privately owned land in western and eastern Montana, from which timber was harvested. The FEP's were installed as replicated and unreplicated plots in the fall or winter following disturbance. In 1988, following widespread criticism of extensive aerial seeding conducted under the NRCS Emergency Watershed Program (EWP), six fire-impacted watershed-monitoring studies were established. The burned, and harvested and mechanically scarified sites were seeded with herbaceous species, mainly grasses. On all sites, the plan was to monitor results during years 1-3, 5, and 10 years after treatment. Results indicate grass seeding had little effect on tree regeneration, invasive species were suppressed on some sites by some seeded species, and on average, soil erosion was reduced by 39% on burned sites and 28% on logged sites in the cool-moist environment. There was no change in unseeded species numbers on the cool-moist and a loss of two unseeded species on the warm-moist environments, but only on the burned sites. Tree establishment was greater on both burned and logged sites in the cool-moist environment. On the burned sites, the numbers of seedlings were 67% of the controls, and on the logged sites numbers of seedlings were 53% of the controls. Even though seedling numbers were reduced, the site is considered fully stocked (1,195 trees ha⁻¹ or 484 trees ac⁻¹). The planting of...
MICROBIAL REDUCTION OF URANIUM IN MINE LEACHATE BY FERMENTATIVE AND IRON-REDUCING BACTERIA

Jeffrey B. Gillow, Bruce D. Honeyman, and John Spear

Abstract. Our hypothesis is that fermentative- and iron-reducing microbial activity in a permeable reactive barrier (PRB) intercepting U(VI)-laden leachate will result in a U(IV) precipitate. The project is composed of two connected phases: 1) batch studies; and 2) column studies. Batch studies are being used to optimize the reductive process and promote synergistic reduction of U by fermentative and iron-reductive microbial processes with efficient utilization of a carbon substrate. Microorganisms include Clostridium sp. and Shewanella putrefaciens. Carbon sources include glucose and cellobiose for Clostridia and acetate for S. putrefaciens. Column experiments will be used to evaluate the U(VI) bioreduction process under flow conditions. Both batch and column experiments will consider bioreduction of U(VI) that is complexed to inorganic (i.e., carbonate) and organic (i.e., citrate and fulvate) ligands.

Additional Key Words: bioreduction, remediation, permeable reactive barriers

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BIOAVAILABILITY OF METALS FROM SPENT HEAP LEACH ORE: A GREENHOUSE STUDY¹

Heidi M. Hoven² and Robert E. Long

Abstract. Rubber rabbitbrush (*Chrysothamnus nauseosus*) and fourwing saltbush (*Atriplex canescens*), representative of anticipated climax cover species for the heap leach pad of gold mining company in northern Nevada, were grown in crushed ore that had been accelerated through the leaching process. Accelerated leaching was done to mimic metal concentrations at closure of the mine. Plants were acquired from a distant nursery and grown in a 2 x 3 factorial greenhouse design, using three soil types, to assess the bioavailability and potential for bioaccumulation of metals in above ground tissues. Plants were transplanted into upwind native soils and two crushed ore composites with moderate and high concentrations of metals, respectively, in March, 2002. Plants were grown at an accelerated rate by keeping soil moisture content just below field capacity. Methods and the potential for risk to grazing livestock and wildlife will be discussed.

Additional Key Words: Arsenic, bioaccumulation, fourwing saltbush (*Atriplex canescens*), heavy metals, metal uptake, mine closure, risk of trophic transfer, Rubber rabbitbrush (*Chrysothamnus nauseosus*), selenium

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EVALUATION OF WATER QUALITY CONDITIONS IN COAL MINE BACKFILL IN THE POWDER RIVER BASIN OF WYOMING

Roberta N. Hoy, Kathy Muller Ogle, and Mark Taylor

Abstract: In the Powder River Basin of Wyoming, water quality monitoring data were evaluated for a number of wells completed in mine backfill, which have sufficiently recharged for evaluation of mining impacts on water quality. Based on the data reviewed to date, the backfill water quality is usually similar to baseline water quality in the Wyodak-Anderson coal aquifer and Wasatch overburden. However, as the backfill materials recharge, the trends in the concentrations of specific constituents (in particular, total dissolved solids and sulfate) may reflect site-specific conditions, including: proximity to recharge sources (e.g., clinker, unmined coal, and coal fenders between mines); changes in mining activities (e.g., temporary cessation of mining); and local conditions (e.g., leakage from impoundments). In some situations, constituent concentrations increase over time, while in others, constituent concentrations are relatively constant or are decreasing.

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RECLAMATION OF THE BLOCK P MILL SITE

John E. Hunt, John E. Carter, and Timothy W. Skoglund

Abstract. The Block P Mill Site is located approximately 18 km east of Monarch, Montana in the Barker-Hughesville Mining District of the Little Belt Mountains. Mining and milling of lead, zinc, and silver ores between approximately 1880 and 1930 led to the presence of unvegetated acidic mill tailings and degraded surface and ground water quality. Between 1998 and 2001, The Doe Run Company prepared an engineering evaluation / cost analysis (EE/CA) as a means of characterizing the magnitude and extent of soil and groundwater contamination and identifying potential options for reducing the risk posed to human health and the environment by conditions at the site. In 2002, the USDA-FS and the USEPA approved the EE/CA and selected a removal action alternative calling for onsite consolidation of the mill wastes and construction of a geosynthetic clay cap to minimize infiltration through the repository. In addition to the waste consolidation, the reclamation work will also reestablish stable stream channels and native vegetation to previously disturbed areas along Galena Creek and Dry Fork Belt Creek. Construction is expected to begin in 2004 and be completed in 2005.

Additional Key Words: EE/CA, lead, zinc, repository

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SHORT-TERM MICROBIAL RESPIRATION AS AN INDICATOR OF SOIL QUALITY FOR RECLAIMED COAL MINE SOILS OF NORTHEASTERN WYOMING

L.J. Ingram, G.E. Schuman, P.D. Stahl, and L.K. Spackman

Abstract. Soil quality and the ability of soil to sustain nutrient cycling in reclaimed soils will influence the subsequent establishment and maintenance of a permanent and stable plant community. We undertook an experiment using a recently developed “three-day CO₂ flush method” to compare a range of soil biological indicators across a series of reclaimed, surface coal-mined sites in the Powder River Basin of northeastern Wyoming. In addition, we were interested in estimating the amount of soil organic carbon (SOC) required to sustain nutrient cycling. Soils were sampled from each of two different reclaimed sites on four different mines in 2000. In 2001 we sampled soils from three sites on three mines - two reclaimed and a native, undisturbed prairie control site. For both years, soils were dried, rewetted, and microbial respiration measured at three and 21 days, using base trap methods. In addition, microbial biomass, nitrogen (N)-mineralization, organic carbon (C) and total N were measured. Regression analyses were accomplished by regressing three-day microbial respiration against the other soil parameters measured. Correlations between three-day microbial respiration and all of the measured soil parameters were generally strong ($r^2 \geq 0.55$) and highly significant ($P < 0.0001$). There were differences between the reclaimed and native sites; the native sites exhibited more variability (although still significantly correlated), probably due to either differences in the relative lability of the substrates present or differences in the structure of the microbial communities present in the native versus reclaimed soils. We believe this method is of use as a relatively fast, accurate, and economical means by which soil quality can be ascertained. Estimates of SOC required to sustain nutrient cycling appears to be in the upper range of 0.1-0.7% C.

Additional Key Words: reclamation, semi-arid climate, microbial activity

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Abstract. The Weed Exclusion / Eradication Demonstration (WEED) is an effort to investigate the long term weed exclusion potential of several species of introduced and native grasses while demonstrating the necessity of first year weed control. This project specifically addresses problematic weed invasion observed in reclaimed areas in the upper Clark Fork Basin in southwest Montana – Butte, Anaconda, and Deer Lodge. The WEED site is located approximately one mile west of Butte and is representative of a frequently encountered scenario in upper Clark Fork reclamation - a recently disturbed area surrounded by perennial weed infestations (spotted knapweed, yellow and dalmation toadflaxes, leafy spurge). Exclusion treatments consisted of six seed mixes that were designed to investigate those species best suited to exclude weeds over time. Seed mixes included competitive introduced grass mixes, less competitive native grass mixes, the Uptown Butte mix that has been used since 1997, and a Russian wildrye / alfalfa mix. Four inch (10.16 cm) drill row spacing, versus the standard eight inch (20.32 cm), was additionally implemented on two of the treatments to investigate the potential weed exclusion benefits of tighter drill row spacing. All eight treatments were replicated three times yielding 24 plots. The eradication treatment consisted of a first season blanket application of a broadleaf selective herbicide, after the grasses had developed sufficient leaf growth. The plots were split, at random, with one half receiving herbicide application. All plots were qualitatively evaluated, with respect to cover, in August of the second season. Second year results indicate that competitive introduced grasses and first year weed control substantially reduce or eliminate weed invasion. The introduced grass seed mixes also exhibited the highest percentages of second year cover.

Additional Key Words: grass and weed competition, herbicide application, weed control
USING TOPSOIL AS A MICROBIAL INOCULANT

John Inkret, Bernie Jensen, Doug Richmond

Abstract: Pastures historically irrigated from the Clark Fork River in southwest Montana exhibit elevated metals and acidity. In 1999, some of these pastures were amended with product lime (CaO-60% / CaCO\textsubscript{3}-40%) and plowed to 12 inches (30 cm). The 1999 remediation strategies acknowledged and emphasized the mineral, inorganic chemistry of the soils yet the 2000 revegetation results were unacceptable. The years of 2000 and 2001 were the driest on record for the project area and spring drought hampered revegetation efforts. In 2002, the authors proposed some biological amendment strategies as a demonstration for improved grass establishment under dry conditions. The biotic component of soil restoration should be considered as an integral part of grassland agriculture. Acid, metal-laden soils are an inhospitable chemical environment for beneficial soil microbes. A liming event that raises the soil pH to 10 or more would also be inhibitory to most microbes. After a limed soil has mellowed to a more neutral pH, beneficial soil microbes and organic matter can be introduced as biological amendments.

This demonstration utilized living grassland topsoil, as a microbial inoculant, at a rate of 2 tons per acre (4.5 metric tons per hectare). Two rates of compost (1.5 % OM and 3.0 % OM) were applied with and without topsoil. The topsoil amendment and the limed control soil were tested for the presence of mycorrhizal propagules. The 3 treatments and respective controls were replicated 3 times for a total of 18 plots. All plots were chisel plowed to a depth of 6 inches (15 cm) prior to amendment applications. After amendment application, all plots were disk plowed twice to 6 inches (15 cm) for amendment incorporation and all plots were drill seeded with the same grass seed mix at the same rate. Each plot represents 0.09 acres (0.04 hectare). The entire demonstration area represents 1.6 acres (0.65 hectare) and will be irrigated in May and June of the first year (2003) if necessary for establishment. Plots will be monitored and evaluated annually in late July or early August using plant cover as the response variable.

Additional Key Words: mycorrhizae, VAM, soil organic matter

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Abstract. ElectroChemical Remediation Technologies (ECRTs) utilize an AC/DC current passed between an electrode pair (one anode and one cathode) in soil, sediment, or ground water to either mineralize organic contaminants through the ElectroChemicalGeoOxidation (ECGO) process, or complex, mobilize, and remove metal contaminants through the Induced Complexation (IC) process, either in-situ or ex-situ. Field remediation data suggest that ECRTs-IC cause electrochemical reactions in soil, sediment, and ground water that generate metallic ion complexes from the target contaminant metals. These complexes, along with naturally occurring dissolved metals, migrate to the electrodes down the electrokinetic gradient and are either concentrated at the electrode (e.g., cesium, strontium) or deposited onto the electrodes (e.g., mercury, cadmium, lead). The metal contaminants concentrated at the electrodes can be pumped and treated, and the metals that deposit on the electrodes can be either disposed of or recycled. ECRTs-IC operates at electrical power levels below those of conventional electrokinetic methods. A unique feature of ECRTs-IC, in marked contrast to electrokinetics, is that metals generally migrate to both the anode and cathode. European field projects include remediation of (1) mercury in brackish water silty sediments, where 76 kg (168 lbs) of mostly mercury were deposited at both electrodes in 26 days of total remediation time; (2) parts per billion ground water contamination of a variety of metals beneath a steel mill waste lagoon, where metal concentration decreases up to 93% were achieved in 30 days of total remediation time; and (3) mercury in sewage sludge contaminated with dental amalgams, which showed an average decrease from 35 mg/kg to 0.185 mg/kg in seven days. A recently completed U.S. laboratory test for the U.S. Department of Energy under fresh water conditions corroborated the European field remediation results. Existing field and laboratory results indicate that ECRTs-IC is a rapid and effective remediation process.

Additional Key Words: innovative, in-situ, contaminant, mercury, lead, zinc, chromium, nickel, copper, heavy metal.

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ECOLOGICAL ASSESSMENT OF THREE OKLAHOMA STREAMS IMPACTED BY MINE DRAINAGE: HABITAT AND WATER QUALITY

Niki J. Iverson and Robert Nairn

Abstract: Eastern Oklahoma’s water resources are impacted by abandoned mine drainage. Passive treatment strategies have been demonstrated to improve water quality at abandoned mines, but watershed reclamation strategies, including a complete assessment of physical habitat degradation of stream ecosystems, are lacking. Mine drainage impacts to three Oklahoma streams were investigated by analyzing water quality, habitat availability, and riffle substrate distribution. Net acidic mine drainage originating from abandoned underground and surface coal mining activities has impacted Pit Creek (Latimer County) for more than 70 years. Beaver and Tar Creeks (Ottawa County) are impacted by net alkaline mine drainage from abandoned lead and zinc mining activities. Overall impact to water quality and habitat availability was assessed. All streams were determined to be impaired by mine drainage originating from discharges, seeps, and leachate derived from mine waste piles. Stream habitat quality varied considerably based on both mining and non-mining related impacts. As a result of this analysis, watershed reclamation strategies, based on passive treatment system design and implementation, will be prioritized and the potential for stream ecosystem recovery evaluated.

Additional key words: habitat availability, water quality, passive treatment

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CHEMISTRY OF STREAM SEDIMENTS AND WATER AS GUIDES TO DETERMINE THE IMPACTS OF ABANDONED MINES ON THE UPPER RED RIVER, TAOS COUNTY, NEW MEXICO

Meghan L. Jackson, Virginia T. McLemore, Bruce M. Walker, and Glen Jones

Abstract. Placer gold deposits, volcanic-epithermal vein systems, porphyry molybdenum deposits, veins and replacements in Precambrian rocks, and pegmatites are found in the Red River watershed, where more than 250 mining properties comprise parts of the Twining, Red River-Rio Hondo, and Questa mining districts. The purpose of this study is to investigate the effects of alteration, mineral deposits, and mining activities on the chemistry of the upper Red River water and stream sediment.

Fifteen samples of water and 15 samples of stream sediment were collected, each from below a major drainage entering Red River between its headwaters and the Fawn Lakes Campground, 4.5 km upstream of the Molycorp Questa molybdenum mine. The total reach of the Red River sampled was 18.7 km. Water samples were analyzed for major anions and cations by flame atomic absorption spectroscopy (FAA) and trace elements by inductively coupled plasma mass spectroscopy (ICP-MS). Sediments were sieved and divided into two size fractions (2mm-63 microns and <63 microns), then analyzed for Mn, Ti, Fe, and trace elements by X-ray fluorescence (XRF) using pressed powder briquettes.

A distinct change in water chemistry was observed at the upstream limit of regional argillic alteration. In water samples, increased concentrations of Mg (3.9 to 10 ppm), Si (below detection limits to 18 ppm), F (below detection limits to 0.35 ppm), SO₄ (8.3 ppm to 87 ppm), and Na (1.6-4.5 ppm to 9.1 ppm) were found downstream of and adjacent to areas of argillic alteration in the Mallette Creek drainage. Some water samples collected from the Red River were found to be higher in Al and Mn than EPA Drinking Water Standards. These high Al and Mn samples (>0.26 ppm Al and >0.2 ppm Mn) were collected from drainages dominated by Tertiary volcanic/intrusive rocks with areas of argillic alteration. No samples were found to be out of compliance with EPA Drinking Water Standards or New Mexico Ground Water Standards for Domestic Supply in any other elements or ions (Cl, SO₄, F, As, Ba, Be, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Se, Ag, U, or Zn).

Downstream of Black Copper Canyon and at West Fork, a relationship is indicated between elevated Cu and Zn in river water and mineralized areas. The highest Cu concentrations (0.053 ppm) measured in the river water were collected downstream of West Fork (sample average = 0.026 ppm). At Black Copper Canyon, Zn concentrations increased from 0.0005 ppm to 0.091 ppm.

Sediment samples show an increase in S concentration from 184-1382 ppm to >2584 ppm in both size fractions downstream of the upstream extent of regional argillic alteration. The increase in S in sediment appears to be due to the oxidation of pyrite and the presence of sulfate minerals including gypsum, jarosite, and others in the altered areas. A plot of Ca versus SO₄ from water sample analyses indicates that upstream of this
limit, carbonate dissolution results in excess calcium relative to the gypsum dissolution line, while downstream of this limit excess sulfate suggests a significant dissolution of pyrite relative to gypsum.

Arsenic and Pb concentrations in both sediment size fractions increase steadily downstream. Pearson correlation coefficients between As and S (>0.80 in both size fractions) indicate a strong correlation between the two, which suggests that As may be present in the stream in the form of a sulfide or sulfate mineral (such as pyrite, arsenopyrite, tetrahedrite/tennantite, and arsenic-bearing jarosite). Strong Pearson correlation coefficients also exist between Fe, Ti, and V (>0.79) in the large size sediment fraction, suggesting the presence of significant magnetite-ilmenite.

Integration of the chemical and mineralogical data with geologic data, information on inactive mining properties, and cultural features shows a spatial relationship between high concentrations of Al (>0.26 ppm), Mn (>0.2 ppm), SO₄ (>50 ppm), F (>0.2 ppm), Si (>12 ppm), Cu (0.025 ppm), and Zn (0.084 ppm) in water samples and the upstream limit of mapped alteration within the drainage. Elevated concentrations of these elements may be associated with the oxidation of pyrite in altered rocks, especially in areas of exposed, intense argillic alteration rather than the areas of most mining activity. These data suggest that hydrothermal alteration and associated acid rock weathering is a more significant factor in the observed changes in stream chemistry than is mining activity.

Additional key words: Alteration, volcanic-epithermal veins, placer, Questa, Twining, Rio Hondo, Great Plains Margin gold, alkaline gold deposits, porphyry molybdenum deposits

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REVEGETATION OF GOLD RESIDUES IN THE EASTERN JARRAH FOREST IN THE SOUTH-WEST OF WESTERN AUSTRALIA

Warren McGrath, Richard Bell, David A Jasper, Christoph Hinz, Iain Struthers, Judy Eastham, and Paul McNeil

Abstract. Revegetation of mine residues (tailings) is an important aspect of rehabilitation after mining, and represents a substantial investment. Therefore it is important to increase our understanding of all aspects of re-establishing a sustainable vegetation community on these materials. We report here on a multi-disciplinary, collaborative research program, focusing on vegetation establishment, soil development, and water-balance modeling on a large residue revegetation experiment.

The study focused on gold residues produced at the Boddington Gold Mine (BGM) and Hedges Gold Mine (HGM), in the south-west of Australia. The residue storage areas will be rehabilitated once no longer required, but revegetation may be hampered by the alkaline, saline, and sodic properties of the residue. A large field experiment was established to examine soil amendments and capping strategies. The treatments were three depths of gravel-rich subsoil (0 cm, 15 cm, and 30 cm) overlying residue treated with gypsum (30 t/ha). All plots subsequently received an application of topsoil (10 cm). The plots were established in 1999 with species from the local jarrah (Eucalyptus marginata Donn. ex Smith) forest, or salt- and waterlogging-tolerant native species.

Ten months after application, gypsum had contributed to a decrease in residue pH and salinity. By March 2000, approximately 90% of the directly seeded species had emerged and survived, and 100% of transplanted seedlings had survived. Applying gravel subsoil in addition to topsoil did not improve plant growth in the first two years. In fact, aboveground biomass production was higher, from 4 to 8.5 t/ha/yr, in the absence of a gravel subsoil. However, in the third growing season, this trend was less apparent. Plant roots were found to grow into the residue, preferentially following shrinkage cracks and exploring coarser-textured layers. Vigorous plant and root growth, and thus high plant water use, has resulted in substantial drying of the residue profile. On-going studies are examining water and salt movement through these profiles and long-term plant performance. At the same time, an overall model is being developed to predict the net water balance if the whole residue area was vegetated.

Additional Key Words: root growth, salinity, topsoil, water balance modeling.

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APPLICATION OF THE LAND RECLAMATION VALUATION SYSTEM TO DISTURBED LANDS AT THE ANACONDA SMELTER NPL SITE

S. R. Jennings, R. B. Rennick and D. R. Neuman

Abstract. Large areas of metal contaminated land surrounding the town of Anaconda, Montana will be reclaimed as mandated by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Barren and sparsely vegetated soils enriched in Cu, Zn, Cd, As, and Zn are common, and have been implicated as unacceptable health risks to both human and ecological receptors. Complex patterns of contaminant deposition by aerial and fluvial processes has resulted in extraordinary variability in ecological function over short distances. The need for refinement of treatment acreage and cost was jointly recognized by government regulators and by the Responsible Party. The Land Reclamation Evaluation System (LRES) was subsequently created as a data predicated decision-making tool designed to determine the location and intensity of remedial action across the site. The system includes several components including guidance criteria driven by statute, quantitative scoring of soil and vegetation condition and modifying criteria reflective of unique physical and cultural conditions observed. Application of the LRES process was initiated in 1998 and continues to guide remedial design for thousands of acres at the site.

