POSTER PAPERS AND ABSTRACTS

SOIL AND OVERBURDEN TECHNICAL DIVISION

Page No.

Methodology for Building Soil Based Vegetation Productivity Equations: A Statistical Approach.
Jon Bryan Burley 789
An Investigation of Brown Iron Ore Spoils in Tennessee.
S.E. Gaither, J.T. Ammons, J.L. Branson, D.E. McMillen, M.E. Essington, V.H. Reich, S. Gaither 799
Crop and Soil Responses to Sewage Sludge Applied to Reclaimed Prime Farmland.
Q. Zhai, R.I. Barnhisel 813
Acid Mine Drainage and Minesite Salinity in Australia.
David J. Williams 821
Organic Matter and Nutrient Accumulation in Reclaimed Kaolin Mine Soils of Georgia.
R.B. Haddock, L.A. Morris, R.L. Hendrick, E.A. Ogden 821
Plant Materials and Amendments for Controlling Wind and Water Erosion on a Fly Ash Disposal Area: TVA Colbert Fossil Plant, Alabama.
Jimmy J. Maddox, David Behel, John M. Soileau, Jimmie Kelsoe 822
Reclamation of Acidic, Denuded Copper Basin Land: Revegetation Performance of Phosphate Rock vs. Other Nutrient Sources.
J.M. Soileau, F.J. Sikora, J.J. Maddox, J.J. Kelsoe 823
Improved Methods for Acid Base Accounting Utilizing Geospatial Modeling.
Michael DiMatteo, Mark Gaylord 824

FORESTRY AND WILDLIFE TECHNICAL DIVISION

Age and Site-Related Patterns of Carbon Allocation to Wood, Foliage, and Roots on Reclaimed Kaolin Mines in Georgia.
A. Legerski, R. Hendrick, E. Ogden 825
Mycorrhizal Fungi + Trees--Practical Beneficial Tools for Mineland Reclamation.
C.E. Cordell, D.H. Marx, B. Jenkins 825

GEOTECHNICAL ENGINEERING TECHNICAL DIVISION

Comparative Assessment of Groundwater Chemistry Evolution at Three Abandoned Mines and Its Practical Implications.
Jaroslav Šolc 826
Injection of Alkaline Ashes into Underground Coal Mines for Acid Mine Drainage Abatement.
William W. Aljoe 827
Closure of the Brewer Gold Mine by Pit Backfilling.
Anne Lewis-Russ, John F. Lupo, Jon Bronson, Joe M. Flynn, B.G. "Bud" Long 827
Leachate Generation, Qualitative Trends and Groundwater Contamination Potential in Dry Deposits of Fly Ash.
Jaroslav Šolc 828
Backfill Hydrologic Characteristics in a Tennessee Area Surface Coal Mine.
Charles G. Blackburn 829
Erosion Control on Tailings Dams Using Soil Bioengineering.
Moreen Miller 830

WETLANDS TECHNICAL DIVISION

Page No.

WQEP - A Computer Spreadsheet Program to Evaluate Water Quality Data.
Robert G. Liddle 831
Limestone Drains to Increase pH and Remove Dissolved Metals from an Acidic Coal-Mine Discharge in Pennsylvania.
Charles A. Cravotta III, Mary Kay Trahan 836
Controlling and Monitoring Flow in Treatment Wetlands Using Weirs.
Thomas M. Walski, Stephen J. Draus 841
Sulfur Acidic Lakes in Germany: What has to be Done?
Helmut Klapper, Walter Geller, Martin Schultze 855
Manganese Removal in Saturated Gravel Beds: Obtaining Design Criteria.
F.J. Sikora, G.A. Brodie, L.L. Behrends 857
Acidic Stream Mitigation by Limestone Sand Addition.
David L. Brant, Anthony J. Marich, Jr., Keith L. Largent 858
Performance of a Wetland/Anoxic Limestone Drain Treatment System at the Douglas Abandoned Mine Land Project
P.L. Sterner, J.B. Cliff, J.G. Skousen, A.J. Sexstone 859
Advanced Design and Construction Techniques for Staged Passive Wetland Treatment Systems for Coal Ash Leachate.
Terry A. Rightnour 860
Passive Treatment of Acid Mine Drainage in Systems Containing Compost and Limestone: Laboratory and Field Results.
G.R. Watzlaf and D.M. Pappas 861
Evaluation of Selected Grasses for the Revegetation of a Coal Slurry Lagoon in Western Kentucky by Direct Seeding.
T.P. Carter, R.I. Barnhisel, B. Gray, J.R. Nawrot 861
Constructed Wetland Treatment System for Upper Blackfoot Mining Complex.
F.S. Sanders 862

ECOLOGY TECHNICAL DIVISION

Reclamation of Degraded Areas in Eastern Amazonia: The Potential of Sclerolobium Paniculatum Vogel.
Silvio Brienza Jr, Luiz Eduardo Dias, Cassio Alves Pereira 863
Field Inoculation Rates of Mycorrhizal Fungi in Revegetation of Abandoned Coal Mine Lands.
Robert K. Noyd, F.L. Pfleger 871
Lateral Thinking on Minesite Rehabilitation in Australia.
David J. Williams 872
Reclamation of the Wasatch Gathering System Pipeline in southwestern Wyoming and northeastern Utah.
D. Strickland, G. Dern, G. Johnson, and W. Erickson 872
Case Studies of Ecosystem-Based Approaches to Remediation.
K. Trimble 873
Abandoned Mined Land Impacts on Water and Sediment Quality, and Invertebrate Assemblages in Two Virginia Watersheds.
J.L. Yeager, J.R. Bidwell, D.S. Cherry, C.E. Zipper 874
Revegetation Standards for Floodplain Forest Ecosystems in western Washington, USA.
B. Zamora 875

METHODOLOGY FOR BUILDING SOIL BASED VEGETATION PRODUCTIVITY EQUATIONS: A STATISTICAL APPROACH[1]

by:

Jon Bryan Burley[2]

Abstract. Reclamation specialists have been interested in developing predictive equations to assess reclamation efforts in reconstructing soils to support vegetation growth. One predictive effort is associated with a statistical approach examining somewhat large data sets containing plant growth yields and soil variables. While the results from such procedures have been reported for the last seven years, a description of the methodology has not been described since 1987. This paper describes this statistical vegetation productivity model building process. To complete the basic analytic steps in the process, a statistical computing software package is required to conduct principal component analysis (PCA) and multiple regression analysis. The field data required to conduct the analysis are extensive. All crops and woody plants of interest (source of dependent variables) should be grown on all soil profiles (source of independent variables) for a period of approximately 10 years. The time period should include dry years, wet years, and average moisture years and should ideally include reclaimed and undisturbed soils. For any individual investigator, this type of data set would be expensive and time consuming to generate; however, the former United States Soil Conservation Service (SCS) has conducted similar work for a fair number of counties in the United States of America and can provide a substantial portion of the undisturbed soil database for investigators interested in developing a vegetation productivity equation for their region. Different units of measure across crop types are not necessarily an issue in vegetation productivity equation modeling, because each vegetation type is standardized to a mean of zero and a variance of 1. Then the various crop types and woody plants are examined with PCA. This statistical treatment allows the investigator to determine the number of dimensions necessary to explain the variance across all vegetation types. Ideally, if all of the crops of interest covary together, they can be combined into one dimension generating one dependent variable; otherwise an investigator may have to develop an equation for each significant dimension indicated in PCA. Soil factors suitable for regression analysis are calculated by employing a soil profile weighting formula. Before conducting regression analysis, a regression screening procedure may be employed to search for the most promising main effect, squared terms, and two variable interaction terms. The Maximum-R-squared improvement technique has been determined to be the best stepwise selection procedure to search for the best equation. Once a regression equation is selected, it can be further analyzed with bootstrap, subsampling, and jackknife statistical procedures. Finally, developed equations should be evaluated with results from reclaimed soils. These procedures for the basis of the methodology.

Additional Key Words: landscape planning, biometric statistics, soil science, prime farmland reclamation, agroecology

Introduction

This paper describes the fundamental procedures specific to the vegetation productivity model building process. To complete the basic analytic steps in the process, a statistical computing software package is required to conduct principal component analysis (PCA) and multiple regression analysis. In my efforts, I used the Statistical Analysis System (SAS) software for the microcomputer (1985); however, for

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investigators wishing to apply the methodology similar statistical software packages may suffice.

