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Note: Abstracts are arranged in Alphabetical Order According to First Author
WATER TREATMENT ISSUES AND BIOTREATMENT SOLUTIONS FOR THE LANDUSKY MINE, MONTANA SPENT ORE HEAP LEACH PADS

D. Jack Adams and Tim Pickett

Abstract. The Landusky gold heap leach mine in north central Montana is currently being reclaimed (see US Bureau of Land Management website http://www.mt.blm.gov). The majority of reclamation measures relate to minimizing current and future impacts to downstream waters. Management and seasonal treatment of approximately 2270 lpm (~600 gpm) of water is associated with the spent ore leach pads, primarily the 87 and 91 Pads. Water in the 87 and 91 Pads have changed from a pH near 10, during mine operation and leaching, to the current pH of 6.5 to 5.5 and are still changing. As the Pad water pH becomes more acidic the dissolved co-contaminants of Al, Ni, Zn, Mn and Fe are starting to precipitate from solution. Past and present water management practices have included conventional water treatment using lime and ferric treatments and land application disposal (LAD) utilizing absorption by percolation through soils and nitrate-uptake by plants. Pilot-scale tests of a biotreatment system configured to remove cyanide, nitrate and selenium (selenate) present in Pad waters, at concentrations of ~0.7 mg/L, ~260 mg/L and ~0.8 mg/L respectively, were successfully completed. A full-scale biotreatment system has been implemented at the Landusky site and operational parameters are being optimized. This paper describes aspects of the pilot-scale biotreatment test results, full-scale biotreatment system implementation and water pretreatment requirements demanded by the changing pad water chemistry.

Additional Key Words: selenium, cyanide, nitrate, bioremediation, microbes

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2 D. Jack Adams, Ph.D., VP Research and Development, Applied Biosciences, P.O. Box 520518, Salt Lake City, UT 84152.
Tim Pickett, President, Applied Biosciences,
A PRELIMINARY STREAM ASSESSMENT FOR WATERSHED RESTORATION

Scott Alexander, Shaun L. Busler, Cliff Denholm, Timothy Danehy, and Margaret Dunn

Abstract. An assessment of Laurel Run, Indiana County, was conducted in the summer of 2001 through a partnership effort between the Pennsylvania Department of Environmental Protection and Stream Restoration Inc. The purpose of the assessment was to evaluate the potential recoverability of a stream affected by abandoned mine drainage (AMD) before construction of a passive treatment system in the headwaters of Laurel Run. Several major discharges have severely degraded the stream to the confluence with Blacklick Creek (Ohio River Basin). At the mouth of Laurel Run, the stream has a flow rate exceeding 4,200 L/min (1,100 gpm) with pH 5.5, 42 mg/L acidity, 2.5 mg/L iron, and 2.9 mg/L manganese. In addition, baseline data were collected to examine the overall health of the watershed for future planning and preliminary Total Maximum Daily Load (TMDL) studies. Twenty-one sites were assessed using standard EPA Rapid Bioassessment Protocol sampling methods, examining physical, chemical, and biological characteristics. The number and variety of benthic macroinvertebrate taxa were much lower when compared to a physically similar, healthy stream. The primary contributors of flow to the headwaters are an acidic, abandoned, underground mine discharge with an average flow rate of 379 L/min (100 gpm) and several spring fed tributaries. Two unnamed tributaries located above the AMD were found to contain low tolerant macroinvertebrate taxa, indicative of excellent water quality and a reference for the future potential of Laurel Run. In September 2001, a passive system was placed online to treat the AMD. This system consists of two vertical flow ponds built in parallel, a flush pond, and a ½-acre wetland. Water quality analysis shows that Laurel Run has improved to the confluence with the next major discharge, located approximately one mile downstream. Even though the passive treatment system has dramatically improved the quality of the water, several other discharges are inhibiting the full recovery of the stream.

Additional Key Words: abandoned mine drainage (AMD), benthic macroinvertebrates, passive treatment, Rapid Bioassessment Protocol (RBP), restoration, stream assessment, Total Maximum Daily Load (TMDL)


2 Scott Alexander, Water Pollution Biologist. PA DEP, BMR, Division of Environmental Analysis and Support, RCSOB, Harrisburg, PA 17105. Shaun L. Busler, Biologist, Cliff Denholm, Env. Sci., Timothy Danehy, EPI, Margaret Dunn, PG. Stream Restoration Inc. (Non-Profit), 3016 Unionville Road, Cranberry Twp., PA 16066.
SOIL ECOLOGICAL INDICATORS OF SURFACE MINELAND
RECLAMATION SUCCESS

Jonathan D. Anderson and Peter Stahl

Abstract: As the nation’s leading producer of coal, Wyoming has thousands of acres of land that are affected by surface mining each year. In the year 2000 alone, over 330 million tons of coal was surface mined in Wyoming (OSM, 2002). Although topsoils are removed from mine sites and stockpiled for protection to be later redeposited, soil organisms including plants, animals and microorganisms are negatively impacted by surface mining activities. Microorganisms in soils play important roles in organic matter decomposition, nutrient cycling, and vegetation reestablishment, as well as soil development and stabilization. The response of soil microorganisms to disturbance and their recovery during reclamation of surface mine sites is not well understood, yet extremely important to sustainable mine land reclamation. The objective of this study was to examine the recovery of soil microorganisms and ecosystem processes they control by analyzing a chronosequence of nine different aged reclamation sites (ranging in age from 2 to 32 years since reclamation was initiated) and adjacent undisturbed sites on the Dave Johnson Coal Mine located in Central Wyoming. Results indicate that the soil microbial community may take much longer than 30 years to recover to native undisturbed levels. Even though the plant community may recover in terms of biomass production and surface cover within twenty years or less, amounts of soil microbial biomass carbon were only approximately half of that found in adjacent undisturbed soils. Concentrations of organic matter in reclaimed soils, however, appear to increase to levels above that found in adjacent undisturbed soils.

Additional Keywords: carbon storage, mine land reclamation, organic matter content, soil physico-chemical properties, soil microbial biomass

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2 Jonathan D. Anderson, Undergraduate student, University of Wyoming Department of Renewable Resources, Laramie, WY 82070.
Dr. Peter Stahl, Assistant Professor of Restoration Ecology, Department of Renewable Resources, University of Wyoming, Laramie, WY 82070
ESTABLISHMENT OF A VEGETATIVE COVER TO CONTROL ACIDIC DRAINAGE FROM COAL COMBUSTION WASTE

C.D. Barton², D. Marx, D.C. Adriano, and H. Bartley

Abstract. The 488-D Ash Basin is an unlined containment basin that received ash and coal reject material from the operation of a powerhouse at the USDOE’s Savannah River Site. The pyritic nature of the coal rejects has resulted in the formation of acidic drainage (AD), which has contributed to groundwater deterioration and threatens biota in down gradient wetlands. Establishment of a vegetative cover is being examined as a remedial alternative for reducing AD generation within this system. The low nutrient content, high acidity, and high salinity of the basin material, however, was prohibitive to plant survivability. As such, studies to identify suitable plant species and potential adaptations, and pretreatment techniques in the form of amendments, tilling, and/or chemical stabilization were needed. A randomized block design consisting of three subsurface treatments (blocks) and five duplicated surface amendments (treatments) was developed. The three blocks included: a) ripped and compost amended, b) ripped only, and c) control. Surface treatments were applied randomly to two 0.5-ha plots within each block. Treatments included: 1) 10-15 cm topsoil, 2) 10-15 cm bottom ash, 3) 10-15 cm flyash/wood mulch blend, 4) apatite (5 kg/ha), and 5) control. One hundred loblolly pines (Pinus taeda) inoculated with Pisolithus tinctorius (Pt) ecto-mycorrhizae were planted on each plot. Bahiagrass (Paspalum notatum) sprigs were also planted on half of the plots in duplicated 1-m² beds. After one growing season, seedling survival and growth was significantly greater in the ripped and amended block. Differences with respect to surface treatments were also evident. Topsoil and ash amended plots exhibited > 80% survival, while control plots showed over 75% mortality. Survival of the grass sprigs between blocks and among treatments was almost identical to that displayed by the seedlings.

Additional Key Words: pyrite oxidation, oxygen cover, mycorrhizal fungi.

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Abstract. The Old Bevier Aerobic Wetland in Macon County, Missouri, was constructed between 1990 and 1991 by the Missouri Department of Natural Resources, Land Reclamation Program for the purpose of treating Acid Mine Drainage (AMD). The principle source of the AMD is from an underground mine that operated during the 1920's through 1950's, which was partially exposed during surface mining in the 1950’s. Limestone bedding of an AMD collection system provided alkalinity similar to an Anoxic Limestone Drain (ALD). Because the original aerobic wetland failed when a critical dilution water supply became unavailable, the total acidity of the AMD overwhelmed the limited neutralization ability of the aerobic wetland. The aquatic vegetation deteriorated and treatment became ineffective. The Missouri Land Reclamation Program with the assistance of the Office of Surface Mining, Mid-Continent Regional Coordinating Center rehabilitated the Old Bevier Aerobic Wetland in 2001, incorporating newer technologies to improve the performance. This paper describes the construction of an extended AMD collection pipeline, a 2-stage Successive Alkalinity Producing System (SAPS) and associated oxidation cells and aerobic wetlands. The improved system is designed to treat a 2.84 liters per second (45 GPM) AMD discharge with high iron (450 mg/L) and total acidity (760 mg/L), but low aluminum content (<2 mg/L). Initial evaluations find that effluent dissolved iron is 4.5 to 56 mg/L, net alkalinity (11 mg/L), and near neutral pH (5.3 to 6.95). Although no specific structures were incorporated in the design for manganese removal, manganese level in the discharge (7.9 mg/L) is


2 Paul T. Behum, Jr. is a Hydrologist, Office of Surface Mining, Mid-Continent Regional Coordinating Center, Alton, IL. Kwang “Min” Kim, is a Hydrologist, Office of Surface Mining. Kevin W. Garnett is a Mining Engineer, Office of Surface Mining. Len Meier is a Physical Scientist, Office of Surface Mining. Angela Glascock, is an Environmental Specialist, Missouri Department of Natural Resources, Air and Land Protection Division, Jefferson City, MO. Brian Hicks is a Hydrologist, Missouri Department of Natural Resources, Air and Land Protection Division. Michael Mueller is a Reclamation Specialist, Missouri Department of Natural Resources, Air and Land Protection Division. Michael Phillips, is a Civil Engineer, Missouri Department of Natural Resources, Air and Land Protection Division.
RECLAIMING WILDLIFE HABITAT AT THE BUCKSKIN MINE

Scott A. Benson

Abstract. The Surface Mining Control and Reclamation Act and supporting regulations contain numerous requirements for the reclamation of wildlife habitat. However, these requirements are often contradicted by other requirements. Historically, regulatory agencies have tended to place more emphasis on those requirements that act to impede the reclamation of wildlife habitat than they have on those requirements that restore and/or enhance wildlife habitat. Wildlife habitat is a principal postmining land use over most of the coalmine lands in Wyoming. The Buckskin Mine has prepared a detailed reclamation plan to enhance wildlife habitat. This paper will present portions of that plan and examine the federal and state of Wyoming regulations that require reclamation of wildlife habitat and suggest permitting strategies to overcome many of these conflicting requirements.

Additional Key Words: reclamation


2 Scott A. Benson, Senior Environmental Engineer, Triton Coal Company, LLC, Buckskin Mine, P.O. Box 3027, Gillette, WY 82717.
GROWTH AND NUTRIENT UPTAKE OF MYCORRHIZAL MAIZE IN SOIL OF DIFFERENT DEPTHS OVERLYING COAL FLY ASH

YinLi Bi, ZhenQi Hu, XiaoLin Li and Peter Christie

Abstract. Application of topsoil over phytotoxic mine wastes is often practiced to establish perennial plant communities on minespoil areas. China has a very large human population to feed and attempts are made to remediate such areas by growing arable crop plants, but efforts to establish agricultural crops often fail. It is not clear if this is due primarily to insufficient depth of topsoil or if other factors such as soil microbial activity can influence plant establishment and growth. Here we report a preliminary outdoor pot experiment that compared the influence of two arbuscular mycorrhizal (AM) fungi, Glomus mosseae (Nicol. and Gerd.) Gerdemann and Trappe and Glomus versiforme (Karsten) Berch, on the growth and nutrient uptake of maize (Zea mays L.) grown in different depths of soil layer overlying coal fly ash. Three depths (5, 7 and 10 cm) of sterilized sieved and air-dried calcareous loam (Ustarents) with low available P status from a coal mining area were placed over three depths (10, 8 and 5 cm) of fly ash in plastic plant pots to give a total substrate depth of 15 cm. Non-mycorrhizal controls and plants inoculated with G. mosseae were grown in all three substrate mixtures. Plants inoculated with G. versiforme were grown in two of the substrates (10 and 8 cm of soil with 5 and 7 cm of fly ash). Two maize seedlings were transplanted in the soil layer of each pot and grown for 8 weeks with regular adjustment of water content to 70-90% of field capacity. There were five replicates of each treatment in a randomized block design. Plant root and shoot dry matter yields were determined and sub-samples were milled and dry ashed by standard methods and subjected to multi-element analysis using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The proportion of plant root length colonized by the AM fungi was determined on washed root sub-samples by standard methods. Stained roots were examined for AM fungal infection by the gridline intersection method. Data were tested by analysis of variance and mean values compared by least significant difference at the 5% level.

Substantial AM fungal colonization was observed in the roots of the mycorrhizal treatments (39-54% of root length colonized), but there was no significant


2YinLi Bi is an Associate Professor in the Department of Resource Development, China University of Mining and Technology, Beijing 100083, China.
ZhenQi Hu is a Professor in China University of Mining and Technology.
XiaoLin Li is a Professor in the Department of Plant Nutrition, China Agricultural University, Beijing 100094, China.
Peter Christie is a Visiting Professor in China Agricultural University and a Lecturer in Agricultural and Environmental Science, Queen's University, Belfast BT9 5PX, UK.
difference between the two AM fungi or the different soil/fly ash depth combinations. Root colonization by both AM fungi increased host plant growth compared with non-mycorrhizal controls, with *G. mosseae* giving higher yields of maize than *G. versiforme* at the same depths of soil. Increasing soil depth led to increased plant yields. Mycorrhizal plants absorbed more nutrients than non-mycorrhizal controls, but translocated less Na to the shoots. These preliminary results indicate that arbuscular mycorrhizae may make a substantial contribution to successful crop establishment in soils overlying areas of coal fly ash. The AM fungi gave higher plant yields, greater uptake of plant nutrients and may have protected the plants against excessive accumulation of Na in the shoots when grown in soil overlying coal fly ash. The data indicated that the maximum soil depth studied (10 cm) was required for satisfactory plant growth. However, under field conditions greater depths may be advisable. Further work is required to determine the optimum soil depth under field conditions.

Our preliminary data indicate that successful growth of maize is possible in soil overlying coal fly ash and can be improved by colonization of the roots by AM fungi. It is therefore advisable to ensure that field remediation strategies include conditions that favour fungal growth and the development of arbuscular mycorrhizae using either indigenous or inoculated AM fungi.

Additional Key Words: arbuscular mycorrhiza, mine soil, plant growth, plant nutrition, phytoremediation.
A PRELIMINARY MODEL TO PREDICT RAINFALL USE EFFICIENCY OF PASTURES ON OPEN-CUT COAL MINES IN CENTRAL QUEENSLAND, AUSTRALIA

Simon A. Bisrat, Ben F. Mullen and Andrew H. Grigg

Abstract. Cattle grazing is a potential post-mining land-use option for open-cut coal mines in the dry sub-tropical region of central Queensland, Australia, but no research has been conducted to determine the grazing capacity of these lands. A study was conducted to develop a model for estimating pasture productivity of rehabilitated mined lands, from which long-term sustainable stocking rates could be predicted. Rainfall-use efficiency (RUE), a reliable indicator of pasture productivity in this moisture-limited environment, was calculated for 17 plots across three minesites over a single growing season, and related by linear regression and stepwise multiple linear regression to several site and mine-soil properties. Plots were dominated by Cenchrus ciliaris (buffel grass), and ranged in age from 3 to 25 years since establishment. Slope ($r^2=0.45$) and surface cover ($r^2=0.44$) were most strongly correlated with RUE. These factors were interpreted as affecting surface retention of rainfall. The factors most correlated with RUE from multiple linear regression were slope ($r^2 = 0.45$), surface soil exchangeable Mg (cumulative $r^2 = 0.71$) and surface exchangeable sodium percentage (ESP) (cumulative $r^2 = 0.77$). ESP is a measure of soil dispersion and surface crusting, which when combined with slope (negative correlation), influenced the ability of incident rainfall to enter the soil profile. Mg was interpreted as a surrogate soil fertility factor, as Mg was strongly correlated with soil total N ($r^2=0.53$) and cation exchange capacity ($r^2=0.74$). Dry matter yield and RUE results are generally consistent with those observed on unmined pastoral lands in the region, but data from additional sites and over more seasons are required to fully develop and validate the model for minesite conditions.

Additional Key Words: pasture productivity, carrying capacity, rehabilitation, post-mining land-use, grazing.


2Simon A. Bisrat is Lecturer in Rangeland Science, Asmara University, Erytria.
Ben F. Mullen is a Research Fellow in Tropical Pasture Agronomy, School of Land and Food Sciences, The University of Queensland, St Lucia, Brisbane QLD 4072, Australia.
Andrew H. Grigg is a Research Fellow, Centre for Mined Land Rehabilitation, The University of Queensland.
LONG-TERM PLANT COMMUNITY RESPONSES TO TOPSOIL REPLACEMENT DEPTH ON RECLAIMED MINED LAND\(^1\)

C.K. Bowen, R.A. Olson, G.E. Schuman and L.J. Ingram\(^2\)

Abstract: The use of topsoil on reclaimed mine lands may enhance plant community development and influence reclamation success. This study assessed the long-term (after 24 years) effects of different topsoil replacement depths (0, 200, 400, and 600 mm) on plant community cover, production, and diversity at a research site established in 1977 in south-central Wyoming. Plant species richness (number of species), canopy cover, aboveground biomass, and diversity were evaluated at the four topsoil depths in 2001. Plants were clipped, by species, to obtain mean biomass and to calculate importance values. Shannon-Weiner diversity indices were calculated for each topsoil depth. Species richness was highest (7.5) at the zero topsoil depth and lowest (5.6) at the 600 mm topsoil depth. Total canopy cover was greatest (average 26.7%) at 400 and 600 mm of topsoil and least (21.5%) at the zero topsoil depth. Seeded species canopy cover and seeded species biomass were also greatest at the 400 mm topsoil depth. Total biomass was similar for the 400 (734 kg/ha) and 600 mm (727 kg/ha) topsoil depths and lower but similar at the 200 mm depth (506 kg/ha) and 0 mm depth (513 kg/ha). Plant species richness and diversity index were highest at 0 mm (7.5 and 2.36, respectively) and lowest at 600 mm (5.6 and 1.87, respectively) of topsoil. Number of species and diversity decreased as topsoil depth increased. Increased plant biomass at the 400 and 600 mm depths and increased diversity at the 0 and 200 mm topsoil depths, indicate that variable replacement depths of topsoil can enhance reclamation success through greater species diversity and by creating a greater mosaic of vegetation. However, the reduced cover observed at these shallower topsoil depths may not be adequate to protect the soil from erosion.

Additional Key Words: plant diversity, rehabilitation, semi-arid climate, rangelands

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\(^2\)C.K.Bowen is a Graduate Research Assistant, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071. R.A. Olson is a Professor of Wildlife Habitat Management, Department of Renewable Resources. G.E. Schuman is a Soil Scientist, USDA, ARS High Plains Grasslands Research Station, 8408 Hildreth Rd., Cheyenne, WY 82009. L.J. Ingram is a Post Doctoral Research Associate, Department of Renewable Resources.
INVASIVE SPECIES -- AN EMERGING ISSUE FOR MINING AND RECLAMATION¹

J. Scott Boyce²

Abstract. The impact of invasive species on agriculture, fisheries, natural systems, human health and the economy is gaining increased attention worldwide. The increased movement of people and goods around the globe has greatly increased the impact of this long-standing problem. Executive Order 13112 established the National Invasive Species Council and directed Federal agencies to take appropriate action using relevant programs and authorities to control the economic, ecological, and human health impacts of invasive species. The proper role of the Office of Surface Mining and State agencies in reducing the negative impact of invasive species remains to be determined. If a regulatory response is required to address the potential spread of invasive species through mining and reclamation, the regulatory approach will likely be different than the approach that is currently used to control the other environmental impacts of mining.

Additional Key Words: noxious plants, regulations, weeds.

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² J. Scott Boyce, Agronomist, Office of Surface Mining, 1951 Constitution Ave., Washington, DC, 20240.
EFFICIENCY OF A SCALE MODEL VERTICAL FLOW AND AEROBIC WETLAND SYSTEM IN TREATING ACID MINE DRAINAGE1.

Fred J. Brenner2, Kimberly D. Kosick, Shaun Busler, Corrie A. Gardner, and Carol Tippie.