Additional Key Words: Smelter fallout, mine tailing, Superfund

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2 Stuart R. Jennings, Research Scientist and Dennis R. Neuman, Director, Reclamation Research Unit, Land Resources and Environmental Sciences Dept., Montana State University, Bozeman, MT, 59717. Robert B. Rennick, CDM Federal Programs Corp., Helena, MT, 59601.
USING MINESOIL AND OVERBURDEN ANALYSES TO LOCATE A HIGHWAY IN WEST VIRGINIA

Jennifer R. Jones, John C. Sencindiver, and Jeffrey G. Skousen

Abstract. Appalachian Corridor H will pass through Beaver Creek watershed in Tucker County, West Virginia. Some of this area has been affected by surface mining of Upper Freeport Coal. The resulting mined lands are currently producing acid mine drainage, and have the potential to produce more if disturbed. In order to document soil development and to predict impacts of disturbance on water quality, a study was initiated to evaluate properties of the minesoils that may be affected by highway construction. Six sampling sites were located on both minesoils and native soils, and both will be disturbed during road construction. Soil profiles were described and horizons were sampled for laboratory analysis. Analyses of pH; total carbon and sulfur; and acid-base accounting were completed for the soils. The pH values ranged from 3.2 to 5.0. Total sulfur was generally low, ranging from 0.01% to 0.64%. Several rock cores drilled along two proposed routes by a private firm were sampled and analyzed by acid-base accounting procedures. The cores indicated generally acidic rock units in this region and the potential of producing additional acidity if unweathered rocks and minesoils are exposed to the atmosphere. The minesoil and core data have been used to assist the West Virginia Division of Highways in locating the corridor through the mined areas.

Additional Key Words: acid-base accounting, acid mine drainage, soil development, reclamation.

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4 Jennifer R. Jones is a graduate research assistant and John C. Sencindiver and Jeffrey G. Skousen are professors in the Division of Plant and Soil Sciences, West Virginia University, P.O. Box 6108, Morgantown, WV 26506-6108.
NON-AGRICULTURAL C AND P VALUES FOR RUSLE

R.D. Karpilo, Jr. and T.J. Toy

Abstract: There is little consensus in the erosion-science community concerning which values for the cover-management factor (C-factor) and the supporting practice factor (P-factor) should be used when the Revised Universal Soil Loss Equation (RUSLE) is applied to non-agricultural lands such as mined lands and construction sites. Likewise, there is uncertainty and inconsistency concerning the C and P values to use to account for the effects of various erosion-control products and devices. The C and P factors developed originally for use on agricultural lands may not be directly applicable to other types of land disturbances, such as mined lands and construction sites. The purpose of this study is to examine the C and P RUSLE factors used for non-agricultural applications. Over 1100 individuals who downloaded RUSLE software from the USDA-ARS-National Sedimentation Laboratory website between December 1998 and February 2003 were contacted via email and asked to complete a survey detailing their use of RUSLE. The departments of transportation in each of the 50 US states were contacted to determine which C and P values they use to calculate soil loss from highway construction sites. Several major manufacturers of erosion-control products and devices were also contacted to ascertain which C and P values they recommend for use with their products and how those values are derived. In addition, several erosion-science professionals were contacted to learn which C and P values (and the sources of those values) they utilize for non-agricultural RUSLE applications. The results of this inquiry indicates that the majority of the C and P values applied to non-agricultural land disturbances are either largely based on the agricultural values or are supported by little or no scientific analysis. Those C and P values found to have been calculated using the methods outlined in Agriculture Handbook 703 (Renard et al. 1997) were considered the most appropriate values to use when RUSLE is applied to non-agricultural land disturbances.

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6Ronald D. Karpilo is a Graduate Student in the Department of Geography at the University of Denver, Denver, CO 80208. Terrence J. Toy is a Professor of Geography at the University of Denver.
TREE SURVIVAL ON A MOUNTAINTOP SURFACE MINE IN WEST VIRGINIA

Jim King and Jeff Skousen

Abstract: Due to increasing environmental pressure, the state of West Virginia has recently changed its regulations that govern reclamation of mountaintop surface mines. The state regulatory authority now requires the development of commercial forestry as the only agronomic post-mining land use acceptable for mountaintop surface mines that seek a variance from returning the land surface to approximate original contour (AOC). The Samples mountaintop surface mine in southern West Virginia has obtained AOC variances and therefore has commercial forestry as a post-mining land use. Operators of the Samples Mine have initiated a reforestation program where about 20,000 trees per year (roughly 20 ha per year) have been planted at the site over the past six years. During 2002, West Virginia University researchers established belt transects (4.8 m wide by 100 to 200 m in length) in 55 plantations at the site to determine survival of planted trees and to evaluate tree height and stem diameter. Evaluations were performed on plantations established in the spring of 1999 and the spring and fall of 2001. In each transect, slope, aspect, and ground cover were measured, and survival and growth of trees were analyzed according to these site conditions. Average tree survival across these three planting seasons and among all tree species was 65%. Black alder (Alnus glutinosa (L.) Gaertn.) was the largest of the planted trees, but sycamore (Platanus occidentalis L.), pine (Pinus spp.), white ash (Fraxinus americana L.), red maple (Acer rubrum L.), and black cherry (Prunus serotina Ehrh.) also showed good growth. Slope was used as a surrogate for soil compaction (steeper slopes tended to be reclaimed with smaller equipment compared to flatter slopes) and tree survival was 75% on slopes >50%, 62% on slopes 31-50%, and 67% on slopes <30%. Tree survival was not different among five aspect classes (ranging from 59% on W aspects to 68% on E aspects). Tree survival was significantly higher (74%) on areas with <50% ground cover and lower (62%) on areas with >70% ground cover.

Additional Key Words: aspect, compaction, ground cover, hardwoods, reclamation, reforestation, slope.

2Jim King, Graduate Research Assistant, Jeff Skousen, Professor, Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV 26506-6108. Corresponding author: jskousen@wvu.edu
BREEDING BIRD SURVEY OF RECLAIMED AND NATIVE WOODLANDS IN NORTH DAKOTA

Donald R. Kirby, Darin J. Eisinger and David J. Nilson

Abstract. Woodlands comprise only about 1% of the landscape of the northern plains and provide valuable habitat for wildlife including breeding birds. Surveys were conducted between 1986 and 2000 for breeding birds on a native and a reclaimed woodland to evaluate the potential of mitigated woodlands lost to surface coal mining operations as replacement for native woodlands. Vegetation characteristics such as species composition and density, canopy cover, structure, amount of edge and ground cover were evaluated. Breeding bird surveys were conducted from mid-May through mid-June using the spot-mapping method. The native woodland had greater plant species diversity, stem density, canopy cover and height structure than the 18 year old reclaimed woodland. Both woodlands had a similar amount of edge of habitat. Breeding bird densities were higher in the native woodland throughout the study period 1986 to 2000. Species richness was higher 12 of 13 sampled years in the native woodland. Trend in density and species richness of breeding birds on the reclaimed woodland was higher throughout the study. Given sufficient time the reclaimed woodland may perform similar functions to native woodlands.

Additional Key Words: reclamation, wildlife, diversity, species richness.

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Lazy K Marsh was constructed in 1999 to enhance habitat for wetland-dependent wildlife in Teton Valley, Idaho. The project received broad financial support because of the unique, sensitive, and threatened wildlife resources being targeted. Teton Valley’s 27,000 acres of wetlands are home to fall staging sandhill cranes (Grus canadensis), breeding long-billed curlew (Numenius americanus), wintering trumpeter swans (Cygnus buccinator), short-eared owls (Asio flammeus) and large concentrations of migrating waterfowl including pintails (Anas acuta). Our primary goal was to create waterfowl brood-rearing and shorebird habitat. Secondary goals included establishing dense nesting cover for resident waterfowl and food plots for spring migrating sandhill cranes. Revegetating the project area was daunting with nearly 30 acres of constructed marsh. We developed cost-effective techniques for establishing emergent marsh, submerged aquatic and upland grass communities in areas historically used for livestock grazing. Alkali soils, aggressive introduced pasture grasses and noxious weeds compounded the problem. Initial revegetation efforts consisted of planting almost 10,000 native wetland plugs. We drill-seeded disturbed uplands (including the dike) with a mix of native grasses and forbs. Wildlife herbivory mostly by Canada geese was the major impediment to establishing vegetation. A constructed peninsula was particularly difficult to revegetate in this regard. Waterfowl concentrated on the peninsula and grazed vegetation to bare soil, increasing soil erosion and weed invasion by Canada thistle (Cirsium arvense). After many failed plantings we enclosed the peninsula with snow fencing in 2002 and replanted. Pre-vegetated coconut matting was used to stabilize soils on the windward side and proved extremely effective. Plant species selection, planting techniques, weed control, and herbivory control were critical for vegetation establishment. Lazy K Marsh has become an important habitat in Teton Basin.

Additional Key Words: waterfowl, revegetation, Canada geese, herbivory
CLASSIFICATION OF MINESOIL SERIES AS NOOSOLS

Alan Kosse

Abstract. Proposals for a separate order of Noosols have been advanced to include soils where anthropogeomorphic processes predominate. Although several soil series for minesoils are established in the United States, these soils have been not been fully incorporated in the U.S.D.A. taxonomic system. Problems in separating minesoils from “natural” soils remain, and these soils are inevitably placed in Entisols (Orthents or Arents). Proposals for recognizing a separate suborder of Spolents have not been approved, while attempts to distinguish minesoils at the subgroup level seem inconsistent with family criteria. Classification of established minesoil series is discussed, and suggestions made to reclassify these as Spolnos in the new soil order. Proposed subgroup taxa for Spolnos are presented, which have more affinities with those in Arents. Specific family criteria are then introduced, following normal protocol; dominant lithology may be indicted where relevant in parentheses after particle-size class.

Key words: Minesoils, Noosols, Spolnos, anthropogeomorphology, anthropedogenesis

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2 Alan Kosse is a retired soil scientist from the Bureau of Indian Affairs (Gallup, NM), whose address is 795-B Tramway Lane, N.E., Albuquerque, NM 87122.
RELATIONSHIP OF SALTCEDAR (TAMARIX RAMOSISSIMA) AGE AND STAND STRUCTURE TO SOIL CONDITIONS IN THE BIGHORN BASIN, WYOMING

Courtney G. Ladenburger, David J. Kazmer, Ann L. Hild, Stephen D. Miller, Larry C. Munn

Abstract: Saltcedar (Tamarix ramosissima Ledebour) is an introduced, invasive shrub that has become established along waterways in many western states. Detrimental changes in the composition of vegetation along these waterways have prompted concern for the biological integrity of Tamarix-invaded sites. The spread of saltcedar into Wyoming and Montana has elicited questions regarding its invasiveness and influence in northern climates. We selected 16 saltcedar sites in the Bighorn Basin of northern Wyoming to address the relationship of saltcedar age and stand structure to soil properties. Sites varied in Tamarix dominance and associated native vegetation (Sarcobatus vermiculatus, Artemisia tridentata, and Populus deltoides). Within each site, we documented soil parameters at five replicates per five microsite positions. The positions were beneath the canopy of large-based Tamarix, beneath the canopy of randomly selected Tamarix, interspaces associated with the large-based Tamarix, interspaces associated with the randomly selected Tamarix, and beneath the canopy of native woody plants. At each position, soil samples were collected from four soil depths (0-5, 6-20, 21-35, and 36-50 cm) and analyzed for electrical conductivity, pH, organic matter, nutrients, and texture. Saltcedar sections from just below the union of stems were collected, sanded, and ring-counted for age determination. In general, surface soils (0-5 cm) have greater electrical conductivity and lower pH than deeper soils. Surface soils (0-5 cm) beneath Tamarix have higher electrical conductivity and lower pH values than interspace soil. However, within the majority of sites, electrical conductivity was at a tolerable level for most plants. Results of this study are of consequence for revegetation following saltcedar control.

Additional Key Words: weed, invasive, electrical conductivity, pH

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2 Courtney Ladenburger, Research Assistant; Ann. L. Hild, Associate Professor; Larry C. Munn, Professor, University of Wyoming Department of Renewable Resources, Stephen D. Miller, Professor, University of Wyoming Department of Plant Sciences Laramie WY 82071; David J. Kazmer, Research Entomologist, USDA-ARS-NPARL, Sidney MT 59270
HOME ON THE RECLAIMED RANGE – CAN A FAMILY STILL MAKE A LIVING?7

Roy S. Liedtke and Wendy S. Hutchinson8

Abstract. Reclamation specialists have been researching and planning reclamation for over 20 years in the West, but have they been facilitating postmining land use development? An economic evaluation of a premining ranching operation compared to a reclaimed area ranching operation shows that a postmining rancher can make a living, providing all of the necessary postmining features are included in the design.

Current reclamation planning needs to focus on the economics of ranching. Pasturelands, water sources, roads, and related features must be included in the reclamation plan. If vegetation and wildlife are the only focus of reclamation planning, the land will be less economically viable; therefore, the reclaimed land will not support the postmining land uses that are currently envisioned. A ten-year cash flow analysis of three cases was conducted. Case 1 assumed premining land conditions. Case 2 assumed currently permitted and encouraged reclamation practices in Wyoming, which focus on wildlife habitat over postmining agricultural use. Case 3 provided agricultural improvements to the Case 2 reclamation plan, by increasing the acreage of reclaimed pasturelands and reconstructing agricultural water source distribution. Analysis of the cases revealed a net present value of $61/acre, $39/acre, and $89/acre respectively for the three cases. Thus focusing reclamation planning on wildlife features is economically worse than the premining situation. However, reclamation planning focused on the agricultural postmining land use can be achieved and yield better financial results than premining, while still providing wildlife habitat.

Additional Key Words: ranching, economics, cash flow, postmining land use, reclamation planning, environmental design, landscape architecture, site planning.

7 Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation and The 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

8 Roy S. Liedtke, Environmental Specialist, Jacobs Ranch Coal Company, Gillette, WY 82717 Wendy S. Hutchinson, Regulatory Affairs Manager, Thunder Basin Coal Company, LLC, Wright, WY 82732
ACID SULFATE WETLANDS IN THE NSW COAST, AUSTRALIA: CHEMICAL CHARACTERISTICS AND THEIR IMPLICATIONS FOR ENVIRONMENTAL REMEDIATION

C. Lin

Abstract. Acid sulfate wetlands are widespread in the New South Wales (NSW) coast, Australia. Acid sulfate soils have caused severe environmental problems in the area with land scalding, accompanied by the discharge of highly acidic drain water into estuarine waterways being the worst-case scenario in these landscapes. The investigated acid sulfate scalds are characterized by an extremely acidified topsoil layer (0–0.6 m). In general, the scalded acid sulfate soils have less organic matter and soluble phosphorus, and a greater salinity, soluble acidity, soluble Al, Mn and Zn concentrations, compared to the adjacent non-scalded acid sulfate soils. These are the most likely soil constraints for re-vegetation of the scalded lands and treatment will require acid neutralization (e.g. application of lime) and addition of P fertilizers to reduce the soluble acidity, immobilize soluble Al, Mn and Zn, and increase P availability. The evidence also shows that the higher soluble Al concentration in the scalded soils, relative to the non-scalded soils, is associated with their lower organic matter content. Hence, rehabilitation of these scalded lands should involve the addition of organic matter to reduce soluble Al concentrations; this may also help reduce Mn and Zn toxicity, and salinity. Water quality monitoring in the estuarine waterways draining the acid sulfate wetlands shows that acidic flows (pH < 4.5) of several months occurred intermittently. This may be attributed to the hydrolysis of Fe$^{3+}$ after the oxidation of Fe$^{2+}$ that is exported into the creek from acid sulfate soils through artificial drainage network. It is hypothesized that Fe$^{2+}$ is being generated by biological iron reduction, which consumes H$^+$ and thereby drives the conversion of retained acids to soluble acids. This allows the release of retained acids and subsequently the translocation of acids from soils to the adjacent waterway. Because many acid sulfate soils in the NSW coast contain large amounts of existing acidity, flooding or liming to eliminate acidity is either ineffective or cost-prohibitive. Treatment of the acidic water appears to be a more cost-effective strategy for managing acid sulfate wetlands in the NSW coast.

Additional Key Words: sulfide minerals, land scalding, acid discharge

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2Chuxia Lin was a Research Fellow at Southern Cross University, Lismore, NSW, Australia when this paper was submitted. He is currently a Professor at South China Agricultural University, Guangzhou, China
ASSESSMENT OF MICROBIAL ACTIVITY IN ANAEROBIC COLUMNS TREATING SYNTHETIC MINE DRAINAGE

M. Logan, D. Ahmann, and L. Figueroa

Abstract. The importance of sulfate-reducing bacteria for metal precipitation in anaerobic passive treatment systems for remediation of acid mine drainage has been established. Conditions leading to decline of sulfate-reducing activity and failure of passive treatment systems are not well understood; however, this study hypothesizes that decline in performance is related to decline in substrate availability for sulfate-reducing bacteria. Other microbial functions break down complex organic material to provide the simple organic compounds required by sulfate reducers, and are essential for sustainability of passive mine drainage treatment systems. An understanding of relationships between microbial activities and system performance is thus essential to the design of anaerobic passive treatment systems for long-term performance. The objective of this research is to develop a method to: (1) assess the activities of important microbial functions that influence sulfate reduction in an anaerobic passive treatment system, and (2) apply the method to an anaerobic column system treating synthetic mine drainage to detect differences in activities as the system ages, for the purpose of determining the rate-limiting step(s) in the degradation of organic material as they relate to sulfate reduction. The approach involves the use of a long-term column study in conjunction with short-term batch studies, which add substrate supplements to the organic material from sacrificed columns in order to probe the activities of important microbial functions. The substrate supplements each target a distinct microbial function at a specific step in the anaerobic degradation of complex organic compounds. Activities measured in batch studies correlate to overall column performance in terms of sulfate-reducing activity. Results of gas analyses from the batch studies illustrate the usefulness of this approach in quantifying important microbial functions, as well as identifying the rate-limiting step(s) in the degradation of organic material as the system ages. Data suggest an overall stimulation of metabolic activities by cellobiose and glucose, and indicate the rate-limiting step(s) lie between cellulose and cellobiose.

Additional Key Words: mine drainage, passive treatment, sulfate reducers, methanogens

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2Miranda Logan is a graduate student and Dianne Ahmann and Linda Figueroa are professors in the Division of Environmental Science and Engineering, Colorado School of Mines, Golden, CO 80401, USA, 303-273-3427, mlogan@mines.edu.
Selenium Availability and Uptake by Vegetation Growing in the Southeast Idaho Phosphate Mining Region

C.L. Mackowiak and M.C. Amacher

Abstract: Plants growing on revegetated phosphate mine waste rock dumps in Southeast Idaho are frequently high in Se and may pose a risk to grazing animals. Forage levels above 5 mg/kg total Se as dry mass may result in livestock selenosis, particularly in sheep and horses. These high Se plants are typically found growing in soils where total Se is above 1 mg/kg. Over the past three years, extensive vegetation sampling was conducted at decommissioned mining sites (Se) on the Permian Phosphoria Formation of Southeast Idaho and their Se content compared with the Se content of vegetation growing on undisturbed lands. The oven-dried tissue was analyzed for Se using hydride generation - atomic absorption spectroscopy. Selenium uptake corresponded with the degree of site disturbance, where plants containing the highest Se were found growing on exposed waste rock shale. Additionally, deeply rooted legumes and trees tended to accumulate more Se than did other plant lifeforms. Although not classified as Se accumulators, alfalfa and some forage grasses were able to deplete bioavailable Se from waste shale over time, thereby lessening future Se uptake, which may prove to be a useful phytoremediation tool. Capping the waste shale with highly weathered soils may also lessen Se uptake by vegetation. We found weathered soils and subsoils containing total Se up to 13 mg/kg supported forage growth with tissue Se below 0.1 mg/kg, far below the 5 mg/kg forage threshold. Soil extraction data revealed that most of the Se in these soils exists as insoluble elemental Se, whereas the majority of waste shale Se exists as highly soluble Fe-oxide bound and free Se species. These data will aid in the selection of revegetation species and capping materials for past and future decommissioned phosphate mine sites.

Additional Key Words: capping, selenium, Phosphoria Formation, mine sites, phytoremediation,

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2Cheryl L. Mackowiak, Postdoctoral Research Soil Scientist, and Michael C. Amacher, Research Soil Scientist, USDA-FS, Rocky Mountain Research Station, Logan, UT 84321.
THIRTY YEARS OF RECLAMATION RESEARCH IN THE ALPINE AND SUBALINE REGIONS IN ALBERTA, CANADA

Terry M. Macyk

Abstract. The Alberta Research Council, Inc. (ARC) has conducted a surface coal mine reclamation research program in association with the operations of Smoky River Coal Ltd. near Grande Cache, Alberta since 1971. The main objective of this long-term study was to develop and refine cost-effective methods of establishing a self-sustaining vegetation cover that is in harmony with adjacent undisturbed areas.