Table 1. Dependent variables and units of measurement as recorded and published by the U.S. Soil Conservation Service (Jacobson 1982).

Abbreviation	Vegetation	Measured Average Yield
Evergreen Trees		
JV	*Juniperus virginiana*	feet/20 years
PG	*Picea glauca densata*	feet/20 years
PP	*Picea pungens*	feet/20 years
PS	*Pinus ponderosa scopulorum*	feet/20 years
CO	*Celtis occidentalis*	feet/20 years
Deciduous Trees		
FP	*Fraxinus pennsylvanica*	feet/20 years
PD	*Populus deltoides*	feet/20 years
ST	*Salix alba tristis*	feet/20 years
UP	*Ulmus pumila*	feet/20 years
Deciduous Shrubs		
CA	*Caragana arborescens*	feet/20 years
CR	*Cornus sericea*	feet/20 years
PA	*Prunus americana*	feet/20 years
PV	*Prunus virginiana*	feet/20 years
SV	*Syringa vulgaris*	feet/20 years
Agronomic Crops		
SW	Spring Wheat	bushels/acre
BA	Barley	bushels/acre
OA	Oats	bushels/acre
SF	Sunflowers	pounds/acre
SB	Sugarbeets	tons/acre
SN	Soybeans	bushels/acre
GE	Grasses/Legumes	tons/acre

1 meter = 3.281 feet; 1 foot = 0.3048 meter
1 hectoliter = 2.837 U.S. bushels;
1 U.S. bushel = 0.363 hectoliter
1 hectare = 2.471 acres; 1 acre = 0.405 hectare
1 kilogram = 2.2046 pounds avoirdupois;
1 pound = 0.4536 kilogram

I (Burley 1988) reviewed the historical development leading to the rise of predictive reclamation modeling as a tool to assist in pre/post-mining landscape planning and design. Significant contributions leading to the development concerning predictive reclamation equations include works by Neill (1979), Pierce *et al.* (1983), Lohse *et al.* (1985), Walsh (1985), Vories (1985), Doll and Wollenhaupt (1985) and Plotkin (1986). In addition to these investigations, Potter (1986) describes two methods to assess the vegetation productivity capacity of the landscape. In the first method an empirical "shot-gun" approach, labeled by Potter as "inductive," is used where a wide array of variables is examined by sampling the landscape and making statistical comparisons/ inferences. The second method is a heuristic approach, labeled by Potter as "deductive," where transects are sampled and the investigator develops generalities about the physical and chemical parameters governing vegetation potential of the landscape. Complementing Potter's descriptions, Reith (1986) provides an explanation of the fundamentals concerning reclamation models across a broad spectrum of reclamation applications ranging from the prediction of rill formation through multiple regression techniques to multi-equation stochastic ecosystem modeling of a grassland. These papers, published by the mid-1980s, represent the general knowledge base prior to the actual development of statistical vegetation productivity models.

Burley and Thomsen (1987) describe a discrete methodology to produce a quantitative reclamation productivity equation. Unfortunately, this approach is labeled by Potter (1986) as the "shot-gun" approach. I would like believe that scientists have been working for generations posing hypotheses and examining variables to determine their importance. Eventually, a somewhat small set of potential predictor variables can be examined in greater refined statistical detail. While some individuals may wish to consider this a shot-gun approach, I would characterize this approach as an indicator of the maturity of soil science and reclamation activities allowing multiple variable studies to be conducted. This advanced multi-variable complexity is evident in other disciplines such a econometrics, wildlife habitat modeling, water quality prediction models, and visual quality modeling.

In my reclamation modeling efforts, the basis for this methodology originated with multivariate statistical concepts presented by Kendall (1939), requiring computationally complex matrix algebra (see Johnson and Wichern 1988). With the advent of the computer to perform matrix algebra operations for dimensions greater than three, multivariate statistical techniques made reclamation productivity development possible. By computing eigenvalues and eigenvectors for all possible dependent variables such as crops and woody plants, an investigator could determine the extent of multi-variable covariance and develop an equation to represent a linear combination of variables to generate a single dependent variable. In other words,

if the first eigenvalue was relatively large and the coefficient loadings of the eigenvector for the first eigenvalue were relatively similar, a simple equation derived from the eigenvector would suggest a linear combination of dependent variables that can be combined into one value per soil type. With one dependent variable value per soil type, it is possible to perform multiple regression analysis using one dependent variable. Gersmehl and Brown (1990) employed Kendall's method to examine multiple crop productivity values across geographic regions in the United States of America. Their work suggests that in the Midwest and Northern Great Plains, multiple crop productivity values often covary across soil types. Their work substantiates the concept that the soil preferences of various agronomic crops are indeed similar. Table 1 lists the vegetation types in Clay County, Minnesota that have been employed by Burley and colleagues to generate dependent variables, generally covarying as a group.

These plant types are employed to predict vegetation productivity. However, the term "vegetation productivity" is a relatively weakly developed construct. In many respects vegetation productivity has been operationally expressed as vegetation yield, such as bushels per acre of harvested seed or feet of new apical terminal shoot growth per year and represents a certain anthropocentric perspective concerning plant growth. A plant physiologist may suggest that an abundance of seeds per acre does not necessarily mean that a vegetation type is internally healthy and an ecologist may suggest that unsustainable lush plant growth is not necessarily a sound ecological condition. Consequently I recognize that there exists the potential to develop new operational constructs for vegetation productivity. Nevertheless, in my vegetation productivity work, I have made that assumption that existing measures of vegetation yield and new plant growth are reasonable indicators of productivity and that my interests lie in the relationships between existing productivity measures and soil parameters. I also assume that these variables can be studied with multiple regression analysis.

In the multiple regression analysis portion of the model building methodology, a single independent variable value for each soil parameter was generated by applying a weighting formula (Equation 1 in Figure 1) suggested by Doll and Wollenhaupt (1985), where the soil parameters in the first foot of a soil profile contribute 40% of a plant's vegetation production, the second foot contributes 30%, the third foot contributes 20%,. the. fourth. foot.. contributes 10%, and the

[Eq 1]

$$V=[(\sum_{i=1}^{12} v_i)*0.4]+[(\sum_{i=13}^{24} v_i)*0.3]+[(\sum_{i=25}^{36} v_i)*0.2]+[(\sum_{i=37}^{48} v_i)*0.1]$$

Where:

V = Weighted Soil Variable Value

v_i = Value for Soil Variable in One Inch Layer of Soil Profile

i = Soil Layer in Profile

Figure 1. Weighting equation based upon soil depth.

remaining layers do not contribute to vegetation growth. With this formula, any soil parameter for a specific soil profile can be measured on a foot by foot basis (even inch by inch) and the investigator can generate a single value for each soil profile, such as a single weighted pH value or a single weighted bulk density value (see Burley and Thomsen 1987). Table 2 lists the typical soil variables employed by Burley and colleagues to generate independent variables. A document written by the Soil Survey Division Staff (1993) describe current methods to measure these variables.

It is also important to recall that most land-use disturbances do not typically affect some plant growth variables, such as climate. Instead, disturbances associated with surface mining activities usually affect the soil. Thus for effective reclamation, a reclamation success predictor such as an equation should focus upon the environmental feature that has been disturbed, the soil. Some investigators and reviewers of vegetation productivity papers have confused "real time crop-yield indexes" with reclamation productivity equations. While real time crop-yield equations can compute the predicted level of vegetation production for a particular year under specific field conditions experienced over the growing season, a reclamation productivity equation predicts the average expected yield across many years of cultivation. This average yield is produced by employing crop yield values that were measured over many years including drought years, wet years, warm growing seasons, and cold growing seasons. This averaging effect thereby negates the yearly variances upon crop yields produced by climate, allowing an investigator to study more closely the influences of soils upon vegetation growth over many growing seasons.

Burley et al. (1989) applied the multiple regression analysis statistical approach to produce a

Table 2. Main effect independent variables and units of measurement from the U.S. Soil Conservation Service (Jacobson 1982 and U.S. Department of Agriculture 1951).