Abstract: The efficiency of a scale model vertical flow wetland (VFW) and aerobic wetland system in treating acid mine drainage was monitored over a two year period. The vertical flow system was constructed using a mixture of mushroom compost and limestone and the aerobic wetland was a cattail (Typha latifolia) dominated system constructed with mushroom compost as the planting medium. Water samples were collected weekly and analyzed for pH, acidity, alkalinity, iron, manganese, iron and manganese oxidizing bacteria. There was nearly a three unit increase in pH (3.73-6.65) along with a 83% reduction in acidity from an average of 300 mg/L to 50mg/L (83%) and corresponding net alkaline discharge of between 40-9 mg/l. The average iron concentrations were reduced from 32 to 4 mg/l (88%), but only an average of 2 mg/L (11%) of manganese was removed with all manganese reductions occurring in the aerobic wetland. The efficiency of the system varied seasonally, as well as between years, and the reductions in iron and manganese concentrations were correlated with bacterial activity within the systems. The majority of reduction in acidity in the VFW occurred within the upper 45 cm of the substrate, whereas alkaline addition and metal removal occurred between 45 and 90 cm of substrate depth. The efficiency of the systems decreased in the second year of operation. The efficiency of the scale model was similar to systems currently treating acid mine drainage in northwestern Pennsylvania.

Key Words: passive treatment, bacteria, iron and manganese 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
NATIVE SHRUB ESTABLISHMENT IN COLORADO

Sandra L. Brown and Mark W. Paschke

Abstract. The Colorado Division of Minerals and Geology is sponsoring a study to evaluate native shrub establishment on reclaimed lands. The goal of the study is provide enhanced wildlife habitat after mining. Dr. Ed Redente and Mark Paschke from Colorado State University are conducting the research. The first phase of the study included a comprehensive literature review. The literature review covered the biology, ecology, and propagation of seven species that are of primary importance for wildlife habitat in Colorado.

Two main limitations to shrub establishment at the Colorado reclaimed mines are browsing and competition from aggressive herbaceous species. The second phase of the project involved a field study to evaluate reclamation techniques to overcome these obstacles. The experimental design used large-scale demonstration plots that were constructed with normal reclamation equipment to test shrub establishment techniques that have commercial practicality. Plots were established at three coal mines in northwestern Colorado. Several treatments are being tested to evaluate shrub establishment on spoil material, 6 inches of topsoil, and 18 inches of topsoil. Plots were strip seeded with native seed mixes, alternating rows of herbaceous species and shrub species. Native shrub transplants were planted at one mine. Half of each treatment was fenced to prevent browsing. Plots were installed in 2000. Soil samples at all plots were collected in April 2001. The first year’s data was collected in July 2001. Preliminary results indicate topsoil and spoil at all mine sites have favorable characteristics for plant growth. Fall seeding at Colowyo resulted in establishment of most of the seeded species but weedy annuals dominated plots during this first growing season. Fall seeding and shrub transplanting at Seneca II mine appears to have been successful but the plots are also dominated by annuals. Spring seeding at Trapper resulted in very poor establishment. More time will be needed to make a suitable evaluation of these treatments.

Additional Key Words: Wildlife habitat, native seed mixes, fall seeding, spring seeding, topsoil depth.


2 Sandra L. Brown is Senior Environmental Protection Specialist, Colorado Department of Natural Resources, Division of Minerals and Geology, Denver, CO 80203. Dr. Mark Paschke is Research Scientist at Colorado State University, Department of Rangeland Ecosystem Science, and Fort Collins, CO 80523.
PRELIMINARY VEGETATIVE ANALYSES TO ASSESS MINE DRAINAGE IMPACTS ON MARSHES

Jessica Brumley, Robert W. Nairn and Keith A. Strevett

Abstract. The ecology of Typha-dominated marshes at the Tar Creek Superfund Site, northeast Oklahoma, was evaluated during the summers of 2000 and 2001. Since 1979, unabated discharges of contaminated mine water (pH 5.9, alkalinity 414 mg/L as CaCO₃, 170 mg Fe/L, 11 mg Zn/L) into a former pasture has led to the development of an extensive volunteer wetland. Study sites included the impacted marsh receiving mine drainage (East Marsh) and an adjacent reference site receiving storm water (West Marsh). Vegetation sampling transects and quadrats were established and monitored for percent cover, species richness, and growth metrics. Above- and below-ground biomass, culm lengths, and culm densities were determined. Ash free dry weight, organic matter content, and Fe, Zn, Pb, and Cd concentrations were measured in roots, stems, leaves, and inflorescences. Percent cover ranged from 75-95%, and although dominated by Typha spp., 11 different species of vegetation were identified in East Marsh. In 2001, West Marsh was co-dominated by Scirpus spp. West Marsh demonstrated the highest total biomass with belowground biomass consistently higher than aboveground biomass. Culm densities in West Marsh were lower than East Marsh, and in 2000, cumulative stem lengths were directly related to densities. Ash free dry weights showed the highest amounts of inorganic matter in roots and lower amounts in above ground foliage. Concentrations of Fe and Zn were greatest in roots, but were also greater than background levels in stems, leaves, and flowers. Vegetation in West Marsh was metal-impacted, most likely due to back flow of mine water during low flow conditions. Variability in ecological metrics for the two summers is likely due to climatic differences (especially precipitation) between years.

Additional key words: environmental impact, ecological engineering, bioaccumulation

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2 Jessica Brumley was a National Science Foundation Research Experience for Undergraduates Summer Fellow and is currently at Department of Biology and Biochemistry, University of Houston, Houston TX, 77204. Robert W. Nairn is Assistant Professor School of Civil Engineering and Environmental Science, University of Oklahoma, 202 West Boyd Street, Room 334, Norman, OK 73019, nairn@ou.edu. Keith Strevett is Associate Professor, School of Civil Engineering and Environmental Science.
GEOCHEMICAL MODELING OF DEEP COAL MINE DISCHARGES: IRWIN SYNCLINE, PENNSYLVANIA, USA

Elizabeth M. Bryant, William R. Winters, and Rosemary C. Capo

Abstract: Understanding natural alkalinity production offers alternative approaches for neutralizing acid mine drainage (AMD) and has implications for predictive models, mining regulations, mine discharge remediation, and resource recovery. To determine the subsurface processes involved in the generation of natural alkalinity, we focused on infiltration rates, discharge geochemistry and overburden mineralogy of the Irwin syncline, a 240 sq.-km bituminous coal basin in southwestern Pennsylvania. The northern portion of the basin is characterized by highly acidic, iron- and aluminum-contaminated discharges. Highly alkaline, iron and sulfate-contaminated discharges dominate the southern portion (Weaver, T. J., et al., 1997, Geol. Soc. Am. Abstr. Prog., v. 29, A-321). Underground mine barrier data were used to divide the basin into six hydraulically related sub-basins; mine waters were collected from nine discharges across the basin (Winters, W.R., et al., 1999, Proc. 16th Ann. Int. Pittsburgh Coal Conf., 6-5:1-36.). A solute-modeling program (PHREEQC 2.4.2; Parkhurst and Appelo, 1999, USGS Water Res. Invest. Rept. 99-4259, 326 p) was used to put constraints on subsurface reactions. Inverse modeling results indicate that the spatial and temporal change in mine water chemistry involves processes other than simple carbonate dissolution or dilution with uncontaminated water. Acidic discharges in the northeastern end of the basin are likely the product of surface water modified by pyrite oxidation and dissolution of aluminosilicate minerals. Modeling results on the southwestern discharges are consistent with the development of net alkaline waters as a result of limestone dissolution enhanced by cation exchange reactions with overburden clays such as illite, montmorillonite and kaolinite. The data suggest these processes occur in deeper sub-basins (overburden thickness greater than 100 m). Transport models incorporating both surface water infiltration rates and interaction with neighboring mine pool waters will be developed to refine the geochemical evolution of the Irwin syncline deep mine discharges.

Additional Key Words: PHREEQC modeling, AMD


2Elizabeth Bryant is a Graduate Student Researcher, Department of Geology & Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260 William R. Winters is a Hydrologist, Office of Surface Mining, Pittsburgh, PA 15220 Rosemary C. Capo is an Associate Professor, Department of Geology & Planetary Science, University of Pittsburgh, Pittsburgh, PA 15260
FIELD ASSESSMENT OF MINE SITE QUALITY FOR ESTABLISHING HARDWOODS IN THE APPALACHIANS¹

J. A. Burger, D. O. Mitchem, and D. A. Scott²

Abstract. In the past five years there has been a major resurgence in the hardwood timber and wood-using industries throughout the Appalachian coalfield region. Major forest companies are investing heavily in the Appalachian hardwood resource, and they are interested in reforestation of mined land with commercially valuable hardwoods. However, post-SMCRA reclamation creates sites that are difficult to reforest due to inappropriate mine spoil chemistry, excessive compaction, and competing ground cover vegetation. A study was installed across the three-state region of Virginia, West Virginia, and Kentucky to test the survival and growth of commercially valuable hardwoods across factorial gradients of mine spoil chemistry, grading intensity, and slope aspect. A total of 10 treatment blocks, each 1 ha in size, were installed over a 3-year period beginning in 1994. Tree survival and growth were measured across the study each year. Green ash survival and growth was relatively unaffected by the site factor gradients, but white oak was influenced by all gradients. Survival and growth was poorest and unacceptable on sites with southwest aspects and soils made up of compacted, finely textured alkaline parent material. Survival and growth of white oak was best on sites with northeastern aspects and loose soils made up of weathered sandstone spoil materials. Site mapping of forest site quality for site-specific species prescriptions appears to be a promising approach for successful reforestation of native hardwoods on mined land.

Additional Key Words: reforestation, tree planting, site quality


²J. A. Burger, Professor; College of Natural Resources, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. D. O. Mitchem and D. A. Scott, Graduate Research Associates
VISUAL DEMONSTRATION OF WATER DISTRIBUTION PATTERNS IN VERTICAL FLOW SYSTEMS

Shaun Busler², Charles Cooper³, Timothy Danehy², Darcy Peart², and Margaret Dunn²

Abstract: Passive treatment of coal mine drainage implies long life with low maintenance using non-dangerous chemicals or treatment media. In 1997 and 1998 four such systems were installed in the Slippery Rock Creek watershed in northern Butler County, PA. These Vertical Flow-type systems utilize organic material known as spent mushroom compost which was either blended with fine limestone aggregate or placed above large size limestone aggregate. In 1998 a series of dye tests were performed on the Jennings VFS to investigate certain presumptions that had been made concerning uniform water distribution through the treatment media. From this study, it was concluded that to avoid short circuiting of the treatment media uniform water distribution is a significant design concern. This present study is an extension of that work to three other systems, SR109, SR 85/86, and SR 87/88, in addition to the Jennings VFS. For all the dye tests, 5/8" diameter non-toxic iridescent dye tablets were added to the flowing water stream at the influent channel stream of each VFS. Where possible, the distribution of the dye in the VFS pond was observed for a number of hours after dye addition was terminated. Separate tests were conducted on three of the four Vertical Flow Systems studied with both green and red dye to determine which was most visible. Still photographs were taken and video recording was conducted, the video camcorder generally providing better recognition of the dye coloring. Dye plumes varied in size and location ranging from 5' at SR85/86 to over 160' at SR87/88. The observations made during this study indicate that these systems may be plugging and further investigation is needed.

Additional Key Words: acid mine drainage, dye test, passive treatment, spent mushroom compost, and vertical flow pond


SOIL WATER PERCOLATION AND EROSION ON UNCOMPACTED SURFACE MINE SOIL IN EASTERN KENTUCKY


Abstract. Previous research has found that little to no compaction of mine spoils has positive effects on tree growth but no studies have evaluated the effect that uncompacted spoils have on soil percolation and erosion. This paper examined the movement of sediment transported by surface erosion and soil water percolation in uncompacted mine spoils located in eastern Kentucky. In sparsely vegetated, uncompacted mine spoils approximately 32% of the incident precipitation percolates as soil water to a depth of approximately 2.6 m (8.5 ft.), which is comparable to forested conditions in eastern Kentucky. Estimated annual erosion rates for the uncompacted mine spoils were 1750 kg ha⁻¹ (0.8 t ac⁻¹), which is above that of forested sites but considerably lower than those on agricultural lands in Kentucky. The relatively low erosion rates are the result rough soil surfaces, depressional storage, and high infiltration and percolation capacities associated with the uncompacted spoils.

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2 E. J. Byrd, Environmental Consultant, Kentucky Business Environmental Assistance Program, University of Kentucky, Lexington, KY 40546. R.C. Warner, Professor, Department of Biosystems and Agricultural Engineering. R.K. Kolka, USDA Forest Service - North Central Research Station, 1831 Hwy. 169 E., Grand Rapids, MN 55744. J.M. Ringe, Associate Professor, Department of Forestry, University of Kentucky, Lexington, KY 40546.
ACID MINE DRAINAGE TREATMENT VIA ALKALINE INJECTION TECHNOLOGY\textsuperscript{1}

G.A. Canty and J.W. Everett\textsuperscript{2}

Abstract. The Oklahoma Conservation Commission conducted a demonstration project to investigate the feasibility of treating acid mine drainage by chemically altering the characteristics of the mine water. The treatment method involved the injection of an alkaline coal combustion byproduct directly into a flooded underground mine. The project was based on the premise that the alkaline materials in the ash would create an \textit{in-situ} chemical condition that would result in acid neutralization, metal precipitation, and would impart alkalinity to the mine drainage. Alkaline injection technology (AIT) was successful at raising pH and alkalinity, while reducing acidity and metals loading, but the duration of the treatment and the environmental significance was temporary. After 15 months, the water quality characteristics appeared to approach pre-injection conditions. However, after reviewing the water quality data from the past 4 years there are statistically significant reductions in acidity (23\%), iron (18\%), and aluminum (47\%), and an increase in pH (0.35 units). Presumably, the mine environment has reached equilibrium with the alkalinity introduced to the system. A second study is currently underway to determine if the total amount of alkalinity was actually limited in the system or if there are other factors involved that limit the effectiveness of AIT.

Additional Key Words: fluidized bed combustion ash, acid mine drainage

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\textsuperscript{2} Geoffrey A. Canty, Ph.D., Oklahoma Conservation Commission, Oklahoma City, OK 73118-1046. Jess W. Everett, Ph.D., P.E., Professor, Rowan University, Glassboro, NJ 08028-1701
WATER QUALITY AND HYDROLOGY OF A NATURAL WETLAND RECEIVING MINE DRAINAGE: IS IT BIOGEOCHEMISTRY OR DILUTION?1

Jennifer Coffey, Kimberley Wahnee, Kathleen Swanson, Robert W. Nairn, and Keith A. Strevett2

Abstract. We examined biogeochemical and freshwater dilution effects influencing water quality in a marsh and stream system at the Tar Creek Superfund Site, Oklahoma. Two abandoned boreholes discharge polluted mine water (pH 5.9, alkalinity 414 mg/L as CaCO3, 170 mg Fe/L, 11 mg Zn/L, 0.01 mg Cd/L and 0.02 mg Pb/L) to an approximately 1-ha *Typha* spp.-dominated wetland. An understanding of water quality changes is required to differentiate between wetland biogeochemical processes and simple dilution effects in order to develop possible remediation designs. Samples were periodically collected at eight locations (two upstream, at two boreholes and four downstream) to determine water quality changes in the wetland and resultant effects upon receiving stream water quality. *In situ* measurements included pH, temperature, alkalinity, conductivity, dissolved oxygen, and turbidity. Samples were collected and analyzed for Fe, Zn, Cd, Pb, Ca, Mg, SO4^{2-}, NO3^{-}, NO2^{-}, PO4^{3-}, Cl^{-}, F^{-}, and Br^{-} concentrations. The drainage basin was surveyed and several surface models were created, allowing calculation of water column and sediment volumes. Two surface runoff models were also produced to better understand storm water flows. In general, concentrations of all cations and anions decreased with flow through the wetland. Nonetheless, Zn, Pb, Cd and Fe concentrations in wetland and stream waters demonstrated toxicity on all sampling dates. Decreases of conservative ion concentrations (e.g., Mg and Cl) indicate significant dilution effects from storm water runoff entering the wetland upstream from the boreholes. Influx of non-mine drainage related storm water flow, although causing contaminant concentrations to decrease, significantly increased metal loading to receiving waters. Modifications of surface runoff models demonstrated substantial peak flow reductions are possible by diverting storm water flows. Factoring dilution effects into our understanding of mine drainage-impacted areas is an important component of remedial design.

Additional key words: treatment wetland, iron oxyhydroxide, hard rock mining

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2 Jennifer Coffey, Kimberley Wahnee and Kathleen Swanson were National Science Foundation Research Experience for Undergraduates Summer Fellows. Robert W. Nairn is Assistant Professor School of Civil Engineering and Environmental Science, The University of Oklahoma, Norman, OK 73019, nairn@ou.edu. Keith A. Strevett is Associate Professor, School of Civil Engineering and Environmental Science.
RECLAMATION TECHNIQUE AFFECTS TREE ROOT DEVELOPMENT
ON RECLAIMED SURFACE MINED LANDS

Paul W. Conrad, Richard J. Sweigard, Viktor Badaker, Donald H. Graves, and James M. Ringe

Abstract. Much of the land reclaimed since enactment of the 1977 Surface Mining Control and Reclamation Act is over-compacted. Research has shown that excessive compaction in replaced growing media is detrimental to establishment of trees. If trees are to be grown on reclaimed surface mined sites, something must be done to either minimize or alleviate excessive compaction in replaced growing media. The University of Kentucky has developed test cells at a reclaimed surface mine in eastern Kentucky to determine the impact of various spoil handling techniques and compaction alleviation methods on soil compaction and tree survival. The spoil handling techniques being evaluated include compacted, loose dumped, and struck-off techniques. The compacted technique represents the reclamation techniques typically practiced at mountaintop removal operations in the eastern United States. The loose dumped technique represents the placing of growing medium material with trucks, but no grading of the material. The struck-off technique represents the placing of growing medium material with trucks and minimal grading to level off the tops of the piles. The compaction alleviation methods being evaluated include shallow tillage using conventional farm equipment and deep tillage using a dozer with a ripping arm. Test cells have been planted with various tree species and data have been collected at the cells for soil compaction, soil mechanical resistance, and tree survival. The data are currently being correlated to determine how reclamation technique and compaction alleviation method affects tree survival. In September 2001, a tree was removed from a cell representing each reclamation technique and each compaction alleviation method to observe the root structure of growing trees. Each tree selected for removal was of the same species (Northern Red Oak) and of approximately the same height (18 to 24 inches) and of the same shape. The removed trees have shown that at reclaimed mountaintop removal sites, roots grow along the joints between the rocks in the growing medium. For the compacted reclamation cells, only a single taproot structure is developing. For


2Paul W. Conrad is a Research Assistant, Department of Mining Engineering, University of Kentucky, Lexington, KY 40506. Richard J. Sweigard is Professor and Chair, Department of Mining Engineering. Viktor Badaker is a Post-Doctoral Researcher, Department of Mining Engineering. Donald H. Graves is Professor and Chair, Department of Forestry, University of Kentucky, Lexington, KY 40506. James M. Ringe is a Professor, Department of Forestry.
RESTORATION AND MONITORING OF AQUATIC QUALITY IN A COAL-MINED WATERSHED, SWATARA CREEK AT RAVINE, PENNSYLVANIA

C. A. Cravotta III, M. D. Bilger, R. A. Brightbill, and D. Bogar

Extended Abstract

Streamflow, chemical, and biological data for the northern part of Swatara Creek, which drains a 112-km² area in the Southern Anthracite Field of eastern Pennsylvania, indicate progressive improvement in water quality since 1959, after which most mines in the watershed had been flooded. Drainage from the flooded mines contributes substantially to baseflow in Swatara Creek. Beginning in 1995, a variety of treatment systems and surface reclamation were implemented at some of the abandoned mines (Cravotta and Weitzel, 2001). At Ravine, Pa., immediately downstream of the mined area, median SO₄ concentration declined from about 150 mg/L in 1959 to 75 mg/L in 2000 while pH increased from acidic to near-neutral values (medians: pH~4 before 1975; pH~6 after 1975). As a consequence of the improved water quality at Ravine, the fish community has rebounded. No fish were present during ecological surveys in 1985 and 1990; however, in 1994 and 1996 six species of fish were found. Increasing numbers of fish species have been found annually since 1996. In 2000, twenty-four species of fish were documented. Although the majority of the fish species are considered to have moderate tolerance to pollution, several intolerant species including river chub, cutlips minnow, and longnose dace, have been reported since 1997. An increased abundance of benthic macroinvertebrate taxa that are considered intolerant of pollution indicates water quality improved from fair in 1994 to very good in 1999 and 2000. Nevertheless, Hydropsychidae (caddisflies) and Chironomidae (midges), which are known to tolerate acidic conditions, were dominant. Although subordinate, the appearance of Ephemeroptera (mayflies) in 1997 and later years is significant in that these animals are sensitive to acidic conditions and considered intolerant to pollution. Nevertheless, recent monitoring indicates elevated concentrations and transport of Fe, Al, Mn, and trace metals during stormflow and elevated concentrations of Fe, Mn, Co, Cu, Pb, Ni, and Zn in streambed sediments relative to unmined areas and to toxicity guidelines for aquatic invertebrates and fish (Cravotta, 2000; Cravotta and Bilger, 2001). The

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metals are ubiquitous in the fine fraction (<0.063 mm) of bed sediment in mining-affected tributaries and Swatara Creek and represent a long-term source of contamination.