Soil handling practice development involved the completion of soil surveys and development of soil salvage and replacement strategies in these regions where salvageable soil materials are minimal to non-existent. Plot studies to determine the suitability and adaptability of various introduced and native grasses and legumes as well as fertilization trials were established and monitored annually. In the early 1970’s the lack of native seed necessitated the use of introduced species for large scale operational revegetation work in the subalpine region. Long-term monitoring results indicated that desirable introduced species will thrive and reproduce at these elevations and that native herbaceous species as well as trees and shrubs will invade the revegetated areas. Revegetation research activities in the alpine involved the use of native grasses and legumes indigenous to the area. Container and bare root conifer seedlings and cuttings of deciduous species were utilized initially to establish trees and shrubs in the subalpine. Direct seeding has also proven to be a viable method for establishment of trees and shrubs in the subalpine. Automated climate monitoring stations were installed at different elevations at three locations in the study area yielding data that support the conclusion that climate is the most limiting factor to reclamation success in the subalpine and alpine regions.

Research results were transferred to the operational scale throughout the term of the study. Recommendations regarding appropriate reclamation practices for the regions including soil salvage and replacement strategies, revegetation techniques and successional processes have been developed.

Additional Key Words: cover soil, native species, introduced species, climate monitoring, direct seeding.

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2Terry M. Macyk is Senior Research Officer, Environmental Technologies, Alberta Research Council, Inc., Edmonton, Alberta, Canada T6N 1E4.
A PRELIMINARY ASSESSMENT OF REMEDIATED SULFIDIC WASTE ROCK USING TERRA B™

Greg Maddocks

Abstract Terra B™ is chemically and physically modified red mud (waste residue from alumina refineries) and has been used in this study as an in-situ soil ameliorant to neutralize soil acidity, immobilize metals and allow simultaneous growth of trees in acid metal contaminated waste rock. Terra B™ + biosolids are compared with lime + biosolids and clay capping against a control in 4 x 400 m² plots. The Terra B™ + biosolids and lime + biosolids were mixed into the top 50 cm of the waste rock dump using an excavator. All amendments and waste rock was characterized chemically at the beginning of the study. 25 x Eucalyptus microcorys (Tallowwood), 25 x E. resinifera (Red Mahogany), 25 x E. paniculate (Narrow Leaved Grey Ironbark) and 25 x E. grandis (Flooded Gum) were planted in each plot as seedlings in December 2001.

After 15 months leachate was collected from lysimeters 50 cm below the amended soil profile. Leachate pH in the control has become increasingly acidic (pH ≈ 4.5 to pH 4). Whereas lime has failed to neutralize sub-soil acidity after 15 months (leachate pH ≈ 5), in the Terra B™ plot sub-soil acidity has been neutralized below the amended profile (leachate pH ≈ 7). After 15 months average heavy metal leachate concentrations (mg / L) in the lysimeters for Al, Cd, Cu, Mn and Zn were (control: 45.9, 5.7, 12.4, 49.3, 123.7), (Terra B™: < 0.1, 0.1, 0.3, 3.4, 13.1) and (lime: 6.5, 2.4, 4.4, 8.2, 56.2). In the clay-capping plot no leachate has been collected showing that the clay cap is fulfilling its purpose of restricting infiltration.

Statistically comparative tree growth has occurred in the Terra B™, lime and clay plots after 15 months. The average height (cm) of E. microcorys, E. resinifera, E. paniculate and E. grandis in the control, Terra B™, lime and clay plots was (control: 18, 20, 21, 20), (Terra B™: 80, 90, 80, 110) and (lime: 80, 80, 100, 120) and (clay: 90, 60, 90, 90).

Additional Keywords; red mud, lime, biosolids, revegetation, spoil, in-situ, immobilization, stabilization, eucalypt.

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2Greg Maddocks is a PhD Candidate at Southern Cross University, Lismore, New South Wales, 2480, Australia. email: greg.maddocks@bigpond.com.
USE OF NATIVE MYCORRHIZAL FUNGI TO ENHANCE ESTABLISHMENT OF QUAKING ASPEN ON SMELTER-IMPACTED SITES (PRELIMINARY REPORT)\textsuperscript{1}

Christopher Mahony\textsuperscript{2} and Cathy L. Cripps

Abstract. Aspen (\textit{Populus tremuloides}) is an important colonizing tree on disturbed landscapes, and is declining in the intermountain west (USA). It is an early successional species in many habitats, and can be particularly important on fire and smelter-impacted sites in the region. In Montana, areas near Butte and Anaconda support little or no vegetation because of the impacts of (copper) mining in the last century. Negative impacts include heavy metal contamination, low pH, destruction of soil structure and ability to hold water, poor CEC ratios, and lack of organic matter. Aspen stands occur naturally in and around these areas, and rely heavily on mycorrhizal fungi to moderate below ground conditions. These fungi increase nutrient uptake (particularly phosphorus) in plants provide protection from drought, and some exclude heavy metals from plant tissue, all of which allow plants to establish and survive on harsh sites. Aspen associates with over 60 species of mycorrhizal fungi, but only a subset occur on acidic, low nutrient soils. Certain native mycorrhizal fungi from Butte-Anaconda aspen stands increased the growth of aspen 250-430\% under laboratory conditions. These, and additional species collected under aspen from this area, are being used to develop soil- and liquid-based inocula which will be utilized to infect aspen seedlings in a greenhouse and plot study. Objectives include 1) development of an efficient method for inoculation and mycorrhization of aspen seedlings with native fungi 2) assessment of effects of various types of inocula on aspen seedlings in pot studies (in soils with high heavy metal content, low moisture conditions, and/or low fertility), and 3) evaluation of the use of mycorrhizal fungi for enhancing the establishment of aspen seedlings outplanted on smelter-impacted sites. Once established, aspen’s clonal nature could be an advantage in revegetating large tracts of land. A progress report will be given.

Key words: aspen, mycorrhizal fungi, \textit{Populus}, smelter sites, native species

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NEW NATIVE PRE-VARIETAL GERMPLASM RELEASES FOR THE NORTHERN GREAT PLAINS AND INTERMOUNTAIN REGION

Mark Majerus

Abstract: The reclamation/restoration industry relies heavily on native plant materials. The majority of native seed is obtained from commercial seed growers, as wildland collections are not a reliable source of the quantity and quality to meet the current demand. Most of the commercially available native plant material for the northern Great Plains and Intermountain region are cultivars, and more recently pre-varietal germplasm, released by USDA-Natural Resources Conservation Service (NRCS) Plant Materials Centers (PMCs) and the USDA Agricultural Research Service (ARS), Logan, Utah. New pre-varietal releases are often composites of multiple ecotypes resulting in more genetic diversity and a wider range of adaptation. Recent releases by the Montana (Bridger), North Dakota (Bismarck), Idaho (Aberdeen), and Colorado (Meeker) Plant Materials Centers and ARS-Logan, Utah, include:

Grasses
- High Plains Sandberg bluegrass (*Poa secunda* J.Presl)
- Bad River blue grama (*Bouteloua gracilis* Willd. ex Kunth)
- Itasca little bluestem (*Schizachyrium scoparium* [Michx.] Nash)
- Garnet mountain brome (*Bromus marginatus* Nees ex Steud.)
- P-7 bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love)
- Sand Hollow bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey)
- Washoe basin wildrye (*Leymus cinereus* [Scribn. & Merr.] A. Love)

Forbs
- Antelope slender white prairieclover (*Dalea candida* Michx. ex Willd.)
- Bismarck purple prairieclover (*Dalea purpurea* Vent.)
- Old Works fuzzy-tongue penstemon (*Penstemon eriantherus* Pursh)

Shrubs
- Open Range winterfat (*Krascheninnikovia lanata* [Pursh] A.D.J. Meeuse & Smit)
- Northern Cold Desert winterfat (*Krascheninnikovia lanata* [Pursh] A.D.J. Meeuse & Smit)
- Snake River fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.)

Trees
- Bridger-Select Rocky Mountain juniper (*Juniperus scopulorum* Sarg.)
- Hunter ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.)

Additional Key Words: reclamation, restoration, northern-adapted ecotypes

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2Mark Majerus, Manager, USDA-NRCS Plant Materials Center, Route 2, Box 1189, Bridger, MT 59014.

3All plant nomenclature and authorities from National Plants Database--http://plants.usda.gov
BIOLOGICAL TREATMENT OF SURFACE AND GROUND WATER FOR SELENIUM AND NITRATE

Tina Maniatis and D. Jack Adams

Abstract. An ex situ biological treatment system was implemented at a gold mine site in South Dakota. The system removes selenium and nitrate from a mixture of groundwater and surface water runoff at ambient water temperatures. The Applied Biosciences’ system replaced a denitrification system that did not perform consistently, did not treat for selenium and required the influent water to be heated. Installation was completed in phases, with the selenium circuit being brought into operation in February, 2002 and the nitrate circuit in March, 2002. System design can accommodate average flows of 380 L/min (100 gallons/minute) and a maximum flow of 1,136 L/min (300 gallons/min). Four cells were designed to remove nitrate from approximately 30 mg/L to below 10 mg/L and two cells were designed to remove selenium from 0.01 mg/L and higher to below 0.005 mg/L. No pretreatment is required to operate the system at ambient temperatures which can fall as low as -12° C in the winter and treat water at temperatures ranging between 8° C to 16° C. Nutrient requirements are met using a sugar based nutrient mixture that includes a balanced C:N:P:S ratio, trace elements and vitamins. Since start up, the system has consistently been in compliance for nitrate and selenium, treating water to below detection limits for both contaminants. This paper discusses laboratory biotreatability testing of a system designed to remove selenium, arsenic, and nitrate and full-scale implementation and optimization of a system to remove nitrate and selenium.

Additional Key Words: microbial, biological treatment, selenium reduction, denitrification, nitrate reduction, arsenic removal
ASSESSMENT AND CLOSURE DESIGN OF THE GLENGARRY ADIT, NEW WORLD MINING DISTRICT, COOKE CITY, MONTANA

M. B. Marks, H. Bogert, A. R. Kirk, and M. Cormier

Abstract. The Glengarry adit and two raises were driven in the mid 1920’s to early 1930’s in the Fisher Creek drainage of the New World Mining District. The USDA-Forest Service rehabilitated the Glengarry adit in 2000 and 2001 for assessment purposes under CERCLA response activities because it is one of the principal sources of metals loading in the headwaters of Fisher Creek. Outflow ranges from 57 to 848 liters per minute of low pH, iron-, zinc-, and copper-bearing water that discharges into Fisher Creek. About 915 meters of workings were surveyed, the geology mapped, and water samples collected for geochemical analysis. Four principal sources of water inflows were identified including two raises, a major crosscutting fracture, and diffuse roof leaks. The main source of contamination is water flowing from the colluvial/bedrock contact in a raise that surfaces in the Como Basin, and contains high concentrations of arsenic, copper, aluminum, cadmium, iron, manganese and zinc. The crosscutting fracture contains the highest concentrations of arsenic, aluminum and cadmium. Mass load analysis provides a basis for identifying significant sources of contamination and quantitative calculations of effectiveness for potential closure options.

Clean-up goals for the Glengarry Adit are based on eliminating or minimizing contaminated inflows and outflows from the adit. Closure alternatives that use engineering controls to plug, contain, or divert water flows were developed and analyzed to meet clean-up goals, and a preferred alternative for closure of the Glengarry Adit was selected. The preferred alternative involves a combination of surface and underground grouting, installation of underground plugs and backfilling a portion of the underground. This combination of closure technologies should eliminate any discharge from the mine. Closure will be implemented in two phases in 2003 and 2004.

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LESSONS LEARNED IN MONTANA – A DESPATCH FROM THE FRONT LINES

Warren D. McCullough

Abstract. When Pegasus Gold Corporation filed for Chapter 7 bankruptcy in early 1999, Montana DEQ’s Environmental Management Bureau became responsible for collecting over $80 million in surety bonds and implementing reclamation plans at four cyanide heap-leach mine complexes: Basin Creek, Beal Mountain, Zortman, and Landusky. No previous DEQ reclamation projects had approached the scale of the Pegasus properties. Lessons learned from four years of hands-on experience directing these projects include:

1) Site maintenance and water treatment costs continue in bankruptcy. Laws and bonds must be written to allow regulatory agencies immediate access to funds.

2) Insurance companies may prefer protracted litigation to settlement of multi-million dollar claims.

3) If reexamination of an approved reclamation plan after bankruptcy or abandonment reveals previously unaddressed issues, the public may demand additional environmental analysis, even if there is no responsible party to pay for it.

4) Bond forms should be written to reflect involvement of federal partners.

5) Bond forms should be written to exclude line-item limitations on costs, and agencies should attempt to collect bond amounts as lump sums to be placed in interest-bearing accounts.

6) It is extremely difficult in the current economic climate for even financially stable companies to obtain surety bonds. Agencies should be flexible, creative, and reasonably patient as companies try to establish acceptable guarantees for reclamation.

7) Indirect costs (administrative overhead, engineering design, inflation, contingencies, etc.) are a much larger part of total reclamation costs than DEQ previously assumed.

8) Real-world emergencies will continue to occur under agency management.

9) Leach pad geochemistry may continue to evolve during reclamation, complicating treatment and increasing costs.

10) When bond calculations include a component for long-term water treatment, DEQ runs the calculation out to 100 years. Projected expenditures beyond 100 years have little effect on a present-value figure.

1Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation and the 9th Billings Land Reclamation Symposium, Billings MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

2Warren D. McCullough Chief, Environmental Management Bureau Montana Department of Environmental Quality Helena, MT 59620
Abstract. Historic open pit coal mining in the Colstrip area dates from as early as 1924. Large-scale mining in the area began in the late 1960’s at the Big Sky Mine and the mid-1970’s at the Rosebud Mine. These two, adjacent mines have a combined permit area of almost 140 square kilometers. Ground-water quality monitoring within and adjacent to the permit areas began in the early 1970’s and continues to the present. Generally, monitoring indicates little to no change in ground water quality upgradient of the mines. Backfilled pit areas and downgradient aquifers are showing variable water quality impacts. Mine monitoring wells have also detected water quality impacts associated with activities at the Colstrip power generating plant.

Changes in water quality due to mining include increases in total dissolved solids (TDS) largely due to increases in sulfate, but also bicarbonate, sodium, calcium and magnesium. In backfilled pit areas, TDS in saturating spoil is typically double that of coal aquifer background concentrations of 1000 mg/L to 3000 mg/L. However, concentrations in spoil vary temporally and spatially and may be three or more times higher than background. Downgradient alluvial, coal, and underburden aquifers show increases in TDS concentrations that range from hundreds to more than a thousand mg/L.

Ground-water quality is expected to improve as dissolved salts are flushed through backfill. The time required for this will vary with the hydrologic setting in each mined area. Although TDS concentrations are still increasing in most spoil wells, improvements in spoil water quality have been observed in others. Some spoil wells in Big Sky Mine Area A and Rosebud Mine Area B show a trend of decreasing TDS concentrations.
USE OF THE NEW MEXICO MINES DATABASE IN RECLAMATION STUDIES

Virginia T. McLemore\(^2\), J. Steven Raugust, Gretchen K. Hoffman, Maureen Wilks, Peggy Johnson, Christian B. Krueger, and Glen R. Jones

**Abstract.** The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) has been collecting data on mining districts, mines, mills, and mineral deposits since it was created in 1927. The NMBGMR has been slowly converting years of historical data into an electronic relational database that eventually will be available on the Web or Internet, as funding becomes available. The database includes information on mining districts, mines, mills, chemistry, photographs (both recent and historic), and bibliography. The available data includes location, production, reserves, geologic, geochemical, resource potential, mining, ownership, and other data. The database is comprised of eight main tables that store data for mines, mining districts, samples, drillhole, waterwells, county, photographs, and projects, with more than 70 supporting tables. Each of these eight tables is linked to the others, where appropriate, and all the supporting tables are linked to one or more of these eight main tables. Once data are entered into appropriate tables and keyed to location, the data can be converted easily to GIS format for displaying on maps. The mine locations are keyed to specific points defined by latitude and longitude, whereas the districts are keyed to polygons. The purposes of this database are to provide computerized data that will aid in identifying and evaluating resource potential, resource development, management, and production, and possible environmental concerns. Environmental concerns include physical hazards (for example hazardous mine openings), indoor radon, regional exposure to radiation from the mines, and point sources of possible pollution in areas of known mineral deposits. These data will be useful to the State of New Mexico, as well as other government agencies to support informed land-use decisions.

**ADDITIONAL KEY WORDS:** GIS, database, economic geology, mining districts, Access 97

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A COMPUTER-BASED MODEL FOR ESTIMATING MINE DRAINAGE TREATMENT COSTS¹

Brent Means², Bob McKenzie, and Tiff Hilton

Abstract. In the last 20 years, coal mining in Appalachia has produced approximately 1500 pollutional discharges. State and Federal agencies are developing a strategy, which includes consideration of treatment costs, to ensure long-term treatment of these discharges. The U.S. Office of Surface Mining Reclamation and Enforcement, in cooperation with the states of Pennsylvania and West Virginia, developed a free Windows-based computer program, termed AMDTreat, designed to estimate the capital and annual costs to abate pollutional mine discharges. AMDTreat uses a three-step approach to estimate treatment costs: 1. Users enter water quality and quantity data, 2. Users “build” an active and/or passive treatment system by selecting the applicable treatment components from the software menu, and 3. Users customize each treatment system to site-specific conditions by controlling the size, quantity, and unit cost of treatment components. Treatment types for which AMDTreat can estimate costs include vertical flow pond, anoxic limestone drain, Mn removal bed, anaerobic and aerobic wetlands, oxic limestone channel, hydrated lime, caustic soda, anhydrous ammonia, pebble quicklime, and soda ash. The model combines costs from these treatment methods with costs of ancillary treatment components, such as settling ponds and ditching, to calculate a site-specific capital cost. Similarly, AMDTreat calculates annual costs by taking into account user-provided information regarding sampling, labor, maintenance, pumping, chemical consumption, and sludge removal. Capital and annual costs can be used in conjunction with AMDTreat’s financial forecasting utility to evaluate the economics of long-term treatment. Additional features of the application include the ability to forward predict or back calculate costs, and an extensive help system. AMDTreat was designed for anyone interested in mine drainage treatment; including State and Federal agencies, industry, and watershed groups. If interested, one can download the computer software program from http://amd.osmre.gov/tt2/download.htm.

Additional Keywords: Passive Treatment, Chemical Treatment, Active Treatment, AMD, Acidity, Iron, and Chemistry

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Abstract: Western Energy, a subsidiary of Westmoreland Mining LLC owns and operates the Rosebud Mine. In over thirty years of production more than 300 million tons have been produced.

Westmoreland Mining purchased Western Energy in 2001 in addition to other mining operations owned by The Montana Power Company and the Knife River Corporation. Westmoreland Mining and its affiliate Westmoreland Resources, Inc together own five surface and coal or lignite mines in the United States. These mines make their parent company Westmoreland Coal Company one of the top ten coal producers in the U.S.

Colstrip was founded in 1923, mining started in 1924. The coal was used to fuel steam locomotive boilers on the Northern Pacific Railway. Forty four million tons of coal was mined during the 34 years of operation. Mining by the Northern Pacific ceased in 1958 when diesel replaced the coal-fired steam locomotives.

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2Robert Montgomery, Western Energy Company, Colstrip, MT 59323.
EVALUATION OF A LARGE AREA SHALLOW EVAPORATION BASIN (LASEB) IN A PLAYA ENVIRONMENT FOR FINAL HEAP LEACH DRAIN-DOWN DISPOSAL


Abstract. A heap leach gold mining company located in northern Nevada is preparing for closure. The mine must dispose of approximately 1.89 billion liters of heap leach drain-down solution from the leach pad. The mine proposes to apply the initial drain-down solution to the surface of a playa for evaporation, located approximately 10 kilometers southeast of the mine property. The mine must demonstrate to the regulatory authorities that solution will not degrade the groundwater or significantly increase the specific constituent load on the playa surface.

AMEC Earth & Environmental (AMEC) in Sparks, Nevada provides engineering consulting services for the mine’s closure preparation. AMEC performed the playa investigation for the design of the LASEB. The investigation involved drilling, sampling and installing two piezometers to 15 meters (m), installing a nested piezometer cluster to 30.5 m, 15 m and 4.6 m, performing a playa surface crust sampling program for profile II analyses, and the design construction and instrumentation of a 36.5 m² infiltrometer coupled with a meteorological station. The total LASEB area is approximately 8.9 million square meters. Solution will be gravity drained via pipeline to the LASEB and discharged at the land surface for containment and evaporation. Materials testing results show that the playa near surface clays and elastic silts have an average hydraulic conductivity of 2.0 x10⁻⁷ cm/sec.

The infiltrometer data, high evaporation rates and the nested piezometer data all support a net upward hydraulic gradient within the playa system. Analytical results from a playa surface crust sampling program indicate that the playa has an average pH of 10.0 and a calculated average total dissolved solids of 195,000 parts per million. The playa investigation results support the hydrologic characteristics of a discharge playa with a net upward hydraulic gradient and meet the design criteria for a solution containment and evaporation basin.

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EFFECTS OF ARBUSCULAR MYCORRHIZAE ON NATIVE PLANTS GROWN IN MINE TAILINGS

O.S. Moynahan2, S. Jennings and C.A. Zabinski

Abstract. Arbuscular mycorrhizae (AM) are plant-fungal symbioses that can enhance plant growth and survival, especially under stressful conditions. Greenhouse and field studies were used to test effects of three AM sources on native plant species growing in mine tailings. Sources of AM included 1) sterilized inoculum, 2) inoculum from a metals-contaminated site, and 3) inoculum from an uncontaminated site. Plant species were selected for their sensitivity to metal-contamination and potential use for mine waste revegetation. Tufted hairgrass (Deschampsia cespitosa) and yarrow (Achillea millefolium) are often used in mine waste revegetation because of their tolerance of soil acidity and elevated metals. Bluebunch wheatgrass (Pseudoroegneria spicata), rough fescue (Festuca scabrella), blue flax (Linum lewisii), and purple coneflower (Echinacea angustifolia) are generally more sensitive to harsh soil conditions and are not widely used for mine revegetation.