Abbreviation	Factor	Unit of Measurement
FR	% Rock Fragments	Proportion by weight of particles > 7.62 cm
CL	% Clay	Proportion by weight
BD	Bulk Density	Moist Bulk Density g/cm cubed
HC	Hydraulic Conductivity	Inches/hour (1 inch = 2.54 cm)
PH	Soil Reaction	pH
EC	Electrical Conductivity	Mmhos/cm
OM	% Organic Matter	Proportion by weight
AW	Available Water Holding Capacity	Inches/inch, cm/cm
TP	Topographic Position	Scale 0 to 5 Where: 0=Low (Standing Water) 2.5=Mid-slope 5=High (Ridge Lines)
SL	% Slope	(Rise/Run)*100

productivity equation for seven agricultural crops: spring wheat, barley, oats, soybeans, sunflowers, sugarbeets, and grasses/legumes. The database for this investigation was the Clay County soil survey (Jacobson 1982). The result was a reclamation productivity equation with a coefficient of multiple determination R^2 = 0.740. In other words, the regressors explain 74% of the sum of squares variation in the regression model. This equation did not consider woody plants and thus is not an all inclusive vegetation productivity model. Since reclamation often includes woody vegetation for the development of housing or commercial/industrial sites, wildlife habitat, agricultural shelterbelts, and forestry post-mining land-use applications, the development of a productivity model which includes woody plants would be more universally applicable in reclamation planning and design, including the development of prime farmland where woody plants composed of shelterbelts and windrows can be intricate components of an agricultural landscape. An equation developed by Burley (1991) using Burley and Thomsen's (1987) methodology, is presented as the best universal reclamation equation, because it was suitable to a lage number of vegetation types. R^2 for this equation is 0.795, explaining approximately 80% in the sum of squares variation for vegetation from the regression model. Other equations reported include a Clay County, Minnesota sugar beet (*Beta vulgaris* L.) equation (Burley 1990), two equations for Polk County, Florida (Burley and Bauer 1993), a two county equation in the Red River Valley of the North (Burley 1995a), and an equation for Oliver County, North Dakota (Burley *et al.* 1996). Burley (1992) presented a series of issues associated with these equations that may merit further investigation.

In contrast to the approach developed by Burley and Thomsen (1987), an alternative productivity index has been applied by several investigators. This approach is termed the "sufficiency approach" and follows more closely the work of Neill (1979) and Pierce *et al.* (1983). Huddleston (1984) and Henderson *et al.* (1990) review the formative development of this approach. With this approach, single independent variable models are developed to predict soil vegetation productivity. The single variable models have some degree of statistical reliance and may be normalized as illustrated by Wollenhaupt (1985). However, each variable is then combined into a full order interaction term where each independent variable is multiplied together as a group and may be corrected with the geometrical mean (Gale 1987). Several investigators have reported experiments with these full interaction term sufficiency equations (Barnhisel and Hower 1994, Burger *et al.* 1994, Barnhisel et al. 1992, Hammer 1992, and Gale *et al.* 1991). My criticism of this approach is that the equations are heuristically derived and the functions are not statistically validated and are therefore less rigorous. It is not surprising to me that efforts to corroborate equations based upon this methodology have met with mixed results. The research conducted with this heuristic approach has several limitations. First, the variables presented in the

equations may potentially be highly over specified as investigators have not demonstrated the contribution of each variable within the equation and have not followed searching procedures associated with regression modeling. Investigators have not accomplished sufficient equation sifting to eliminate linear models, squared terms, second-order interaction terms, or any other equation configuration. In my opinion, investigators have prematurely jumped to full interaction terms and geometric means. Second, the soils employed in the models are often restricted in external validity applications, meaning that significant results may be limited to a small set of soils studied, sometimes only two or three soil types. The data sets are not broad and thus are not applicable to many soil types. Third the vegetation types studied often consist of one dependent variable type, meaning the reported results are actually only applicable to the crop studied, such as corn or Eastern white pine. These three issues are my current reservations about this heuristic approach.

The sufficiency approach and the multiple regression modeling approach are two current vegetation productivity approaches. Regardless of the shortcomings for either approach they are models that may merit potential use in landscape planning. Numerous states require quantitative reclamation assessment procedures (primarily for coal surface mining reclamation on prime farmlands), suggesting that soil productivity equations are potentially compatible with these quantitative assessment demands and could make a contribution in evaluating the post-disturbance soil environment. Burley and Thomsen (1990) have described the application of a soil productivity equation for reclaiming surface mines. The application illustrates how these equations may be used to interpret landscape reconstruction configurations and how to evaluate the effectiveness of various reclamation treatments.

Discussion

The Dependent Variables

The field data required to conduct the analysis are extensive. All crops and woody plants of interest should be grown on all soil profiles of interest for a period of approximately 10 years to gain a perspective of vegetation performance on soils across climate variability. The time period should include dry years, wet years, and average moisture years. For any individual investigator, this type of data set would be expensive and time consuming to generate; however, the United States Soil Conservation Service (SCS) has conducted similar work for a fair number of counties in the United States of America and can provide a substantial portion of the database for investigators interested in developing a vegetation productivity equation for their region. Since the SCS operates under a county administrative structure, the data sets are naturally organized by county. These data sets are derived from soils on non-mined land. Ideally, a investigator should include results from reclaimed soils also. Nevertheless, I am somewhat disappointed in the conviction expressed privately by some colleagues that a statistical equation derived from soils not disturbed by mining is not valid for reclaimed soils, especially when many of these soils formed within the last 12,000 years, deposited by glacial and related surficial activity. Consequently, the soils that Burley and colleagues have used are relatively new and originated from relatively freshly disturbed materials. In addition, many of these soils are highly disturbed due to recurring fluvial processes, wind erosion, deep tilling, and soil amendments. Thus, these soils are not necessarily undisturbed material weathering in one location for millions of years, such as the soils that may be found in the tropics. Compared to millions of years, 12,000 years is a rather short time span, meaning the glacially deposited soils may have much in common with reclaimed surface mine soils. Concurrently, other than variations in physical parameters such as bulk density and chemical parameters such as nitrogen levels, no investigator has presented any information to suggest that reclaimed soils are intrinsically any different than pre-mine soils. No investigator has suggested that unmined versus mined soils should be a qualitative independent regression variable. If a reclaimed surface mine soil originated from substrate within the bounds of the soils studied to develop a soil productivity equation, and if the mine soil is within the physical and chemical bounds of soils studied to develop the soil productivity equation, then in theory, the soil productivity equation based upon non-reclaimed soils should be applicable to the reclaimed surface mine soil. The work of Burley et al. (1996) suggests that a such an equation may be able to predict productivity on reclaimed soils. Unless an investigator can find the physical or chemical variable that indicates reclaimed soils are substantially different, I will maintain there is no fundamental difference. In fact, within the horticulture and construction industry, soils are rebuilt everyday from highly disturbed areas to support turf growth, wood plants, and vegetable gardens. If these reconstructed soils were really any different from what we know and apply from non-mined soils, then theoretically, landscape construction

activities to build soils for lawns and gardens should not be successful. However, careful soil profile development on construction sites results in successful soil conditions for plant growth. Unless the reclaimed soils generate unsuspected toxic conditions such as high selenium values, surface mine soils are really no different than the collective properties of non-mined soils. For example, in the study areas I have examined, I have found dense clays, acidic clays, alkaline clays, clays on slopes, clays in wetlands, permeable clays, deep clays, and shallow clays, replicating almost any non-toxic soil condition found on reclaimed clay soils. This broad variability of the data set allows reclaimed soils with properties that fit within the parameter bounds of this data set to estimate vegetation performance. I would suggest that those studies that have been unsuccessful at predicting vegetation productivity have either been working with heuristic equations or have not generated a data set with substantial breadth across many years with many soil types and many vegetation types to develop statistically predictive results.