Selected References


NEW METHOD TO ESTIMATE SIZE AND LONGEVITY OF ANOXIC LIMESTONE DRAINS

C. A. Cravotta III

Extended Abstract

A new method is proposed using first-order decay equations with data from short-term closed-container (cubitainer) tests previously described by Watzlaf and Hedin (1993) to estimate the mass of a limestone bed for anoxic treatment of acidic mine drainage (AMD) and the expected alkalinity concentration at the outflow or intermediate points within the limestone bed. The longevity of an anoxic limestone drain (ALD) or the remaining mass of limestone (Mt) at any time (t) is determined as a function of the initial mass of limestone (M0) and decay constant (k), with units of 1/year:

\[ Mt = M0 \cdot \exp\{-k \cdot t\}. \]

Detention time (td) within the limestone bed is estimated as a function of the estimated mass of limestone and associated estimates of flow rate (Q), porosity (\( \phi \)), and limestone density (\( \rho_S \)):

\[ t_d = Mt / \left( \rho_S \cdot Q \cdot (1 - \phi) / \phi \right). \]

The concentration of alkalinity at the outflow or intermediate points within the limestone bed is determined as a function of the detention time, the influent alkalinity (C0), the maximum or steady-state alkalinity (CM), and the rate constant (k'), with units of 1/hour:

\[ Ct = CM - (CM - C0) \cdot \exp\{-k' \cdot t_d\}. \]

The cubitainer tests, which used an initial mass of 4 kg crushed limestone and solution volume of 2.8 liter, provided estimates for the rate constants, k' and k, and the initial and maximum alkalinitities, C0 and CM (Cravotta and Watzlaf, in press). Application of the above equations using these estimates, and assuming limestone density of 2.65 g/cm3 and porosity of 0.49, provided accurate estimates for the long-term (5- to 11-yr) trends of declining alkalinity in effluent at the Howe Bridge, Morrison, and Buck Mtn. limestone drains, which effectively treat AMD in Pennsylvania (e.g. Hedin et al., 1994; Cravotta and Weitzel, 2001). The equations and rate constants also can be used to estimate the initial mass of limestone required to achieve a future mass, detention time, and associated alkalinity. This application avoids the assumptions of Hedin and Watzlaf (1994) of constant alkalinity and CaCO3 mass flux over the lifetime of the ALD.
Selected References


VERTICAL FLOW POND PIPING SYSTEM DESIGN CONSIDERATIONS

Timothy P. Danehy, Tiff Hilton, George R. Watzlaf, Fred Johnson, Shaun L. Busler, Clifford F. Denholm, Margaret H. Dunn

Abstract. Abandoned mine drainage is a major source of water pollution in Pennsylvania, West Virginia, and other historical mining districts. Technology which utilizes no harsh chemicals and no electricity, and requires minimal maintenance known as passive treatment is being developed to address this pollution problem in a relatively cost-effective manner. Specifically, acidic drainage with dissolved aluminum and/or high iron content is now being successfully abated utilizing a type of passive system which uses a component known as a Vertical Flow Pond (VFP). VFPs are also referred to as Reducing and Alkaline Producing Systems or RAPS. Numerous papers and technical investigations have provided documentation on the effectiveness of these systems in treating discharges of various qualities and flow rates. Very little information, however, is available regarding the piping systems used for the collection of the water after passing through the treatment media. These piping systems are often referred to as underdrains. Experience gained during installation and from on-going monitoring of successful VFPs at the Jennings Environmental Education Center and Ohiopyle State Park (PA Dept. of Conservation and Natural Resources) and within the Slippery Rock Creek Watershed has led to the development of an innovative double-tiered, multiple-quadrant, underdrain system. This type of underdrain has been recently installed at the De Sale Restoration Area - Phase II (De Sale II) site in Venango Township, Butler County, PA. This underdrain system is expected to aid in eliminating “dead areas” and in maintaining the hydraulic conductivity of the treatment media by improving flow distribution and by improving the ease and thoroughness of the flushing operation to remove accumulated metal solids.

Additional Key Words: Passive Treatment, Constructed Wetlands, Acid Mine Drainage, Flow Distribution, Flushing


MULTI-COMPONENT PASSIVE TREATMENT SYSTEM: A CASE STUDY

Timothy Danehy, Shaun Busler, Tiff Hilton, Fred Johnson, Robert Hedin, Clifford Denholm and Margaret Dunn

Abstract: In late 1999, an effective passive system was designed and installed through a public-private partnership effort to treat a 30-gpm abandoned mine discharge containing high dissolved metal concentrations on an old 120-acre, surface clay and coal mine within Ohiopyle State Park, PA. This multi-component passive treatment system was constructed in six weeks and consists of an Anoxic Collection System, Anoxic Limestone Drain (ALD), Settling Pond #1, Vertical Flow Pond (VFP), Settling Pond #2, Aerobic Wetland, and Horizontal-Flow Limestone Bed (HFLB). In theory, the high concentration of dissolved iron (155 mg/L) in the discharge would consume the alkalinity (190 mg/L field) generated by the ALD. The iron solids would be retained in Settling Pond #1 and the effluent with the remaining dissolved iron would then enter the VFP, which would generate sufficient alkalinity to neutralize the acidity generated as the iron precipitated in Settling Pond #2 and the Aerobic Wetland and to ensure a net alkaline final effluent. Although the calculated residence time was more than 20 days for Settling Pond #1, a range of 10 to 40 mg/L of particulate iron flowed from Settling Pond #1 into the VFP. Dye testing indicated that, although constructed properly, residence time was only a few hours, indicating that the acceptable method for calculating residence time was not applicable. Baffle curtains, a standard practice used in conventional treatment systems, were installed to increase residence time and promote settling. These baffles have successfully decreased the particulate iron concentration in the effluent from Settling Pond #1 by 50 to 75%. After passing through the entire system, the total iron concentration is about 1 mg/L. There is a total decrease in loading of an estimated 31,000 lbs/yr of acidity and 11,000 lbs/yr of metals.

Additional Key Words: acid mine drainage, baffles, field alkalinity, passive treatment


EFFECTS OF BIOSOLIDS APPLICATION ON GROUND WATER NITRATE-N LEVELS IN SAND AND GRAVEL MINE RECLAMATION IN VIRGINIA

W. Lee Daniels, Steve Nagle, G. Richard Whittecar, and Greg Evanylo

Abstract. Sand and gravel mine reclamation in eastern Virginia is hampered by low mine soil water holding capacity and fertility levels. Application of biosolids at higher than agronomic rates has been recommended for these areas, but agency concerns over the potential for NO₃-N leaching to shallow ground water persist. In the fall of 1998 and the spring of 1999, a mixture of two different biosolids was applied to a 20-ha reclaimed site in the Virginia Coastal Plain at various rates ranging from 1.5 to 5x the agronomic N rate for corn (Zea mays). By the end of the 2000 growing season, the majority of the biosolids treated areas supported at least 90% vegetative cover, and most of the area supported 100% ground cover, with average standing biomass > 5 Mg/ha. Nitrate-N levels remained low in all wells within the treated areas over the winter/spring/summer of 1998/1999, indicating that a mixed application of two biosolids materials to the majority of the site had little effect on ground water with regard to NO₃-N. Of 13 monitoring wells under and downgradient of the application areas, only three showed any significant treatment effects, and all levels dropped to < 2 mg/L by the spring of 2001. Nitrate-N levels in several wells directly adjacent to an area receiving a 3x agronomic rate application of lime-stabilized biosolids slowly began to increase in the fall of 1999, peaked at 50 mg/L in late winter/early spring of 2000, and then dropped below drinking water standard levels (10 mg/L) by May, 2000. Neither the surface water within the site nor two external downgradient wells adjacent to the Mattaponi River showed any elevation in NO₃-N levels through the late winter of 2001. Significant background levels of NO₃-N appeared to be entering the site via ground water flow from an adjacent agricultural field. Overall, these data support earlier findings that while application of biosolids at higher than agronomic rates will lead to an ephemeral (first winter) leaching loss of NO₃-N, that the impact to ground water is highly localized, small in magnitude, and relatively short lived.

Additional Key Words: Water quality, nitrogen leaching, sewage sludge.


2W. Lee Daniels, Professor, Dept. of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, VA 24061-0404. Steve Nagle, Research Specialist, Dept. of Crop and Soil Environmental Sciences Greg Evanylo, Professor, Dept. of Crop and Soil Environmental Sciences. G. Richard Whittecar, Associate Professor, Dept. of Ocean, Earth and Atmospheric Sciences, Old Dominion University, Norfolk, VA, 23529.

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RECLAMATION OF PRIME AGRICULTURAL LANDS AFTER COAL SURFACE MINING: THE MIDWESTERN EXPERIENCE

R.G. Darmody, R.E. Dunker, and R.I. Barnhisel

Abstract. This paper is a review of the reclamation research conducted in the Midwestern US, primarily at the Universities of Illinois and Kentucky. Chemical problems associated with surface mining, such as acid generating materials, are important and well documented. However, reclamation research has shown that poor soil physical condition is the most limiting factor to successful row crop production on reclaimed mined land in the Midwest. Critical to success are selection of the best available soil materials used in soil construction and a material handling method that minimizes soil compaction. Excellent corn and soybean yields have been achieved on low strength soils both in high weather stress years as well as low stress years. Total crop failures have occurred on high strength soils in years of weather stress. Some deep tillage practices have been successful in improving compacted soils, but it is preferable to avoid compaction in the first place, when the soil materials are handled. Soil strength measurements with a cone penetrometer have proven to be a useful tool in evaluating rooting media and reclamation practices. Research has shown that surface mining can be a short term land use that may be followed by productive farmland, if reclamation is done correctly.

Additional Key Words: strip mining, important farmlands, restoration, soil compaction, deep tillage.


2Robert G. Darmody is Professor of Soil Science, Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign, 1102 S. Goodwin, Urbana IL, 61801. Robert E. Dunker is an Academic Professional, Department of Crop Sciences. Richard I. Barnhisel is Professor of Agronomy, Department of Agronomy, University of Kentucky, Lexington, KY, 40502.
SAMPLING STRATEGIES FOR TMDL OF AMD-AFFECTED STREAMS

Brian A. Dempsey, Benjaphon Paksuchon, Ratda Suhataikul, and Jon Dietz

Abstract. Water quality was monitored during March 1999 to May 2001 at 106 AMD stream sites, within eleven watersheds in Western Pennsylvania. Data were used to prepare Total Maximum Daily Load (TMDL) reports using a probabilistic model (@Risk) to determine the required percent removals of acidity and of total Al, Fe, and Mn in order to comply with water quality criteria at least 99% of the time. Water quality was measured as a function of stream stage during storm events for some sites. Sites were divided into five categories, based on pH and sulfate concentration. Category 1 (pH<3.5 and sulfate>50 mg/L) accounted for 17% of total sites. Removal of >90% of the current load of acidity and aluminum was required in all category 1 cases. The relative standard deviations for water quality parameters were low for category 1 sites. We recommend that TMDL water quality sampling be limited to four expeditions for these streams, to conserve resources and to speed the development of remediation efforts. Category 2 sites (3.5<pH<6.0 and sulfate>50 mg/L) required removal of lower percentages of metals, and we recommend more sites per stream mile and an early intensive survey to determine the important sources of contamination. Stream sites in Category 3 (3.5<pH<6.0 and sulfate<50 mg/L) required removal of acidity, but in most cases no removal of total metals was required. Stream sites in Category 4 (pH>6.0 and sulfate>50 mg/L) occasionally required removal of acidity and of metal loads. Stream sites in Category 5 (pH>6.0 and sulfate<50 mg/L) did not require removal of metals for compliance. For these three categories, we recommend: an early intensive stream survey; continuous monitoring of conductivity and pH at some sites to determine possible impacts during high water events; and measurement of dissolved or monomeric Al(III), Fe(II), and Mn(II) in addition to total metals.

Additional Key Words: AMD effects, water quality, modeling


2 Brian A. Dempsey is Professor of Environmental Engineering, The Pennsylvania State University, University Park, PA 16802. Benjaphon Paksuchon, Ratda Suhataikul, and Jon Dietz are Graduate Students, The Pennsylvania State University, University Park, PA 16802.
HETEROGENEOUS OXIDATION OF FERROUS IRON FOR TREATMENT OF MINE DRAINAGE

Brian A. Dempsey², Jon Dietz, Byong-Hun Jeon, Heath C. Roscoe, and Ryan Ames

Abstract. Heterogeneous oxidation of ferrous iron in AMD was studied at bench-top in the laboratory, at two passive abiotic treatment systems for AMD, in an aerated ditch to which ferric oxide sludge had been added, and in batch and recirculated sludge systems that were designed for abiotic heterogeneous oxidation of AMD at pH between 5 and 6.8. Heterogeneous oxidation accounted for between 60 and 99% of total oxidation of Fe(II) for the conditions that were tested. In bench-scale lab tests, the heterogeneous rate constant was \( k_2 = 3.1 \times 10^{-8} \) (mg/L\(^{-1}\)sec\(^{-1}\)) for 19.3 to 23.5°C using synthetic mine drainage solutions and \( E_{act} \) was 180 kJ/mol for \( k_2 \) (Ames 1998). In field tests at passive treatment facilities, average \( k_2 \) was 2.2x10\(^{-8}\) (mg/L\(^{-1}\)sec\(^{-1}\)) for 11.7 to 19.2°C (Roscoe 1999). In large-scale tests with recirculated ferric oxide sludge, ferrous iron removal rates were above 1000 g/m\(^2\)/d for pH as low as 5.4 and \( k_2 \) was 1.7 x 10\(^{-8}\) (mg/L\(^{-1}\))s\(^{-1}\) at 15°C (Dietz & Dempsey, 2001). The \( k_2 \) values were consistent with values previously reported by Tamura & Nagayama (1976) and by Sung and Morgan (1980), but both of those studies were conducted at higher pH and for low ferric oxide and sulfate concentrations. Sung & Morgan concluded that heterogeneous oxidation became more important as the pH rose above 7, but this was due to their dependence on fresh precipitation of a relatively low concentration of ferric oxide. Our work showed that heterogeneous oxidation is particularly useful for AMD treatment at pH 5 to 6.8. Heterogeneous oxidation at moderately acidic pH also resulted in relatively dense sludge. These kinetic parameters and mass transfer constants for O\(_2\) and for CO\(_2\) provide a basis for design of treatment processes that can operate at high areal capacity (greater than 1000 g/m\(^2\)/d) for net alkaline AMD waters while producing sludge that exceeds 15% (w/w) after settling.

Additional Key Words: auto-catalysis, passive treatment, oxidation rate

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² Brian A. Dempsey is Professor of Environmental Engineering, The Pennsylvania State University, University Park, PA 16802. Jon Dietz and Byong-Hun Jeon are Ph.D. candidates at Penn State in Environmental Engineering. Heath Roscoe is Assistant Professor of Environmental Engineering, U.S. Military Academy, West Point, NY 10996. Ryan Ames is Project Engineer with Gannett Fleming Engineers, Baltimore, MD 21215.
INNOVATIVE TREATMENT OF ALKALINE MINE DRAINAGE USING RECIRCULATED IRON OXIDES IN A COMPLETE MIX REACTOR

Jonathan M. Dietz and Brian A. Dempsey

Abstract. A demonstration study was undertaken to develop an abiotic iron oxidation process to increase the Fe(II) removal rates (IRR) at low pH (6 to 7) compared to conventional oxidation ponds and aerobic wetlands (typical IRR is 10 to 20 g/m²/d) while producing a high-quality sludge. An alkaline mine drainage from an underground mine pool containing 60 to 80 mg/L Fe(II) was used in the study. Batch tests were conducted in a 330 gal tank at various initial concentrations ranging from 5 to 1300 mg/L added Fe(III) solids. Results indicated test durations to obtain less than 1 mg/L of Fe(II) decreased from greater than 48 hours for low initial Fe(III) to less than 2 hours in tests with initial Fe(III) greater than 1000 mg/L. Following batch tests a flow-through reactor system was employed consisting of two-330 gal tanks, a complete-mix oxidation reactor followed by a clarifier tank. Fe(III) solids were recirculated from the clarifier to the reactor to obtain reactor concentrations ranging from 10 to 2000 mg/L. The reactor lowered Fe(II) to approximately 3 mg/L when Fe(III) was 2000 mg/L and contact time was 2.3 hours. IRR of 0.52 mg/min or 740 g/m²/d were achieved during this flow-through test. IRR exceeding 1 mg/min or 1300 g/m²/d were obtained when Fe(III) was 1800 mg/L and contact time was 1.3 hours, but with a slightly higher effluent of 14 mg/l Fe(II). The recirculated Fe(III) sludge had a specific resistance to filtration (SRF) of 4×10¹¹ m/kg, a coefficient of compressibility of 0.37 and solids concentrations greater than 20%. The SRF is similar to that observed for flocculent solids formed at high pH (>8), but the compressibility is similar to high-density sludges. This research demonstrated the effectiveness of a recirculated sludge process to increase IRR over passive treatment and to obtain similar IRR as conventional chemical (lime) treatment.

Additional Key Words: AMD treatment, iron removal, heterogeneous iron oxidation

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2Jon Dietz, Ph.D. Candidate Environmental Engineering Program, Department of Civil Engineering, Pennsylvania State University and principal at Dietz et al Consulting, LLC, 672 Devonshire Drive, State College, PA 16803 Brian A. Dempsey, Professor of Environmental Engineering, Department of Civil Engineering, Pennsylvania State University, 205 Sackett Building, University Park, PA 16801
A DETERMINISTIC MODEL FOR PREDICTING ALKALINITY FROM LIMESTONE FOR DESIGN OF AMD PASSIVE TREATMENT SYSTEMS

Jonathan M. Dietz and Brian A. Dempsey

ABSTRACT. Mine drainage (MD) water quality varies from highly acidic pH (<3) to circumneutral pH (6-7). Passive treatment systems for MD usually require additional alkalinity, and this is often accomplished by dissolution of calcite limestone. Proper design of alkalinity-producing components of treatment systems for MD requires accurate models that account for effects of temperature, ionic strength, pH, and initial calcium and carbonate concentrations. Design parameters are typically based on past performance from constructed systems for different MD characteristics or from on-site cubitainer or pilot-scale studies. In this investigation a deterministic model was developed for prediction of the maximum alkalinity (at infinite reaction time) and the rate of alkalinity generation, for various MD types. The model consists of two components. The first component is a maximum alkalinity estimation model (MAEM) that accounts for alkalinity, calcium, pH, ionic strength, and temperature to predict a maximum alkalinity. The MAEM model predicted maximum alkalinitities to within ten percent of measured alkalinitities from long term cubitainer studies and ALD systems. The second component of the model is an alkalinity kinetic model (AKM) that was developed using data obtained from several time-varying alkalinity cubitainer studies, conducted on various water types. The analysis of this time-varying data indicated alkalinity generation was a second-order rate reaction, which is consistent with the stoichiometry of the calcite reaction. A second-order reaction rate coefficient ($k_{\text{alk}}$) of $3.1 \times 10^{-10} \text{ M}^{-1}\text{s}^{-1}$ at $12^\circ\text{C}$ was determined from the data. A study is underway to determine the activation energy ($E_a$) for the reaction rate coefficient. The combined MAEM-AKM provides estimates of maximum alkalinity and alkalinity for various MD chemistries and for any limestone contact time. The MAEM-AKM model is an important tool to assist managers and engineers in developing projects and designs to abate mine drainage discharges.

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2Jon Dietz, Ph.D. Candidate Environmental Engineering Program, Department of Civil Engineering, Pennsylvania State University and principal at Dietz et al Consulting, LLC, 672 Devonshire Drive, State College, PA 16803. Brian A. Dempsey, Professor of Environmental Engineering, Department of Civil Engineering, Pennsylvania State University, 205 Sackett Building, University Park, PA 16801
PRELIMINARY ANALYSIS OF SPOIL SETTLEMENT AT A MOUNTAIN-TOP-REMOVAL COAL MINE: STAR FIRE TRACT, EASTERN KENTUCKY COAL FIELD


SETTING

The method of mining coal by the mountain top removal (MTR) process can create gently rolling land that may be used for multiple purposes that provide economic diversity for the Eastern Kentucky Coal Field region, part of the Appalachian Plateau physiographic province. A major limiting factor of post-mine development is the settlement of mine spoils over time. Between 1981 and 1996, approximately 1,000 acres of land were mined at the Star Fire Mine in Perry, Breathitt, and Knott counties by MTR processes using shovel and truck, and a 64-yd³ bucket dragline (Fig. 1). Spoil thickness ranges from approximately 50 ft to 300 ft over buried valley fills with a large percentage of the area having approximately 200 ft of spoil. Two publications detail the mining process and spoil hydrogeology, and initial spoil settlement around groundwater monitoring wells (Wunsch et al., 1992, 1996). From September 1995 to August 2000, seven leveling surveys were completed on 80 monuments placed on 200 ft centers (where possible) along four lines (A through D) across the spoil (Fig. 1). The vertical precision of these surveys is 0.01 ft.