In the greenhouse, AM from metals-contaminated soil increased biomass of rough fescue (53%), blue flax (283%), and purple coneflower (798%) relative to nonmycorrhizal plants. Uncontaminated soil AM increased biomass of blue flax (262%) and purple coneflower (646%), but not rough fescue. Biomass of yarrow, tufted hairgrass, and bluebunch wheatgrass was not affected by either AM source in the greenhouse. In the field, the same 3 sources of AM inoculum were tested on plant communities composed of container-grown tufted hairgrass, bluebunch wheatgrass and yarrow that were transplanted into several tailings types. While these plant species showed little or no response to AM in the greenhouse, the metals-contaminated soil AM had a positive effect on plant communities in the field. The metals-contaminated soil mycorrhizae increased total biomass of constructed plant communities by 19%, and increased the number of flowering stalks by 20% over nonmycorrhizal plants. There was no effect of the uncontaminated soil AM in the field.

This research shows that AM effects vary with plant species, AM inoculum source, and abiotic conditions, which may have important implications for revegetation practices. Re-evaluating growth of plant species in mine tailings with their natural AM symbioses will expand the pool of desirable revegetation species and lead to more stable, productive and diverse plant-soil systems.

Additional Key Words: plant diversity, restoration, soil ecology, microbiology

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2October Seastone Moynahan, Plant and Soil Ecologist, Seastone Environmental Consulting, Missoula, MT 59803. 406-370-9233. moynahan@bigsky.net. Stuart Jennings, Research Scientist, Reclamation Research Unit, Montana State University, Bozeman, MT 59717. Cathy Zabinski, Assistant Professor, Land Resources and Environmental Sciences, Montana State University, Bozeman, MT 59717.
NATURAL RESOURCE DAMAGE PROGRAM: IT'S ROLE IN RESTORATION IN THE UPPER CLARK FORK

Gregory Mullen

Abstract. Decades of mining and mineral processing operations in and around Butte and Anaconda released substantial quantities of hazardous substances, such as metals, into the Upper Clark Fork River Basin (UCFRB) between Butte and Milltown. These hazardous substances extensively harmed the area’s natural resources. On behalf of Montanans, the state filed a natural resource damage lawsuit, which was partially settled in 1998. As a result, the Atlantic Richfield Co. (ARCO) paid the State approximately $130 million to restore or replace the Basin’s public natural resources, particularly its fish, wildlife, vegetation, groundwater and rivers and streams. The State of Montana is presently using these settlement monies to restore or replace the injured resources in the UCFRB. Projects funded over the last three years total over $20 million dollars for projects such as revegetation of riparian habitat and development of a greenway trail corridor along Silver Bow Creek, waterline replacement projects, acquisitions, and tributary restoration. The settlement also resulted in an additional $80 million for remedial cleanup by Montana Department of Environmental Quality (MDEQ) along Silver Bow Creek. The Natural Resource Damage Program (NRDP) is working closely with MDEQ on restoring Silver Bow Creek.

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12 A poster presentation will display some of the injuries pursuant to the lawsuit with explanations of pending claims. Also displayed will be photos and explanations of restoration projects approved for funding over the last three years in the basin. Restoration projects, that involve the restoration or replacement of injured groundwater, aquatic and terrestrial resources, will be the main focus of poster displays.

13 Gregory J. Mullen is an Environmental Scientist; Montana Natural Resource Damage Program; Montana Department of Justice; 1301 East Lockey; Helena, MT 59601. gmullen@state.mt.us
PHYTOSTABILIZATION PERMANENCE WITHIN MONTANA’S CLARK FORK RIVER BASIN SUPERFUND SITES

F.F. Munshower², D.R. Neuman, and S.R. Jennings

Abstract. Many land reclamation technologies have been used on mining-impacted lands within the Clark Fork River Basin Superfund sites over the past 20 years. Several sites are examples of in-situ reclamation or phytostabilization. Since phytostabilization does not remove metal contaminants, the permanence of this technology as a remedial alternative has received significant scrutiny. Many of these projects have had limited long-term monitoring, and as such, the permanence of these efforts to evaluate the permanence of in-situ treatment strategies. The purpose of this investigation was to generate sufficient data and information from areas receiving phytostabilization treatments, varying in age from 6 to 19 years, so that the permanence and self-sufficiency of the established and reconstructed ecosystem(s) can be assessed. Six different field sites were selected that represent phytostabilization implementation in different landscape positions, using slightly different equipment, and at different times. The sites are similar in that each was degraded because of impacts from the metal mine/mill/smelter processes. Soils or tailings at the sites contain acid producing materials and are elevated in metal concentrations compared to adjacent, non-impacted landscapes. At each site, neutralizing amendments were added to raise the soil or waste pH to a target level of seven, and at some sites, other amendments were also added. Vegetation response variables observed or measured at the six sites included cover, species richness, evidence of reproduction, evidence of nutrient cycling, evidence of succession, and biomass. Soil response variables measured included pH, acid buffering capacity, and metal concentrations. This paper will present these data and discuss the efficacy of phytostabilization in terms of the sites’ ability to sustain current land use and their ability to support other possible land uses. The permanence of the amendments to perform their function of attenuating acid production and immobilization of metals will also be addressed.

Additional Key Words: revegetation, metal tolerance, tailings reclamation, Superfund

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2 Frank F. Munshower, Plant Ecologist, Dennis R. Neuman, Director and Research Scientist, and Stuart R. Jennings, Research Scientist. Reclamation Research Unit, Department of Land Resources and Environmental Sciences, 106 Linfield Hall, Montana State University, Bozeman, MT 59717.
Abstract. Coal bed methane production has recently begun in the vicinity of the North Antelope Rochelle Mine (NARM) in Campbell County, Wyoming, the world’s largest coal mine. In order to supplement the mine’s water supply and to reduce use of deep water supply wells placed in the Fort Union and Fox Hills Formations, the mine’s upstream flood control system has been designed to capture and temporarily hold water produced from coal bed methane operations. Water will then be pumped into the mine and held for dust suppression operations and facilities use. Water from coal bed methane operations will also aid in the establishment of wetlands and other reclamation features and will help to raise mine backfill water levels. Water discharged from the coal bed methane operations near to NARM is expected to be of very high quality. Water discharged from the mine has also been shown to be of high quality by monitoring of flow on downstream Porcupine Creek. This should continue when coal bed methane development in the Porcupine Creek drainage reaches its full potential. The use of coal bed methane produced water at NARM will lessen the impact of coal bed methane production on the Cheyenne River, where irrigators are concerned about the detrimental impact of produced water on the surface water quality.

Key Words: Dust Suppression, Wetlands, Alluvial Valley Floors, Geochemistry, and Reclamation
Abstract. Two sections of the Porcupine Creek alluvial valley floor have been reconstructed at Powder River Coal Company’s North Antelope Rochelle Mine using specialized reclamation methods. The lower section of Porcupine Creek (AVF Reach 1) was re-constructed in 1985, but flow was bypassed by a diversion until early-2001. In addition, the lower creek was reconstructed using old channel design criteria that utilized a guide channel and limited the amount of pooled water. The lower reclaimed Porcupine Creek was constructed from native alluvium as required by the Wyoming Department of Environmental Quality / Land Quality Division (WDEQ/LQD) at the time. TDS and selenium concentrations in the alluvial monitoring wells in the lower reclaimed channel have been higher than in premining alluvial waters. The water quality reflected the new mobility of the constituents after mixing and oxidation of the highly mineralized alluvial material occurred during mining and aquifer construction. The alluvial water quality slowly improved between 1985 and 2001, but the future postmining water quality remained a concern. Following construction of pools and counter-weirs on AVF Reach 1 in early 2002 as part of a wetland establishment project, alluvial water levels have risen significantly. Boron concentrations spiked upward in the alluvial waters as water flushed through the vadose zone, but are now lower. Selenium concentrations are now much lower and geochemical conditions appear to be more reducing. The results of recent monitoring highlight the important geochemical processes ongoing in the aquifer and show that the construction of the pools and wetlands has improved the alluvial water quality in the AVF Reach 1. Further study of AVF Reach 1 is warranted as water quality in the reclaimed alluvium stabilizes. An upstream section of Porcupine Creek (AVF Reach 2) was reclaimed in 1999 primarily using selected overburden material as alluvium. TDS and selenium concentrations are much lower in AVF Reach 2.
WATER QUALITY IMPROVEMENT AND BIOLOGICAL DEVELOPMENT IN MINE DRAINAGE TREATMENT WETLANDS

Robert W. Nairn, Matthew N. Mercer, Choice M. Cogburn, Denae Athay, Stephanie A. Lipe, Virginia B. Arvidson, Megan Sprowls, and Keith A. Strevett

Abstract: Metal retention, alkalinity production and biological community structure were evaluated for an enhanced successive alkalinity producing system. The treatment wetlands consist of four 185-m² in-series cells comprised of alternating vertical-flow wetlands and surface-flow settling ponds. Acid mine drainage (AMD) from an abandoned underground mine in southeastern Oklahoma (USA) was directed to the pilot-scale system for two years. Mean influent water quality was characterized as follows: 660 mg/L net acidity as CaCO₃, pH 3.4, 215 mg/L total Fe, 36 mg/L Al, 14 mg/L Mn, and 1000 mg/L SO₄²⁻. Final effluent water quality consistently met regulatory criteria for an active mine, with the exception of Mn concentrations, which decreased significantly in the final two cells. Metals were effectively retained in both aerobic and anaerobic portions of the treatment system. Substrate analyses indicated metals were sequestered in oxide/oxide-bound, carbonate, exchangeable, organically bound and sulfide forms, depending on mass loading, location and time. Alkalinity was generated in the vertical-flow cells by a combination of biogeochemical processes, including limestone and hydrated fly ash dissolution and bacterial sulfate reduction. Mean acidity removal rates (69 g m⁻² day⁻¹) are comparable to other similarly designed systems. Although constructed solely for water quality improvement, the treatment system underwent substantial ecological development over the two years of study. Several species of macroinvertebrates, fish and vegetation volunteered into the systems. Over 50 families of macroinvertebrates representing more than 20 orders colonized the cells. *Typha*, *Ludwigia*, *Juncus* and *Salix* spp. dominated vegetation communities, but metal uptake in *Typha* was minimal and contributed little to overall metal budgets. Fish species found included *Lepomis macrochirus* and *Gambusia affinis*. Over all, treatment wetlands represent a cost-effective and sustainable technology for water quality improvement. Furthermore, these systems may provide desirable and vital habitat in mining impacted watersheds.

Additional Key Words: constructed wetlands, coal mining, ecological engineering, bioassessment

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SUBSIDENCE WETLANDS: AN ASSESSMENT OF VALUES

Jack R. Nawrot, Laura Kirk, and Elise Elliott-Smith

Abstract. Underground coal mining and unplanned subsidence have occurred adjacent to and under Rend Lake, an 18,000 Ac impoundment in southern Illinois, for more than 90 years. Recent longwall mining permits for Rend Lake have emphasized wetland habitat enhancement as a benefit of planned subsidence that occurs under upland areas adjacent to the shoreline. However, planned subsidence under existing mudflats was viewed as a potential habitat loss. To evaluate subsidence effects, shorebird and waterfowl utilization, benthic invertebrate density, and plant communities of subsided and unsubsided habitats were monitored during 2000 to 2002. Spring waterfowl surveys (2001 and 2002) documented greater than 120,000 ducks and geese using the Rend Lake study areas. Surveys identified 3,780 shorebirds using the wetland study areas during summer - fall surveys of 2000, and 6,382 shorebirds during 2001. Shorebird utilization in 2000 was approximately two times greater at the subsided study area compared to the unsubsided study area; however, in 2001 shorebird abundance was greater at the unsubsided study area. Wetland surveys identified benthic invertebrate density and biomass values were also higher at the subsided basins during 2000; however, there was no difference between sites in 2001, suggesting that lake hydroperiod may be the principal factor affecting habitat suitability.

Additional Key Words: waterfowl, shorebirds, mitigation.

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SURFACE MINE RECLAMATION SETTINGS: FACILITATING LANDSCAPE PLANNING, DESIGN, AND MANAGEMENT EDUCATION

Paul E. Nieratko and Jon Bryan Burley

Abstract. Landscape planning, design, and management educators are interested in assigning educational studio projects which facilitate the development of students to create meaningful environments. We have employed the use of surface mines in Minnesota, Colorado, and Michigan for educational purposes for a combined total of eighteen years and we believe that they make excellent projects at the university level in the studio classroom. Surface mine projects are valued environments to teach students about housing, wildlife and fisheries, city centers, agriculture, forestry, recreation, multiple land-use planning and design, design development, and site design because the landscape is completely altered and can become something different in the post-mining land-use phase. In addition, we apply the principles developed by Ken Schellie that surface mining is a transitional land-use, promote simultaneous excavation and rehabilitation, encourage the use of mining operations to create land for post-mining land-uses, suggest that the post-mining land can be more valuable than the pre-mining landscape, encourage the search for integrating multiple post-mining land-uses, and indicate that surface mine planning results in fewer delays, efficient mining, and increased profits. We would like to share these projects with the meeting attendees.

Additional Key Words: environmental design, landscape architecture, higher education, natural resources

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WOODLAND RECLAMATION IN NORTH DAKOTA: A 20-YEAR PERSPECTIVE

David J. Nilson

Abstract. Surface mining through native woodlands in the Missouri Breaks area of North Dakota was an environmentally sensitive issue both before and after passage of the Surface Mining Reclamation and Control Act in 1977. Wildlife agencies and environmental groups were skeptical that reclamation of these unique habitats would be successful. Use of the traditional shelterbelt technology had failed in the late 70’s and resolution of this issue was paramount to future mining operations. Consequently, a concerted effort was made to demonstrate success using non-conventional establishment and management techniques. Following an in depth ecological study of why native woodlands occur where they do, a plan was developed in the early 80’s where woodlands would be re-established on slopes and aspects similar to natural settings. To accomplish this, surface grading plans were modified and plant community response to several establishment and management techniques was observed from 1978 to the present time. The reclamation plan included the establishment of high-density woodland plantings of mixed native species on landscapes specifically constructed to enhance plant available water and consequently enhance woody species survival and growth. Woodland Establishment and management techniques are discussed. Additionally, photos showing changes in vegetative structure over time are provided along with stem density and species diversity data. These data were collected on initial demonstration sites as well as numerous woodlands established on various reconstructed soils and soil depths over a period of 20 years. Over this time frame, initial reclamation success varied relative to periods of highly variable weather patterns typical of the Northern Great Plains. Reclaimed plant community stem density and species diversity were found to be similar to native tall shrub communities. Other factors affecting success including plant community changes due to succession, herbaceous competition, disease and the livestock grazing are discussed.

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THE NEED FOR TWO-DIMENSIONAL COUPLED SOIL-ATMOSPHERE NUMERICAL MODELING FOR MINE WASTE COVER SYSTEM DESIGN

D. Christensen and M. O’Kane

Abstract. A significant percentage of the surface area associated with decommissioning and reclaiming mining wastes possesses sloping surface conditions. The design of engineered cover systems for the underlying waste has typically focused on a simplistic one-dimensional (1D) approach. However, the hydraulic performance of these cover systems are significantly influenced by the sloping surface conditions; and as such a more rigorous and defensible approach is required.

This paper will present cover system designs for different climate regimes (from arid to humid), and with different design objectives (oxygen ingress control, net percolation control, surface water management) using a simplistic 1D approach and a rigorous 2D approach. The design results will be summarized to demonstrate that depending on climate conditions a cover system design developed using a simplistic 1D approach can underestimate or overestimate performance as compared to the more representative and rigorous 2D approach.

Finally, a case study will be presented to demonstrate the need to move from a simplistic 1D approach to a more rigorous and defensible 2D coupled soil-atmosphere approach for predicting the long-term performance of a full-scale cover system for a sloping surface.

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NATIVE VERSUS ACTIVE REVEGETATION ON ABANDONED MINE LANDS IN HIGH ELEVATION WETLANDS

L.J. Olsen, and C. Zabinski

Abstract: Wetlands and riparian areas are critical habitats in the inland west for overall species and landscape diversity. These areas were often the sites of hard rock and placer mining beginning in the late 19th century. The result of these mining activities is toxic and persistent pollutants, including heavy metals associated with ore bodies, mine tailings and acid mine drainage. The Ontario Mine, in the Little Blackfoot River drainage in west central Montana, is partially located on National Forest land, and was reclaimed in 2002. Bare tailings piles were removed, replaced with clean backfill and soil, and revegetated through seeding and planting of native plants. Tailings that were naturally revegetated were left in place. There has been no treatment of adit water that drains into the wetland, so the reclaimed site will continue to receive low pH, high metal concentration water inputs. The main objectives of this study are 1) to compare survival rates and tissue metal concentrations for Carex rostrata (beaked sedge) grown from seeds collected on site versus commercially available seeds; 2) to measure survival rates and metal uptake of Alnus sinuata (sitka alder) and Carex aquatilis (water sedge) across a contaminated-water gradient; and 3) to compare plant cover and frequency, and tissue metal levels across native plant species. Five of these species occur in both contaminated and uncontaminated wetlands, and an additional two species only occur in the contaminated site. We are using an adjacent uncontaminated site as a baseline for vegetation dynamics and metal levels in uncontaminated vegetation. Data on water and sediment metal levels on the Ontario Mine site is being gathered by Chris Gammons, Montana Tech, and will be compared to plant tissue metal concentrations. Baseline vegetation and metal information gathered in 2002 will be presented. Preliminary analysis of metals in the native species shows variable metal levels by species, both above- and belowground. The reference site shows significantly lower metal concentrations, although this varies by plant species and metal.

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2Lois J. Olsen, Forest Ecologist, Helena National Forest, USDA, Helena, MT. 59601, and Catherine Zabinski, Assistant Professor, Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT. 59717
Abstract. How well have generalized hydrologic models predicted infiltration and water quality impacts at hardrock mine sites? The mine water balances developed with site-specific data in this study gave greatly different results than ones based on regional data and general methods. The lined leach pads and seepage capture systems at the Zortman and Landusky mines allowed entire rock dumps and small drainage basins to be evaluated as huge lysimeters, enabling direct estimates of groundwater recharge and evapotranspiration. The average steady-state water balances, based on data from years 1997-1999, were calculated for 22 facilities/basins on the 210-hectares Zortman Mine, and 36 facilities/basins on the 580-hectares Landusky mine. Infiltration rates (as % of precipitation) calculated for, a) unreclaimed leach pads, b) pits, and c) reclaimed pads and rock dumps were 70.5%, 56%, and 45%, respectively for the Zortman mine, and were 69%, 62% and 48.6%, respectively for the Landusky mine. The annual water budget for the two mines averaged: evapotranspiration 51.4%, infiltration 43.8%, and surface runoff 4.8%. The results of previous water budget estimates using more general methods gave results of approximately 81%, 5.0% and 14%, respectively. Based on the facility-specific water budgets, chemical mass loading models of both mines were developed to estimate the total loads of contaminants generated by all mine facilities, and evaluate the ultimate fate of the contaminants. Average annual loads of total dissolved solids, acidity, sulfate, nitrate, arsenic, selenium and seven cationic metals were calculated. Site-specific water balances are valuable tools for analysis of hydraulic and contaminant loading rates from various mine facilities and cover types. A check of the models with independent data showed that they should not be applied outside the period of record or hydrologic conditions for which they were developed, without further verification and calibration.

Additional Key Words: Mine Hydrology, Infiltration, Water quality
ECOLOGICAL DEVELOPMENT OF CONSTRUCTED WETLANDS BUILT FOR TREATING MINE WATER AT TARA MINES, IRELAND¹

Aisling D. O’Sullivan², Declan A. Murray and Marinus L. Otte

Abstract. Mine associated wastewater is characteristically elevated in metals and other contaminants and has been conventionally treated with costly chemical applications. The development of passive treatment systems such as wetlands, which employ both biotic and abiotic processes, has been recognized as an economically feasible, ecologically acceptable treatment technology in the last decade. Not only can constructed wetlands provide an efficient facility for treating wastewater, they can also offer ancillary benefits such as ecological niches and therefore be of educational and often recreational value to society as well. Two experimental-scale treatment wetlands were constructed at an active lead/zinc mine near Navan, Ireland in 1997 to treat water enriched with sulfate and metals. Each system comprised three 12 m² (2 m depth) in-series surface-flow cells viz., inflow, vegetated and outflow. Sulfate-reducing bacteria were indigenous in the anaerobic spent mushroom substrate used, where biological reduction of sulfate to sulfide occurred. Sulfide subsequently precipitated with metals from the water. The treatment efficiency of the wetlands was promising with concentrations of sulfate (up to 29 g m⁻² day⁻¹ (69%)), lead (6.6 mg m⁻² day⁻¹ (64%)) and zinc (70 mg m⁻² day⁻¹ (98%)) successfully removed from the wastewater. The ecological functioning of these constructed wetlands was also demonstrated with food webs, nesting niches and refuge sites afforded by colonizing communities of macroinvertebrates, macrophytes, microorganisms and other visiting wildlife. By 15 months following construction of the treatment wetlands, 30 species of macroinvertebrates were identified in system 1 and 21 species in system 2, while 3 plant species, 3 algae species and 1 moss had also colonized the ecosystems. Sulfate reducing bacteria genera included Desulfotomaculum, Desulfovibrio, Desulfococcus and Desulfobulbus. Annual dieback of planted species Typha latifolia and Phragmites australis contributed substantial amounts of biomass to the ecosystems, which led to a renewal of the carbon supply that drove the biologically mediated treatment process. It is speculated that the ecological diversity of the wetlands contributed to their treatment success based on inherent ecosystem complexity.