In my studies, crop harvest data and woody plant growth rates are the typical dependent variables employed in a vegetation productivity equation study. Crop harvest data may be in bushels per acre, tons per acre, pounds per acre or any other quantitative harvest value typical for the crop of interest. The woody plant growth rates have been presented by the SCS in feet per years of growth, although other forest measurements or horticultural vegetation growth rates or plant volumes could potentially be employed. In addition, the crop logical types do not have to be consistent. For example, a woody crop species and a mixed crop such as a grasses and legume mix can be employed in the study. The analysis will indicate the statistical relationship between the various vegetation types. This is a difficult concept for some investigators to intellectually grasp because apples and oranges plus many other types of numerical information can actually be compared and combined. Different units of measure across crop types are not necessarily an issue in vegetation productivity equation modeling, because each vegetation type is standardized to a mean of zero and a variance of 1. Then the various crop types and woody plants are examined with PCA. This statistical treatment allows the investigator to determine the number of dimensions necessary to explain the variance across all vegetation types. Ideally, all of the crops of interest covary together and can be combined into one dimension; otherwise an investigator may have to develop an equation for each significant dimension indicated in PCA. In other words, PCA is a data reduction tool that may allow an investigator to determine whether corn, soybeans, wheat and *Fraxinus pennsylvanica* can be combined together or must be analyzed separately. This is an important issue. If all vegetation types do not covary in productivity, then the investigator must develop a large number of individually tailored vegetation productivity equations and the reclamation specialist may reclaim a landscape suitable for one crop but not suitable for another, thereby excluding future production options for the farmer. If the crops do covary, a universal vegetation productivity equation may be possible for the study site.

PCA results typically begin with presentation of an eigenvalue for each dimension in the data set. The largest number of dimensions is equal to the number of variables present in the data set. For example if three crop types are presented for PCA, then the largest number of dimensions is three. This approach is extremely useful for a large number of variables, because the mathematics employed in the technique can examine a data set in a multidimensional space greater than three dimensions. Until the development of the computer, PCA was often limited to three dimensions as the matrix algebra required to compute the eigenvalues was difficult to compute by hand. The important feature of the eigenvalue is that each dimension is orthogonal to every other dimension, meaning that the information associated with each eigenvalue is independent of every other dimension. PCA assumes that the latent roots of the data set are definite and real and the data set is composed of multivariate-normal variables.

The largest eigenvalue is presented as the first eigenvalue in PCA. With standardized variables, the eigenvalue can be no larger than the sum of the variables under study. For example if five crop types are being studied, the largest eigenvalue can be no greater than 5.0. In addition, the sum of all the eigenvalues can be no greater than 5.0. This means that if the largest eigenvalue is 4.8, the sum of the remaining eigenvalues must be equal to 0.2. The proportion of the sum for any combination of eigenvalues indicates the amount of variance explained by those eigenvalues. Suppose two eigenvalues from standardized variables sum to 3.0 and there are four variables in the analysis. These two eigenvalues represent 75 percent of the variance in the data set.

Eigenvalues greater than 1.0 originating from standardized variables are considered to represent significant dimensions. The significant dimensions are then inspected by examining the eigenvector

coefficients. Each variable in the analysis contains an eigenvector coefficient associated with each eigenvalue. The eigenvector coefficient indicates the strength of association the variable has with the eigenvalue. In vegetation productivity analysis studies, the investigator is interested in which variables are associated with which dimensions. Burley *et al.* (1989) discovered that crop variables in their study covaried together and that the eigenvector coefficients were relatively equitable across the first eigenvalue. Thus Burley *et al.* (1989) were able to develop a linear equation to compute the generation of one combined plant growth productivity value per observation case. The eigenvector coefficients indicate the weighting of each crop variable for a specific dimension and range in value from 1.0 to -1.0. The crop value multiplied by the weighting coefficient and then summed with the results from the other crops forms a linear combination equation to build a combined vegetation productivity value for each observation case. Consequently, an investigator may be able to build a data set containing one dependent variable per observation case from a set of many dependent variables.

The Independent Variables

The independent variables are comprised of soil characteristics from each soil profile of interest. A major issue associated with soil characteristics is the variability of any one soil parameter within any soil profile. Where should the investigator measure soil reaction? Doll and Wollenhaupt (1985) suggest that any soil parameter should be measured through the first four feet of the profile and weighted according to the equation identified in Equation 1. While some researchers may question the accuracy of the weighting formula, this formula represents the current understanding and state-of-the-art of profile contribution in vegetation growth, and therefore this is the weighting equation employed in my work.

Analysis

Once the soil profile weighting formula has been employed and the dependent variables have been constructed, the data set is ready for regression screening. In SAS, regression screening can be accomplished with the RSREG procedure. This procedure examines main effect, squared terms, and two variable interaction terms for association with the dependent variable. The most promising variables can then be entered into a regression stepwise procedure to evaluate various combinations of regressors.

The Maximum-Rsquared improvement technique has been determined to be the best stepwise selection procedure (SAS 1982). The investigator must then examine the results of the stepwise procedure to assess which equation is the best from those presented. Typically the investigator will examine the multiple coefficient of determination, preferring larger values which explain a larger percentage of the variance in the data set. Values near 0.4 are considered weak and values near 0.9 are considered strong. In addition, the investigator will examine the p-value for the overall regression and the p-value for each regressor. I recommend that one examine p-values that originate from Type II Sum of Squares, a technique which computes the p-value for the regressor assuming that all other regressors are already in the equation. This is a conservative approach to determining p-values and is consistent with not overestimating the p-value's significance. P-values less than or equal to 0.05 are considered statistically significant. P-values less than or equal to 0.01 are considered highly significant. Therefore, the investigator is searching for an equation which has at least significant p-values and explains as much of the data set's variance as possible.

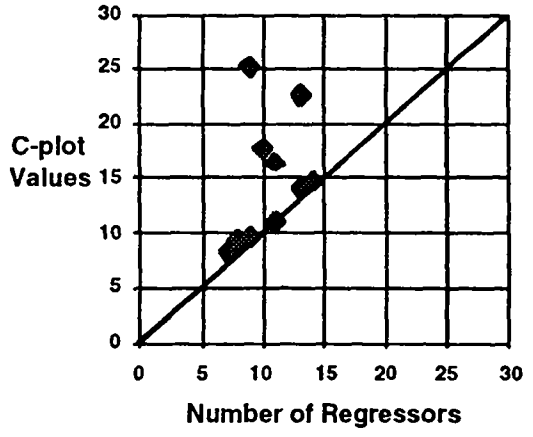

Figure 2. Plot of regressors and C-plot values for equations presented by Burley (1995b).

However, the investigator must be concerned about over specifying and multicollinearity issues associated with regression modeling. One approach in evaluating various equations is to prepare a C-plot of the equations, where the number of regressors are plotted against the C-plot value (Younger 1979). The equations above the 45 degree line are considered equations which are not over specified. Equations that approach the 45 degree line without crossing into the lower portion of the quadrant are preferred over

equations distant from the 45 degree line (Figure 2). Those equations which are further from the origin and along the 45 degree line are preferred over equations close to the origin. This technique can remove much of the collinearity problems inherent in regression modeling. One can also conduct collinearity diagnostics to determine the collinearity associated with any regression equation (SAS Institute 1982). The diagnostic procedure produces a condition index number indicating the degree of collinearity associated with dimensions of a regression equation. A condition index of less than 10 is considered to indicate relatively little or no collinearity (Rawlings 1988). A value greater than 10 indicates weak collinearity. A condition index number between 30 to 100 indicates moderate to strong collinearity. Values above 100 indicate serious collinearity problems. With each condition index, weighting coefficients indicate the level of association for regressor variables. Regressors containing coefficients approaching 1.0 are strongly associated with that particular dimension. More than one regressor with substantial values for a single condition index identifies the potential collinear variables.

[Eq. 2]

Pseudo-Value = k * (parameter estimate calculated from the whole sample) - (k-1)*(parameter estimate calculated from the group with the j sample removed)

Where: k = total number of observation cases

Figure 3. Nonparametric pseudo value jackknife equation.

[Eq. 3]

Standard Error =

$$(\text{Variance of the Pseudo-values}/(k-1))^{0.5}$$

Where: k = total number of observation cases

Figure 4. Nonparametric standard error estimate equation for jackknife procedure.

Analysis of the Analysis

There are several methods to evaluate the estimates of parameters and validity of a particular regression equation. One method is the jackknife approach (Efron 1982). With this technique a nonparametric statistic is produced for each regression parameter by applying Equation 2 in Figure 3. The variance for this sampling procedure is employed to calculate the standard error associated with the estimates of each parameter (Equation 3 in Figure 4, Mathsoft 1988).