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2 James S. Dinger, Head of Water Resources Section, and Robert E. Andrews, Hydrogeologist, Kentucky Geological Survey, University of Kentucky, Lexington, KY. David R. Wunsch, State Geologist of New Hampshire, Concord, NH. C. Douglas R. Graham, Geologist, Kentucky Division of Waste Management, Frankfort, KY. Richard J. Sweigard, Chair, Department of Mining Engineering, University of Kentucky, Lexington, KY Paul W. Conrad, Research Assistant, Department of Mining Engineering.
Abstract. The objective of this research was to determine whether acidic-contaminated soil systems amended with alkaline industrial by-products enabled plant growth equivalent to that attained with a commercial grade mixture of CaCO$_3$ and CaO. In addition, it was determined whether an alkaline by-product dosage threshold existed, above which plant growth was impaired. Three types of cement kiln dust, three types of lime kiln dust, and two other alkaline by-products (Dicalcium Silicate, Carbide Lime) were applied to metalliferous tailings (pH 1.8) and a metal contaminated natural soil (pH 5.0) in a greenhouse pot study. Most alkaline products (pH 9.9 – 13.7) contained enriched metal concentrations of Al, As, B, Ba, Cd, Cr, Cu, Mn, Ni, Pb, Se and Zn. However, phytotoxic concentrations may have been mitigated i) when diluted in the soil profile at an application rate of 2 % to 10 % (soil dry weight basis), and ii) by the final amended soil pH in the range of 7.0 – 8.4 where these metals of concern were present at very low concentrations in the soil solution. All alkaline products produced a desired soil pH (7.0 – 8.4) in the root zone during plant growth tests. Following a 111-day plant growth period with Basin Wildrye (Leymus cinereus) and Redtop (Agrostis alba), all alkaline industrial by-products tested had plant growth equal to- or greater than- the CaCO$_3$/CaO mixture. For each alkaline industrial product, including the CaCO$_3$/CaO mixture, the greater the application rate, the less was the plant growth. Over the alkaline product dosage range of 0 % to 12 % (soil dry weight basis) the loss in aboveground plant biomass was 65 % for Basin Wildrye and 88 % for Redtop.

Additional Key Words: tailings, lime, contaminated soil, industrial by-products
RECLAMATION ON LAND DISTURBED BY SURFACE MINING IN ROMANIA

Elisabeta Dumitru and Agatha Popescu

Abstract: Within the Oltenia surface mining region of Romania, 14,890 ha have been disturbed and only 1,002 ha have been reclaimed. The majority of this disturbance has involved agricultural land (12,208 ha), of which only a small amount has been reclaimed (552 ha). Forest land disturbed by surface mining in this region amounted to 2,682 ha, of which only 450 ha have been reclaimed. Therefore, huge land areas remain unreclaimed. Two experiments for the recultivation of sterile dumps were conducted: one without fertile soil covering on Garla dump and another one on Cicani dump which was covered by 30-40 cm of fertile soil. The study took into account 10 crops: Lolium perenne, alfalfa, Lotus corniculatus, winter wheat, maize, soybean, pea, mixture of barley or oats with a leguminous plant, sunflower, and sorghum. Three fertilization levels were applied: N₀P₀K₀, N₁₀₀P₈₀K₆₀, and N₂₀₀P₁₆₀K₁₂₀. Yield gains obtained in the case of fertilization with N₁₀₀P₈₀K₆₀ on the Garla non-covered sterile dumps were 48% Lolium perenne, 22% alfalfa, 200% winter wheat, 300% maize, 50% soybean, 80% pea, 122% mixture of barley or oats with a leguminous plant, 60% sunflower, and 164% sorghum. Higher yield gains were obtained with N₂₀₀P₁₆₀K₁₂₀ on the Garla non-covered sterile dumps (74% Lolium perenn, 37% alfalfa, 46% Lotus corniculatus, 264% winter wheat, 366% maize, 75% soybean, 150% pea, 146% mixture of barley or oats with leguminous plant, 180% sunflower and 252% sorghum). The yield gains obtained on the Cicani dump which was covered with 30-40 cm of fertile soil with N₁₀₀P₈₀K₆₀ were 60% Lolium perenne, 30% alfalfa, 19% Lotus corniculatus, 171% winter wheat, 550% maize, 50% soybean, 58% pea, 117% mixture of barley or oats with a leguminous plant, 83% sunflower, and 118% sorghum. High yield gains were obtained by applying high rates of fertilizers on the Cicani dump. The highest yield gains were obtained for maize, sorghum, sunflower, winter wheat, pea, and mixture of barley or oats with a leguminous plant, and the lowest yield gains were obtained for alfalfa and Lotus corniculatus. In both cases, the first crops do not change their order, the best results being obtained with the mixture of barley or oats with a leguminous plant, alfalfa, Lotus corniculatus, winter wheat, and maize. In all cases, the highest yield was obtained when the highest fertilization rate was applied.

Additional Key words: stockpile, reclamation, demonstrative experiments, organic and mineral fertilizers, agricultural crops.

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2 Elisabeta Dumitru, Research Institute of Soil Science and Agrochemistry, Bucharest Romania, Blvd. Marasti 61, Sector 1, Code 71331 E-mail mdumitru@icpa.ro
Agatha Popescu, University of Agricultural Sciences and Veterinary Medicine, Bucharest Romania, Blvd. Marasti 59, Sector 1, Code 71331, E- Mail: agatha_popescu@hotmail.com
ITRC - What Does It Mean For Me?\textsuperscript{1}

Paul Eger\textsuperscript{2} and Robert Mueller

\textbf{Abstract.} The Interstate Technological Regulatory Council (ITRC) was formed in 1995. The primary objective of the group was to provide assistance to state regulatory personnel so they could better understand innovative technologies and permit them more quickly, thereby providing less expensive alternatives to standard treatment techniques. Assistance is provided in the form of technical documents and classroom and internet training.

Since 1995, ITRC has grown from 10 to 40 actively participating states. With major funding from the Departments of Defense and Energy (DOD, DOE), much of the initial work focused on problems associated with site remediation at military bases and energy producing facilities. Technical and regulatory documents have been produced and hundreds of state regulators have been trained in topics ranging from natural attenuation of contaminants to the use of permeable reactive barriers to treat mine drainage. The time required to permit innovative approaches has been reduced by 20\textendash{}50\%, and DOE alone has saved millions of dollars in treatment costs.

Membership in ITRC is open to all who are willing to commit a minimum of 10\% of their time to work on a particular problem area. Each year the ITRC selects topics to be addressed, and teams are formed to develop guidance documents.

A constructed wetland team began work in the fall of 2001 and plans to have a guidance document done by the fall of 2002. Potential future topic areas of particular interest to the mining community include mine waste and TMDLs.


\textsuperscript{2}Paul Eger is a Principal Engineer at the Minnesota Department of Natural Resources, Division of Lands and Minerals, St. Paul, MN, 55155. Robert Mueller works for the New Jersey Department of Environmental Protection, Box 409, 401 E. State Street, Trenton, NJ 08625.
THE USE OF WETLANDS TO REMOVE NICKEL FROM MINE DRAINAGE - IS PERPETUAL TREATMENT REALLY POSSIBLE?¹

Paul Eger² and Jon Wagner

Abstract. Although wetland treatment systems have been shown to be effective for treating both coal and metal mine drainage, the longevity of the treatment has always been a question. Data collected from a wetland in northeastern Minnesota suggests it may be possible to build a wetland that will provide long term treatment.

A 7000 square meter overland flow wetland was built in 1992 to treat a mine drainage with an average pH of 7.2 and an average nickel concentration of 5.1 mg/L. Nickel removal exceeded 90% for the first three years of operation. In 1995, the stockpile which contributed the major input to the wetland was capped, and both flow and concentrations in the drainage were reduced. An intensive study was conducted on one section of the wetland where a large percentage of the overall removal was occurring. Nickel concentrations in the substrate reached 1.5% by weight and the calculated nickel mass in the substrate was about the same as the overall mass removal calculated from the water quality and flow data.

Based on a model of substrate accumulation in wetlands, the wetland generates 7 kg of nickel removal capacity each year. Since the annual input of nickel has been reduced to around 10 kg, the projected lifetime of the wetland is about 300 years.

² Paul Eger is a Principal Engineer Minnesota Department of Natural Resources, Division of Lands and Minerals, St. Paul, MN, 55155.
Jon Wagner is a Mineland Reclamation Specialist, Minnesota Department of Natural Resources.
IMPROVEMENT OF WATER QUALITY BY LAND RECLAMATION AND PASSIVE SYSTEMS AT AN EASTERN U.S. COPPER MINE

Ben B. Faulkner and Franklin K. Miller

Abstract. The Copper Basin in southeast Tennessee was the site of extensive copper and sulfur mining activities. For more than 150 years, numerous companies and individuals were involved in mining, refining and manufacturing operations in the area. It is one of the most dramatically impacted mining areas in the eastern United States. As part of voluntary remediation efforts at the site, Glenn Springs Holdings performed a demonstration project that included land reclamation and installation of a 1 hectare (2 acre) anaerobic wetland in October, 1998. Those efforts have been used to test and evaluate the effectiveness of reclamation and passive systems to treat acidic surface waters and acid mine drainage. These activities have successfully reduced the concentrations of key metals, including iron, copper, zinc and aluminum from typical mg/l concentrations by one or more orders of magnitude. The demonstration passive system has also consistently neutralized the acidity of the entire targeted watershed with average influent flows of 1100 Liters per minute (300 gallons per minute) through sulfate reduction and limestone dissolution. It is anticipated that in the future, effective land reclamation and installation of innovative passive systems will be the key methods whereby this massive remediation project will continue to improve water quality to the Ocoee River.

Additional Key Words: Ducktown, acid mine drainage, Ocoee River, anaerobic wetland

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2 Ben B. Faulkner, consultant at Bratton Farm, Princeton, WV; e-mail: BratFarm@POL.net; Franklin K. Miller, Vice President, Operations and Project Manager of the Copper Basin Project of Glenn Springs Holdings, Inc., a subsidiary of Occidental Petroleum Corporation. http://www.glennsprings-copperbasinproject.com/links.htm
RECIRCULATING – REDUCING AND ALKALINITY PRODUCING SYSTEM (RERAPS) FOR THE TREATMENT OF ACIDIC COAL PILE RUNOFF

By William E. Garrett, Jr., Alfred A. Bartolucci, Robert R. Pitt, Michael E. Vermace

Abstract. The treatment of acidic coal pile runoff (CPR) using an alternative constructed wetland design was evaluated. This alternative design, which provided improved wetland performance, was based on the partial re-circulation of treated water into a detention basin located immediately upstream from a Reducing and Alkalinity Producing System (RAPS). This modification created a semi-passive RAPS-based system we refer to as a Recirculating RAPS (ReRAPS).

Previous work suggested that this wetland, utilizing the ReRAPS modification, could dampen the effects of intermittent, or “shock”, loading usually associated with CPR and still achieve desired effluent contaminant concentrations. The purpose of this study was to confirm the previous results through more frequent chemical and hydrological monitoring. The ReRAPS was monitored during 41 days of CPR treatment, which included four storm events during January through March 2001. The CPR contained an average iron concentration of 12.8 mg/L, 24.8 mg/L of aluminum, 2.9 mg/L of manganese, and 178.0 mg/L of acidity. The detention pond removed 82% of the total iron, 59% of the aluminum, and 35% of the acidity loading prior to the RAPS component. Manganese behaved conservatively in the detention pond. Average concentrations at the wetland discharge for total iron, aluminum and manganese were less than 0.20 mg/L. The 2001 wetland monitoring has confirmed that the ReRAPS modification enhances the basic RAPS wetland design by moderating the pH of contaminated water and reducing the contaminant loading prior to the RAPS component.

Additional Key Words: RAPS, successive alkalinity producing system, SAPS, recirculating RAPS, ReRAPS, sulfate reduction


2Ph.D. Candidate, Department of Civil and Environmental Engineering, The University of Alabama (UA) and Supervisor, Environmental Affairs Laboratory and Field Services, Alabama Power Company, GSC#8, P.O. Box 2641 Birmingham, AL 35291, wegarret@southernco.com. Alfred A. Bartolucci, Professor; Dept. of Biostatistics, UAB, Birmingham, AL. Robert R. Pitt, Professor; Dept. of Civil/Environmental Engineering, UA, Tuscaloosa, AL. Michael E. Vermace, TOM COD Data Systems, Decorah, IA
THE USE OF MULTIPLE AND SYNERGISTIC RECLAMATION TECHNOLOGIES TO IMPROVE WATER QUALITY FROM KYANITE MINE TAILINGS

Gwendelyn Geidel and Frank T. Caruccio

Abstract. Various reclamation strategies are implemented within a drainage basin containing three kyanite mine tailings ponds and the sequential strategies are based on each pond’s unique geochemical and hydrologic characteristics. The Graves Mountain mine site in Lincolnton, Georgia, extracted kyanite from a quartzite-kyanite-pyrite host rock with associated sericite schist and iron oxides. During various stages of mining, tailings ponds were constructed on the south, west, and north slopes of the mountain and the acidic drainage from each set of tailings ponds effects a different drainage basin. Reclamation of the southern ponds was previously presented (Geidel et al., 1999), however, different reclamation strategies are implemented on each of the north ponds reflecting the unique hydrologic and geochemical characteristics of each set of ponds. The northern side includes three small tailings ponds and one settling basin from which the combined flows are discharged. The discharge from individual tailings ponds as well as the final discharge have been monitored for approximately eight years. The water quality from the final discharge prior to this study had a pH of about 2.5, acidity of approximately 800 mg/l as CaCO₃, high specific conductance, sulfate and metals. Due to variations in construction and discharge quality of the three tailings ponds, a number of reclamation technologies are employed within the drainage basin. These technologies include: an alkaline recharge trench (A-6); a 0.17 m surface layer of limestone on the unmined forest floor; a constructed wetland on the surface of one tailings pond (A-3); the addition of lime into the groundwater (A-4); the incorporation of two anoxic limestone systems (one vent and one drain) within the settling basin (A-2); and the construction of a wetland below the settling basin. The study showed that the various reclamation technologies significantly improved the overall water quality. Although each of the strategies independently produced ameliorative effects, the overall significant improvement was related to the synergistic effects of the combined technologies. As a result of the use of multiple reclamation technologies, the terminal water quality under low flow conditions (resulting from a three year drought) has a pH between 6 and 7, a low to negative acidity and significantly decreased metals concentrations.

Additional Key Words: acid mine drainage, acid rock drainage, alkaline recharge trench, limestone applications, constructed wetlands.


2 Gwendelyn Geidel is a Research Professor of Geological Sciences and the Associate Dean of the School of the Environment, University of South Carolina, Columbia, SC
Frank T. Caruccio is a Distinguished Professor Emeritus of Geological Sciences, University of South Carolina, Columbia, SC.
LONGITUDINAL STUDY OF FOUR SUCCESSIVE ALKALINITY PRODUCING SYSTEMS IN WESTERN PENNSYLVANIA

B.P. George and T.O. Morrow

Abstract: Successive Alkalinity Producing Systems (SAPS) have been used for over a decade to passively treat Acid Mine Drainage (AMD). Typically, SAPS consist of piping overlain by a limestone layer, which in turn is covered by an organic layer, typically spent mushroom compost in this area. The limestone and organic layers are then flooded, forming a water layer of 0.5 to 2 meters in depth that maintains sufficient head to drive AMD vertically through the organic and limestone layers. Alkalinity is generated biotically in the organic layer by sulfate reducing bacteria and abiotically by dissolution of the limestone layer. In addition, the reducing properties of the organic layer prevent armoring of the limestone by oxidized metals. The purpose of this study was to compare the efficiencies of one to ten year-old SAPS over time and to evaluate the compost layers ability to maintain a reducing environment from 1997 to 2001 in one of the SAPS (Howe Bridge). Water chemistry parameters including pH, conductivity, total acidity and alkalinity, iron, aluminum, manganese, and sulfates were measured at the inflow and outflow of each SAPS. Flow measurements were used to calculate loading and metal removal efficiency. A novel apparatus called an equilibrator was utilized to measure the remaining depth of reducing zones in the compost layer. The compost layer at the Howe Bridge SAPS became less reduced in the 1997 to 2001 time interval. The older systems experienced reduced flows over time but are still effectively treating the AMD able to pass through them. Our findings suggest that SAPS designs can operate effectively for long periods but should include features that maintain planned porosity over the projected life span of the materials used in the system.

Additional key words: acid mine discharge, water pollution, pyrite, passive treatment systems.

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2 Brendan P. George, Graduate Student, Department of Biology, Clarion University, Clarion, PA 16214. Terry O. Morrow, Professor, Department of Biology
INITIAL SURVIVAL OF COMMERCIAL HARDWOODS ON RECLAIMED MINESOILS IN WEST VIRGINIA

Jim Gorman, Jeff Skousen, and Jim King

Abstract. Due to increasing environmental pressure, some eastern states, including West Virginia, have proposed legislative changes in acceptable post-mining land use for surface mined lands. The current regulatory trend is toward more economically beneficial and environmentally stable post-mining land uses such as commercial forest production. 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.), yellow poplar (*Liriodendron tulipifera* L.)] into north- vs south-facing aspects, ripped vs unripped minesoils, mowed vs unmowed groundcover, and direct seeded vs planted 1-0 seedlings. Results after the first year of planting showed very good survival (>85% for all species of planted seedlings). All 192 planted white ash seedlings survived. Yellow poplar survival was slightly lower on the south vs the north aspect. Mowing increased black cherry survival on the north aspect, but did not improve it on the south aspect. Ripping generally increased survival of all species, and especially those trees on the south aspect. Seeds of only large-seeded tree species (black walnut and red oak) germinated and established generally at a low rate (8 to 27%). All red oak and black walnut trees, which established from seeds, survived the first year. Survival was lower on the south aspect, and ripping was especially important for black walnut survival from seeds. Toward the end of the first growing season, rodents and deer browsing began having a detrimental effect on the trees. All species were noticeably damaged, but black cherry and red oak were damaged the most. First year results of this study look promising, but only after several years of varied weather conditions and deer and rodent predation will we know if hardwoods are sustainable on these sites.

Additional Key Words: black cherry, black walnut, red oak, reforestation, white ash, yellow poplar.


2James Gorman, Research Instructor, Division of Plant and Soil Sciences, West Virginia University, Morgantown, WV 26506-6108. Corresponding author: jgorman@wvu.edu Jeff Skousen, Professor, West Virginia University. James King, Graduate Assistant, West Virginia University.
Abstract. An investigation of litter decomposition was undertaken at the Kidston Gold Mine in Queensland, Australia with the aim of assessing the status of nutrient cycling capacity on a directly-revegetated tailings dam. Weight loss from leaf litter contained in litterbags placed in a 5-year old revegetated section of the dam were similar to losses observed at two unmined reference sites over the 18 month study period, representing a relatively rapid improvement in nutrient cycling capacity in the reconstructed ecosystem. However, fitted decay curves for each site predicted a slower decay constant and a longer litter half-life on the dam which indicated that full pre-mining capability had not yet been achieved. Analyses showed that weight loss in the reconstructed system was most constrained by the low build-up of microbial biomass within the surface soil, which is expected to take at least 10 years to achieve pre-mining levels. In contrast, weight losses in the unmined sites appeared more related to the abundance of invertebrate fauna rather than microbial content. The study highlights the range of factors that need to redevelop after disturbance to ensure full ecosystem functioning, and the importance of each will reflect those that are most limiting over the course of ecosystem recovery.

2 Andrew H. Grigg. Centre for Mined Land Rehabilitation The University of Queensland, St Lucia QLD 4072, Australia email. a.grigg@cmlr.uq.edu.au
Abstract. The history of passive treatment of acid rock drainage dates back over 20 years. It is only recently that engineers and scientists have been able to discern how Mother Nature has been immobilizing metals in natural wetlands and to mimic her handiwork. Since 1988 (when engineers and scientists gathered at two major technical conferences in Pittsburgh and Chattanooga), the geochemistry of metal precipitation in oxidizing and reducing environments has become better understood and the capacity of passive treatment systems for mine drainage has reached levels of 1,200 gpm. Systems operating in tropical and alpine environments indicate that this technology has broad application. While there have been advances, a “cook book” approach to design has yet to be realized. However, a staged design protocol of laboratory, bench-, and pilot-scale testing has yielded full-scale designs that have been functioning as intended. Future advancements needed include a focus on sulfate removal and the recovery of resources that might make this already economical water treatment method even more so.