Additional Key Words: metals, sulfate, macroinvertebrates, microbes, plants, biota

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REVEGETATION OF MINE TAILINGS THROUGH THE USE OF BIOSOLID AMENDMENT

I.L. Pepper, S.A. Bengson, P.R. Rao, and K.L. Josephson

Abstract. Mine tailings represent the end product of mineral ores that are processed to extract specific metals such as copper. Tailings are in essence crushed rock with 0% organic matter, and can be layered to depths of 30–36m. We evaluated revegetation of mine tailings through the one time application of municipal biosolids. Specifically a 2 hectare copper mine-tailing plot near the Mission Mine in Southern Arizona was designated for this study. Approximately 220 dry tons per hectare of biosolids was added and incorporated in December 1998. The potential for successful revegetation was evaluated by monitoring soil microbial populations, which quickly become established at \( \approx 10^7 \) heterotrophic bacteria per gram of biosolid amended mine tailings. By September 2001 vegetative cover had increased from zero to 77%. Initially bermudagrass and Russian Thistle were the predominant species involved. More recently Buffalo grass and Lehman's Lovegrass have become more prominent. Monitoring of soil metal concentrations as a function of depth showed that the tailings were the major source of metals, not the biosolids. There was no evidence that metals were leaching under the low rainfall, non-irrigated conditions. Plant tissue metal concentrations showed that phytoremediation could remove metals from the surface depths of tailings. Soil nitrate concentrations varied seasonally and with tailing depth. Nitrogen transformations included ammonification, nitrification and denitrification, which allowed nitrogen to be removed from tailings. Leaching of nitrate appeared to be minimal. Overall biosolid amendment of mine tailings appeared to be a successful technological approach to enhance revegetation of the mine tailings.

Additional Key Words: municipal waste reuse, tailings stabilization

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2 Ian L. Pepper, Professor and Director of the Environmental Research Laboratory at The University of Arizona, Tucson, AZ 85706; S.A. Bengson, Agronomist, ASARCO-Copper Operations, Sahuarita, AZ 85629; P.R. Rao, P.E., Pima County Wastewater Management Department, Tucson, AZ 85701; and K.L. Josephson, Research Specialist Principal, The University of Arizona, Tucson, AZ 85721.
EFFECTS OF SURFACE IRRIGATION WATER QUALITY AND WATER TABLE POSITION ON THE ABILITY OF SELECTED PLANT SPECIES TO PRODUCE BIOMASS, CRUDE PROTEIN, AND REMOVE SODIUM, CALCIUM AND MAGNESIUM FROM SHALLOW GROUNDWATER

Shannon D. Phelps

Abstract. Coalbed methane (CBM) exploration and development has increased substantially over the past ten years in the United States. The Powder River basin in Wyoming and Montana has emerged as one of the most active new locations for exploration. Today, almost 7.5% of United States natural gas production occurs in this area. CBM extraction wells co-produce water that is typically characterized as both saline and sodic. This water has the potential to elevate the saline-sodic conditions within soil or water systems it contacts.

This research was undertaken to examine the effects of surface irrigation water quality and water table position on the ability of selected plant species to produce biomass, crude protein, and to remove the base cations sodium (Na\(^{+1}\)), calcium (Ca\(^{+2}\)), and magnesium (Mg\(^{+2}\)) from shallow groundwater. It was hypothesized that selected species could effectively produce biomass, crude protein, and potentially phytoremediate saline-sodic irrigation water by reducing the sodicity and salinity of that water.

A column experiment was conducted in the greenhouse. Columns were arranged as a two water qualities x three water table positions x three species randomized block design with four replications of all 18-treatment combinations. A simulated CBM water treatment and a simulated Powder River water control serve as irrigation treatments. Three water table positions at 114, 76, and 38 centimeters were imposed to the columns. Species Wytana saltbush (Atriplex wyrtana), Big saltbrush (Atriplex lentiformis) and Maritime barley (Hordeum marinium) were selected for their livestock forage and salt tolerant (halophytic) characteristics.

Harvest analyses evaluated selected plant species ability to produce biomass, crude proteins, and uptake base cations from shallow groundwater. It can be concluded that plant biomass, crude protein, and base cation uptake were less affected by irrigation quality and more a result of column species and water table position.

1 Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation at the 9th Billings Land Reclamation Symposium, Billings, MT, June 3-6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

LESSONS OF STEEP-SLOPE REVEGETATION FROM THE GOLDEN SUNLIGHT MINE, MONTANA¹

R. A. Prodgers²

Abstract. Effective revegetation on 50% slopes is possible in a semiarid climate. Placer Dome’s Golden Sunlight Mine in southwest Montana was a pioneer in 2H:1V slope revegetation. Elements of satisfactory revegetation include nearly two-foot-thick coversoils that combine 30% to 50% rock content for erosion resistance with good texture for plant growth, short-term erosion-control measures such as benches and properly aligned dozer basins, a seed mix that balances strong-establishing species with persisting ones, and seeding equipment that churns and harrows the ground surface following broadcasting. Nitrogen-fixing symbioses also can be important both to increase cover to limit erosion and by increasing productivity and transpiration – important considerations when acid-producing mine waste rock underlies the coversoil. Since steep slopes must be worked almost normal to contours, remedial measures to improve unsatisfactory revegetation are limited when compared to slopes of 3H:1V or less. This makes steep-slope revegetation very dependent on initial revegetation establishment, where weather plays an important role. Since weather during the establishment phase is beyond control, steep-slope revegetation cannot be assured. However, the practices and materials discussed here have proven themselves at the Golden Sunlight Mine.

Additional Key Words: mine reclamation, plant cover, coarse fragments, coversoil, dozer basins, erosion control.

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MEANINGFUL MEASUREMENT OF REVEGETATION DIVERSITY

R. A. Prodgers

Abstract. In revegetation, the glitzy concept of diversity, once so promising, now lies tarnished if not discarded due largely to the unjustified use of the species as the fundamental unit of diversity. The species can be used to measure floral diversity, but no one knows what functional attributes, if any, accompany floral diversity. Thus, most diversity requirements for revegetation are arbitrary as well as indefensible. Can anyone demonstrate that an assemblage with one or two or five percent blue flax or yarrow is superior to one lacking weeds? To convince people that it matters, diversity must be linked with land use and postmine utility. For some postmine land uses, such as most ranching operations, diversity hardly matters. If wildlife habitat is the postmine land use, the time has come to return to the spirit of the original, breathtaking works relating vegetation to wildlife use. Measurements should focus on community structure and physiognomy, which can be used to define revegetation diversity. Within plant communities, the appropriate focus should be structure, with genuinely different and approximately equally different growth-forms or synusiae replacing the focus on species. The usual planimetric measurement of plant cover could be augmented with horizontal measurements -- a more realistic way to view wildlife habitat for many species. At the landscape scale, the focus should be the relative proportion and interspersion of physiognomic types in a landscape. Proportion can be measured by – what else – a proportional abundance index. Interspersion could be indexed using number of units in an area, average size or circumference, etc. The area evaluated should be large enough to consider the needs and preferences of mobile wildlife species, including temporal considerations, as well as specific requirements for less wide-ranging wildlife.

Additional Key Words: land use, structure, synusiae, physiognomy, wildlife.

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2Richard A. Prodgers, Plant Ecologist, Bighorn Environmental Sciences, 610 Monroe Ave., Dillon, MT 59725.
USING DIRECT ENVIRONMENTAL ORDINATION TO MATCH PLANT SPECIES TO FLUVIAL RIPARIAN SITES
PART I: INTRODUCTION AND METHODS

Thomas J. Keck and Richard A. Prodgers

Abstract. This investigation had two objectives: 1) to provide a scientific basis for revegetating a Superfund riparian area along Silver Bow Creek, Montana, and 2) to provide the Natural Resources and Conservation Service (NRCS) with detailed riparian vegetation information for the Silver Bow County Soil Survey. Substrates and vegetation along Silver Bow Creek were so drastically altered by historic floods and tailings depositions that the floodplain offered few clues for restoring native vegetation. The remedy entails removing contaminated materials in the floodplain and stream channel and reconfiguring the stream and floodplain using clean borrow material to achieve a stable stream gradient and associated floodplain. Rather than rely on guesswork to determine the placement of seedings and transplants, we investigated the abundance of naturally occurring riparian plant species on nearby clean substrates in relation to important soil properties. Sites, soils, and vegetation were sampled at 65 fluvial riparian sites. Soil texture and drainage classes (essentially depth to persistent wetness) are the primary factors controlling the distribution of riparian plant species. We identified four particle-size classes based on standard USDA criteria for classification at the family level, ranging from fine-loamy to sandy. Based upon USDA criteria for soils in Montana, six drainage classes from very poorly drained to well drained plus a ponded category covered the range of soil hydrology. These soil classes were used to ordinate the average relative cover of about 60 species that could be useful in revegetation. Results are applicable to revegetation because it entails careful mapping of the same soil properties. This is an adapted-species approach to revegetating within a scientific framework. Emphasis in this first of a two-part paper is on the criteria and methods used to partition soil environmental space as the basis for relating plants and their habitats.

Additional Key Words: particle-size classes, soil classification, drainage classes, plant habitats.

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Abstract. The 3-D graphs resulting from the methods and procedures described in Part 1 indicate appropriate sites in which to seed or transplant locally common riparian species into the Silver Bow Creek floodplain, if seed or transplants are available. Ten graphs are presented, most of them representative of a broader class of plants and habitats. Two main patterns are evident. One class of plants is restricted to a rather narrow hydrologic range with particle-size class playing a minor role. Another class of species occurs in one of the wetter hydrologic classes on coarse substrates, and also on somewhat drier sites when combined with finer-textured substrates. Ordinations also identified a few species of broad amplitude that can be the best choices for revegetation where long-term hydrology cannot always be predicted with certainty or where it fluctuates greatly. For most species, the soils-hydrology ordinations provided a useful and relatively unambiguous approximation of where plants should be seeded or transplanted into a reconstructed riparian zone. Some species’ edaphic habitats must be considered in the context of historical fluvial processes. For example, a set of species might typically establish on raw, moist substrates. Once established, the plants trap sediments during floods while stream downcutting lowers the water table, so that when sampled the remaining original plants are in a drier hydrologic regime than the one required for establishment. Some deep-rooted species persist in the drier habitat by maintaining contact with the capillary fringe; others are replaced by species better adapted to the new hydrologic regime and texture. A revegetation plan based solely on the observed hydrology of mature plants could erroneously indicate sites too dry for seedlings to survive. In some cases, therefore, our results must be tempered with a deeper understanding of species autecologies and fluvial processes. Matching plant species to appropriate habitats remains the basis for adapted-species revegetation. Preliminary practices and results along Silver Bow Creek are briefly mentioned.

Additional Key Words: revegetation habitat types, soil particle-size class, hydrology, adapted species.

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CREATING A DIVERSE AND EROSIONALLY STABLE HABITAT AT LA PLATA MINE, NORTHWESTERN NEW MEXICO¹

T. C. Ramsey², B. A. Buchanan, and N. Bugosh

Abstract. La Plata Mine is located in Northwestern New Mexico. The pre-mine landscape was characterized by rough broken topography with moderately steep to steep scarp and dip-slopes. The majority of the pre-mine lease area consisted of south facing dip-slopes. The Mine was faced with designing post-mining landscapes that had a 35% spoil swell. Potentially, the new habitats would have longer and steeper slopes than the pre-mine slopes. The design also has to consider the requirement that post mine landscape where stable having a soil-loss rate less than or equal to pre-mining conditions. The final surface configuration (FSC) was designed with the primary purposes of 1) creating habitat diversity, 2) and maintaining surface stability. Special land features such as talus slopes, scalloped slopes, rock-piles, rock-rims, water harvesting features, and geomorphic patterned drainages, were included to meet these objectives. In addition, variable soil substrates, including suitable spoil materials, and coarse textured topsoil materials were targeted for steep slopes to minimize soil loss and to promote shrub establishment. Finer textured topsoil materials were targeted for lowlands and valleys to promote establishment of grasses. Stability of the final surface design was validated using the RUSLE model. Various seed mixtures were applied to the diverse landscape to further promote biodiversity in the habitats. Well-designed reclamation plans can enhance post-mine biodiversity through the use of variable landscapes, soil substrata and seed mixtures.

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COALBED METHANE DISCHARGE WATER INTERACTION WITH STREAM CHANNEL SEDIMENT IN THE POWDER RIVER BASIN, WYOMING

Marji Patz, Katta J. Reddy, and Quentin D. Skinner

Abstract. Extraction of methane (natural gas) from coal deposits is facilitated by pumping of aquifer water. Coalbed methane (CBM) product water, produced from pumping groundwater, is discharged into associated unlined holding ponds or downstream channels. The objective of this study was to examine the chemistry of CBM discharge water reacting with an ephemeral stream channel sediment in the Powder River Basin, Wyoming. Water samples were collected bimonthly from three CBM discharge points and seven channel locations in Burger Draw and Sue draw, and Powder River, WY. Before sample collection, pH and electrical conductivity (EC) were measured in the field. Samples were transported to the laboratory and analyzed for alkalinity, major cations and anions, and trace elements. Results suggest that pH of CBM discharge water ranged between 7 and 7.1 and EC ranged between 4.25 and 4.35 dS/m. CBM discharge water within the Burger Draw watershed contains high sodium (Na) and alkalinity. The pH of CBM discharge water increased in downstream channels of Burger Draw and Sue Draw. However, pH of the channel sediment water interface (2cm) was decreased. In addition, dissolved calcium (Ca\(^{2+}\)) concentrations of CBM discharge water decreased significantly in the downstream channel water, which increased sodium adsorption ratio (SAR). Dissolved iron (Fe) and manganese (Mn) concentrations decreased, while dissolved arsenic (As) and selenium (Se) concentrations increased in the downstream channel. The only significant difference in water chemistry above and below of the confluence of Burger Draw with the Powder River was pH, which increased from 8.36 to 8.52. Overall, the significant increase in SAR values of CBM discharge water in Burger Draw and Sue Draw tributaries suggest further monitoring is needed to evaluate the buffering capacity of receiving streams and rivers in the Powder River Basin of Wyoming.

Additional Keywords: water quality, water chemistry, salinity, sodicity, trace elements, ephemeral stream, semi-arid environment

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FATE AND TRANSPORT OF METAL AND SEDIMENT IN SURFACE WATER

Rosalia Rojas\textsuperscript{2} and Pierre Julien

\textbf{Abstract.} This effort focuses on surface water and sediment transport, with an emphasis on the fate and transport of metals in rivers from mining wastes. The main objectives of this project are to: (1) improve and develop computer modeling tools for the simulation of erosion and sedimentation of sediment and metals in surface waters; and (2) develop methodology for evaluating impacts from sediment and metals on watersheds. The CASC2D-SED numerical model is used as a basic framework to simulate metals transport and fate. This model is directly coupled with GIS-based site characterization data and remote sensing sources. Physical characterization of waste rock piles such as degree of erosion, slope stability, distance from surface water, proximity to a drainage channel, presence of vegetation on mine waste and presence of a kill zone are taken into account in the model. CASC2D-SED allows the simulation of an unlimited number of soil and metal particle types from different source areas (e.g. different waste piles and uncontaminated areas) and the total delivery of solids is computed as the sum of all particle types simulated. The simulation of heavy metals transport during a rainfall event is visualized as an animated sequence of raster grids. At the end of the simulation, spatial variability of deposited or scoured volumes is shown for each metal as a raster grid.

The CASC2D-SED model is applied to the EPA California Gulch Superfund site, Colorado. Raster data sets collected on the site consist of a Digital Elevation Model (DEM), land use / land cover map, soil type map, digital orthophoto quadrangles, and AVIRIS mineral map. AVIRIS images are used to map the spatial distribution of minerals associated with the sources of acid rock drainage and heavy metal contamination. The main benefit of this research includes an improved understanding and representation of metals transport and fate in mine waste impacted hillslopes and streams. The results of this study provide remediation managers with a tool to examine the contribution of individual contaminated areas to the total impairment of a site in terms of heavy metals transport.

Additional Key Words: CASC2D-SED, AVIRIS, GIS, DEM

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CASE STUDIES OF LIMESTONE-BED PASSIVE SYSTEMS FOR MANGANESE REMOVAL FROM ACID MINE DRAINAGE

Arthur W. Rose, P.J. Shah and Brent Means

Abstract. The main method for passive removal of manganese is the “Pyrolusite” system, in which a bed of limestone is inoculated with Mn-oxidizing bacteria. Nine sites of this type, plus four limestone-lined channels, have been studied. Other information is incorporated from published work. Effective Mn removal requires oxidizing well-aerated water, as well as prior removal of essentially all dissolved Fe and Al, and pH above about 6.5. Most of the Pyrolusite systems removed Mn from influent values of 6 to 30 mg/L to effluent levels between 0.5 to 1.5 mg/L for a period of 2 years or more. Based on the depth distribution of dissolved O₂ and Mn oxide precipitate, most Mn removal occurs in the top 0.3 m of the bed, just below the water surface. The deeper parts of beds do not appear to contribute significantly. Most Mn removal rates range from 1.5 to 5 g/m²/day, with the lower values from beds with influents containing appreciable Fe and Al. Several of the systems have failed because of plugging of the inlet area with silt, leaves, Fe and/or Al precipitate, grass and other materials. Several field tests and experiments suggest that special bacterial inoculation may not be necessary. Three successful limestone-lined channels have been observed, one with an Mn removal rate of about 10 g/m²/day. A shallow bed or channel, lined with limestone, and containing algae to enhance O₂, appears to be an improved design.

Additional key words: Pyrolusite Systems, coal mine drainage, bacteria

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MITIGATING CUTTHROAT TROUT HABITAT LOSSES USING CONSTRUCTED SPAWNING BEDS IN A WYOMING SPRING CREEK

Katie M. Salsbury

Abstract. Artificial spawning beds and adjacent pools with cover were constructed to increase the available spawning habitat and adult holding water for Snake River cutthroat (Oncorhynchus clarki) on Three Channel Spring Creek in Jackson, Wyoming. Three Channel Spring Creek is a perennial spring creek with an average baseflow of 1.42 cubic meters per second (50 cfs) and is a tributary to the Gros Ventre River at its confluence with the Snake River. Constructed levees throughout the Snake River drainage in Jackson Hole have cut off the historic flood plain and have reduced the available spawning habitat. In 2001, a total of eight spawning beds were constructed throughout a 500 m stretch of lower Three Channel Spring Creek. Spawning beds were constructed using 2.5 cm – 5 cm washed, quarried gravel at a ratio of two parts 5 cm to one part 2.5 cm. Spawning beds were constructed by placing gravels directly onto the existing substrate in areas where the average velocity exceeded 0.04 cubic meter per second (1.5 cfs) and the average post-construction depth exceeded 15 cm. Pools were excavated downstream of each constructed spawning bed to an average depth of 1.06 m. Native cottonwood logs were submerged in each of the pools by driving them into the banks with an excavator. Redd and fish counts conducted by the Wyoming Game and Fish Department before and after the construction of the project reflected an increase in the cutthroat utilization throughout the project area. The number of redds within the constructed area increased by 60% and the estimated number of spawning fish increased by 50%. All of the constructed beds were utilized by multiple spawning pairs in the first year post-construction. We concluded that artificial spawning beds are an effective tool to increase cutthroat production in spring creeks with existing populations.


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BIO-ENGINEERED STREAMBANK STABILIZATION USING WETLAND SOD ON THE TETON RIVER: A CASE STUDY¹

Katie M. Salsbury²

Abstract. Wetland sod in combination with erosion control fabric was used to reconstruct and stabilize an eroding streambank on the Teton River in southeast Idaho. The river has an average base flow of 5.67 m³/s and an average peak flow of 34 m³/s. Above and throughout the study area the Teton River is a predominantly ground water fed, free flowing system with a moderate spring run-off. Conditions at the study site pre-construction included an average bank height of 1.07 m, an average bank slope of 2:1 and dominant bank vegetation consisting of introduced pasture grasses. The dominant soil type was a silty clay loam. The existing bank was reconstructed by first excavating the bank down to the base-flow water line to a width of 3.66 m. Two layers of long-term erosion control fabric were staked onto the base of the excavated bank using 20 cm wire staples. Soil was compacted onto the erosion control fabric layers to a depth of 0.30 m. Approximately 1 m of the erosion control fabric was wrapped up onto the compacted soil to build the initial toe of reconstructed bank. The remaining soil was sloped back to create a bank with an average slope of 3:1. Wetland sod, a pre-vegetated coir product planted with native sedges and rushes, was installed in two rows onto the constructed toe and remaining bank to a width of 1.83 m. A total of 77 m of eroding bank was reconstructed in 2 days at a cost of $195 per linear meter. In 1 month post construction the pre-vegetated coir material was fully rooted and could not be displaced by human or animal disturbance.