In contrast to the jackknife approach, the bootstrap technique samples the data set with replacement to build a larger observational set to compute parameter estimates (Mathsoft 1988 and Efron 1982). For bootstrap analysis, the standard deviations of the coefficient estimates are the standard error estimates for the coefficients. In other words, an estimated distribution of the coefficients can be calculated. Wide distributions indicate unstable coefficients and narrow distributions indicate relatively stable coefficients.

Another procedure which can be employed to study the applicability of a regression equation is the subsampling procedure, where a portion of the data set is removed from the equation development process and then employed later to compare the results from the equation with the subsample.

In addition to the collinearity diagnostics, jackknife techniques, bootstrap techniques, and subsampling procedures, one can inspect the plots of the residuals associated with a specific regression equation. The plots can identify regression assumption violations concerning constant variance and histogram plots can identify violations concerning the normality of the residuals.

Finally, selected vegetation productivity equations developed with the procedures described by Burley and Thomsen (1987) should be assessed with data sets from reclaimed soils. Considering the number of reclamation research centers in North America, one might expect that suitable data sets exist for conducting a reclaimed soil investigation. However, these potential data sets often do not contain observations according to depth, nor do they contain all of the desired soil variables needed by the developed equation. While equations derived from non-mined soils are certainly possible to construct, the methodology described in this paper is directly applicable to unreclaimed data sets also, providing the data set is comprised of all vegetation types across all disturbed soil types. However, it appears that currently, no reclamation center or reclamation investigator has such a large and extensive data set.

Concluding Remarks

This technique represents the basic approach I have folllowed in developing vegetation productivity equations and presents a few more assessment procedures not initially described by Burley and Thomsen (1987). It is my belief that investigators across the globe and especially in North America will employ the methodology that I have described in this paper and build regionally specific equations to study the reconstruction of soils to support plant growth..

Bibliography

Barnhisel, R.I. and J.M. Hower. 1994. The use of productivity index to predict corn yields on restored prime farmland. International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Volume 3: Reclamation and Revegetation. United States Department of the Interior, Bureau of Mines Special Publication SP O6C-94:20-27.

Barnhisel, R.I., J.M. Hower, and L.D. Beard. 1992. Development of a soil productivity model for use in prime farmland reclamation. Dunker, R.E., R.I. Barnhisel, and R.G. Darmody (Eds.) In: Proceedings of the 1992 National Symposium on Prime Farmland Reclamation. Department of Agronomy, University of Illinois, Urbana, Illinois 61801, :205-211.

Burger, J.A., J.E. Johnson, J.A. Andrews, and J.L. Torbert. 1994. Measuring mine soil productivity for forests. International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Volume 3: Reclamation and Revegetation. United States Department of the Interior, Bureau of Mines Special Publication SP O6C-94:48-56.

Burley, J.B. 1988. Development and Application of an Agricultural Soil Productivity Equation for Reclaimed Surface Mines in Clay County, Minnesota. M.L.A. Thesis, University of Manitoba.

Burley, J.B. 1990. Sugarbeet productivity model for Clay County Minnesota. Journal of Sugar Beet Research 27(3 & 4):50-57.

Burley, J.B. 1991. A vegetation productivity equation for reclaiming surface mines in Clay, County Minnesota. International Journal of Surface Mining and Reclamation 5:1-6.

Burley, J.B. 1992. Vegetation productivity equations: an overview. Dunker, R.E., R.I. Barnhisel, and R.G. Darmody (Eds.) In: Proceedings of the 1992 National Symposium on Prime Farmland Reclamation. Department of Agronomy, University of Illinois, Urbana, Illinois 61801, 259-265.

Burley J.B. 1995a. A multi-county vegetation productivity equation for soil reclamation. Hynes, T.P. and M.C. Blanchette (Eds.) In: Proceedings of Sudbury '95 - Mining and the Environment. CANMET, Ottawa, Volume 3, 1113-1122.

Burley, J.B. 1995b. Vegetation productivity soil reclamation equations for the North Dakota coal fields. PhD. dissertation, University of Michigan.

Burley, J.B. and A. Bauer. 1993. Neo-sol vegetation productivity equations for reclaiming disturbed landscapes: a central Florida example. Zamora, B.A. and R.E. Conally (Eds.) In: The Challenge of Integrating Diverse Perspectives in Reclamation: Proceedings of the 10th Annual National Meeting of the American Society for Surface Mining and Reclamation. ASSMR, Spokane, WA, 334-347.

Burley J.B., K.J. Polakowski, and G. Fowler. 1996. Vegetation productivity equation for reclaiming surface mines in Oliver County North Dakota. In: The 1996, Annual Meeting of the American Society of Surface Mining and Reclamation, Knoxville, Tennessee.

Burley, J.B. and C.H. Thomsen. 1987. Multivariate Techniques to Develop Vegetation Productivity Models for Neo-Soils. 1987 Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation. University of Kentucky, 153-161.

Burley, J.B. and C.H. Thomsen. 1990. Application of an agricultural soil productivity equation for reclaiming surface mines: Clay County, Minnesota. International Journal of Surface Mining and Reclamation 4:139-144.

Burley, J.B., C.H. Thomsen, and N. Kenkel. 1989. Development of an agricultural soil productivity equation for reclaiming surface mines in Clay County, Minnesota. Environmental Management 13(5):631-638.

Doll, E.C. and N.C. Wollenhaupt. 1985. Use of soil parameters in the evaluation of reclamation success in North Dakota. Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, 91-94.

Efron, B. 1982. The Jackknife, the Bootstrap and Other Resampling Plans. Society for Industrial Applied Mathematics.

Gale, M.R. 1987. A forest productivity index model based on soil-root distributional characteristics. Ph.D. Dissertation, University of Minnesota, St. Paul.

Gale, M.R., D.R. Grigal, and R.B. Harding. 1991. Soil productivity index: Predictions of site quality for white spruce plantations. Soil Science Society of America Journal 55:1701-1708.

Gersmehl, P.J. and D.A. Brown. 1990. Geographic differences in the validity of a linear scale of innate soil productivity. Journal of Soil and Water Conservation, May-June:379-382.

Hammer, R.D. 1992. A soil-based productivity index to assess surface mine reclamation. Prime Farmland Reclamation. Prime Farmland Reclamation National Symposium, University of Illinois, :221-232.

Henderson, G.S., R.D. Hammer, and D.F. Grigal. 1990. Can measurable soil properties be integrated into a framework for characterizing forest productivity? Sustained Productivity in Forest Soils. Proceedings of the 7th North American Forest Soils Conference, University of British Columbia, Faculty of Forestry Publications, :137-154.

Huddleston, J.H. 1984. Development and use of soil productivity ratings in the United States. Geoderma 32:297-317.

Jacobson, M.N. 1982. Soil Survey of Clay County, Minnesota. USDA, SCS and Minnesota Agricultural Experiment Station.

Johnson, R.A. and D.W. Wichern. 1988. Applied Multivariate Statistical Analysis. Prentice Hall.

Kendall, M. 1939. The geographical distribution of crop productivity in England. Journal of the Royal Statistical Society 102:21-48.

Lohse, J.S., P. Giordano, M.C. Williams, and F.A. Vogel. 1985 Illinois agricultural land productivity formula. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, 24-39.

Mathsoft. 1988. Statistics I: Tests and Estimation. Mathsoft, Inc, Cambridge, Massachusetts.

Neill, L.L. 1979. An evaluation of soil productivity based on root growth and water depletion. M.S. Thesis, Univ. of Missouri, Columbia.

Pierce, F.J., W.E. Larson, R.H. Dowdy and W.A.P. Graham. 1983. Productivity of soils: Assessing long-term changes due to erosion. Journal of Soil and Water Conservation 38:39-44.

Plotkin, S.E. 1986. Overseeing reclamation: From surface mine to cropland. Environment 28(1):16-20, 40-44.

Potter, L.D. 1986. Pre-mining assessments of reclamation potential. Reith, C.C. and L.D. Potter (eds) In: Principles & Methods of Reclamation Science: with Case Studies from the Arid Southwest. University of New Mexico Press, 41-67.

Rawlings, J.O. 1988. Applied Regression Analysis: a Research Tool. Wadsworth & Brooks/Cole Advanced Books & Software.