Additional Key Words: Constructed wetlands, acid mine drainage, heavy metals, sulfate reduction
STRONTIUM ISOTOPE RATIOS AS TRACERS OF WATER MOVEMENT IN A GROUTED MINE

Barbara Hamel, Ann G. Kim and Brian W. Stewart

Abstract. Acid Mine Drainage continues to discharge from the formerly grouted Omega coal mine near Morgantown, West Virginia. It was originally grouted to prevent subsidence, the oxidation of pyrite, and to neutralize any remaining AMD. Strontium isotope ratios are being utilized in a study that is attempting to determine the source of the discharge and the effectiveness of the grouting procedure.

Additional Key Words: AMD, remediation, CCB

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Barbara Hamel, Graduate Student Researcher, University of Pittsburgh, Pittsburgh, PA 15260
Ann G. Kim, Team Leader, National Energy Technology Laboratory, Pittsburgh, PA 15236
Brian W. Stewart, Associate Professor, U. of Pittsburgh, PA 15260
THE USE OF AIRBORNE MAGNETIC AND EM CONDUCTIVITY SURVEYS TO LOCATE GROUNDWATER FLOW PATHS AT THE SULPHUR BANK MERCURY MINE SUPERFUND SITE¹

Richard W. Hammack², Garret A. Veloski, James I. Sams III, and Jennifer S. Mabie

Abstract: Airborne magnetic and electromagnetic (EM) conductivity surveys were conducted at the Sulphur Bank Mercury Mine Superfund Site near Clearlake, California to identify potential pathways for groundwater flow. The total field magnetic survey identified four fault zones that are potential conduits for mercury-contaminated, groundwater flow out of the flooded pit of the abandoned Sulphur Bank Mercury Mine. The location of the four fault zones was corroborated by the EM conductivity survey, which also provided evidence that the fault zones contained highly conductive water, either from deep, geothermal origin or from meteoric water made acidic by weathering of sulfide minerals and oxidation of H₂S-bearing gases. This information was used to locate groundwater-monitoring wells and to provide assurance that all potential avenues for groundwater leaving the site were identified.


² R. W. Hammack and G. A. Veloski are research chemists with the US Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA 15236. J. I. Sams III is a hydrologist with the US Geological Survey, Water Resources Division, Pittsburgh, PA 15205. J. S. Mabie is a research associate with West Virginia University, Dept. of Geology and Geography, Morgantown, WV 26506
RECOVERY OF MARKETABLE IRON OXIDE FROM MINE DRAINAGE

Robert S Hedin

Abstract. Iron oxide sludge was recovered from a channel at an abandoned coal mine, processed, and used as a raw material in pigment production. The site is a former coal mining and processing facility in southwestern PA. Over the last 60 years, a channel carrying the mine discharge (1500-1800 gpm, pH 6.3, Fe 73 mg/L, alkalinity 313 mg/L as CaCO₃) had filled with iron sludge. As a “proof-of-principle” project, approximately 2000 tons of sludge were removed and processed. The sludge was screened and dewatered using frame filter presses. Screening removed vegetative debris, litter, and coal refuse. Dewatering increased the solids content of the product from 25-30% (in place sludge) to 50-52%. A total of 1,000 tons of product were trucked to a pigment manufacturer where it was further dried, calcined, and milled. The company is using the finished product to produce pigments used in a variety of coloring applications. The mine drainage product is replacing natural (mined) sources of iron oxide obtained in the United States and imported from Mediterranean and Asian countries. Work is continuing on developing methods that will decrease the processing costs so that iron oxide can be produced from mine drainage in a profitable manner.

Additional Key Words: AML, AMD, goethite, pigment, dewatering.


2 Robert Hedin is President of Iron Oxide Recovery, Inc. Pittsburgh, PA 15228
SOCIOECONOMIC ANALYSES TO PRIORITIZE RESTORATION OF STREAMS IMPACTED BY MINE DRAINAGE

K. L. Hoover, T. A. Rightnour, R. P. Brooks, and J. S. Shortle

Abstract: Acid mine drainage (AMD) can impair or eliminate streams as aesthetic, recreational, fisheries, or drinking water resources, resulting in socioeconomic losses to surrounding communities. The degree of this loss and the justifiable cost of stream restoration are not generally known. To quantify the value of stream restoration to a rural community, a willingness-to-pay survey was conducted in the Broad Top region of Pennsylvania, an area impacted by AMD. In a parallel study, a Watershed Restoration Analysis Model (WRAM) was developed to model the effects of AMD treatment on Shoup Run within this region, and to predict the local costs per mile of stream restoration. Willingness-to-pay results for fishable water quality ranged from $0 to $94.70 per household per year, and for drinking water quality from $227.53 to $335.97 per household per year. Annualized 15-year construction, operation, and maintenance costs for treatment systems on Shoup Run ranged from $34,200 to $86,000 per mile per year, with costs increasing trending downstream from headwaters to main stem restoration. The annualized cost for headwaters restoration was compatible with the local willingness-to-pay, while the annualized cost for main stem restoration suggested a need for outside funding. Based on WRAM results, a progressive watershed restoration plan was prepared for Shoup Run, and a generalized methodology for implementing watershed-scale restoration projects was developed to guide future efforts. It is recommended that cost-benefit analyses of this type be used for assessing and prioritizing watershed restoration projects to maximize the benefits of allocating available funding.

Additional Key Words: socioeconomic benefits, stream restoration, AMD treatment

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2 Kevin L. Hoover, Gannett Fleming, Inc. Clearfield, PA 16830 Terry A. Rightnour, Gannett Fleming, Inc. Robert P. Brooks, Professor, School of Forest Resource, The Pennsylvania State University, University Park, PA 16802 James S. Shortle, Department of Agricultural Economics and Rural Sociology.
SPATIAL-TEMPORAL VARIATION OF RECLAIMED SOILS FILLED WITH FLY ASH

Zhenqi Hu, Yinli Bi, Jitao Si, Xuelin Xu, Xianfeng Yue and Bo Zhang

Abstract. Reclaiming subsided land with fly ash is an effective reclamation method in China. The paper studied spatial-temporal variation of the reclaimed soil filled with fly ash. Reclaimed soil samples were collected from Anhui Province. This research was conducted on four different reclaimed lands with different reclamation years (1, 4, 8 and 12 years) for their temporal variation. Samples from different profiles were chosen for their spatial variation analysis. The results indicated the significant difference of physical and chemical properties between reclaimed soil and normal soil. Water infiltration of reclaimed soil was lower than that of normal soil, but their water infiltration increased with reclamation years. Bulk density of reclaimed soil was higher than that of farmland, but it was improved with time. The 12-year-old reclaimed soil had the most similar value of bulk density to normal soil. It was helpful to plant growth. The pH of reclaimed soil was higher than normal soil because of fly ash. The pH value of reclaimed soil was decreased after 12 years. The topsoil’s OM contents were increased with reclamation years. The total N and Olsen-P contents of reclaimed soil were lower than those of normal soil, but total N and Olsen-P and available K contents of topsoil were increased in the 12-year-old reclamation land. The results showed that soil properties had been improved with time. Properties of topsoil were much sensitive than that of subsoil. The physical and chemical properties of reclaimed soil were worse than that of normal soil. They need a long time to adjust soil fertility for similar to normal soil and application of some suitable fertilizers is needed in reclaimed soil.

Additional Key Words: reclaimed soil, fly ash, physical and chemical properties

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2 Zhenqi Hu is a Professor in China University of Mining and Technology (Beijing). YinLi Bi is an Associate Professor in the Department of Resource Development, Jitao Si Graduate Assistant, Plants and Soils Department, Oklahoma State University, Stillwater, OK. Xuelin Xu, Center of Land Consolidation and Rehabilitation, Ministry of Land and Resources, P.R. China Xianfeng Yue and Bo Zhang, Bureau of Land and Mineral Resources of Yanzhou City
DEVELOPMENT AND EVALUATION OF SEQUENTIAL EXTRACTION PROCEDURES FOR IRON-RICH PRECIPITATES ASSOCIATED WITH COAL MINE DRAINAGE

C. L. Kairies, R. C. Capo and G. R. Watzlaf

Abstract: Numerous sequential extraction procedures are currently used for the analysis of contaminated soils. However, no such methods exist for the analysis of precipitates associated with coal mine drainage (CMD). Most CMD precipitates consist primarily iron oxides, hydroxides and oxyhydroxides (e.g. goethite, ferrihydrite). Precipitates collected from various Appalachian bituminous coal mine discharges are dominantly goethite; some exhibit elevated levels of metals such as aluminum, arsenic, manganese, zinc, nickel and cobalt. These associations could be related to the depositional environment and chemical properties of the coal and the overburden from which the discharge originates. Subsurface cation exchange and sorption processes can influence the trace elements that accumulate in the precipitates. In order to determine how trace elements are sorbed or bound to the iron hydroxide precipitates, sequential extraction procedures were developed and carried out on precipitates collected from bituminous coal mine discharges (including Pittsburgh, Freeport, Kittanning, Clarion and Brookville coals). The results of the sequential extraction procedures will be presented.

Additional Key Words: goethite, AMD, heavy metals, bituminous, geochemistry

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USE OF RECLAIMED MINE LAND BY DISTURBANCE-ORIENTED AVIAN SPECIES: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

Andrew C. Kasner and R. Douglas Slack

Abstract. Human disturbed landscapes such as those in early stages of mine reclamation provide habitat for disturbance-oriented species. Disturbance-oriented birds that are uncommon or absent from the surrounding region may be concentrated at large-scale human disturbed sites such as surface mines. Implications for conservation and management of such species are important considerations, given the possibility one or more of those species may be federally protected. Recent expansion of the breeding range of Interior Least Terns (Sterna antillarum athalassos), a federally endangered species, in Texas has many implications for management on private lands. Interior Least Terns first nested on reclaimed mine spoil at Big Brown Mine in East-Central Texas in 1997. Management objectives for reclamation planning were subsequently established to provide suitable nesting and foraging habitat for terns while seeking to reduce the risk of interference with mining activities at Big Brown Mine. Since 1997, an average of 29 nests per year have occurred on artificial sites created for tern nesting, with average annual nest success 49%, hatching success 47%, and fledging success 46%. Average annual reproductive success (fledglings per female) is 0.40. We discuss colonization of reclaimed mine land by disturbance-oriented avian species and present research on the nesting and foraging ecology of Interior Least Terns in Texas as a case study. Implications for conservation and management of disturbance-oriented birds in reclamation are discussed.

Additional Key Words: Interior Least Tern, avian colonization of reclaimed mine lands.

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2 Andrew C. Kasner is a PhD student and TXU Environmental Research Fellow in the Department of Wildlife and Fisheries Sciences, Texas A&M University, 2258 TAMU, College Station, TX 77843-2258.
R. Douglas Slack is Professor of Wildlife and Fisheries Sciences, Texas A&M University, 2258 TAMU, College Station, TX 77843-2258
Abstract: Fabricated Soil is a complex of components, which may substitute for topsoil on areas free from ground cover and plant communities. Using fabricated soil it is possible to enhance the process of landscape creation. The main component of the fabricated soil is the aluminum-silicate matrix that might be a crystal basis for the organic polymers (humus) formation. The aluminosilicate matrix and humus form the soil micelle - the primary unit of any soil complex. Humus formation is a process based on carbon-nitrogen interaction. Sources of carbon can be materials rich in easily composted products like cellulose and polyphenols (plant leaves) or aged lignin polymers (saw dust from different woody plants). The pathways of carbon-nitrogen complexes are discussed. Properties of the fabricated soil components were tested by enhanced bio-tests and plant models.

Additional Key Words: fabricated soil, soils, reclamation, landscape creation

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2 Dr. Valentine I. Kefeli, PhD soil scientist, Slippery Rock Watershed Coalition, 3016 Unionville Road, Cranberry Twp., PA 16066
EFFECTS OF IRON SOLIDS AND BACTERIA ON IRON OXIDATION RATES IN MINE DRAINAGE

Carl S. Kirby and Paul G. Kostak, Jr.

Abstract: Published laboratory rate laws suggest an abiotic homogeneous mechanism, an abiotic heterogeneous mechanism, and a bacterial-heterogeneous mechanism for aqueous iron oxidation. This study attempts to groundtruth these laboratory rate laws against rates measured in the field and from mine drainage brought to the laboratory. Rates of oxidation were measured with varying pH and ferric oxyhydroxide concentrations.

Figure 1 shows rates from this study compared to other published rates. The addition of low concentrations of ferric oxyhydroxides from field sites to pH 5.7 and 6 mine water had little effect on oxidation rates, while it increased the rates at pH 3. At pH 6.5, the abiotic heterogeneous rate law overestimated the oxidation rate in the field when there is sediment present. At pH 5.7, the range of measured rates of oxidation fell between the predictions of the abiotic homogeneous and abiotic heterogeneous rate laws. At pH 3 the rate was very similar to those predicted by the bacterial-heterogeneous rate law.

Additional Key Words: kinetics, microbial catalysis, heterogeneous catalysis

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2Carl S. Kirby, Associate Professor and Chair, Department of Geology, Bucknell University, Lewisburg PA 17837. Paul G. Kostak, Jr, Assistant Director of Admissions, Avon Old Farms School, 500 Old Farms Road, Avon, CT 06001
PROBLEMS IN ACIDITY AND ALKALINITY MEASUREMENTS IN MINE DRAINAGE

Carl S. Kirby

Extended Abstract

Introduction and Methods

Not all mine drainage is acidic, and problems in the interpretations of alkalinity and acidity measurements arise especially in mine drainage containing alkalinity. Synthetic and field samples of mine drainage were analyzed using seven titration methods, and the results were compared to theoretical definitions and calculated concentrations of alkalinity and acidity.

Synthetic mine drainage solutions were prepared with known concentrations of Fe(II), Fe(III), ± Al, ± Mn, ± HCO₃⁻, ± CO₂, ± N₂ (to drive off O₂). Field samples with varying concentrations of metals, HCO₃⁻, and pH values were collected. Samples were titrated by three alkalinity methods (Standard Methods [APHA, 1992]; H₂O₂ addition; H₂O₂ addition + one week storage) and four acidity methods (Standard Methods [APHA, 1992]; H₂O₂ addition; H₂O₂ addition + one week storage; N₂-purge + H₂O₂ addition). Samples were analyzed for metal concentrations using inductively coupled plasma spectroscopy and colorimetry. Calculated acidity was determined using

\[ \text{Acidity}_{\text{calc}} = 50\left(\frac{2\text{Fe}^{2+}/56}{56} + \frac{3\text{Fe}^{3+}/56}{56} + \frac{3\text{Al}/27}{56} + 2\text{Mn}/55 + 1000(10^{\text{pH}})\right) \]  

from Hedin et al. (1994), where metal concentrations are in mg L⁻¹ and acidity is in mg CaCO₃ L⁻¹. Acidity was also calculated from PHREEQC (Parkhurst, 1995) speciation.

Additional Keywords: theoretical, measured, standard methods, treatment, net alkalinity

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²Carl S. Kirby, Associate Professor and Chair, Department of Geology, Bucknell University, Lewisburg PA 17837
Results and Discussion

Figures 1-3 show titration results. Samples with pH < 4.5 gave consistent results for all titration methods, causing no problem in the interpretation of the acidity in such samples. In synthetic samples containing alkalinity, standard methods for alkalinity returned the same values as calculated alkalinity before metal oxidation and hydrolysis are allowed. Following metal oxidation and hydrolysis, calculated alkalinity can be negative, but measured alkalinity is constrained to be greater than or equal to zero.

![Figure 1](image1.png)

Figure 1. Comparisons of measured alkalinity methods. All alkalinites are reported in mg L⁻¹ as CaCO₃. The diagonal line shows where values on the x- and y-axes are equal.

Samples containing both alkalinity and acidity present serious problems in the interpretation of laboratory results and comparison to theoretical values. Measured acidity values varied significantly among titration methods. Standard acidity titration methods intentionally cause the hydrolysis of iron, which allows H⁺ to react with alkalinity present in the sample. PHREEQC modeling of synthetic samples supports this conclusion. Standard methods also can return negative values for acidity, but some laboratories report negative values as zero. Standard method acidity results (if negative values are reported) are consistent with the most rigorously defined theoretical calculated acidity (if CO₂ is excluded).

Using "net alkalinity" (measured alkalinity – measured acidity) to design mine drainage treatment can lead to ineffective systems with insufficient alkalinity to neutralize metal and H⁺ acidity. The use of (measured alkalinity – calculated acidity) is recommended in the planning of mine drainage treatment.
Figure 2. Comparisons of acidity methods. All acidities are reported in mg L\(^{-1}\) as CaCO\(_3\). The diagonal line shows where values on the x- and y-axes are equal.

Figure 3. Standard Method acidity *versus* net acidity (calculated acidity [Eqn. 1] minus Standard Method alkalinity). All values are reported in mg L\(^{-1}\) as CaCO\(_3\). The diagonal line shows where values on the x- and y-axes are equal.
Literature Cited


PHYSICAL LIMNOLOGY AND GEOCHEMISTRY OF TWO CIRCUM-NEUTRAL PH MINE PIT LAKES IN NE WASHINGTON

Rodney T. Lentz

Abstract: Limnologic and water chemistry data from Echo Bay Mineral’s Key West and Equinox Resources’ Van Stone mines were collected between August, 2000 and September, 2001. Pit lake elevations, areas and depths are 1,318 and 1,050 m; 1.1 and 1.9 ha; and 28 and 31 m, respectively. Depth profiles of temperature, pH, specific conductivity, oxidation-reduction potential (ORP), and dissolved oxygen were collected on a monthly basis during this period. Results indicate that both water bodies are oligotrophic and dimictic, experiencing complete mixing during the spring and fall. Seasonal water temperatures range between near 0° and 22° C and ice covers the lakes approximately 5 months per year. Thermal stratification becomes well developed in both water columns during late summer. The dissolved oxygen profile at Key West is clinograde, ranging from 8-10 mg/l at the surface to 1-2 mg/l at total depth, except during turnover. Van Stone displays an orthograde oxygen profile with relatively high concentrations (>6 mg/l) at lake bottom through out the year. Values for pH tend to fall with depth in both lakes. Waters in Key West and Van Stone pits are slightly alkaline (7-8.5), calcium-sulfate types. TDS concentrations average 628 mg/l at Key West and 386 mg/l at Van Stone; likewise sulfate currently averages about 336 mg/l and 138 mg/l, respectively. Metal concentrations are low in both waters. Contrary to expectation, sulfate concentrations in Key West lake waters have decreased over time, despite abundant sulfide minerals in the pit wall. Also unanticipated, were diminished concentrations of dissolved zinc, arsenic, molybdenum, antimony and selenium concentrations in the oxygen deficient hypolimnion at Key West.

The observations and empirical data from Key West and Van Stone pit lakes are useful for, and should be considered, when developing, calibrating, and validating water quality models for circum-neutral mine pit lakes in temperate climates.

Additional Key Words: dimictic, oligotrophic, sulfate.

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2Rodney T. Lentz is an Area Mining Geologist, USDA Forest Service, 1240 2nd Ave. South, Okanogan, WA 98840-9723.
SURFACE MINE POOL RECLAMATION WITH DIRECT ASH PLACEMENT

Caroline M. Loop\textsuperscript{2}, Barry E. Scheetz, and William B. White

\textbf{Abstract.} A demonstration project has been put in place to evaluate the effect of ash placement in an acid mine pool. The surface mine pool, initially 510 million liters, is a remnant of pre-WWII mining of the Mammoth vein in the Eastern Middle anthracite field of Pennsylvania. Fly and bottom ash are placed at the face of two ash platforms in 32 Mg loads and later pushed into the mine pool with bulldozers. Natural compaction of the ash provides a load-bearing capacity of greater than 69 MPa, which is sufficient to permit trucks and bulldozers on the ash platforms. Once subaqueous deposition has been completed, the FBC ash will be covered with four feet of soil and seeded.

The pH value of the mine pool increased from 3.6 to 12.1 following ash placement. Calcite now precipitates from the top few feet of the water surface. The alkaline water has caused the precipitation of metals typically associated with acid mine drainage. Water samples collected from two test borings in the ash platform show a chemical signature very close to that of the surface mine pool. Despite the dramatic and homogeneous change in surface mine pool chemistry, no effect has been observed in any of the monitoring wells or at the outflow point of the basin.

Additional Key Words: culm, FBC, acid mine drainage, chemistry, anthracite.

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\textsuperscript{2}Caroline M. Loop is a graduate student in the Department of Geosciences, 209 MRL, The Pennsylvania State University, University Park, PA 16802.

Barry E. Scheetz, Department of Materials, 107 MRL, The Pennsylvania State University, University Park, PA 16802.

William B. White, Departments of Geosciences and Materials, 210 MRL, The Pennsylvania State University, University Park, PA 16802.
A SUBSIDENCE ENGINEERING INVESTIGATION AT THE WILDLIFE PRAIRIE PARK

Gennaro G. Marino Ph.D., P.E.