Additional Key Words: erosion, pre-vegetated coir, wetland revegetation

²Katie M. Salsbury is a principal owner of Intermountain Aquatics, Inc. Driggs, ID 83422.
EVALUATION OF TOPSOIL DEPTH EFFECTS ON VARIOUS PLANT PARAMETERS WITHIN A RECLAIMED AREA IN NORTHEASTERN WYOMING

Brenda K. Schladweiler, George F. Vance and Rose Haroian

Abstract: A project was initiated in 1998 to investigate the effect of varying topsoil depths on soil parameters, plant cover, production and diversity on a coal mine in northeastern Wyoming. Soil and vegetation information was collected for three consecutive growing seasons (2000 through 2002) on reclaimed areas with three topsoil treatment depths (15, 30 and 56 cm) and from two native reference areas (Upland Grass and Breaks Grass) at the mine. For the vegetation analysis, total vegetation cover, total cover, average number of species and total number of species were the primary parameters. Vegetation production was measured in 2002 only. Analyzed soil parameters included pH, electrical conductivity and sodium adsorption ratio at 15 cm intervals throughout the treatment depth and the immediate underlying spoil material. Although three years of data has been collected for this project, the primary emphasis of this paper will be 2002. No significant differences in vegetation and soils were noted by treatment in the 2000 through 2002 data. Location effects, however, were numerous, which emphasizes the difficulty in utilizing native reference areas as standards for reclamation success on reclaimed areas. All vegetative parameters were generally higher in reference areas with the exception of production. Diversity indices on the reclaimed and reference areas were also evaluated. The Shannon-Wiener indices were significantly different by location throughout 2000 to 2002 and by treatment in 2001, i.e., the 30 cm treatment was significantly higher in diversity than the 56 cm treatment. Previous research has indicated diversity differences in topsoil depth treatment levels increase over time. For this project, differences in topsoil depth treatments will likely increase over time and/or with more typical precipitation patterns.

Additional Key Words: plant diversity, diversity indices, variable topsoil depth, soil chemistry, reclamation.

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AGGREGATE MINING AND WETLAND BANKING

Darcy C. Schmitt, Anthony M. Bauer, and Jon Bryan Burley

Abstract. Reclamation specialists are interested in developing and designing post-mining land-uses that are locally meaningful. Wetland banking, the creation of new wetlands in compensation for the destruction of other wetlands is one post-mining land-use that is especially pertinent to aggregate mining because the aggregate mining landscape often contains great intrinsic potential to generate new wetlands. The Bend Area mine in Georgetown Township, Ottawa County, Michigan, illustrates this potential for wetland banking. This poster demonstrates through the design process, the application of wetland banking in the development of a master plan for the Ottawa County Parks and Recreation Commission. The case study illustrates creation of wetland banking areas through the act of aggregate mining operations and illustrates the integration of recreation resources with wetland environment.

Additional Key Words: landscape architecture, park design, site planning, aquatic habitats, aquatic environments

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MINE & TAILINGS RECLAMATION AT BEAR CREEK URANIUM: A SUCCESS STORY

E.Y. Scott

Abstract. The Bear Creek Uranium open pit mining and milling operation is located in the southern Powder River Basin in Converse County, Wyoming operated from 1976 until 1985. Early termination of the uranium sales contract and closure of the mine required major modification of the approved reclamation plan. The approved plan included a lake in the final pit; however at the time of termination the pit sequencing had not progressed to the approved point and the USFS would not approve leaving a lake on their property. The plan was modified to include total backfill of all open pits. Final mine reclamation operations commenced in July 1985 and were completed in December 1999. The Wyoming DEQ has granted bond release on approximately 1800 acres of mine disturbance.

Tailings reclamation regulated by the U.S. Nuclear Regulatory Commission must satisfy 10 CFR 40, Appendix A and other NRC guidelines to ensure that radioactive emissions meet Criterion 6 levels for radon (20 pCi/m²/sec), and gamma is at background levels. The long-term stability and containment of tailings must last for 1000 years without active maintenance. The tailings cover is designed with a three-foot compacted clay radon barrier, flat surfaces that reduce PMF runoff velocities to sub-erosive velocities of <2 fps. Rock riprap structures placed adjacent to the tailings control velocities through elevation drops as surface runoff exits the reclamation area. Placement of the reclamation cover commenced in 1997 and was completed in 1999. The tailings site is now ready for transfer to DOE for long term stewardship.

Additional Key Words: open pit reclamation, bond release, uranium tailings reclamation, radon barrier, erosion protection, DOE long-term stewardship

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EFFECT OF SOLID PHASE ORGANIC SUBSTRATE CHARACTERISTICS ON SULFATE REDUCER ACTIVITY AND METAL REMOVAL IN PASSIVE MINE DRAINAGE TREATMENT SYSTEMS

J. Seyler¹, L. Figueroa¹, D. Ahmann¹, T.R. Wildeman¹, and M. Robustelli²

Abstract. This paper is a progress report on studies whose objectives are to determine methods of analysis that will rate metal sorption and sulfate reduction activity of organic materials for use in passive treatment systems (PTS). Substrates tested include agricultural residues (alfalfa pellets, sugar beat pulp pellets, brewery waste, corncobs, and walnut hulls), inoculums (dairy manure and wetland inoculum), and a variety woods (maple, oak, pine, poplar, and walnut). Characteristics targeted include moisture, organic and nutrient content; water, ethanol and acid soluble and insoluble fractions and metal sorption capacity. The short-term and long-term effects of organic substrate characteristics on metal removal and sulfate reduction rate are being evaluated in batch and column experiments receiving mine water. These data are not presented in this paper but will be included in the oral presentation. Measured values of moisture and organic content ranged from 5.5 to 65% and 7.4 to 95% relative to raw sample weights, respectively. The water-soluble fractions and protein content ranged from 0 to 32% and 2 to 23% relative to dried samples, respectively. Low concentration zinc sorption studies were described well by Freundlich isotherms. Using a wider range of concentrations, manganese sorption to substrates was more closely modeled by Langmuir isotherms. The highest manganese sorption was observed for manure, corncobs, walnut hulls and wetland inoculum (8-13 mg Mn / gram substrate at an equilibrium concentration (Cₑ) = 50 mg/L Mn). Corncobs and walnut hulls can be included in substrate specifications to target manganese removal. Moisture and organic content are important parameters in the specification of organic substrates as a significant portion of the raw organic substrate weight can be inorganic. A high soluble fraction should correlate with a rapid startup of SRB activity and thus is an important element in substrate specification. All substrates have some capacity for metal sorption and their quantification is essential for use in PTS.

Additional Key Words: mine drainage, metal treatment, passive treatment, organic substrate, lignin, polysaccharide

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RESEARCH ACTIVITIES AT THE ROCKY MOUNTAIN REGIONAL HAZARDOUS SUBSTANCE RESEARCH CENTER¹

Charles D. Shackelford²

Abstract. The Rocky Mountain Regional Hazardous Substance Research Center (HSRC) is one of five HSRCs established by the U. S. Environmental Protection Agency (EPA) in 2001. Each of these HSRCs is affiliated with one to three of the 10 EPA Regions and focuses on basic and applied research including technology transfer with respect to a primary regional issue related to protection of human health and the environment. Accordingly, the Rocky Mountain Regional HSRC is affiliated with EPA Region 8 states (Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming) with the primary research focus on developing new and improve existing methods or technologies for in situ remediation of mine waste sites. The purpose of this paper is to describe the scope of the research activities at the Rocky Mountain Regional HSRC. After defining the nature and extent of the types of research activities that are conducted through the Rocky Mountain Regional HSRC, a brief overview of the six research projects currently being funded is presented. This presentation is followed by a description of the short-term (≤ 5 yrs) direction of the Rocky Mountain Regional HSRC, followed by a description of the future role of the Rocky Mountain Regional HSRC with respect remediation of mine waste sites.

Additional Key Words: acid mine drainage, EPA, metals, mine waste remediation, treatment, remediation technologies

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MECHANICAL AND HYDROLOGICAL PROPERTIES OF TWO OHIO MINED SOILS TWENTY-FIVE YEARS AFTER RECLAMATION

M. K. Shukla, R. Lal, J. F. Underwood and M. H. Ebinger

Abstract. Surface mining results in extreme changes in soil properties. Reclamation plus natural pedogenesis over time gradually restores quality of drastically disturbed soil. The temporal changes in soil mechanical and hydrological properties were assessed for two reclaimed mined soils in Jackson (Fairpoint, FP soil) and Vinton (Bethesda, BT soil) counties in southeastern Ohio. The study was undertaken on three land uses viz.: (1) undisturbed soil (unmined; UMS), (2) reclaimed mined soil (RMS), and (3) spoil (SP). The UMS and RMS were under continuous tall grass cover since 1975-76 for both FP and BT locations. Soil fertility treatments imposed from 1979-1994 were studied for each RMS for three rates of nitrogen, phosphorous and potassium application 0-0-0 (FL1), 112-25-46 kg ha\(^{-1}\) (FL2), and 224-49-92 kg ha\(^{-1}\) (FL3). Soil development was clearly evident from the increase in the depth of Ap horizon, soil organic carbon (SOC) pool, clay eluviation, total porosity, effective porosity, available water capacity, water stable aggregation (WSA), total infiltration (I), sorptivity (S), and decrease in bulk density (\(\rho_b\)). The SOC pool for RMS in 0 to 10 cm of the Ap horizon increased from 14.2 Mg ha\(^{-1}\) in 1981 to about 28.7 Mg ha\(^{-1}\) in 2001 for FP soil and from 15.1 Mg ha\(^{-1}\) to 30.2 Mg ha\(^{-1}\) for BT soil. Fertility treatments decreased mean \(\rho_b\) by 9% for 0 to 10 cm depth and 5% for 10 to 20 cm depth for FP soil, and by 4% for only 0 to 10 cm depth for BT soil. The average values of WSA and mean weight diameter (MWD) were in the order UMS > RMS > SP for both FP and BT soils. The magnitude of clay eluviation between 1981 and 2001 was about 26% for 0 to 10 cm depth and 16 % for 10 to 20 cm depth for FP soil, and 8% for 0 to 10 cm depth for BT soil. The high S and I values for RMS and UMS land uses indicated that together with natural pedogenesis, macropore channels formed by roots also had a significant impact on water transmission properties.

Additional Key Words: Drainable porosity, Available water content, Soil bulk density,

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Abstract. A pulsed limestone bed (PLB) treatment plant for remediation of acid mine drainage (AMD) has been tested at the Friendship Hill National Historic site in southwestern Pennsylvania. The plant performed well, neutralizing over 50 metric tons of acidity over a 14-month period, but the cost of disposal of the 450 metric tons of sludge generated was high, because the sludge was hauled from the site and disposed of in a commercial landfill to minimize the impact on park property. Although the sludge was found to be non-hazardous based on the Toxicity Characteristics Leaching Protocol (TCLP), hauling and disposal costs were still elevated, at $40 per m³. Since sludge handling and disposal was a significant fraction of the operating cost of the facility, a study of the sludge characteristics and possible alternate handling methods was undertaken. Samples of AMD influent, treated water and settled sludge were used in a series of small-scale treatment studies. These tests showed that the sludge volume produced by limestone neutralization was less than half of that for lime, sodium hydroxide or ammonia. The settling rate was also greater for the limestone-based sludge. Vacuum filtration tests demonstrated that the limestone sludge was more readily filtered than sludges generated with sodium hydroxide or lime and that solids contents of up to 28% could be achieved. Because of lower maintenance costs, pressure filtration using a plate and frame filter is recommended for future plant operations. In this case, solids contents of as high as 31% were realized. As an alternative to the operating costs of mechanical filtration, a settling/percolation process was tested. Percolation tests showed that solids content of the settled sludge could be increased from 8% to 25%. These results show that sludge disposal costs for the treatment plant could be decreased through installation of a settling or filtration process. Moreover, the PLB process offers saving not only in reagent costs, but also in sludge disposal costs, through decreased sludge volume generated, rapid settling rates and ready filterability.
Abstract. The Surface Mining Control and Reclamation Act (SMCRA, Public Law 95-87) established national environmental performance standards for surface mining and reclamation. These standards require operators as a minimum to "restore disturbed land to an original or better condition." Implementation of these standards was through a nationwide permit program (commonly administered by State regulatory programs). These Federal/State programs required operators to submit comprehensive mining and reclamation plans that provide detail necessary to demonstrate the operations ability to meet the performance standards during and after mining and the capacity of reclaimed lands to support a variety of land uses.

On Western surface mines wildlife habitat is often considered a joint land usage along with livestock grazing and while the reestablishment of diverse native plant communities on these lands does benefit wildlife, maximum benefit from these reconstructed ecosystems can be achieved by providing adequate postmining wildlife water facilities.

The following narrative and figures characterize the development of one of these postmining water resources at the Dave Johnston Coal Mine (Mine). The Mine is located in east central Wyoming on the southern edge of the Powder River Basin coal field. Mine topography is characterized by low, rolling hills and buttes capped with sandstone. Elevations on the Mine range from 5,400 to 5,800 feet.

Soils on the Mine are deep to moderately deep; textures range from sandy to sandy loam. However, finer soil textures are common within drainage area alluvial deposits.

The Mine lies within a semiarid climatic zone and is characterized by cold, dry winters and hot summers. Annual precipitation is 11.54 inches; temperatures range from -30.0 to 96.0 degrees Fahrenheit. Winds blow constantly; the average annual velocity is 14.7 miles per hour.

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INITIAL RESULTS OF NATIVE SPECIES ESTABLISHMENT ON HIGHWAY CORRIDORS IN WEST VIRGINIA¹

Jeff Skousen and Ron Fortney²

Abstract. Introduced and invasive species have been recognized as potential threats to natural plant communities. Many such plant species are introduced along roadways, which then can spread to adjacent fields and forests. The West Virginia Division of Highways is required to develop seeding mixtures comprised of native plants for revegetating highway corridors and thereby to reduce the potential for introducing non-native species along roads. Therefore, the objective of this project was to identify native plants that are suitable for seeding on highway sites, and to document survival and growth of these species after seeding on highway cut and fill areas. Three sites (Baker, Hazelton, and Parkersburg) in West Virginia were chosen as demonstration sites and seeded in April 2002. At each site, five seed mixes (Control, Native, DOH, DOH-Native, and DOH½-Native) were seeded into fertilized and unfertilized plots. Plots were 2m by 2m and each treatment (seed mix and fertilizer) was replicated four times (40 plots per site). First year results show that fertilized plots showed a trend for promoting higher ground cover compared to unfertilized plots. Unseeded, unfertilized plots generally had more weedy species than other plots. Native species establishment was poor and plots seeded to native species were mostly colonized by non-native species from adjacent areas. Regardless of seed mixture, most plots contained birdsfoot trefoil (*Lotus corniculatus* L.) and annual ryegrass (*Lolium multiflorum* Lam.) as dominant plants. Due to their slow-establishing nature, native species were not seen during the first year. In subsequent years, it is anticipated that the native species will emerge and become a more prominent contributor to the ground cover. It is also anticipated that plots with a combination of less-aggressive introduced species with low fertilizer rates will allow opportunities for the later-establishing native plants to develop and grow.

Additional Key Words: fertilization, highway construction, invasive species, revegetation, seed mixtures.


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USE OF STABLE ISOTOPES TO EXAMINE METAL ATTENUATION AND RELEASE PROCESSES IN A FLUVIAL TAILINGS DEPOSIT 1,2

Kathleen S. Smith3, James F. Ranville, Paul J. Lamothe, and Brian P. Jackson

Abstract. The upper Arkansas River south of Leadville, Colorado, contains deposits of fluvial tailings from historical metal-mining operations. These sulfide-bearing deposits are possible non-point sources of acid and metal contamination to surface- and ground-water systems. We conducted a pilot study to evaluate the use of stable-metal isotopes to help ascertain metal retention and release mechanisms that influence metal transport from the deposits to shallow ground water. To accomplish this, we excavated an intact core from a small fluvial tailings deposit and performed laboratory column experiments to examine the amount of metals leaching through the core under different geochemical conditions. Deionized water was continuously applied to the top of the core, and effluent was collected from the bottom of the core for a period of about 2 months. The core was sequentially leached under unsaturated, partially saturated, and fully saturated conditions to simulate changing water-table levels within the deposit. Reducing conditions developed upon partial and complete saturation of the core. During all leaching phases, core effluents were acidic (pH 2.8-3.5) and contained elevated metal concentrations. During a portion of the unsaturated leaching phase, stable-metal isotope spikes (111Cd, 65Cu, 54Fe, 207Pb, and 68Zn) were applied to the top of the core along with conservative tracers. None of the isotope spikes exhibited breakthrough with simultaneously added conservative tracers during the unsaturated leaching phase. However, some of the isotope spikes did break through when reducing conditions developed (during partial- and complete-saturation conditions). By comparing the behavior of metal-isotope spikes with total-metal concentrations in the effluent from the core, we were able to gain insights into geochemical conditions that might promote release of particular metals from the fluvial tailings deposits to the shallow ground-water system at our field site. Hence, use of stable-metal isotopes facilitated the determination of different metal-attenuation processes, metal-release processes, and metal sources in the fluvial tailings deposit in response to changing geochemical conditions.

Additional Key Words: cadmium, copper, iron, lead, zinc, prediction, geochemical, leaching, column experiments

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2 Use of brand names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.
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THE USE OF A MODIFIED SNOWCAT FOR STEEP SLOPE AND RIPARIAN REVEGETATION

Troy C. Smith

Abstract. Few environmental factors challenge the budget of a reclamation project more than steep slopes. The cost of reducing the slope of a waste material often greatly exceeds the cost of amendments and capping materials. Great cost savings, and often environmental benefits, from reduction in disturbed and surface areas can be obtained when waste material slopes are left steep. The maximum stable slope angle and length depends on cover material texture and climate. In semiarid climates where intense thunderstorms are not common, coarse textured soils can maintain 2:1 (%50) slopes for lengths of several hundred feet. Models are available for predicting stability. If a project can realize savings and disturb less ground by steepening the design for waste material slopes, it becomes illogical to further reduce the slope for the sole purpose of working the slope with standard agricultural tillage and seeding tools. In the past, alternative seeding techniques such as hydroseeding, helicopter seeding or using bulldozers has been expensive. Currently, several types of tracked vehicles are available which can climb 2:1 slopes. To date, Arrowhead's modified Thiokol snowcat has been the best. The modifications include, heavier tracks, heavier undercarriage, extra cooling capacity, a broadcast spreader mounted on the front and an implement lift system mounted on the back with a harrow for seed incorporation. This machine can seed several 2:1 slope acres per hour at a fraction of the cost of hydroseeding. By incorporating the seed, it is a far better method than broadcasting alone. The snowcat generally runs up and down the slope seeding and harrowing at the same time. The large grouser bars on the tracks help eliminate vertical patterns up and down the slope even though the harrow drags behind the tracks. Arrowhead's snowcat has been successfully used for the last several years at many of Montana's open pit mines. It has lately found a valuable niche scarifying and seeding wetland projects where conventional equipment causes too much damage.

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BIOSOLIDS REMEDIATION OF A BASE METALS MINING SITE

Mark D. Sprenger², Harry Compton, Amanda Maxemchuk, Sally Brown, and Mike Zimmerman

Abstract: The USEPA has been evaluating emerging cost-effective green engineering solutions, such as application of biosolids to large area metals mining sites developed by the U.S. Department of Agriculture (USDA). A portion of the California Gulch Site in Leadville, Colorado was characterized by discrete 0.5-1.0 hectare parcels of fluvial mine tailings deposits which occurred along the embankment of the Upper Arkansas River. The contaminants of concern in the tailings were zinc, lead, cadmium, copper and manganese, with zinc concentrations ranging from 50,000 - 100,000 ppm. During a 4.5-hectare pilot demonstration project, biosolids and agricultural lime were applied to the tailings at a rate of 224 MT/hectare each, and incorporated the mix using heavy equipment. One and two years after the amendments had been applied, the Environmental Response Team evaluated changes in soil physical, chemical, biological and toxicological characteristics, through metals analyses, agronomic assessment, evaluation of soil microbial community structure and function, and rye grass and earthworm toxicity testing. At two years post treatment field bioaccumulation investigations were also conducted to support the evaluation of residual ecological risks. The short term results demonstrated that biosolids amendments were effective for treating large area, highly impacted, base metals mining sites, and reducing metals toxicity and availability and promoted the establishment of microbial and plant communities. Results of the field bioaccumulation assessments are promising in terms of the degree of accumulation observed.

Key Words: mine tailings, soil treatment, and ecorisk

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ACCUMULATION OF ORGANIC CARBON IN RECLAIMED COAL MINE SOILS OF WYOMING¹

Peter D. Stahl², Jonathan D. Anderson, Lachlan J. Ingram, Gerald E. Schuman, and Daniel L. Mummey¹

Abstract. The potential to sequester carbon and increase organic nutrient storage in disturbed soils, such as those reclaimed after surface coal mining, appears to be significant. Quantification of organic carbon accumulation is complicated, however, by the presence of coal and coal dust in these soils. Our preliminary data on organic matter content of reclaimed soils at surface coal mines in Wyoming suggest they are sequestering carbon at a rapid rate. Data from a surface mine reclamation site near Hanna, WY indicate that surface (0-15 cm) soil organic carbon content has increased from a low of 10.9 g C kg⁻¹ soil in 1983 to 18.6 g C kg⁻¹ soil in 1998 and to 20.5 g C kg⁻¹ soil in 2002. Undisturbed soil directly adjacent to the reclaimed site has a mean organic carbon content of 15.1 g kg⁻¹ soil. At a mine near Glenrock, WY, soil organic carbon at a site reclaimed in 1979 increased from an estimated low of 5.8 g C kg⁻¹ soil to a current level of 18.4 g C kg⁻¹ soil. Organic carbon content of undisturbed soils adjacent to the reclaimed area range from 9.9 to 15.7 g C kg⁻¹ soil. In contrast to the elevated organic carbon content, amounts of microbial biomass in reclaimed soils at both mines are lower than in nearby undisturbed soils (ca. 60% or less). We have collected similar data from a number of other surface coal mines in Wyoming. We hypothesize that decomposition rates are slow in reclaimed mine soils due to low microbial activity relative to that in undisturbed soils.