Reith, C.C. 1986. Understanding reclamation with models. Reith, C.C. and L.D. Potter (eds) In: Principles & Methods of Reclamation Science: with Case Studies from the Arid Southwest. University of New Mexico Press, 85-107.

SAS Institute Inc. 1985. SAS Introductory Guide for Personal Computers, Version 6 Edition. SAS Institute.

SAS Institute Inc. 1982. SAS User's Guide: Statistics, 1982 Edition. SAS Institute.

Soil Survey Division Staff. 1993. Soil Survey Manual. U.S. Department of Agriculture, Handbook No. 18.

U.S. Department of Agriculture. 1951. Soil Survey Manual. U.S. Department of Agriculture, Handbook No. 18.

Vories, K.C. 1985. Proof of vegetative productivity: Research needs. 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. University of Kentucky, :145-149.

Walsh, J.P. 1985. Soil and overburden management in western surface coal mines reclamation - findings of a study conducted for the Congress of the United States -Office of Technology Assessment. In: Bridging the Gap Between Science, Regulation, and the Surface Mining Operation. ASSMR Second Annual Meeting, Denver, CO, :257-264.

Wollenhaupt, N.C. 1985. Soil-water characteristics of constructed mine soils and associated undisturbed soils in southwestern North Dakota. Ph.D. dissertation, North Dakota State University, Fargo, North Dakota.

Younger, M.S. 1979. Handbook for Linear Regression. Duxbury Press, Wadsworth, Inc.

AN INVESTIGATION OF BROWN IRON ORE SPOILS IN TENNESSEE

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Abstract. Many acres, concentrated primarily in the eastern United States, have been disturbed by iron ore mining in the past 250 years. Much of the disturbed soils research to date has been conducted on coal minesoils which is not usually applicable to iron ore spoils. The objective of this study was to compare properties of 140-170 year old brown iron ore spoils (minesoils) in Tennessee to those in adjacent undisturbed soils (native). Two minesoils and two native soils were described and sampled according to National Cooperative Soil Survey Standards. Variances of selected chemical properties were compared between sites using a grid sampling design and Hartley's test for homogeneity of variances. Differences in origin of overburden material and the degree of weathering prior to disturbance accounted for morphological and chemical differences between the minesoils. Minesoil 1 had developed a cambic horizon and minesoil 2 had not developed a diagnostic subsurface horizon. Bridging voids were observed in both minesoils but not in the native soils. Trace elements were highest in the surface horizons of both minesoils and native soils and the buried surface horizon in minesoil 1. Variations for total carbon, total aluminum, barium, manganese, phosphorus, titanium, and zirconium between 40-60cm were not consistently significantly different between minesoils and native pedons at a 0.05 alpha level.

Additional Key Words: Iron Ore Spoil, Minesoil, Minesoil Morphology, Bridging Voids, Minesoil Genesis

Introduction

The current *Soil Taxonomy* system used for soil mapping usually does not adequately identify properties in minesoils (Thurman and Sencindiver 1986; Schafer et al. 1980; Schafer 1979). Characterization studies of minesoil properties are critical to develop appropriate criteria to better separate, classify, and manage minesoils. As a result, better decisions can be made for their profitable use under field crops, pasture, or wood-land.

The differences in characteristics of a disturbed soil from its premined condition depend on several factors including the type of equipment used for mining and reconstruction, the chemical composition of material exposed to/near the surface, the pre-weathered condition of the material prior to disturbance, site factors (i.e. slope, irregular topography, etc.), and the time since disturbance (Potter et al. 1988; Thurman and Sencindiver 1986; Haering et al. 1993; Bell et al. 1994). Properties altered by surface mining generally include soil horizonation, soil structure (affecting macroporosity and permeability), bulk density, coarse fragment content, uniformity in color and chemical properties of parent material, and hydraulic conductivity (Haering et al. 1993; McSweeney and Jansen 1984; Ammons and Sencindiver 1990; Bell et al. 1994; Potter et al. 1988; Indorante and Jansen 1984). The rock type dominating the overburden and the degree of in situ weathering of that material before disturbance by mining strongly determines immediate properties such as pH, extractable bases, and weathering rates of minesoil material (Haering et al. 1993).

Much of the disturbed soils research to date has been conducted on coal minesoils which is not usually applicable to iron ore spoils. Iron ore spoils are not often associated with acidity problems, unlike coal minesoils which typically contain pyrite and sulfur compounds (Smith et al. 1971). Many acres, concentrated primarily in the eastern United States, have been disturbed by iron ore mining in the past 250 years. The Western Highland Rim physiographic region of Tennessee was a

large producer of iron ore during the 1800's (Burchard 1934; Safford 1856). Most of the Western Highland Rim's uppermost geology is of Mississippian age(Hershey and Maher 1963). Thin quaternary-aged loess, Upper Cretaceous gravel, sand, and clay non-uniformly overlie these geologic units (Burchard 1934; Springer and Elder 1980)(Fig. 1).

LOESS (0-1 M.Y.B.P.)
CRETCACEOUS (65-140 M.Y.B.P.)
MISSISSIPPIAN (330-365 M.Y.B.P.) St. Louis Limestone
Warsaw Limestone
Fort Payne Formation
Chattanooga Shale

Figure 1. General geologic cross section of Tennessee's Western Highland Rim physiographic region.

The iron ore mined here is believed to have formed during the Tertiary period. Glauconitic sand beds, of Upper Cretaceous age, are postulated to have been the source of iron (Burchard 1934). Theoretically, iron moved readily through the sand layers, precipitated as iron oxides, and accumulated as ore at the interface of cherty portions of underlying limestone (Safford 1856; Killebrew 1874). The ore was deposited in irregular pockets, veins, or banks of variable size and was commonly located on ridge crests in zones of clay and cherty masses. This depositional pattern may reflect areas of the limestone that had formed sink holes or areas of preferential water flow. Depth to the ore deposits varied between 30 and 100ft parallel to the surface. This was shallow enough for the ore to be mined in shallow open mine pits. Soils disturbed during iron mining operations at that time were not reclaimed and offer an opportunity to study soil development from a known date of disturbance. The objective of this study was to compare properties of 140-170 year old iron ore minesoils to adjacent undisturbed soils.

Materials and Methods

Site selection and History

The study sites were located in Montgomery Bell State Park, in Dickson County Tennessee, near the former Laurel Furnace (Fig 2). The Laurel furnace was a steam cold-blast charcoal type furnace, operating between 1815 and the late 1850's (Smith et al. 1988). The spoils left from the mining operation at the Laurel furnace provided an ideal study site because they have not been influenced by intense anthropogenic activities or natural catastrophes since the mining ceased, and spoil piles were easily identified adjacent to excavated pits.

Field Methods

Study sites were located within 800 meters northwest of the Laurel Furnace remnants. Two minesoil profiles and two soil profiles on adjacent undisturbed soils were described and sampled according to National Cooperative Soil Survey Standards (Soil Survey Staff 1993). Soil samples were taken from the entire thickness of each horizon. A grid design was also sampled for each profile to allow statistical analysis for selected chemical properties. The profile grid was 1 meter deep and 1 meter wide and was divided into 20 cm by 20 cm square sections (Fig. 3). Samples were taken and homogenized from the entire squares that were in columns 2 and 4 and row 3. The variance of selected chemical properties for each sampled column and row was compared between all profiles to determine if they were significantly different between the native pedons and spoils. Hartley's test for comparison of homogeneity of two independent variances was used (Snedecor 1956; Ott 1993). The test compares a calculated F value (F_c) to a tabular F value (F_t). F_c is determined by dividing the larger of the two variances by the smaller as shown by the following equation