ABSTRACT. An investigation of the potential for subsidence and associated damage at the Wildlife Prairie State Park was undertaken. The park contains a variety of existing structures on about 2,000 acres of land. The investigation consisted of obtaining the best available information on the geologic and mining conditions across the site, in order to perform subsidence and damage assessment at the existing structure locations and to assess the more suitable building sites for future construction from a subsidence potential standpoint. This paper presents the results as well as the analysis conducted to achieve these objectives.

Additional Key Words: mine subsidence, mine stability, subsidence potential

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2Gennaro G. Marino, Ph.D., P.E. is President of Marino Engineering Associates Inc., 907 Fairview Ave., Urbana, IL 61801.
EFFECTS OF NICKEL MINING ACTIVITIES ON WATER QUALITY

C. Muzenda, and I. Pumure

Abstract. Acid Mine Drainage (AMD) originates from the sulphide mineral oxidation in the presence of water and oxygen, and to some extent bacteria, yielding sulphuric acid. The acid generated mobilizes some metals resulting in their increased bioavailabilities, creating a hazardous environment for aquatic animals and plants. The groundwater quality emanating from adjacent mine sites is a useful tool for measuring AMD. The purpose of this study was to determine extent of mine drainage from an active nickel mine and to develop mitigation. Major mining pollution sources were identified for constant monitoring. Recommendations for possible remediation and abatement of AMD were made. Several liquid samples were taken from selected sites along two streams, which flow out of the mining complex. Eight water samples were collected once a month from June to October. pH and conductivity were immediately measured followed by determination of Cu, Fe, Ni, sulphates, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS).

Elevated concentrations of sulphate, high conductivity and TDS were observed indicating the presence of AMD. An increase in sulphate concentration, TDS and Conductivity levels for the Community Rivers was observed. This was caused by the water flowing from the nickel mine. The quality of the natural river water was grossly affected.

A passive treatment strategy would need to be developed. For the treatment process to succeed, a complete characterisation of the contaminated mine drainage is needed. Topsoiling and revegetation are other cheaper methods that can be used to reduce the extent of sulphide oxidation.

Additional Key Words: Acid Mine Drainage, oxidation of sulphides, pyrite, pyrhottite

2 Constancia Muzenda is an Inorganic Chemistry Lecturer, Department of Chemistry, Bindura University of Science Education, P. Bag 1020, Bindura, Zimbabwe. Innocent Pumure is an Analytical Chemistry Lecturer, Department of Chemistry, Bindura University of Science Education
Abstract. The mining of oilsands near Fort McMurray, Alberta involves the stripping of saline-sodic overburden to access the underlying oilsands. The overburden is placed in mined out pits or in piles on the surface and reclaimed by means of soil covers, which must provide a sufficient rooting zone for vegetation establishment while minimizing percolation into the shale to prevent the occurrence of slope instability and salinization. A multi-year study was initiated in 1999 to observe the performance of three 1-ha peat over till layered soil covers and a 5-year-old single layer (peat/mineral mix) cover. This paper will outline the extensive instrumentation program and will present a preliminary water balance for the observed areas.

Additional Key Words: reclamation, water balance, Bowen Ratio, interflow
MILL RUN: RECOVERY OF A SMALL STREAM IN WESTERN MARYLAND USING LIMESTONE SAND APPLICATION AND PULSE LIMESTONE BED TECHNOLOGY

Joseph E. Mills and Constance Lyons

Abstract. Mill Run is a small, fast flowing, mountain stream located in western Allegany County, Maryland. Its headwaters support a population of wild brook trout, while its lower half is impacted to various degrees by acid mine drainage (AMD) from three abandoned deep mines. Prior to restoration efforts, the first portion of the AMD impacted stream showed the effects of the AMD in reduced population densities and species diversity while the lower third of the stream was so severely impacted that no aquatic life--other than bacteria and algae--existed. Restoration efforts began in July 1998 by application of a limestone sand mixture into the stream at various locations. Due to funding issues the limestone sand application project was reduced to only one partial application in 2001 and no application in 2002. In December 2000, construction of a second remediation project, an experimental purge diversion well, was initiated. The construction of this system was completed and operation began on December 17, 2002. The well uses limestone sand and re-circulates carbon dioxide gas to increase the dissolution of the sand. The hydraulic head pressure of the AMD is used to operate the system. In addition to these two abatement projects, a preliminary characterization study at the third mine site was completed in December 2000. The study evaluated various AMD abatement technologies with respect to the mine’s characteristics. Funding to design and implement an abatement project at this site will be sought from available sources in the future. The results of the two abatement projects completed to date can be seen at sample Station #4, which is located near the mouth of Mill Run. The pH at this station has increased by approximately 2 units, the water is now alkaline and dissolved metals have been reduced by over 75%. This paper discusses the AMD abatement projects, their impact on the water quality of Mill Run, and the subsequent and remarkable biological response to implementation of the first of the three projects.


2 Joseph E. Mills, Natural Resources Planner IV, Maryland Department of the Environment, Bureau of Mines, 160 South Water Street, Frostburg, MD 21532. Constance Lyons, Natural Resource Planner V, Maryland Department of the Environment.
Abstract: The Tar Creek Superfund Site is a portion of an abandoned lead and zinc mining area known as the Tri-State Mining District (OK, KS and MO) and includes approximately 104 km$^2$ of disturbed land and contaminated water resources in extreme northeastern Oklahoma. Underground mining from the 1890s through the 1960s degraded over 1000 surface ha, and produced nearly 500 km$^2$ of tunnels, 165 million tonnes of processed mine waste materials (chat), 325 ha of tailings impoundments, 94 million m$^3$ of contaminated ground water and over 2600 shafts and boreholes. In 1979, metal-rich waters began to discharge into surface waters from natural springs, bore holes and mine shafts. The site was listed on the National Priorities List in 1983. Approximately 70% of the Superfund site is Native American owned. In 1993, an Indian Health Service study established that 35% of children had blood lead levels above threshold levels dangerous to human health. Since 1995, residential remediation efforts have been ongoing, but a holistic watershed restoration strategy has not been implemented. Current research focuses on the biogeochemistry, ecology and hydrology of existing natural wetlands, and the development of sub-watershed restoration plans. These efforts indicate that environmental problems at this site are not insurmountable, but that solutions do require substantial cooperation among federal, state, tribal and local entities. The principal final recommendation of a recent state task force was the creation of a massive wetland and wildlife refuge to ecologically address health, safety, environmental and aesthetic concerns. This plan involves the removal of two communities, construction of a large reservoir and several treatment wetlands, and creation or restoration of marshes and prairie habitat. However, significant concerns regarding the long-term effectiveness and feasibility of this plan need to be addressed.

Additional key words: ecological engineering, ecosystem restoration, mine land reclamation.
IRON OXIDATION IN NET ALKALINE CO₂-RICH MINE WATERS¹

Robert W. Nairn, Aisling D. O’Sullivan and Jennifer Coffey²

Abstract: Iron oxidation and hydrolysis were examined in net alkaline mine waters exiting abandoned underground lead and zinc mines. It was hypothesized that degassing of excess CO₂ would result in increased pH, and thus positively influence rates of iron oxidation, despite subsequent proton production during hydrolysis. It was also hypothesized that the addition of iron oxide solids would positively influence iron removal rates. The relative roles of CO₂ degassing and iron solids additions were evaluated in a field microcosm experiment in June 2001. Five treatments were established in triplicate (closed, open, open + Fe, open + aeration, open + aeration + Fe). After 36 hours, greatest water quality changes were found in the open + aeration + Fe treatment. Dissolved oxygen was greater than 7.5 mg/L and pH was greater than 7.7, while alkalinity and Fe decreased to 52 and 0.81 mg/L, respectively. In non-aerated treatments, dissolved oxygen was less than 1.6 mg/L and pH was less than 6.2. Alkalinity decreased in all aerated treatments to less than 70 mg/L, but remained greater than 200 mg/L in all other treatments. Iron concentrations remained greater than 70 mg/L in non-aerated treatments. Aeration and the active degassing of excess CO₂, coupled with the presence of iron oxide solids, resulted in the greatest changes in water quality.

Key Words: carbonate equilibria, iron removal, wetlands, water quality

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²Robert W. Nairn is Assistant Professor; School of Civil Engineering and Environmental Science, The University of Oklahoma, Norman, OK 73019; Aisling D. O’Sullivan is Post-Doctoral Fellow, Division of BioSciences, University College Dublin, Belfield, Dublin 4, Ireland; Jennifer Coffey was National Science Foundation Research Experience for Undergraduates Summer Fellow, School of Civil Engineering and Environmental Science, The University of Oklahoma, Norman, OK 73019; nairn@ou.edu.
PLANT GROWTH AND SOIL METAL CONCENTRATIONS A SPATIAL EFFECTS MODEL

D.R. Neuman, S.R. Jennings, and M.K. Reeves

Abstract. In situ reclamation techniques are proposed for remediation of areas affected by metal mine wastes in Montana’s Clark Fork River Basin. In 1990, an in situ reclamation project was implemented on a fluvially-deposited tailing areas adjacent to the Clark Fork River. As part of this project, a 2.3 ha field containing tailing deposits was tilled to 1.2 m, lime was incorporated into the soil, and rangeland grasses were initially planted. In June of 2000, the field was plowed and seeded with six-row barley (Hordeum vulgare). Variable growth of this species was observed. It was hypothesized that plant growth was negatively correlated with metal and arsenic concentrations in the soil. Variability in barley growth attributable to other measurable soil characteristics was statistically quantified and modeled to account for the effects of landscape spatial heterogeneity. A stratified sampling method was employed for plot selection, with plots selected based on plant height. Three short, five medium, and four tall plant plots were selected. Within each plot, two vegetation and co-located soil samples (0-15 cm) were collected. The <2 mm fraction of the each soil was analyzed for factors related to plant growth and total elemental concentrations of: arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). Elemental data were first reduced using Principal Components Analysis (PCA) to provide a primary “metals” predictor variable for subsequent regressions. All subset regression analyses were used on the principal components to determine which component was the best predictor of plant biomass. Spatial regression analyses were then performed to assess whether a model that accounts for spatial heterogeneity in the landscape was necessary, or whether ordinary multiple regression techniques adequately modeled plant response to soil metal concentrations adequately. Metal concentrations in the soil were the only statistically significant predictors of plant biomass among all factors tested. No spatial autocorrelation was found in the residuals of the ordinary least squares model used. Therefore, a spatial regression model was not required to explain the relationships.

Additional Keywords: Principal Components Analysis, barley, spatial regression, mine tailings.


2 Dennis R. Neuman, Director and Research Scientist and Stuart R. Jennings, Research Scientist, Reclamation Research Unit, Department of Land Resources and Environmental Sciences, Montana State University, 106 Linfield Hall, Bozeman, MT 59717. Mari K. Reeves, Fish and Wildlife Biologist, U.S. Fish and Wildlife Service, Ecological Services Division, 605 W. 4th St., Suite G61, Anchorage, AK 99501
LONG TERM LAND USE PLANNING FOR DRASTICALLY DISTURBED LAND

Thomas J. Nieman and Zina Merkin

Abstract: The success of planning for use of surface mined land after the cessation of coal mining in Kentucky has been mixed and varied. While a great deal of “developable” or relatively flat land has been created, little has actually been used for the purposes intended. In the early 1980s planning was begun for the 17,000 acre Star Fire mountain top removal mining site with the intention of utilizing it for an assortment of land uses from industrial, to residential, to wildlife refuge. By the early 1990s the wildlife portion of the master plan was achieved with the introduction of Canada geese and later an elk population. In the mid 1990s Cyprus Minerals sold Star Fire to Addington Resources, and planning and development appeared to have been abandoned. By 1998, with proposals to develop a 500-megawatt power plant designed to burn waste coal, the planning process was revived. Plans are now in progress to provide utilities and an entryway into the site through state and private cooperation. The prospects for the long-term development of a large-scale project are positive. The major issue here is that long term planning should be viewed as just that, long term. Not a lot will be achieved unless all of the considerable number of pieces are brought together at the correct moment. However, if the initial planning to construct land forms for future use had not been undertaken development would not have been possible.

Additional Key Words: economic development, surface mining.

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2Thomas J. Nieman is Professor of Landscape Architecture, Department of Landscape Architecture, University of Kentucky, Lexington KY 40546-0091. Zina Merkin is a research specialist in the Department of Landscape Architecture at University of Kentucky.
EVALUATION OF SULFIDIC MATERIALS IN VIRGINIA HIGHWAY CORRIDORS

Zenah W. Orndorff, W. Lee Daniels, and Luiz E. Dias

Abstract. Road construction through sulfidic materials in Virginia has resulted in localized acid rock drainage (ARD) that threatens water quality, fill stability, integrity of building materials, and vegetation management. Two objectives of this study were: i) to develop a statewide sulfide hazard rating map based on characterization of the geologic formations associated with acid road cuts, and ii) to evaluate potential acidity testing procedures on geologically diverse materials. Characterization of geologic materials included potential peroxide acidity (PPA), expressed as calcium carbonate equivalence (CCE), and total content S. Formations identified at acid road cuts were grouped into four categories based on potential acid-producing severity: i) the Tabb Formation in the Coastal Plain (PPA < 6 Mg CCE/1000 Mg; S < 0.2%), ii) the Lynchburg Group of the Ashe Formation in the Blue Ridge (PPA < 18; S < 2.0%), iii) Chesapeake Group and Lower Tertiary deposits in the Coastal Plain, and Millboro shale, Marcellus shale, and the Needmore Formation in the Valley and Ridge (PPA < 60; S < 2.6%), and iv) Chattanooga shale in the Valley and Ridge and Quantico slate in the Piedmont (PPA < 99; S < 3.9%). Comparison of PPA and conventional Acid-Base Accounting (ABA) for 14 diverse samples indicated that PPA and ABA were highly correlated, with PPA consistently predicting less acidity than ABA. Potential acidity by Soxhlet extraction and PPA were equivalent for 3 of 4 diverse samples. Sulfide hazard analysis should be an essential step in the pre-design phase of highway construction and other earth-disturbing activities.

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2Zenah W. Orndorff is Senior Research Associate of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. W. Lee Daniels is Professor of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University. Luiz E. Dias is Professor of Soil Science, Federal University of Vicosa, Vicosa, MG, 36571-000, Brazil.
TWENTY-PLUS YEARS AFTER SMCRA: REFLECTING ON THE RESULTS

Vern R. Pfannenstiel and Gary W. Wendt

Abstract. In the twenty-plus years since the Surface Mine Control And Reclamation Act (SMCRA) was passed into law, successful reclamation of coal mining disturbances has been accomplished. This has not been accomplished easily or without great cost. Industry, research organizations, environmental groups, and regulatory personnel struggled and partnered to develop balanced federal and state regulatory programs. Detailed environmental baseline studies, complicated mine and reclamation plans, and the need to develop methods to achieve and measure successful reclamation threatened to overwhelm the process. Research aided in developing methods and procedures to achieve reclamation and environmental compliance. Operators, realizing the need to move away from agronomic reclamation approaches and adopt an ecological approach, applied practical research on a large scale, developed new technology, and continued the research relationship. The application of best practices and innovation has become a standard of industry reclamation programs. Research studies, baseline data acquisition, and compliance monitoring continue to evolve through the availability of on-site or regional data. Standards for measuring success are now based on more on-site specific postmine land use goals. By necessity, the regulatory process continues to evolve to provide flexibility and better reflect realistic goal achievement while still meeting the intent of SMCRA. However, excessive oversight and reporting requirements, bureaucratic processes, and required mitigation or monitoring that are without technical merit continue to be problematic and limit resources. Environmental compliance and reclamation success are in the best interest of industry and are further guaranteed by the bonding process and effective SMCRA regulation. The results of a conscientious industry effort speak for themselves in the tens of thousands of acres of stable and productive reclaimed lands with successful post mine land use implementation and environmental protection. Yet there is still a public relations need to dispel a persistent public perception that pre-SMCRA mining impacts are still the case. OSMRE’s Awards program and the many state and professional recognition programs, validate reclamation results and successes. Continued application of sound reclamation technology, allowance for innovation, a reasonable level of regulatory oversight balanced with economic considerations, and continued industry responsibility and environmental stewardship will continue the reclamation successes and environmental protection mandated by SMCRA.


2Vern R. Pfannenstiel is Sr. Environmental Scientist, Peabody Western Coal Company, P.O. Box 650, Kayenta, AZ 86033. Gary W. Wendt is Environmental Program Supervisor, Peabody Western Coal Company.
LINKING FOREST PRODUCTION AND SOIL CARBON ACCUMULATION ON SURFACE MINE LANDS: A LITERATURE REVIEW

C.C. Rhoades1 and R.K. Kolka

Abstract: To offset increases in atmospheric CO$_2$ resulting from anthropogenic activities, society is challenged to better exploit the natural capacity of terrestrial ecosystems to accumulate carbon (C). Since the initial C inventory of reclaimed lands is typically extremely low, the potential to increase mineland C inventory may be significant. As soil often contains equal or more C as forest vegetation, assessment of the total reclaimed mineland C capital must quantify both above- and belowground C pools. To develop a regional estimate of the potential to store significant C on mine lands reclaimed to forest, we review both studies of forest productivity and soil development on mine spoils. Our estimate of C accretion during a century of spoil development is based on a chronosequence of mine spoils from 7 independent studies. Soil C stocks ranged from 3-33 in the upper 10 cm of mineral soil and 17-82 Mg C ha$^{-1}$ in the top 50 cm. Soil C increased by an average of 0.2 and 0.7 Mg C ha$^{-1}$ yr$^{-1}$ in the upper 10 and 50 cm of mineral soil, respectively. Our calculated rates are comparable to a global estimate used by policy makers to predict C accumulation on unspecified degraded lands (0.3 Mg C ha$^{-1}$ yr$^{-1}$). We will discuss the linkages between forest production and strategies to maximize C sequestration on reclaimed min lands.

Additional Key Works: Reforestation, Soil development, pedogenesis, carbon sequestration

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2 Charles C. Rhoades, Assistant Professor Department of Forestry, University of Kentucky, Lexington, KY 40546-0073. Randall K. Kolka, USDA Forest Service - North Central Research Station, 1831 Hwy. 169 E., Grand Rapids, MN 55744
ASSESSMENT OF RISK OF ADVERSE EFFECTS OF CATTLE EXPOSURE TO SELENIUM ON SOUTHWESTERN COAL MINES


Abstract. Consumption of grasses, herbs and shrubs is the primary pathway that may expose herbivores to potential risks associated with selenium (Se) at Southwest surface-coal mines. To assess the potential for adverse effects of exposure of grazing cattle to Se, average concentrations were estimated in biotic and abiotic media and compared to no observed effect levels to determine the potential for adverse effects. Risks were assessed separately for grasses, forbs and shrubs on native soil and regraded spoil areas. Average plant Se concentrations (SePLT) for each plant type were estimated for each of 4 mines. Potential for toxic effects was assessed by comparing mine-wide average Se concentrations with a literature-derived no observed adverse effect concentration (NOAEC) of 5000 µg/kg. Mine-wide average comparisons was considered appropriate because it is representative of the integrated chronic exposures that cattle would likely encounter. Upper 95% confidence limits were below the NOAEC level for all combinations of plant and soil types. McKinley Mine had the highest average SePLT for four-winged saltbush (1530 µg/kg) in regraded spoils. Risk was also assessed at a smaller scale (mine-areas) using linear regression to estimate correlations between average SePLT and hot-water soluble Se (SeHW) in soil materials for samples of specified depth intervals (top 1, 2 and 4 feet). The strongest correlations were found for cool season grasses and shrubs with the SeHW in the top 4 feet of soil. The upper 95% prediction limit for the mine-area with the largest average SeHW was below the NOAEC for all combinations of plant and soil types. Risk of adverse effects due to Se exposure at the mines studied in the SW appears to be minimal or nonexistent at both the mine-wide and the mine-area scale.

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2 D.E. Romig is with the New Mexico Energy, Minerals and Natural Resources Dept., Santa Fe, NM J.W. Kern, and R. E. Remington are with Kern Statistical Services, Inc., Pullman, WA
CASE STUDIES OF PASSIVE TREATMENT SYSTEMS:
VERTICAL FLOW SYSTEMS

Arthur W. Rose and Jonathan M. Dietz

Abstract. As part of the Acid Drainage Technology Initiative (ADTI), case studies of 30 vertical flow systems (VFS or SAPS) have been compiled. Data includes inflow and outflow chemistry, flow rates, dimensions, design features and problems encountered. The increase in net alkalinity ranges widely, from 7 to 686 mg/L CaCO₃ (median 160 mg/L), but is positive for all systems. Systems having low influent acidity added little net alkalinity compared to units with high influent acidity. Increased retention time shows a correlation with increase in net alkalinity, suggesting that a standard retention time is not necessarily optimum. A regression of influent acidity loading vs. effluent alkalinity indicates that an acidity loading less than 40 g/m²/d, on average, produces net alkaline effluent (r²=0.55, p=0.0002). Similarly, 12 of the VFS had net acid effluent and are interpreted to be at the limit of VFS effectiveness. Most of the 12 units decrease acidity by between 25 and 50 g/m²/d. These values are similar to the 25 g/m²/d determined by Dietz and Stidinger (1996). A value of 25 g/m²/d is suggested as a design criterion for VFS, in place of retention time. Results for several units suggest that this loading may be increased by addition of fine limestone to the compost layer, and multiple regressions suggest that pH and acidity may modify the expected effectiveness.