Additional Keywords: carbon sequestration, reclaimed mine soil, soil organic matter, surface coal mine, soil microbial biomass

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DRY CREEK ABANDONED MINE LAND RESTORATION DEMONSTRATION PROJECT: A COOPERATIVE EFFORT

Martin Stearns, Terry Schmidt, Tim Eagle, Dave Turner

Abstract: Historic coal mining that occurred on the Cumberland Plateau of middle Tennessee prior to the passage of the Surface Mining Control and Reclamation Act of 1977 left a lasting mark on the upland watersheds. Early exploration methods normally consisted of walking stream channels looking for coal outcrops. Where the outcrops were encountered, mining operations were started, often within the streambeds and advancing upstream and outward following shallow overburden cover. When these operations ceased they normally left open pits that became part of the stream channel. Acid forming material that was exposed during the operations oxidized and created pockets of standing and flowing surface water with depressed pH, elevated mineral content, and minimal aquatic habitat.

In 1999 Sequatchie Valley Coal Corporation (SVCC) and Tennessee Department of Environment and Conservation (TDEC) began discussions regarding acid rock drainage discharges from abandoned mine lands adjacent to the Sequatchie Valley Mine. A cooperative agreement was signed where restoration costs would be shared between SVCC, the TDEC Abandoned Mine Land Program, and the U.S. Environmental Protection Agency (EPA) through the Clean Water Act Section 319 Program. Work at the chosen site was to be demonstrative of accepted practices outlined in EPA’s Coal Mining Best Management Practices Guidance Manual. Grubbing and clearing began in March 2002. Construction, which included diversion ditches, oxic alkaline addition channels, anoxic limestone drains, oxidation basins, and polishing wetlands, was completed in July 2002. Immediate improvement in the water quality of the receiving stream has been documented.

Additional Key Words: Acid rock drainage, best management practices, cooperative agreement

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GILLETTE AREA GROUNDWATER MONITORING ORGANIZATION: WHAT HAVE WE LEARNED IN 20+ YEARS? 1

Martin W. Stearns 2

Abstract. The Gillette Area Groundwater Monitoring Organization (GAGMO) was formed in 1980 to serve as a data gathering organization. Membership is limited to those companies with operating or proposed coalmines in the Powder River Basin of Wyoming and to interested State and Federal regulatory agencies. GAGMO compiles member coal mining company’s annual ground-water data collected in October of each year. These ground-water data are tabulated in a regional database and published in an Annual Report with ten-year cumulative assessment reports done in 1990 and 2000.

Through the mid-1990’s, the impacts to surrounding ground-water static water levels had been limited to areas immediately surrounding active mine pits. Measured drawdown in monitoring wells constructed as part of the coalmine permitting process was less than predicted by pre-mine modeling. In the mid-1990’s, a method to economically dewater the Wyodak coal seam and recover methane was developed. This led to extensive coal-bed methane development in the Gillette area of the Powder River Basin. Over 8,000 wells have been constructed with an additional 39,000+ proposed within the next five years. The drawdown affect of the existing wells has been extensive and rendered a number of monitoring wells associated with coalmines “gassy” and useless. The additional proposed wells will continue to expand the impact area both horizontally and vertically. Potential concerns that will need to be addressed are the assessment of cumulative hydrologic impact associated with new coal mine permits by state agencies, the need for continuation of current ground-water monitoring programs, and bond release of reclaimed areas that continue to show water level drawdown.

Additional Key Words: Groundwater monitoring, coalmines, drawdown, coal-bed methane, cumulative hydrologic impact assessment, bond release

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MINING LEGACY IMPACTS ON BOND RELEASE1

Greg Passini, and Jay Stender2

Abstract. Historical business practices at Big Horn Coal Company (BHCC) resulted in 2.1 acres of hydrocarbon contaminated area, formerly a retail sale yard, within the mine permit area. BHCC is pursuing final bond release and this area is within the reclamation area. The retail sale yard consisted of a coal loadout structure, rail yard, and scale house which operated since 1945. The surface soils within the sale yard area were contaminated, at trace levels, with hydrocarbons (Bunker C and waste oils) used for dust suppression. Remediation of the contaminated soils, to satisfy regulatory standards, had to be completed and approved prior to contouring, topsoiling, and reseeding efforts dictated by the reclamation plan. BHCC used a collaborative agency approach and a newly enacted statute to assess, remediate and then, after acceptance, reclaim the area in accordance to the mine reclamation plan. This process required an initial assessment of contamination conditions in groundwater and soils, excavation, verification of contaminant levels, and further excavation to meet changing regulatory clean up limits. Unique to this process was a newly enacted statute – Article 16, Voluntary Remediation of Contaminated Sites of the 2000 Environmental Quality Act, which, if meet, would essential require no further action (NFA) at the site. BHCC chose to pursue Article 16 to achieve a clear and defined closure decision, which in turn, enabled bond release activities to be implemented without cross jurisdictional disputes. BHCC reclaimed and closed the area in accordance with the Article 16 standards and the mine reclamation plan approved by Wyoming DEQ Land Quality Division.

Key Words: Retail Coal, Bunker C, Reclamation, Remediation

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CHARACTERIZATION OF NATURAL WETLAND SOILS RECEIVING ACID MINE DRAINAGE

Kyle M. Stephens, John C Sencindiver, and Jeffery G. Skousen

Abstract. A proposed section of Appalachian Corridor H will pass through an area of the Beaver Creek watershed in Tucker County, WV previously mined for the acid-producing Upper Freeport coal. Presently, partially-reclaimed spoils from past mining activities are generating acid mine drainage. Wetlands adjacent to the spoils are supporting vegetative communities and they appear to be naturally treating the drainage. We characterized soils of the acid mine drainage-impacted wetlands and non-impacted wetlands to establish baseline soil status and to compare the acid mine drainage-impacted soils and non-impacted soils. We analyzed soil samples for pH, sulfate, acid volatile sulfides, chromium reducible sulfides, organic sulfur, total sulfur, total carbon, and total iron. Platinum redox electrodes were placed in some of the wetland soils to assess near surface redox chemistry. Wetlands receiving acid mine drainage generally contained higher levels of total sulfur, and the sulfur in these wetlands was more likely to be in the form of acid volatile sulfides, sulfate, and/or chromium reducible sulfides. Chromium reducible sulfides ranged from 0.0 to 103.4 \( \mu \text{mol g}^{-1} \) and acid volatile sulfides ranged from 0.0 to 32.3 \( \mu \text{mol g}^{-1} \) in all wetlands. The carbon content in wetlands receiving acid mine drainage was generally lower than the non-impacted wetlands and the iron content was generally higher in the acid mine drainage-impacted wetlands. Redox values indicated that conditions are present in impacted wetlands for iron and sulfur reduction to occur.

Additional Key Words: Acid volatile sulfides, Chromium reducible sulfides, Beaver Creek Watershed, Redox potential

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IMPLEMENTATION OF EPA'S NEW WESTERN ALKALINE COAL MINING SUBCATEGORY

J.P. Tinger and J.R. Galetovic

Abstract: The discharge of wastewater from coal mines is regulated under the Environmental Protection Agency's effluent limitations for coal mines at 40 CFR Part 434. In January 2002, EPA promulgated a new Western Alkaline Coal Mining Subcategory to control erosion and sediment. The new subcategory will cover alkaline mine drainage from reclamation areas and certain non-process areas in the arid and semiarid west.

Although the previous regulations established effluent limitations for reclamation areas, the regulations required all reclamation areas throughout the U.S. to meet the same discharge limits. These regulations basically required the construction of large sediment ponds to control sediment. The construction of large sediment ponds in the west to contain runoff from areas that naturally contain large amounts of sediment can result in non-water quality impacts that harm the environment, including disturbing the natural hydrologic balance and impacting large areas of land for pond construction. To address these impacts, EPA has established a new subcategory that requires coal mine operators to implement BMPs so that post-mined lands are reclaimed to mimic natural conditions.

The new regulations require that a coal mining operator must design and implement BMPs to maintain the average annual sediment yield equal to or below pre-mined, undisturbed conditions. This will ensure that natural conditions are maintained, and will not allow a coal mining operator to increase the discharge of sediment over background conditions. To achieve these results, EPA will require that the operator develop a site-specific sediment control plan using established watershed modeling techniques. EPA's regulations and guidance documents are available at www.EPA.gov/ost/guide/coal.

Additional Key Words: sediment modeling, reclamation, regulations.

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EFFECTS OF GRAZING ON DIVERSITY AND SEASONAL BALANCE ON RECLAIMED GRASSLANDS IN NORTH DAKOTA

Christopher J. Trosen, Donald R. Kirby and David J. Nilson

Abstract. The purpose of this study was to evaluate the influence of prescribed seasonal grazing on diversity and seasonal balance of 2-yr old, 3-yr old and 4-yr old reclaimed grasslands in western North Dakota. Research was conducted on the Glenharold Mine in Oliver County, which is located in the Missouri Slope Physiographic Region of North Dakota. The 55 ha study area was comprised of adjoining 22, 24, and 9 ha areas reclaimed in 1994, 1995, and 1996, respectively. The seed mixture used contained 71 to 77% warm-season grasses. Grazing by 20 cow/calf pairs was implemented on the 55 ha site from May 26 to August 1, 1998 utilizing approximately 50% of aboveground biomass. In 1999 and 2000, grazing was conducted by 30 cow/calf pairs from May 8 to July 29 and May 7 to July 29, respectively. In 2001 and 2002, grazing by 45 cow/calf pairs was deferred until mid-July (July 15 to October 16) in efforts to maintain green needlegrass (Stipa viridula), a declining species on each site. Each site was randomly sampled for basal cover and species composition using a 10-pin point-frame. Alpha (intra-community) diversity fluctuated between sites early in the study; however, diversity trended higher on reclaimed sites in the last two years of the study. Total basal cover throughout the five year study ranged from 3.65 to 7.20%, 4.00 to 8.60% and 4.90 to 9.30% for the 1994, 1995 and 1996 reclaimed grasslands, respectively. Herbaceous biomass was estimated from 0.25 m² quadrats by clipping at ground level, separating by grass species, forbs, and shrubs, and drying and weighing samples. Yields on reclaimed sites were highest in the early stages of research when compared to the reference site but trended similar in later stages. Seasonal balance of cool- and warm-season grasses on the 1994, 1995 and 1996 reclaimed grasslands shifted from 73:27, 70:30 and 28:72 in 1998 to 65:35, 24:76 and 38:62 in 2002, respectively.

Additional Key Words: North Dakota, reclamation, prescribed grazing

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AMELIORATION OF DEGRADED MINE SOIL FOR RECLAMATION PURPOSES USING AN INDUSTRIAL BYPRODUCT AND AN ORGANIC WASTE.

WF Truter* and NFG Rethman

Abstract: The South African mining industry has been the backbone of the countries economy for much of the past century. Mining has, however, often caused the degradation of productive soils. The amendment of these soils, is often very expensive and not sustainable. The University of Pretoria in co-operation with Eskom TSI, has over the past seven years conducted a series of trials. These trials have demonstrated the feasibility of using alkaline class F fly ash (from the coal-based Lethabo power generating facility) and organic materials to ameliorate acidic and infertile soils. Various pot and on-site field trials were established to measure and monitor the dry matter production, basal cover, botanical composition and the effect of amendments on the soil chemical properties. Based on the results obtained in the pot trials, it was concluded that both fly ash and fly ash/organic material mixtures, improved dry matter production as well as the pH, Ca, Mg and P levels. This led to the expansion of the research programme. A field trial at a surface mine, in the Mpumalanga Province was established. The results from this field trial confirmed pot trial findings. All parameters measured had been influenced by the fly ash and fly ash/organic material mixtures. Industrial byproducts (such as fly ash) either by itself, or together with organic waste can serve as a soil ameliorant for the reclamation of surface mined land.

Additional Key Words: acidic soils, fly ash, infertile soils, organic materials, soil ameliorant

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MICROBIAL EFFECTS OF NATURAL PHOSPHATE ROCK (NPR) ADDITION TO MINING WASTES

Masato Ueshima, Margarete Kalin and Danielle Fortin

Abstract. Various treatments have been proposed to attenuate and eventually inhibit the generation of acid mine drainage (AMD) or acid-rock drainage (ARD). Previous work performed by Boojum Research Ltd. indicated that the addition of a mining waste product from the TexasGulf (North Carolina) phosphate mine showed some promising results when pyritic waste rocks from a northern Quebec Cu/Zn mine were mixed with NPR during an outdoor weathering experiment that lasted 989 days. Scanning electron microscopy (SEM) observations of the waste rock surfaces submitted to NPR addition in the weathering experiment indicated the presence of both iron and phosphorus in bacterial biofilms, whereas rock surfaces in the control experiments (i.e., without NPR) showed microbial corrosion. In order to revive the biofilms on the rock surfaces, samples from the weathering experiments with NPR were submerged in a growth medium adjusted to pH 7.2 for 7 days (which was similar to the pH measured in the effluents from the drum experiment). ESEM (Environmental Scanning Electron Microscopy) observations revealed microbial colonization and fine grain precipitation on the microbial cells present in the biofilms. To further assess the interactions between NPR, bacteria and the waste rocks, fresh cut surfaces of waste rocks were mixed with NPR and acidophilic bacteria at pH 2.2. NPR addition first neutralized the acidity of the growth medium by supplying soluble phosphate and carbonate and prevented the development of corrosion pits on the fresh rock surfaces. The reactivity of the waste rock surfaces appears to depend on the microbial activity at the surface, i.e., whether bacteria produced a biofilm or not. It is also clear that the presence of NPR favored the development of biofilms.

Additional Key Words: inhibition of acid rock drainage, mine waste management.
CRITICAL UNSATURATED SOIL PROPERTIES FOR SOIL COVERS

R. B. Valceschini, and S.A. Morrow.

Abstract. Monolithic soil covers are becoming more widely accepted as viable alternatives to standard resistive barriers for covers at mining facilities in arid and semi-arid regions. Design procedures and available models have been documented as have the results of monitoring data from soil covers that have been in operation for a number of years. The primary soil response associated with the design and performance of a soil cover is the Soil Water Characteristic Curve (SWCC). The SWCC test is a relatively expensive and time consuming test to perform. The next logical step in advancing the state-of-practice of soil covers from the conceptual stage to implementation on a routine basis is to develop a detailed understanding of the unsaturated soil properties, specifically the aspects of the SWCC that are critical to the performance of a soil cover; i.e. air entry pressure, storage function etc. Ideally, these properties can be reliably correlated to simple index tests; grain-size-distribution and Atterberg limits, in-place density in such a manner that a few SWCC tests can be performed for a site and the index tests used to delineate acceptable soils. The results can also be used to develop construction quality assurance and construction quality control (CQA/CQC) procedures.

This paper presents the results of a parametric modeling study performed on typical cover soils. Variations in SWCC properties are utilized in the model and their impact on cover performance assessed. Changes to the SWCC as a result of changes in index properties are estimated based on trends published in the literature. Conclusions are drawn with respect to correlating index properties, cover performance and SWCC results.

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PROPOSAL FOR THE DEVELOPMENT OF A WESTERN STATES LAND RECLAMATION CENTER

George F. Vance

Abstract: A Western States Land Reclamation Center with programs in reclamation science and restoration ecology would provide the needed expertise to the western U.S. through problem solving, training and technology transfer. Both the strength of our economy and the quality of life for western state citizens depends upon the viability and sustainability of our natural resources and environment. Land disturbance due to human activities such as mining, urban sprawl and road construction, and from natural events including fire, wind and water erosion and drought require a better understanding of how disturbed ecosystems can be functionally restored. Programs that focus on these concerns are essential to the preservation and improvement of our western lands. The Center will provide a focus that would help manage and protect terrestrial and aquatic resources for future use, solve problems facing the western states such as coalbed methane impacts, provide education and training opportunities and interact with agencies and the public on concerns involving reclamation issues. The Center would consist of multi-disciplinary reclamation and restoration ecology fact-finding, educational and outreach programs that focus on the identification, assessment and rehabilitation of disturbed ecosystems. Coordinated efforts involving research and education endeavors would provide a more efficient use of resources, help centralize western states cooperative research funding in the area of ecosystem reclamation, attract grant support through enhanced national and international visibility and provide services to the agricultural, mineral and energy economic base of the western U.S. through enhanced science and technology.

The mission of the Center would be to pursue and disseminate impartial, scientifically-based information related to the reclamation, rehabilitation and restoration of disturbed ecosystems, to educate students so that they will be able to analyze, synthesize and integrate findings, results and related research for use in protecting and improving western state's ecosystems and to serve as a resource for citizens and communities, state and federal agencies, and private industries requiring assistance in reclamation science and ecological restoration endeavors. The primary goal of the Center would be to achieve prominent recognition as a state-of-the-art resource center for investigating research problems and developing solutions to issues and challenges confronting western state's citizens, communities, agencies and private industries. An Advisory Board comprised of stakeholder groups - industry, regulatory agencies, and environmental advocacy groups - as well as scientists, policy makers, public and private land managers and interested citizens, would assist a Center Director in setting priorities, identifying needs and developing research, education and outreach programs.

Additional Key Words: Revegetation, Mining, Federal Support

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IDENTIFICATION AND CHARACTERIZATION OF MINING WASTE USING LANDSAT THEMATIC MAPPER IMAGERY, CHEROKEE COUNTY, KANSAS

Gregory S. Vandeberg

Abstract. Mining wastes and tailings are present throughout much of the world and United States including the Tri-State lead and zinc mining district in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma. These wastes and tailings are often associated with heavy metals, acid mine drainage, and other physical hazards. Many tools have been utilized and proposed for the rapid inventory and characterization of these wastes including the use of Landsat Thematic Mapper (TM) images. A Landsat TM image of the Cherokee County, Kansas portion of the Tri-State mining district was evaluated in an attempt to inventory mining waste and tailings in the county, and characterize the gross mineralogy of these wastes. False color TM composites were used to perform supervised and unsupervised landcover classifications of Cherokee County to identify the locations of mining waste and tailings. In addition, several TM band combinations (mineral indices) were used to characterize the mineralogy of these wastes. The accuracy of the classifications in identifying mining wastes from other land types was less than 60 percent. However, false color composites of Landsat TM bands were a useful tool in identifying these wastes, and determining their gross mineralogy.

Additional Key Words: Tri-State District, Remote Sensing, Landsat TM

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HEAP LEACH PAD RECLAMATION AT THE GOLDSTRIKE MINE, NEVADA – A UNIQUE CASE STUDY (INTERIM PROGRESS)¹

Steven R. Viert² and Ron A. Espell

Abstract. In recent years, closure and revegetation of heap leach facilities in Nevada has been subjected to a new set of technical challenges. One such challenge, in response to an old problem, has been to design a natural cover or cap that is capable of absorbing and holding (temporarily) the vast majority of meteoric water that contacts the surface thereby precluding infiltration into the spent ore. At the same time, this cap must be stable and capable of providing necessary life requisites for long-term perennial plant community health that in turn facilitates transpiration of absorbed moisture. Such a design has been affected at Barrick Goldstrike’s AA Leach Pad. In 2000, approximately 250 acres of spent ore were reconfigured to mimic neighboring landforms, capped with an average of four feet of an alternate growth media from the active pit (excepting a small portion that was capped with topsoil), contoured with engineered drainages to preclude excessive erosion, and then reseeded in March, 2001. A seed mix developed from on-site research and containing 15 species was applied by broadcast techniques at a rate of 12.25 pounds PLS per acre, and then harrowed. Organic mulch was hydraulically applied at a rate of 4 tons per acre followed by 150 pounds per acre of PT-TAC tackifier. In an effort to help reduce wind erosion until the permanent mixture could establish, a cover crop of a sterile hybrid grass (“ReGreen”) was applied with the seed mix at a rate of 2.8 pounds per acre. Soil moisture has been continuously monitored at two typical locations and both plant emergence and ground cover have been monitored during each of the last two growing seasons with over 300 (1ft²) quadrats and 90 point-intercept transects (9,000 intercepts) each year. Though it is still premature to declare success, the interim data suggest strongly that the program has exceeded expectations.