$$F_c = \frac{s^2max}{s^2min}$$

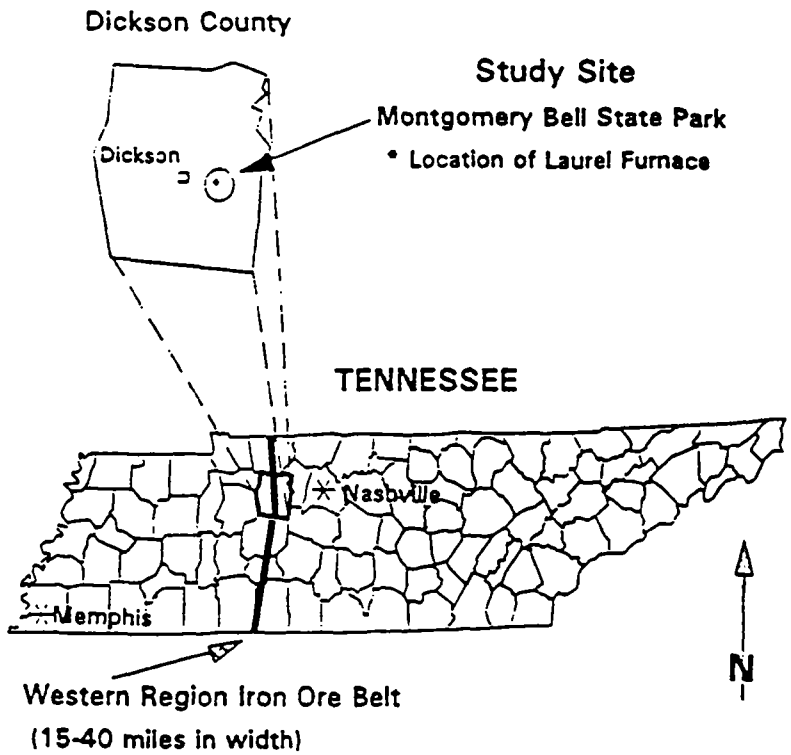

Figure 2. General location map of study area.

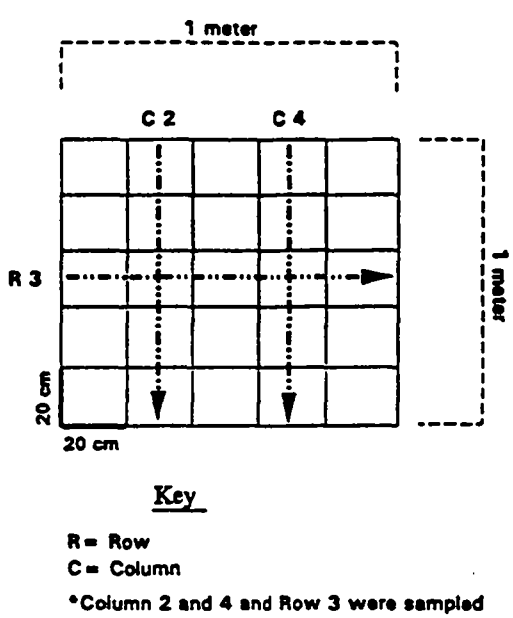

Figure 3. Grid outlay used for vertical and horizontal sampling for statistical analysis.

The null hypothesis states that $\sigma^2_1 = \sigma^2_2$ if F_c is less than or equal to F_t. If F_c is greater (>) than F_t, then the compared variances are significantly different at that chosen alpha level. Note that the degrees of freedom (n=4) were the same for both compared variances and that a 95% confidence level was used for this study.

The undisturbed soils were referred to as native pedon 1 and 2, and the disturbed soils were referred to as spoil 1 and 2. Native pedon 1 developed on the shoulder of a convex side slope, and native pedon 2 developed on a nearly level portion of a ridgetop. Spoil 1 developed in overburden material on a ridgetop, and spoil 2 developed in overburden material in a drainageway.

Laboratory Methods

Horizon samples were air dried, sieved through a 2mm diameter limiting sieve, and homogenized thoroughly (Soil Survey Staff 1984). A sand sieving and sedimentation-pipette method was used to determine particle size distribution of clay, silt, and sand size fractions (Kilmer and Alexander 1949; Gee and Bauder 1986). Fine clay fractions were determined using a combination of the pipette method and centrifugation. Samples with > 0.5% organic carbon were pretreated with hydrogen peroxide (30%) to reduce potential interference of organic matter with sedimentation rates. Concentration of iron oxides, cation exchange capacity (CEC), exchangeable bases, total concentration of 24 elements, and pH were the selected chemical analyses. All procedures included two replications of each sample.

Iron oxides were extracted using a citrate-dithionite (cd) method described by Olsen and Ellis (1982). Exchangeable cations were extracted by saturation with ammonium acetate at pH7 combined with a NaCl vacuum extraction procedure (Jackson 1958; and Baker and Suhr 1982; Hammer and Lewis 1987). The extracts for both procedures were analyzed for Fe and bases using a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. A direct displacement method and titration with 0.01 M HCl was used to determine CEC (Rhoades 1982) which was measured with a Lab Conco distillation unit. A modification of Nadkarni's (1984) microwave oven acid digestion technique which uses HF and an aqua regia solution (mixture of HCl and HNO_3) to digest inorganic matrices was used to solubilize the soil samples for elemental analysis (Gallagher 1993; Ammons et al. 1995). After the neutralization of the unreacted HF with boric acid, extracts were analyzed with a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Spectrometer (ICAP-AES) for 24 elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu , Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Ti, Zn, and Zr). A combination pH electrode and a 1:1 soil sample to water ratio was used to determine pH (McLean 1982).

For purposes of simplification, results graphed by depth were plotted by midpoint depth for each horizon so that the plot point value represents the value for the entire horizon.

Results and Discussion

Native pedon 1 formed in colluvial material over a residual paleosol, and native pedon 2 developed in loess over a residual paleosol. The horizonation sequence in both native pedons included argillic horizons (Table 1). Percent base saturation, pH, color, and clay content in both paleosols were similar, indicating that the paleosol in both native pedons formed in the same residual material (Tables 1 and 2). Fine clay to total clay ratios, free iron, and cation exchange capacity all reached maximums in the argillic horizons of both profiles (Fig 4).

Spoil 1 developed in backfill material which appeared to have been highly pre-weathered prior to deposition in a spoil. Properties in spoil 1 (2 - 140 cm) such as base saturation, CEC, pH, and matrix color greatly resembled those for the paleosols in native pedons 1 and 2 (Tables 1,2,3 and 4). This suggests that the buried paleosols in the native pedons are the dominant source of overburden material in which spoil 1 formed (Fig 5). Assuming this, the red color due to high iron content in spoil 1 reflect the development of the spoil material (paleosol

Table 1. Morphology of native pedons 1 and 2.

Horizon	Lower Depth	Color	Texture	Structure	Boundary	Cons.	Mn Concr.†	Mottles
Native1	cm	moist				moist		
Oe	3-0							
A	16	10YR 4/4	SiL	2 mgr	cw	vfr	--------	--------
EB	35	7.5YR 5/6	SiL	1 mgr	cw	vfr	--------	--------
Bt1	60	5YR 5/6	gr. SiCL	1 msbk	cw	fr	c,f	c,d 7.5YR 5/6
Bt2	78	7.5YR 5/6	C	2 msbk	cw	fi	--------	f,p 10R 4/8
BC	94	10YR 6/6	vgr. C	1 fsbk	cw	vfr	--------	c,p 5YR 5/8
2Bt	116+	5YR 4/6	gr. C	2 msbk	--------	fi	--------	c,p 10YR 6/6
Native 2								
Oe	3-0	--------	--------	--------	--------	--------	--------	--------
A	21	10YR 4/4	SiL	2 mgr	cs	vfr	--------	--------
BE	32	7.5YR 4/6	SiL	1 msbk	cs	fr	--------	--------
Bt	58	7.5YR 4/4	SiCL	2 msbk	cw	fr	--------	--------
2Ab	95	10YR 5/4	vgr. SiL	1 fgr	cs	vfr	--------	--------
3Bt	108+	5YR 4/6	v.cob. C	2 msbk	--------	fi	--------	f,p 10YR 6/6

† Manganese concretions

Table 2. Chemical properties including exchangeable cations, base saturation, and pH, and total clay of native pedons 1 and 2.