Multiple regressions show that net added alkalinity depends positively on influent Fe and negatively on Mn, as found by Jage et al. (2001), but also on H⁺ (antilog pH) and retention time in compost. Many units have operated satisfactorily for 5 to 10 years, but regular inspections are desirable to correct minor problems. Thin spots in compost are deleterious because of channeling, and high-Fe inflows may suffer from accumulation of Fe precipitates in the VFS pond.

Additional key words: Acid mine drainage, SAPS, vertical flow wetlands.


2 Arthur W. Rose is Professor Emeritus of Geochemistry, Department of Geosciences, Penn State University, University Park, PA 16802 (rose@ems.psu.edu) Jonathan M. Dietz is a consultant and Ph.D. candidate in the Department of Civil and Environmental Engineering, Penn State University, University Park, PA 16802.
INFLUENCE OF VARIABLE TOPSOIL REPLACEMENT DEPTHS ON SOIL AND PLANT CHARACTERISTICS AT A COAL MINE IN NORTHEASTERN WYOMING

B.K. Schladweiler, G.F. Vance and R. Haroian

Abstract: A five-year project was initiated in 1998 to investigate the effect of varying topsoil depths on soil parameters and plant cover and diversity on a coal mine in northeastern Wyoming. Soil and vegetation information was collected for two consecutive growing seasons (2000 and 2001) on reclaimed areas with three topsoil treatment depths, i.e., 15, 30 and 56 cm and from two native reference areas (e.g., upland grassland and breaks grassland) at the mine. The data were analyzed using two-factorial weighted analysis of variance (SAS/STAT Version 6.12). For the soil analysis, pH, EC and SAR were evaluated to determine differences with respect to topsoil depths and vegetation status. Soil pH, EC and SAR in the top 30 cm of the reclaimed soil profile were significantly different from either native reference area on this project; however, statistical differences are not likely biologically significant at this point, but these results support the concept of inversion and mixing of the original soil profile. No significant gradient for pH, EC and SAR exists on the reclaimed treatments within this study. Inherent gradients for pH, EC and SAR were evident on native areas. No significant differences in measured soil or plant parameters were evident by the end of the second growing season in the variable depth treatments, which may reflect the young age of the reclaimed area and/or reduced precipitation during the 2000 and 2001 growing seasons. Previous research has indicated differences in treatment levels do occur over time. One additional sampling period will be conducted in 2002. Differences in treatment will likely be enhanced given time or increased precipitation prior to or during the 2002 growing season.

Additional Keywords: Chemical Properties, Salinity, Vegetation, Climate


2Brenda K. Schladweiler, Ph.D. Soil Science Candidate, Department of Renewable Resources, University of Wyoming and Owner of BKS Environmental Associates, Inc., bksenvironmental@vcn.com; George F. Vance, Soil and Environmental Sciences Professor, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-3354 gfv@uwyo.edu; Rose Haroian, Environmental Supervisor, North Antelope/Rochelle Mine Complex, Powder River Coal Company.
IRON OXIDATION IN SEMI-PASSIVE TREATMENT SYSTEMS¹

Karl T. Schroeder², George R. Watzlaf and Terry E. Ackman

Abstract. Since the 1980's, numerous passive systems have been constructed to treat mine drainage. Some of these systems have been successfully treating water for over a decade and are projected to out-live their original 20-year design. Unfortunately, not all waters can be treated with these low-cost, low-maintenance designs. High flows and limiting terrain often combine to preclude the implementation of a totally passive system because of the large land areas required to treat the water. For this reason, the inclusion of a powered devise in an otherwise passive system is being considered as a means of increasing the rate of iron oxidation and removal and thus decreasing the land needed for remediation of the drainage. Work underway at the DOE - National Energy Technology Laboratory seeks to assist in the development of emerging semi-passive technologies. For net alkaline water, preliminary laboratory results indicate that simple aeration can raise the pH (5.8 to 8.0) and dissolved oxygen concentration (0.2 to 9.0 mg/L) within a four-hour period and thereby significantly increase the iron oxidation rate. Implementation of a low-pressure blower at one site has reduced the required detention time by up to 10 hours. Additional evaluation of the effect of an active aeration will be obtained from field studies using a small, portable system. On a much larger scale, progress in the construction and operation of a flexible semi-passive system in the Swatara Watershed, Schuylkill County, Pennsylvania will be described.

Additional Key Words: mine drainage treatment, aeration.

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²Karl T. Schroeder, Chemist; George R. Watzlaf, Environmental Engineer; and Terry E. Ackman, Engineer; National Energy Technology Laboratory, U. S. Department of Energy, Pittsburgh, PA 15236
MINDED LAND RECLAMATION IN THE NORTHERN GREAT PLAINS: HAVE WE BEEN SUCCESSFUL?

Gerald E. Schuman

Abstract. The enactment of state reclamation laws in the 1960's and enactment of Surface Mining Control and Reclamation Act (SMCRA) in 1977 brought the subject of mine land reclamation to the forefront. Early reclamation research was aimed at protection of the soil and water resources. Therefore, early emphasis was placed on proper topsoil salvage technology and re-establishment of a plant community that would protect the soil from erosion. With resource stability accomplished came the desire to establish a more diverse plant community and landscape that would allow the multiple use of the lands in this region, e.g. season-long forage production, recreation/aesthetics, watershed and wildlife habitat. Much research needs to be undertaken and technology developed before we will be able to create the diverse plant communities required to fully meet these multiple uses. Because of a general lack of understanding of many of the basic mechanisms by which plant communities develop, function and succeed, requirements for re-establishment of native warm-season grasses, forbs, and shrubs in the reclaimed community to reflect the diversity of the native or desired landscape remain unresolved. Past research has focused on community level issues in reclamation and has not assessed reclaimed lands at the ecosystem and landscape level, leading to considerable discussion and confusion as to a working definition of reclamation success and subsequent bond release. It is critical that all interested parties come together to develop the definition of reclamation success and understand the role of plant succession in achieving "final" reclamation success. To achieve successful reclamation that meets the needs of potential land uses and takes into account natural succession will require a broader and more open-minded regulatory approach.

Additional Key Words: topsoil, plant establishment, reclamation success, species diversity, mulch, erosion.


2Gerald E. Schuman is Research Soil Scientist, USDA, ARS, High Plains Grasslands Research Station, 8408 Hildreth Road, Cheyenne, WY 82009.
MODELING OF WATER MOVEMENT WITHIN RECLAMATION COVERS ON OILSANDS MINING OVERBURDEN PILES

Robert E. Shurniak and S. Lee Barbour

Abstract. The hydrologic performance of four different soil cover systems used to cover saline-sodic overburden has been studied at the Syncrude Canada Limited mine site since 1999. Part of this study requires the creation of computer models, using the program SoilCover 2000, that can accurately simulate the water movement within these soil covers. During the modeling process, due to the heterogeneity of the soils used in the cover systems, multi-modal soil-water characteristic curves and hydraulic conductivity functions were implemented for better reproduction of the field measurements and for increased ease of calibration. The vegetation on the covers also had a profound effect on the water movement within the covers. By understanding these three key parameters, the authors were able to greatly improve the models’ results.

Additional Key Words: multi-modal soil-water characteristics, instantaneous profile method, setaria viridis, bromus inermis, saline-sodic shale, peat
USE OF STEEL SLAG LEACH BEDS FOR THE TREATMENT OF ACID MINE DRAINAGE: THE McCARTY HIGHWALL PROJECT¹

Jennifer Simmons, Paul Ziemkiewicz and D. Courtney Black²

Abstract. Steel slag leach beds were constructed at the abandoned McCarty mine site in Preston County, West Virginia. The leach beds were constructed as slag check dams below limestone-lined settling basins. Acid water was captured in limestone channels and directed into basins to leach through the slag dams and discharge into a tributary of Beaver Creek. Since installation in October 2000, the system has been consistently producing net alkaline, pH 9.0 water. The water is still net alkaline and has stabilized at a neutral pH after the treated water encounters several other acidic seeps downstream. In addition, other than elevated Cr, which exceeds EPA water criteria for freshwater aquatics at the Beaver pond discharge, metals in the system effluent are within acceptable limits.

Additional Key Words: Passive Treatment, AMD Neutralization.


²Jennifer Simmons is Program Coordinator, West Virginia Water Research Institute, West Virginia University, Morgantown, WV 26506. Paul Ziemkiewicz is Director, WVWRI, WVU, Morgantown, WV 26506. D. Courtney Black is Director, National Environmental and Technical Education Center, WVU, Morgantown, WV 26506.
EVALUATION OF SELENIFEROUS PLANTS AND SOILS WITHIN DISTURBED AND NATIVE LANDS

Catherine P. Skinner-Martin and George F. Vance

Abstract: Fort Carson is situated in southeastern Colorado where selenium (Se) occurs naturally in erosive geological formations. Due to both water and wind erosion on the military base, deposition of seleniferous sediments can augment soil Se levels, often exceeding the suitable management level of 0.5 mg/kg extractable Se and creating the potential for some vegetation to accumulate more than the 5 mg Se/kg total plant Se concentrations that are of concern for food chain transfer. Our objective was to locate areas in Fort Carson where plant Se concentrations can occur at levels high enough to impact wildlife, and where programs for prevention and control of soil erosion might be implemented. Soil, geology and vegetation attributes were identified in GIS coverages for sampled descriptive units exceeding suitable Se levels (> 5.0 mg Se/kg in plants, > 0.5 mg Se/kg in soils), which were then used to project the potential for similar Se levels in comparable units that were not sampled. Plant Se levels followed the order: forbs > shrubs > grasses > trees; no sampled tree material exceeded the Se suitability limit. Plant Se uptake was not necessarily dependent upon land disturbance or Se concentration in soils; however, areas having the highest plant and soil Se concentrations were primarily coincident with areas of greatest plant productivity, plentiful water supply, and soils derived from or overlying Cretaceous shales.

Additional Keywords: Vegetation, geology, erosion, GIS, Fort Carson, Colorado

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2Catherine P. Skinner-Martin, former graduate student, George F. Vance, Soil and Environmental Sciences Professor, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-3354, (307) 766-2297, gfv@uwyo.edu.
A BRIEF OVERVIEW OF CONTROL AND TREATMENT TECHNOLOGIES FOR ACID MINE DRAINAGE

Jeffrey G. Skousen

Abstract. Acid mine drainage (AMD) occurs when metal sulfides are exposed to oxidizing conditions. Leaching of reaction products into surface waters pollute over 20,000 km of streams in the USA alone. Mining companies must predict the potential of creating AMD by using overburden analyses. Where a potential exists, special handling of overburden materials and quick coverage of acid-producing materials in the backfill should be practiced. The addition of acid-neutralizing materials can reduce or eliminate AMD problems. Placing acid-producing materials under dry barriers can isolate these materials from air and water. Other AMD control technologies being researched include injection of alkaline materials (ashes and limestone) into abandoned underground mines and into buried acid material in mine backfills, remining of abandoned areas, and installation of alkaline recharge trenches. Chemicals used for treating AMD are Ca(OH)₂, CaO, NaOH, Na₂CO₃, and NH₃, with each having advantages under certain conditions. Under low-flow situations, all of the chemicals except Ca(OH)₂ are cost effective, while at high flow Ca(OH)₂ and CaO are clearly the most cost effective. Floc, the metal hydroxide material collected after treatment, is disposed of in abandoned deep mines, refuse piles, or left in collection ponds. Wetlands remove metals from AMD through formation of oxyhydroxides and sulfides, exchange and organic complexation reactions, and direct plant uptake. Aerobic wetlands are used when water contains enough alkalinity to promote metal precipitation and anaerobic wetlands are used when alkalinity must be generated by microbial sulfate reduction and limestone dissolution. Anoxic limestone drains are buried trenches of limestone that intercept AMD underground to generate alkalinity. Under anoxia, limestone should not be coated with Fe⁺³ hydroxides in the drain, decreasing the likelihood of clogging. Successive alkalinity-producing systems pre-treat oxygenated AMD with organic matter to remove oxygen and Fe⁺³, and then the water is introduced into limestone underneath the organic matter. Open limestone channels use limestone in aerobic environments to treat AMD. Coating of limestone occurs and the reduced limestone dissolution is designed into the treatment system. Alkaline leach beds, containing either limestone or slag, are used to add alkalinity to acid water. At present, most passive systems offer short-term treatment, and are more practical for installation on abandoned sites or watershed restoration projects where effluent limits do not apply and where some removal of acid and metals will benefit a stream.

Additional Key Words: Acid-Base Accounting, acid-producing material, alkalinity-producing systems, anoxic limestone drains, chemical treatment, open limestone channels, passive treatment, wetlands


2Jeff Skousen is professor and reclamation specialist, West Virginia University, Morgantown, WV 26506-6108. jskousen@wvu.edu.
CHARACTERIZATION OF AN ACID MINE DRAINAGE SITE IN SOUTHERN ILLINOIS

Philip A. Smith

Abstract: Two seams at the Tab-Simco abandoned underground coal mine site in southern Illinois were mined intermittently from the 1890’s until 1955, and later surface mined. The stripping operations resulted in several break-ins into the old underground works which were later buried by mine spoil. The resulting mine pool in the lower of the two seams has been producing an average of ~150 m³ per day of acid mine drainage (AMD) for the past few decades. After exiting through the break-ins, the contaminated water flows along discrete pathways through the base of the spoil and emerges as 5 perennial seeps. The AMD has contaminated a nearby stream and has produced a 4 ha “kill zone” within its otherwise forested floodplain. AM production at this site is a result of the interplay among (1) site geology, (2) mine geometry and location, and (3) climate. Limited hydrologic and geochemical data gathered over a 9-month period in 1997 and 1998 suggest that AMD production is strongly influenced by seasonal mine pool elevation changes. These elevation changes may govern the cycles of formation and release of acid sulfate salts (stored acidity) within the underground mine works.

Additional Key Words: room and pillar mining, mine pool, hydrogeochemistry.


2 Philip A. Smith, Environmental Protection Geologist, Illinois Department of Natural Resources, Springfield, IL 62701
PASSIVE TREATMENT OF LOW-PH, FERRIC IRON-DOMINATED ACID ROCK DRAINAGE IN A VERTICAL FLOW WETLAND I: ACIDITY NEUTRALIZATION AND ALKALINITY GENERATION

Robert C. Thomas and Christopher S. Romanek

Abstract. Passive treatment of acid rock drainage (ARD) is typically limited by the chemistry of the ARD. Anaerobic, ferrous iron-dominated ARD can be treated directly with limestone in an anoxic limestone drain (ALD), but alkalinity generation is limited because the high pH (5 – 6) reduces limestone solubility. Oxygenated, ferrous iron-dominated ARD cannot be treated directly with limestone due to the potential for armoring by iron oxyhydroxide precipitates. Vertical flow wetlands that rely on biological processes are typically employed. Reducing and alkalinity producing systems (RAPS) are one type of VFW that requires biological pretreatment of ARD to remove oxygen. The biological pretreatment typically adds alkalinity to the ARD, limiting the alkalinity generated in the RAPS via limestone dissolution by lower the solubility of limestone. The low pH (< 3) of oxygenated, ferric iron-dominated ARD is prohibitive to the biological processes typically required for effective passive treatment. In this study, highly oxidized (i.e., 99% Fe\(^{3+}\)), low-pH (2.4), ARD is treated with a VFW system amended with fine-grained (1.2 mm) limestone-buffered organic substrate (LBOS). Nearly 100% of the influent acidity (averaged >1300 mg·L\(^{-1}\)) is neutralized in the LBOS with an average 600 mg·L\(^{-1}\) of additional alkalinity measured in the effluent; total alkalinity generated in the LBOS averages > 1800 mg·L\(^{-1}\). Limestone dissolution accounts for 80 – 95% of the total alkalinity generated in the system. Limestone dissolution is very rapid and occurs in a thin (2 – 5 cm) dissolution front that advances as the limestone is depleted. Armoring due to iron oxyhydroxide precipitates apparently does not limit limestone dissolution, as limestone consumption above the dissolution front is nearly complete with greater than 85% of the limestone removed; limestone below the front is apparently unaffected. Sizing recommendations are made based on the influent acidity load and the volume of limestone in the LBOS.

Additional Key Words: limestone-buffered organic substrate, limestone dissolution, armoring, biological oxidation of organic matter, anaerobic wetland

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2 Robert C. Thomas is Graduate Research Assistant, Department of Geology and Savannah River Ecology Laboratory, University of Georgia, Aiken, SC 29802. Christopher S. Romanek is Associate Professor of Geology and Associate Research Scientist at the Savannah River Ecology Laboratory, UGA, Aiken, SC 29802.
PASSIVE TREATMENT OF LOW-PH, FERRIC IRON-DOMINATED ACID ROCK DRAINAGE IN A VERTICAL FLOW WETLAND II: METAL REMOVAL ¹

Robert C. Thomas and Christopher S. Romanek ²

Abstract: A limestone-buffered organic substrate (LBOS) is used to passively remove iron (140 mg·L⁻¹) and aluminum (85 mg·L⁻¹) from low pH (<3), ferric iron-dominated acid rock drainage (ARD). Iron and aluminum removal is attributed to an increase in pH with precipitates of both elements segregated along a pH gradient. The increase in pH is rapid and occurs across a limestone dissolution front. Three distinct mineralogical zones demarcate the limestone dissolution front. The oxide zone overlies the dissolution front and contains organic material, iron oxyhydroxides, and quartz; all of the original limestone has been dissolved. Below the limestone dissolution front, the limestone is pristine and largely unreacted. Iron sulfides predominate. The zone of transition between iron oxyhydroxide and sulfide is also the zone of active limestone dissolution and the focus of aluminum precipitation.

Additional Key Words: limestone-buffered organic substrate, iron oxyhydroxide, aluminum hydroxysulfate, limestone dissolution, anaerobic wetland


² Robert C. Thomas is Graduate Research Assistant, Department of Geology and Savannah River Ecology Laboratory, University of Georgia, Aiken, SC 29802. Christopher S. Romanek is Associate Professor of Geology and Associate Research Scientist at the Savannah River Ecology Laboratory, UGA, Aiken, SC 29802.
AN EVOLUTION OF RECLAMATION APPROACHES THROUGH THE LIFE OF A SOUTHERN ONTARIO GRAVEL PIT

Kevin D. Trimble, Monique Seibert

Abstract. Over the thirty-year life of the Lafarge Canada Inc. Uxbridge Pit, an evolution of regulatory constraints, social values, rehabilitation technologies and environmental imperatives has been documented. The pit is located northeast of Toronto in one of the largest re-forested regions in the Greater Toronto Area. Traditionally, after-use design of most pits in the area focused primarily on agricultural uses with uniform grades, soil applications and a stabilizing vegetative cover. However, progressive rehabilitation has evolved to reflect changing social and ecological conditions. Grading and soil management at the site are evolving to increase the diversity of topographic conditions, soil depth and density of ground cover. The establishment of tree cover on the site has included ornamental specimens, intensive but costly sapling plantings, widespread seedling plantings, application of forest plugs, nodal plantings, and natural regeneration. A comprehensive rehabilitation strategy has now been implemented to utilize local successional processes in the forest ecosystem surrounding the site. The strategy considers early successional invaders, predicted or targeted climax communities, local regeneration rates and factors that enhance or retard natural woodland expansion. We also introduce the concept of “cumulative rehabilitation” to deal with multiple aggregate sites in a regional context.

Additional Key Words: aggregate extraction, rehabilitation, ecology, forestry.

2 Kevin D. Trimble, Senior Project Manager, ESG International Inc., 160 Research Lane, Guelph, ON N1G 5B2 CANADA Monique Seibert, Resource Manager-Central Ontario Region, Lafarge Canada Inc., 7880 Keele St., 3rd Floor, Vaughan, ON L4K 4G7 CANADA
SOIL DEVELOPMENT IN TWO OHIO MINESOILS UNDER CONTINUOUS GRASS COVER FOR TWENTY-FIVE YEARS FOLLOWING RECLAMATION

John F. Underwood and Neil E. Smeck

Abstract. During 2001, two Ohio surface mined sites were re-examined to assess soil development in Bethesda and Fairpoint minesoils that have been in continuous, tall cool-season grass cover, principally tall fescue (*Festuca arundinacea* Shreb.), since reclamation in 1975-76. Topgrowth was cut and removed from 1979-94 while being utilized for forage research. Bethesda (loamy-skeletal, mixed, acid, mesic, Typic Udorthent) and Fairpoint (loamy-skeletal, mixed, nonacid, mesic, Typic Udorthent) have each been mapped on more than 60,000 hectares of minespoils in Ohio and neighboring states. Five years after reclamation (1981), morphological descriptions and physical and chemical characterization of samples collected from pits showed negligible evidence of pedogenesis. Twenty-five years after reclamation, morphological descriptions and physical and chemical analyses of samples were again obtained at these sites. During the 20 year interval from 1981 to 2001, organic carbon content has increased ≥2.6-fold in the surface 9 to 11 cm, soil structure now extends 23 to 27 cm below the Ap horizon into the spoil, soil consistence has become more friable, rooting depths have increased, the release and oxidation of Fe has yielded higher chroma colors in the uppermost portion of the spoil, significant quantities of extractable Na and K have been released by mineral weathering, and calcite has been removed from the Fairpoint minesoil by dissolution. These changes indicate that significant soil development has occurred during this 20 year period. Whereas the minesoils were described in 1981 with only A and C horizons, the uppermost portion of the spoil in 2001 was described as a Bw horizon in Bethesda and as a CB horizon in Fairpoint. Because both the Bw and CB horizons qualify as cambic horizons, both the Bethesda and Fairpoint minesoils now classify as Dystric Eutrudent and Typic Eutrudent, respectively.