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ASSESSING THE FEASIBILITY OF DEVELOPING TECHNICAL STANDARDS TO EVALUATE REVEGETATION SUCCESS AT COAL MINES IN THE SOUTHERN POWDER RIVER BASIN OF WYOMING

R. B. Vincent and R. N. Hoy

Abstract. Interest in using technical standards to evaluate revegetation success, specifically for cover, production, and diversity parameters, at coal mines is increasing. To help evaluate the feasibility of developing such standards in Wyoming, a vegetation database was established for five mines in the Southern Powder River Basin. The baseline vegetation data for these mines comprised fifteen data sets (individual studies), and within these sets, the data were separated into five major and six minor standardized plant communities. Baseline data were collected during twelve years from 1978 through 1999, although not all standardized plant communities were sampled in each of those twelve years. In the two predominant plant communities, Mixed Grass Prairie (MGP) and Big Sagebrush Shrubland (BSS), statistical evaluations of the data sets revealed two important considerations. First, for cover data, the results are statistically different between quadrat and point-transect sampling methods. Second, herbaceous species production data can be correlated with precipitation over a relatively small area (e.g., an individual mine), but the influence of other factors, such as sampling methodology, preclude correlations over larger areas. Production data could not be correlated with Palmer Drought Indices, and cover data could not be correlated with either climate factor. The statistical evaluations also indicated significant differences between the data sets and between the mines. Based on all the evaluations of the available data, calculation of a regional data technical standard using detailed statistical methods may be difficult. While a simple approach, such as selection of a conservative number (e.g., the highest mean production value)


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IS THERE A CHARACTERISTIC FLORA OF APPALACHIAN PRE-SMCRA SURFACE MINES?\(^1\)

G. L. Wade\(^2\) and R. L. Thompson

**Abstract:** Within a landscape, specific physical habitats (shale barrens, limestone glades, acid bogs, etc.) are often characterized by their floras – the collection of plant species or taxa that inhabit them. Composition of some floras can be unique because their environments have characteristics that allow colonization by some taxa and select against colonization by others. A significant proportion of Appalachia was mined with limited reclamation before the Surface Mine Control and Reclamation Act of 1977 (SMCRA). Successional processes have, over time, enriched the plant communities on these mines to the point that their taxonomic richness is comparable to similar unmined areas. But are the floras of these mines distinctive unto themselves? Five mines in eastern Kentucky have been completely inventoried and we use the species lists to determine whether pre-SMCRA mines have their own distinctive flora. Altogether, these five mines supported 617 vascular plant taxa or 18 percent of the documented flora of Kentucky. Species richness of the individual mines ranged from 272 to 360 taxa. There were 85 core taxa (species present on all five mines, 13.8 percent of total). Peripheral taxa (present more than half but not all mines) numbered 195 (31.6 percent) and casual taxa (present on half or less of the mines) numbered 337 (54.6 percent). Pair-wise Sørenson’s indices of similarity (the proportion of one mine flora also found on another) ranged 0.48-0.75. We list core and peripheral taxa that were found on there pre-SMCRA mines, but we do not conclude that pre-SMCRA surface mines have their own distinctive flora.

Additional Key Words: succession, revegetation, floristics, restoration, reclamation, biodiversity

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SOIL AND VEGETATION SAMPLING OF IRRIGATED MEADOWS IN THE UPPER ARKANSAS RIVER VALLEY

Dan Wall and Dale Hoff

Abstract. The California Gulch site (Site) in Leadville, Colorado, is a historic mining site located in the northern half of the upper Arkansas River valley in the Southern Rocky Mountains, approximately 100 miles southwest of Denver, Colorado. Mine waste has impacted soil and surface water in and around California Gulch and downstream to the Arkansas River and adjacent irrigated and riparian lands. The USEPA placed the Site on the National Priorities List (NPL) in 1983 to initiate clean-up of mine wastes contributing to contamination of the Arkansas River watershed. Remedial action in, and around the town of Leadville and California Gulch continues to date, but little work in either assessment, or remedial action has taken place in impacted flood plain soils along an 11 mile stretch along the upper Arkansas River downstream of the confluence with California Gulch. This 11-mile reach was the focus of this investigation. Significant portions of the 11-mile reach have been, and continue to be, used by private landowners for hay production and livestock grazing. Irrigation water for these areas has largely come from the Arkansas River and thus the soils have become contaminated from contamination in the river water. Previous investigations about the health of the riparian plant community have led to the following conclusions: 1) Zinc induced iron deficiency/chlorosis has been reported; 2) Plant tissue concentrations of zinc exceed literature threshold concentrations for healthy vegetation; 3) Existing data are inadequate to determine the spatial extent of potential zinc toxicity to vegetation; 4) No quantitative analytical data were available for vegetation in lower reaches. The current investigation proceeded in two phases: 1) the objective of Phase I was to characterize the nature and extent of metal contamination, pH and total organic matter in riparian soils outside of visible fluvial tailings deposits, and in upland meadows; 2) Phase II stations were then selected to bracket a range of metals concentration, soil pH and organic carbon, allowing the development of site-specific exposure-response relationship(s). Phase I sample locations were placed on a triangular grid over the defined study area. One hundred twenty unbiased stations were placed on grid nodes, and nine biased samples were placed manually to fill in small features that did not contain grid nodes. Phase I results demonstrated a wide range of metals concentrations concurrently with high variations in pH and total organic carbon. Twenty stations were selected to bracket the Phase I soil parameters and additional Phase II analyses were undertaken: 1) metals concentration in soils and plants; 2) plant available metals in soils; 3) phytotoxicity studies with alfalfa, wheat grass and yarrow; 4) vegetation demographics. Positive correlations with phytotoxicity, bulk metals; plant available metals; and bioaccumulation of metals in the plants were demonstrated. These relationships were then extrapolated to the entire 11-mile reach to identify areas of decreased productivity of the vegetative community in the flood plain.

Additional Key Words: Plant, Metals, Soil, Toxicity, and Bioavailability

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AN EVALUATION OF GROUND WATER CONDITIONS IN THE COLSTRIP COAL DEPOSIT, MONTANA\textsuperscript{1}

Kirk Waren and Angela McDannel\textsuperscript{2}

Abstract. An evaluation of groundwater conditions in the vicinity of coal mines near Colstrip, Montana was conducted in 2001 as part of a cumulative hydrologic impact analysis. This analysis was required due to permitting activities associated with an expansion of the Rosebud Mine.

Active coal mining operations at the Rosebud mine have expanded outward as low-cover coal is sought. Much of the remaining, unmined coal nearest to Colstrip and the adjacent coal-fired power plant is relatively high-cover coal, so mining has slowed in the interior area of the coal deposit in favor of lower-cost mining at the edges. Because the interior, high cover coal will eventually be mined according to mine plans, presently inactive pits remain open for future use. As the mine expands, additional information gained through hydrologic monitoring contributes to and increases the understanding of the groundwater system and how it is affected by mining.

Overall, groundwater flow directions are similar to pre-mine conditions. Where coal has been mined out, mine pit backfilled spoil maintains the groundwater flow formerly occurring in the coal seam. However, groundwater head distribution has changed significantly in some areas, and some of these head differences may be retained in the post mining groundwater environment. As mining operations have expanded, data suggests recharge to the principle coal seams may be more localized than was previously thought, and groundwater recharge from the Little Wolf Mountains southwest and upgradient of the coal deposit is limited. Drawdown of groundwater levels in the McKay coal seam, which lies beneath the mined Rosebud coal exceeds that observed in the Rosebud coal at many sites. While this phenomenon has previously been attributed to the presence of inadequately plugged coal exploration boreholes, data suggests this explanation is less likely near recent mining activities.

Additional Key Words: aquifer, confined, drawdown, spoil

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PASSIVE TREATMENT OF COAL MINE DRAINAGE

George R. Watzlaf, Karl T. Schroeder and Candace L. Kairies

Abstract. Passive treatment systems utilize chemical and biological processes to neutralize acidity and decrease concentrations of metals. These systems have been successfully applied at numerous coal mine discharges over the past 20 years. The three most commonly applied passive unit operations are aerobic ponds/wetlands, anoxic limestone drains (ALDs), and reducing and alkalinity producing systems (RAPS). The selection of the most effective unit operation, or combination of unit operations, is based on water quality. The unit operations are sized based on flow or contaminant loads. Net alkaline water is treated with ponds and aerobic wetlands that promote iron oxidation, precipitation, and settling. Empirical data have shown that 10 - 20 grams of iron is typically removed per square meter of surface area of the pond or wetland. Net acidic water with low ferric iron and aluminum levels can be treated with ALDs, which are used to add bicarbonate alkalinity (typically 100 - 300 mg/L of alkalinity as CaCO₃). To attain near maximum levels of alkalinity, ALDs are sized to maintain a 12 –15 hour detention time. Net acidic water containing ferric iron or aluminum is treated using RAPS, which add bicarbonate alkalinity via sulfate reduction and limestone dissolution. The amount of alkalinity generated is dependant on influent water quality, but empirically has been found to range from 15 - 60 grams of alkalinity (as CaCO₃) per square meter of pond surface. Many of these systems are constructed to facilitate flushing of retained metals, however, the ability of these systems to maintain adequate permeability has not been determined.

Additional Key Words: acid mine drainage, wetlands, anoxic limestone drains, reducing and alkalinity producing systems, metal removal, limestone dissolution, sulfate reduction.

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FLUSHING OF METALS FROM REDUCING AND ALKALINE PRODUCING SYSTEMS\textsuperscript{1}

George R. Watzlaf, Candace L. Kairies and Karl T. Schroeder\textsuperscript{2}

\textbf{Abstract.} Reducing and alkalinity producing systems (RAPS) are used to passively treat low-pH mine water containing ferric iron and aluminum. RAPS typically contain a layer of water (0.3 - 1 m), organic matter (0.15 – 1 m), and limestone (~1 m). A network of perforated pipes, placed in the bottom of the limestone, forces water to flow downward through the system. Both iron and aluminum are removed within these systems. RAPS may be less prone to plugging with aluminum than anoxic limestone drains because of their larger cross-sectional areas (perpendicular to flow paths) and higher available head pressures. Reduction in permeability of these systems can occur due to the precipitation of metal hydroxides and sulfides. To extend the life of these systems, most are periodically flushed, though guidelines have not been developed for the design of flushing systems nor the frequency, duration, and intensity of the flushes. In general, the flush valves are opened until the water “runs clear.” The cloudy water can persist for a few minutes to a few hours. Results from the flushing of four RAPS indicate that less than 5\% of iron and aluminum retained in each system is removed during the flushing events. While none of these flushes removed a significant percentage of the metals from any of the systems, only a small percentage of the void volume (0.25 - 5\%) in each RAPS was calculated to be filled with precipitates at the time of the flushes. A possibility is that too little material has accumulated to be flushed effectively. The precipitates may occur as a band rather than being distributed uniformly throughout the available void volume. The width and position of the band would be determined by the pH gradient and rates of precipitation and agglomeration. Therefore, the permeability of the RAPS could significantly be reduced long before 100\% of the void volume was occupied.

Additional Key Words: acid mine drainage, wetlands, anoxic limestone drains, successive alkalinity producing systems (SAPS), vertical flow systems, metal removal, limestone dissolution, sulfate reduction.

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The performance of two horizontal limestone beds for the removal of manganese

George R. Watzlaf, Candace L. Kairies and Karl T. Schroeder

Abstract. Horizontal limestone beds (HLBs), which are kept open to the atmosphere, are being constructed for the passive removal of manganese from mine drainage. Two of these beds, located in the bituminous coal fields of Pennsylvania, have been monitored for over two years. Each of the HLBs is the last unit operation within a larger passive treatment system consisting of ponds, reducing and alkalinity producing systems, and wetlands. The bed at the DeSale I site was constructed in the spring of 2000 and contained 1450 tonnes of AASHTO #1 limestone (35 m x 20 m x 1.4 m deep). Water, flowing an average of 136 L/min into the HLB, had a pH of 6.9 and contained 6.5 mg/L dissolved oxygen, 35 mg/L net alkalinity (as CaCO₃), < 1 mg/L Fe and Al, and 54 mg/L Mn. After passage through the HLB, the water had a pH 6.9 and contained 1.8 mg/L DO, 65 mg/L net alkalinity, <1 mg/L Fe and Al, and 45 mg/L Mn. The HLB at DeSale II was constructed in the summer of 2000 and contained 2630 tonnes of AASHTO #1 limestone (52 m x 24 m x 1.4 m deep). Water, flowing an average of 201 L/min into the HLB, had a pH of 7.0 and contained 7.9 mg/L dissolved oxygen, 80 mg/L net alkalinity (as CaCO₃), < 1 mg/L Fe and Al, and 34 mg/L Mn. After passage through the HLB the water had a pH of 7.1 and contained 2.6 mg/L DO, 105 mg/L net alkalinity, <1 mg/L Fe and Al, and 31 mg/L Mn. Neither HLB significantly altered pH and only slightly decreased concentrations of Mn (3 – 9 mg/L or 9 – 17%). The HLBs increased alkalinity (25-30 mg/L) and consumed approximately 5 mg/L of dissolved oxygen.

Additional Key Words: acid mine drainage, wetlands, anoxic limestone drains, reducing and alkalinity producing systems, limestone dissolution, pyrolusite.

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RESTORATION OF THE FLOODPLAIN OF THE SOUTH FORK OF THE
COEUR D’ ALENE RIVER: A CASE STUDY OF APPLIED RESTORATION
THEORY¹

Timothy A. White², Gary W. Rome, John H. Rogers, Brenda K. Osterhaug, Carmela L. Grandinetti, and
Joan Stoupa

Abstract. Remediation of the South Fork Couer d’Alene River floodplain (the Flats) in
Smelterville, Idaho, offered a unique opportunity to test ecological restoration theories
regarding the relationship between plant community establishment and abiotic
environmental conditions. Successful re-creation of the abiotic environment is the
primary consideration for restoration of a given plant community type. Failure associated
with many wetland restoration projects can often be traced to inappropriate soils and
hydrologic conditions for the target community. This paper reports the preliminary
results of an 80 ha floodplain restoration project that occurred without artificial replanting
of herbaceous wetland plant communities. Over 760,000 cubic meters of tailings-
contaminated materials were removed from the floodplain. Ground-water modeling prior
to excavation and re-grading served as the basis for developing post-excavation grading
plans. Grading was coupled with placement of 15 cm of high quality native topsoil.
Coversoils required relatively little amending following placement and establishment of
final grades. No herbaceous wetland plants were installed on the site. Drill seeding with
grasses and forbs helped stabilize upland areas and slopes. Woody plants were installed
along the streambank and in places throughout the floodplain in the springs of 2001 and
2002. Four years later, the floodplain is naturally regenerating to a diverse and vigorous
palustrine emergent marsh (PEM) community. Species currently established in wetlands
on the site include sedges, rushes, cattail, reed, hardstem bulrush, and spike rush, among
others. Additional woody species, such as cottonwood and willow, are naturally
regenerating. By successfully establishing wetland hydrology and use of native topsoils,
the project has been able to produce a diverse and vigorous PEM community capable of
supporting wildlife and delivering at least some wetland functions that had not been
available to the Coeur d’Alene basin for many decades while saving almost $900,000 in
proposed replanting costs.

Additional keywords: wetlands, abiotic, palustrine emergent marsh, Superfund,
CERCLA, remediation, wetland functional restoration

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THE BUNKER HILL HILLSIDES: SITE HISTORY AND PLANNING FOR EARLY SUCCESSIONAL RESTORATION ON THE NATION’S LARGEST SUPERFUND SITE

Timothy A. White, Dennis L. Mengel, and Carmela L. Grandinetti

Abstract. Good project planning is essential to developing appropriate and achievable restoration programs. This paper discusses the history of the Bunker Hill site and its prior condition. It further discusses the planning approaches that were used and the guidance statements that were obtained. These guidance statements generated clarity for prescription development and measurement of success on the Bunker Hill hillsides project in the Silver Valley of northern Idaho. The hillsides are part of the Bunker Hill Superfund site, a 54 km² area centered in Kellogg, Idaho that has been contaminated by heavy metals from a long history of mining and metallurgical activity. Environmental documentation found within the site’s remedial investigation/feasibility study (RI/FS) and Record of Decision provided some general concepts of restoration work that could occur on the site but was insufficient to avoid long-term conflicts between stakeholders. In particular, a 425 ha area on the south end of the site was composed of steep, heavily eroded, denuded, and inaccessible hillsides that were contributing substantial quantities of sediment to the Coeur d’Alene River basin. Successful restoration of the hillsides required agreements between stakeholders with respect to specific goals, objectives, performance standards, and monitoring methods. These and other guidance elements guide design and execution of the restoration program. Accordingly, the authors convened a series of three workshops with project stakeholders that outlined project-specific guidance statements for this undertaking to ensure that conflicts were minimized and that the path forward for the project was well-founded. These statements have guided project development, execution, monitoring, and mid-course corrections and has resulted in a successful project with few to no stakeholder conflicts.

Additional keywords: conflict resolution, goals, objectives, performance standards, monitoring methods.

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THE BUNKER HILL HILLSIDES: A CASE STUDY IN THE USE OF ADAPTIVE MANAGEMENT IN EARLY SUCCESSIONAL RESTORATION ON THE NATION’S LARGEST SUPERFUND SITE

Timothy A. White, Carmela L. Grandinetti, Stephen D. Miller, Timothy B. Hill, Dennis L. Mengel, and Shane M. Waechter

Abstract. Active hillsides restoration included development and installation of site prescriptions using adaptive management and monitoring of results. Initial prescriptions for hillsides restoration and their implementation were based on a combination of site characterization and demonstration studies. Prescriptions were modified over time as the results of past activities became evident. Hillsides have responded well to prescriptions and successional processes appear to have been re-initiated. Adaptive management induced prescription modifications including changing liming materials to improve performance, increasing seeding rate to improve initial plant canopy cover, adjusting seed mix composition to remove poorly germinating species and adding herbaceous species with exceptional establishment and growth performance, increasing shrub sizes to improve establishment, and selecting tackifiers that reflected actual site performance of the products. Target plant covers were 50 percent or greater and overall plant canopy cover from 1998 and 1999 operational hydroseeding averaged over 61 percent after two growing seasons. Red top, bluegrass, sheep fescue, Idaho fescue, and timothy dominate the seeded communities. Plant and mulch cover is approximately 10 percent higher on east-facing slopes compared to west-facing slopes. Areas of low cover are often composed of rock pavement surfaces. New seedlings are emerging and volunteer plant species are appearing on the slopes. Turbidity of surface water emanating from the hillside watersheds has dropped substantially from past years. Instantaneous comparisons between background turbidity at the mouths of Government and Deadwood creeks indicate that State of Idaho water quality standards are being met in most cases. Early successional processes appear to be emerging on the hills with assistance provided by wildlife.

Additional keywords: monitoring, surface water quality, plant cover, remediation

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DEVELOPMENT OF A SIMPLE SCHEME TO DETERMINE THE CHEMICAL TOXICITY OF MINE WASTES

T. R. Wildeman, J. F. Ranville, J. Herron, and R. H. Robinson

Abstract. A decision tree that uses simple physical and chemical tests has been developed to determine whether a mine waste poses a toxicity threat to the aquatic environment. For the chemical portion of the tree, leachate tests developed by the US Geological Survey (USGS), the Colorado Division of Minerals and Geology (CDMG), and modified 1311 TCLP test of the EPA have been extensively used. The multi-element power of modern inductively coupled plasma, atomic-emission spectroscopy (ICP-AES) is also a necessary component of the scheme. At two sites in Colorado, Virginia Canyon in the Idaho Springs/Central City Superfund Site and in the Upper Animas River Basin, 25 sediment samples and the water flowing over the sediments were collected. General analytical measurements were made in the field, and then, the water and extracts from the three leachate tests were analyzed for 31 elements by ICP-AES. Then, element concentration pattern graphs (ECPG) were produced that compared selected groups of the elements from the three leachates and the water. When the pHs of the water and the leachate were below 5.0, the element concentration patterns of all four solutions were quite similar and aquatic toxicity from metals such as Pb, Cu, Zn, Mn and Al was clearly indicated. When the pHs of the water and the leachate were above 5.0, the element concentration patterns from the four solutions were different and inferred aquatic toxicity depended on the leachate test. Usually when there was a difference, it was found that in the TCLP test, elements from carbonate minerals and oxides dissolved and these elements in the CDMG and USGS tests were not as readily released from solution. In a study done in 2002 in Russell Gulch near Central City, CO, that rated mine waste piles, it was necessary to rate the contamination possibility of the piles on separate physical and chemical scales for the most complete assessment.

Additional Key Words: aquatic toxicity, metal contaminants, aquatic chemistry


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CONTAINMENT OF SPILLED PETROLEUM IN SOIL USING ACTIVATED COAL

Terril E. Wilson, Debasmita Misra, Wei Zhou, Abhijit Dandekar, and Neil D’Cunha

Abstract. Investigation to determine the feasibility of containment of spilled petroleum in soil or near surface mineral matter, using finely-divided, heat-activated sub-bituminous coal as a sorbent and binder, has begun. Cylindrical samples (75mm diameter x 150 mm height) prepared separately from organic-rich soil and an underlying silt-clay horizon, both typical of substrates in the central Alaskan zone of the Trans-Alaska petroleum pipeline, were studied, along with a well-sorted sand (used in concrete-making) as a reference material. Downward permeation of run-of-pipeline crude petroleum through the organic soil, clay-rich subsoil, and sand, at one hour, eight hour, and 24 hour intervals, with and without a 30-minute delayed topical application of fine coal, is determined. Direct adsorption of the crude petroleum and formation of coal-oil agglomerates occurs when supernatant oil remains on the sample surface (as in the case of the clay-rich substrate). Wicking and partial adsorption occurs if the crude petroleum has migrated below the sample surface. Separation of the coal-oil agglomerate may be possible by simple mechanical means – or if necessary, by froth flotation – to yield a value-added fuel which can be briquetted for ease of handling. Phase One of this study, reported here, addresses phenomena at ambient indoor temperature. Phase Two will address similar phenomena under frozen conditions, typical of Alaskan continuous and discontinuous permafrost zones. Phase Three will address the absorption of oil remaining in the substrate long after an oil spill or leak has occurred.

Additional Key Words: petroleum-contaminated soil, coal-oil agglomeration, adsorption

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