Additional Key Words: pedogenesis, soil formation, soil morphology, soil classification


2John F. Underwood, Professor Emeritus, The Ohio State University, Columbus Neil E. Smeck, Professor, College of Food, Agricultural, and Environmental Sciences, The Ohio State University, Columbus, OH 43210-1066.
Abstract. Reclamation and Restoration Ecology undergraduate minor and graduate certificate programs are now available at the University of Wyoming, which is one of only a few institutions in the U.S. that provides training in these fields of study. Students completing a Reclamation and Restoration Ecology minor or certificate are more marketable for jobs requiring training in applications of ecosystem reclamation, rehabilitation, and/or restoration. Because mining, rehabilitation of disturbed lands, and restoration for production and wildland uses are major economic activities throughout the U.S., graduates with Reclamation and Restoration Ecology education are needed to meet the job market demands for these skills.

The Reclamation and Restoration Ecology undergraduate minor and graduate certificate at the University of Wyoming has broad appeal and considerable relevance to students, state and federal agencies, and private industry. These programs are available to students throughout the country that are interested in Reclamation and Restoration Ecology education. The Reclamation and Restoration Ecology programs were designed to build upon strengths that exist across the University of Wyoming campus; the Renewable Resources department has actually been offering education and training in Reclamation and Restoration Ecology for several decades. The Reclamation and Restoration Ecology undergraduate minor and graduate certificate reinforces the identity and enhances professional opportunities of students completing the programs.

Additional Key Words: Soil, Revegetation, Disturbed Lands, Rehabilitation, Education, Course Work, Renewable Resources, University of Wyoming

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2George F. Vance is Associate Director for Research, College of Agriculture and Soil and Environmental Sciences Professor, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-3354, (307) 766-2297, gfv@uwyo.edu.
Flora of the Fonda Surface Mine Demonstration Area, Bell County, Kentucky

G. L. Wade and R. L. Thompson

Abstract. The pre-SMCRA, 7.3-ha Fonda Surface Mine Demonstration Area supported a vascular plant flora of 299 taxa after 24 years of succession. Relative richness of this mine was 88 percent of that to be expected in an unmined area of this size in the Mixed and Western Mesophytic Forest Regions, and this relative richness is similar to that found in other completely inventoried pre-SMCRA mined areas in Appalachia. One species, Scirpus fluviatilis, is on the Kentucky list of threatened plant species. Native taxa comprised 82.2 percent of the flora. Out of 31 taxa that were planted for reclamation and research purposes, 26 still remained. The planted herbaceous taxa have, for the most part, yielded to native taxa. Abundances of 73 percent of the taxa were rated as infrequent or rare. This abundance distribution is similar to that obtained when lognormally distributed species are assigned to abundance categories. Other studies of reclaimed mined lands using sampling methods returned lower relative richness and located no threatened or endangered species. Given the inherent advantages and disadvantages of inventories and sampling studies, we suggest that a combination of both methods is most desirable for future studies of succession and biodiversity on reclaimed surface mines and other areas.

Additional Key Words: reclamation, revegetation, succession


2 Gary L. Wade is Research Ecologist, Northeastern Experiment Station, USDA Forest Service, Burlington, Vermont 05402-0968. Ralph L. Thompson is Associate Professor of Biology and Curator of the Herbarium, Berea College, Berea, KY 40404
NORTH AMERICAN BATS AND MINES PROJECT: A COOPERATIVE INTERAGENCY APPROACH TO BAT CONSERVATION THROUGH MINE LAND RECLAMATION

Faith A. Watkins

Abstract: Human safety and liability concerns prompted a national campaign to close abandoned mines. These closures, along with renewed mining in historic districts, present a significant threat to mine-dwelling bat populations. Over half of North America’s 45 bat species have been documented using abandoned underground mines. The need for mine habitat increases as traditional cave and tree hollow roosts disappear. Bats are a primary consumer of night flying insects, many of which cost farmers billions of dollars annually in crop damage. Likewise, if the role of some species as pollinators and seed dispersers is compromised, entire ecosystems could be imperiled. To prevent further losses of mine roosting bats during abandoned mine land reclamation, Bat Conservation International and the USDI-Bureau of Land Management created the North American Bats and Mines Project (NABMP). This proactive program focuses on education, provides national leadership, and coordinates partnerships with federal, state, and private agencies. To date, the project has involved federal and state mine-land and wildlife managers and the mining industry and has trained hundreds of mine-land and wildlife managers in mine assessment techniques for bats and bat-compatible closure methods. This collaboration with numerous federal, state, and private partners has resulted in the protection of some of the most important mine-roosting bat populations. Since the program’s inception, more than two million mine roosting bats have been protected, hundreds of miles of mine passage have been preserved to allow the stabilization and growth of bat populations, and thousands of mines have been safeguarded from public entry. In addition, the mines offer tremendous opportunity for conservation-based research. Future cooperation will ensure the long-term protection of mine roosting bats.

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2 Faith A. Watkins is the director of the North American Bats and Mines project for Bat Conservation International, Austin, TX 78746.
A CASE STUDY IN HYDROLOGY, GEOLOGY, CHEMISTRY AND HISTORY: THE CONSTRUCTION OF I-80 AND THE GENESIS OF MINE DRAINAGE TO JONATHAN RUN

Kimberly R. Weaver

Abstract. When Interstate 80 was constructed across Pennsylvania in the late 1960’s, major changes to the landscape took place. In Centre County, extremely large cut and fill areas were required. The Jonathan Run stream channel was moved, put into a culvert, and buried under approximately 80 feet of interstate fill material. The swampy headwaters of the stream was also filled with 6 feet of material and leveled to construct a staging area. The fill material consisted of highly pyretic sandstone. Severe pollution of Jonathan Run resulted.

Hedin Environmental was hired by the Beech Creek Watershed Association to investigate the site and provide treatment alternatives. Seven discharges were initially targeted for sampling. The 1-year-long sampling program revealed that a small, inconspicuous flow emerging directly from the I-80 fill material was the primary source of pollution. Due to the highly contaminated state of this discharge, passive treatment is not possible and mitigation alternatives are being explored.

The focus of the project shifted to finding the source(s) of the highly contaminated discharge. Through various efforts, it was determined that the discharge could only be coming from a spring under I-80 or a trapped pool of water in the fill material. Monitoring wells constructed within the I-80 median showed that 9 feet of water was being retained within the fill. Efforts to drain the fill were only partially successful. Grout dams will be installed in order to prevent the passage of water along the culvert wall. Results on this work will be available for the conference.

Additional Key Words: acid mine drainage, acid rock drainage.

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2Kimberly R. Weaver is a Project Engineer for Hedin Environmental, Pittsburgh, PA 15228.
THE EPA ROCKY MOUNTAIN REGIONAL HAZARDOUS SUBSTANCE RESEARCH CENTER¹


Abstract. The Rocky Mountain Regional Hazardous Substance Research Center (RMRHSRC) for remediation of mine waste sites has recently been formed. The RMRHSRC is funded by the U. S. Environmental Protection Agency (EPA), represents EPA Region 8 states, and consists of a consortium of participants from Colorado State University, Colorado School of Mines, and several academic and non-academic participants from other regions of the U. S and Canada. The research goal of the RMRHSRC is to develop new and improve existing methods or technologies for remediation of mine waste sites that are cost effective and lead to clean ups that are protective of human health and the environment. Also, the activities of the RMRHSRC include training, technology transfer and outreach programs that will focus on the development of new technologies. A number of issues were considered in establishing an action plan and in choosing the research projects to fund. Some of these issues, such as cost, apply to every possible method of treatment. Others such as whether to concentrate on abandoned or active operations are somewhat mutually exclusive. The issues that were considered, the conclusions that were made, and how these conclusions affected the decision of which research projects to fund is the subject of this paper.

Additional Key Words: mine wastes, acid mine drainage, abandoned mine lands.

²Thomas R. Wildeman and Donald Macalady, professors Department of Chemistry and Geochemistry, Colorado School of Mines, Golden, CO 80401; Charles D. Shackelford and Sandra L. Woods, professors Department of Civil Engineering, Colorado State University, Fort Collins, CO 80523
AQUATIC PLANT ESTABLISHMENT ON NICKEL TAILINGS FIVE YEARS AFTER FLOODING ¹

F. Wilkinson and P.J. Beckett²

Abstract. Nickel tailings were deposited between 1978 and 1988 in Falconbridge’s New Tailings Area located northeast of Sudbury, Ontario, Canada. In 1996, construction of a new dam and dredging split the site into an Upper Terrace (56 ha) and a Lower Terrace (30 ha) to facilitate flooding. Water covers minimize the oxidation of acid generating tailings but some oxidation and release of metals may still occur. The effectiveness of a water cover could be improved with aquatic plant establishment to control tailings resuspension, remove metals from the water column and develop an organic layer to consume oxygen and support sulphate-reducing bacteria.

In the New Tailings area the natural development and changes in the aquatic plant community over the five years since flooding was monitored. In 1999 and 2001 aquatic plant distribution was assessed at 121 plots along 5 transects across the Lower Terrace. Every 10 m along each transect a 0.25 m² quadrat was established from which aboveground biomass was harvested and samples were analyzed for nutrients. In the Lower Terrace, Potamogeton pusillus and Chara were the dominant aquatic species. In 1999, 88 plots contained aquatic plants, which increased to 113 by 2001. Over the same period, mean biomass increased from 40.2 to 103.0 g DW/m². Biomass decreased, however, at 22 sites from 166.3 g DW/m² in 1999 to 74.6 g DW/m² in 2001. Potamogeton pusillus tissue nitrogen and phosphorus concentrations decreased from 2.18 % and 0.20 % to 1.43 % and 0.12 % with 1.3 % and 0.13% being the critical concentrations that indicate potential deficiencies. The nitrogen phosphorus ratio is typically 7 but in the Lower Terrace is 12.9 indicating that phosphorus is more limiting than nitrogen.

Additional Key Words: plant colonization, acid mine drainage, wetlands, reclamation

² Fred Wilkinson, Owner, F.H.W. Consulting, 147 Hemlock, Timmins, Ontario, Canada. P4N 6S5. Email: fred.wilkinson@sympatico.ca Peter J. Beckett, Professor of Biology, Laurentian University, Sudbury, Ontario, Canada. P3E 2C6
RE-CREATING WOODLAND AND HEATHLAND ON SLATE WASTE IN WALES

Julie C. Williamson, Edwin C. Rowe, John R. Healey, Davey L. Jones, Peter J. Holliman and Mark A. Nason

Abstract. We report on ecological restoration at Penrhyne, Europe’s largest slate quarry, which lies adjacent to Snowdonia National Park and a Site of Special Scientific Interest. Broadleaf woodland and heathland were targeted, to provide wildlife corridors to adjacent habitats of high conservation value. Young tree seedlings (six species) of local provenance were planted into slate pockets amended with nutrients (readily available mineral NPK or an organic mix of biosolids and paper sludge with an estimated five-year impact) and water retentive materials (clay overburden or polyacrylamide gel). Applying mineral NPK increased tree basal area by 70% in the first 18 months. The organic mix gave an increase of 130% in tree basal area, promoted water retention and stimulated nutrient cycling. Both N-fixing tree species and non-fixers responded to fertilization and small-seeded species responded more than large-seeded ones. Tree basal area increased by 50% in the clay treatment compared with trees planted in bare slate ± gel.

The transfer during quarrying of heath vegetation with associated peat to a site designated for restoration proved effective in establishing key heathland subshrubs. Bilberry re-sprouted easily from buried shoots whilst heather turf died, but within one year a flush of heather seedlings had germinated from the seedbank in the transferred peat. Three years on, there was complete ground cover of target heathland species, provided that sheep were excluded. Grazing by rabbits was beneficial in reducing grass and increasing heather cover. Where availability of heathland topsoil was limited, heathland brash was applied to clay-covered slate. Germination of heather proved slow and sparse, with no germination of bilberry.

Seed rain and litter deposition from re-created islands of vegetation will accelerate natural colonization. Trials at Penrhyne Quarry have demonstrated pragmatic and inexpensive technologies to achieve this, largely using on-site by-products and local wastes.

Additional Key Words: substrate amendments.
Sciences, UWB, WALES. Peter J. Holliman is Lecturer, Department of Chemistry, UWB, WALES. Mark A. Nason is Scientific Officer, IES, UWB, WALES.
ECOLOGICAL RECOVERY OF THE RIVER PELENNA (SOUTH WALES) FOLLOWING THE PASSIVE TREATMENT OF ABANDONED MINE DRAINAGE1

Ian M. Wiseman, Paul J. Edwards, and Graham P. Rutt2

Abstract. From the 1960s to the late 1990s, the River Pelenna in South Wales was impacted for a distance of 7 km by five significant discharges from abandoned coal mines. Elevated iron and low pH caused significant orange staining and had detrimental effects on the river ecology. The River Pelenna Minewater Project constructed a series of passive wetland treatment systems to treat these discharges. Monitoring of the performance and environmental benefits of these has been undertaken as part of an ongoing Environment Agency R&D project. This project has assessed the changes in water quality as well as monitoring populations of invertebrates, fish and birds between 1993 and 2001.

Performance data from the wetlands show that on average the three systems are removing between 82 and 95% of the iron loading from the minewaters. Downstream in the rivers the dissolved iron concentration has dropped to below the Environmental Quality Standard (EQS) of 1 mg/l for the majority of the time. Increases in pH downstream of the discharges have also been demonstrated.

Trout (Salmo trutta) recovered quickly following minewater treatment, returning the next year to areas that previously had no fish. Intermittent problems with overflows from the treatment systems temporarily depleted the numbers, but the latest data indicate a thriving population. The overflow problems and also background episodes of acidity have affected the recovery of the riverine invertebrates. However there have been gradual improvements in the catchment, and in the summer of 2001 most sites held faunas, which approached unpolluted controls. Recovery of the invertebrate fauna is reflected in marked increases in the breeding success of riverine birds between 1996 and 2001.

This study has shown that constructed wetlands can be an effective, low cost and sustainable solution to ecological damage caused by abandoned mine drainage.


STABILITY MONITORING OF A COAL MINING EXCESS SPOIL FILL

X. Zeng, R.A. Rohlf, B. Hippley, and J.D. Reynolds

Abstract. The disposal of excess spoil created by coal mining operations in the Appalachian Coal Field is usually accomplished by placing this material in valley fills. As a result, hundreds of excess spoil fills have been built in Kentucky, Tennessee, West Virginia, and Virginia. The stability of these structures is regulated by the Federal Office of Surface Mining and state regulatory authorities.

A joint Office of Surface Mining and Kentucky Department for Surface Mining fill team inspected an excess spoil fill located just outside Prestonsburg, KY. The fill was finished in 1998. In the design of the fill, the phreatic surface was assumed to be very low, resulting in a factor of safety of 1.5 for slope stability. The factor of safety (FS) for a slope is defined as the ratio of the moment resisting sliding over the moment causing sliding. However, during the field inspection water was observed exiting the structure at about 1/3 the height of the fill, resulting in a factor of safety near 1.27. There is concern that during the late winter and spring wet season, the phreatic surface could increase further. Failure of the fill could result in blockage of a headwater stream with potential increased sediment loads to the nearby Corps of Engineers Dewey Lake, contaminating water in the reservoir, and effect a proposed industrial, residential, and recreational development project nearby.

This paper reports the results of a study that installed a comprehensive deformation monitoring system on the fill, investigated water movement, and tested soil samples obtained at the site. The deformation of the fill at a number of surface points has been surveyed over three years. The moisture content changes at selected locations on the surface of the fill were monitored as well. Soil properties for slope stability analysis have been determined in the laboratory. This study is supported by grants from the National Science Foundation and Office of Surface Mining.

Additional Key Words: soil test, slope stability analysis, survey

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2 X. Zeng is Associate Professor of Civil Engineering, Case Western Reserve University, Cleveland, OH 44106, R.A. Rohlf is Environmental Engineering Consultant, Kentucky Dept. for Surface Mining Reclamation and Enforcement, Frankfort, KY 40601, B. Hippley is Graduate Student at Dept. of Civil Engineering, University of Kentucky, Lexington, KY 40506, J.D. Reynolds is a lecturer at Dept. of Civil Engineering, University of Kentucky
Abandoned land reclamation planning in coastal area in North-East of China¹
Shan Zhao, Zhenqi Hu, Yinli Bi and Yanling Zhao²

Abstract. The damaged environment is a global problem. It is more serious in China because of the cultivable land destroyed. So the agroecosystem reconstruction is the primary object in China. A case of reclamation planning in LiaoNing Province was studied in this paper. A large number of abandoned land sites have become an urgent task for the local government since farmland is so short in this area. The land suitability and usage should be determined before the land reclaimed. Based on land-use mathematical models and software MATLAB 6.0, optimum land-use structure should fit for local ecological and economic requirement. The horizontal, vertical structure and food chains of the system should be considered. Ecological engineering was used to planning as the shelter-forest, farmland and livestock farms. Irrigation work was designed to remove the salt. The forestry, fishery, poultry breeding were set up after rehabilitation. Therefore, the regional environment can get a great progress and their economy will have a sustainable development.

Additional Key Words: Abandoned land, reclamation planning, Ecological engineering

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² Graduate is a student in the Department of Resource Development, China University of Mining and Technology, Beijing 100083, China. ZhenQi Hu is a Professor, China University of Mining and Technology. Yinli Bi is an Associate Professor China University of Mining and Technology
A METHOD FOR EVALUATING THE RISK OF BACKFILLING COAL MINES WITH COAL COMBUSTION BYPRODUCTS AND STEEL SLAG

Paul F. Ziemkiewicz and Jennifer S. Simmons

Abstract. Industrial waste by-products, such as coal fly ash and steel slag, are being used increasingly in mine land applications. These wastes may be used in surface or underground applications for the neutralization of acid forming materials, formation of barriers to acid mine drainage formation and transport, subsidence control, pit filling, and soil reconstruction. Many of these applications place wastes in direct contact with acidic materials and/or groundwater. In these situations there may be an increased risk of metal leaching from the wastes into groundwater. Several leaching test have been developed to predict the leaching behavior of these waste materials. The most widely used procedure has been the Toxicity Characteristics Leaching Procedure (TCLP). However, this single leaching procedure may underestimate the long-term leaching behavior of many wastes under acidic conditions. The Mine Water Leaching Procedure (MWLP) was developed especially for these unique conditions. This paper outlines the procedures and benefits of this method and compares the results of 2 industrial wastes by-product MWLPs with TCLPs conducted on the same wastes.

Additional Key Words: Mine reclamation, AMD neutralization

2Paul F. Ziemkiewicz is Director of West Virginia Water Research Institute, West Virginia University, Morgantown, WV 26506. Jennifer S. Simmons is Program Coordinator, WVWRI, WVU, Morgantown, WV 26506.
LINKING RESEARCH AND REGULATORY POLICY TO ENABLE ADVANCES IN RECLAMATION PRACTICE

C.E. Zipper, B.C. Lambert, J.A. Burger, W.L. Daniels

Abstract. Advances of coal-mine reclamation practice commonly involve scientists who conduct mining and reclamation research, industry reclamation specialists who apply those scientific advances in the field, and regulatory agency personnel who must approve of those changes by interpreting state and federal laws. In the state of Virginia, interactions between the Virginia Division of Mined Land Reclamation and Virginia Tech researchers have enabled adjustments of regulatory procedures to accommodate research findings. Elements of those interactions include (1) development of research designs that consider regulatory issues while addressing scientific principles; (2) effective communication between researchers and regulators prior to and during research, and in response to research findings; and (3) cooperative involvement by university and state-agency personnel in communicating practical implications of research findings to federal agencies and industry.

Additional Key Words: Surface Mining Control and Reclamation Act.

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2 Carl E. Zipper is an Assistant Professor, Department of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University (Virginia Tech). Blacksburg Virginia 24061. B. C. Lambert is Policy and Planning Specialist with Virginia Department of Mines, Minerals and Energy. PO Drawer 900, Big Stone Gap VA 24219. James A. Burger is Professor in the Department of Forestry, and W. Lee Daniels is a Professor in the Department of Crop and Soil Environmental Sciences, Virginia Tech.