Horizon	Lower Depth	NH_4OAc Extractable Cations				Total Bases	NH_4OAc CEC	Base Saturation	pH 1:1 H_2O	Total Clay
		Ca	Na	K	Mg					
	cm	$cmol_c\ kg^{-1}$						%		%
Native 1										
A	16	0.92	0.04	0.22	0.42	1.60	8.10	19.8	4.7	19.2
EB	35	0.47	0.04	0.13	0.66	1.30	4.40	29.5	4.8	23.9
Bt1	60	1.39	0.04	0.12	1.53	3.08	9.19	33.5	4.7	38.5
Bt2	78	1.84	0.05	0.16	1.37	3.42	12.11	28.2	4.7	54.7
BC	94	1.85	0.05	0.14	1.09	3.13	8.83	35.4	4.6	45.5
2Bt	116+	2.13	0.05	0.20	1.51	3.89	13.23	29.4	4.6	67.0
Native 2										
A	21	0.55	0.08	0.20	0.45	1.28	6.30	20.3	4.5	16.0
BE	32	0.87	0.06	0.21	0.82	1.96	7.54	26.0	4.5	25.1
Bt	58	2.70	0.10	0.19	1.19	4.19	11.67	35.9	4.7	33.4
2Ab	95	0.88	0.10	0.18	0.46	1.61	7.21	22.3	4.7	24.0
3Bt	108+	1.91	0.05	0.25	1.04	3.25	11.24	28.9	4.7	54.1

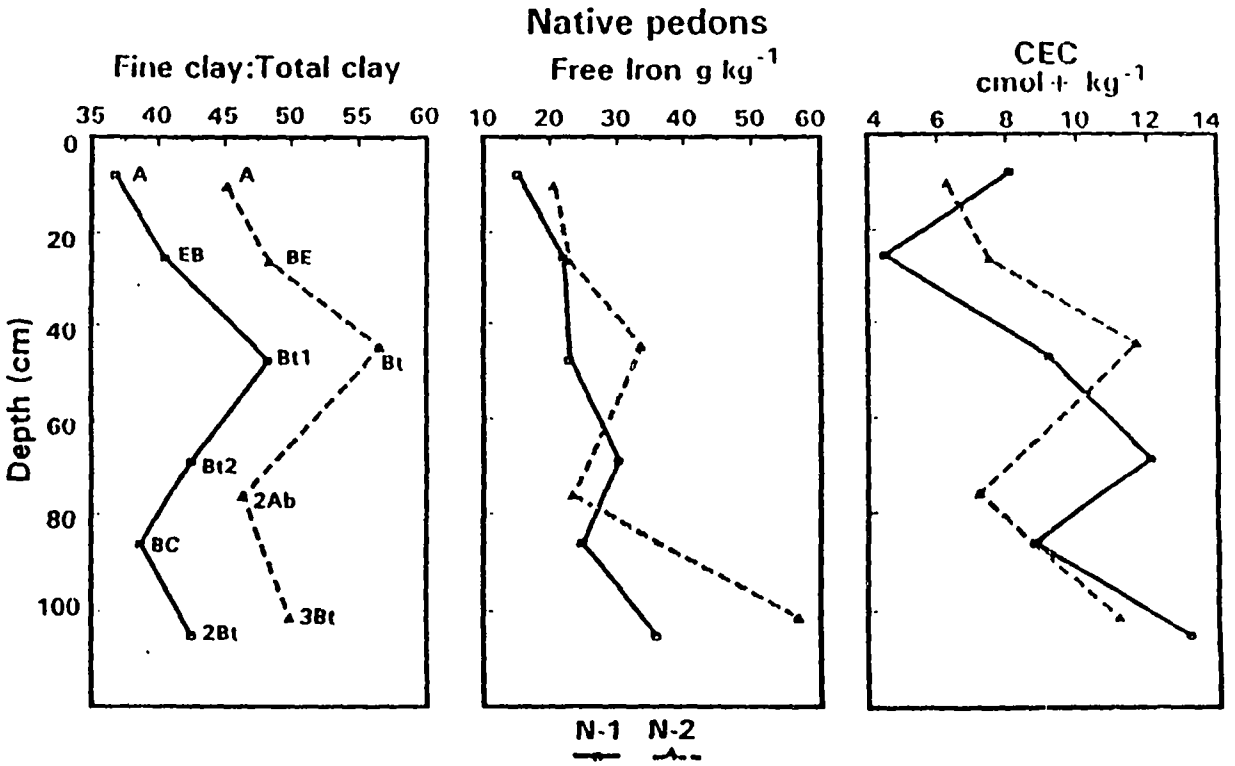

Figure 4. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in native pedons 1 and 2.

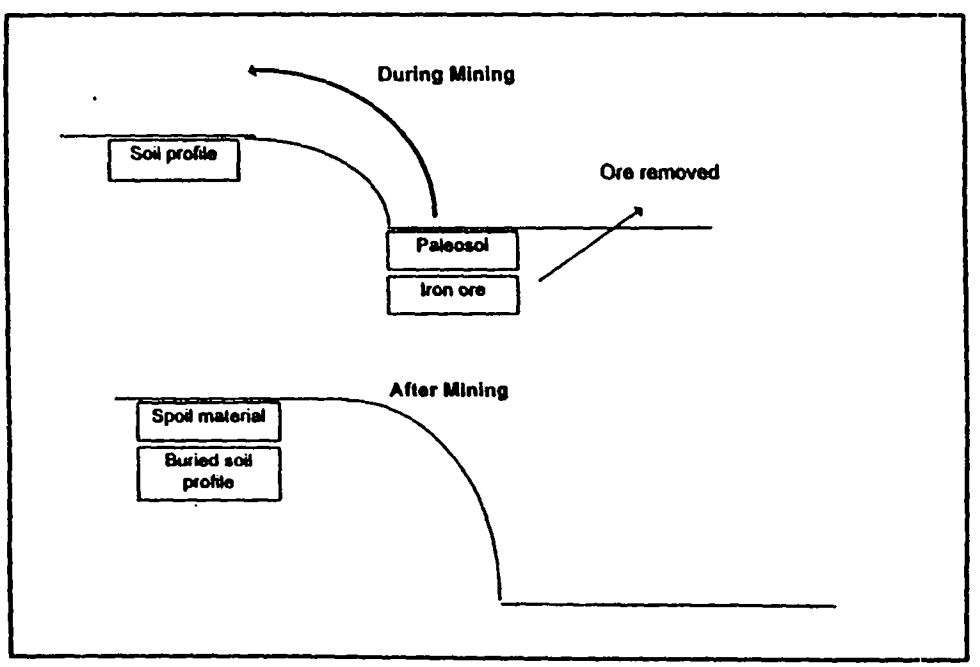

Figure 5. Hypothesized origin of spoil material for spoil 1.

Table 3. Morphology of spoils 1 and 2.

Horizon	Lower Depth	Color	Texture	Structure	Bridging Voids	Boundary	Cons.	Mn Concr.†	Mottles
Spoil 1	cm	moist					moist		
Oe	3-0	----------	----------	----------	----------	----------	----------	----------	----------
A	2	7.5YR 3/1	CL	2 mgr	----------	as	vfr	----------	----------
Bw1	30	5YR 4/6	SiC	2 mgr*	few	cs	l	c,f	c,d 7.5YR 4/4
Bw2	70	2.5YR 4/8	vgr. SiC	2 mgr*	common	gs	l	----------	m,d 7.5YR 4/4
C	140	2.5YR 3/6	SiCL	2 mgr*	common	gw	l	----------	c,d 7.5YR 4/6
2Ab	160+	7.5YR 4/4	SiCL	2 mgr*	----------	----------	fr	----------	----------
Spoil 2									
Oe	2-0	----------	----------	----------	----------	----------	----------	----------	----------
A	6	10YR 3/4	gr. CL	2 mgr	----------	cw	vfr	----------	----------
C1	41	7.5YR 5/6	ex.cob. C	0 m	few	cs	fr	c,f	m,p 2.5YR 4/8
C2	93	7.5YR 4/4**	vgr. C	0 m	few	cw	fr	c,f	c,d 7.5YR 5/8
C3(L)»	108	2.5YR 4/8 10YR 4/6	vgr. C	0 m	----------	cs	fr	c,f	c,d 7.5YR 3/2 c,p 7.5YR 6/8
C3(R)»	108+	7.5YR 5/6	ex.gr. C	0 m	----------	----------	fr	----------	f,p 2.5YR 4/6

† Manganese concretions
*Material did not fit morphology structures in Soil Survey. To avoid confusion of field descriptions, the Taxonomy structure the material resembled most was selected.
**Mottled matrix color
»Material contrasted in horizon between left and right portion of the profile

Table 4. Chemical properties including exchangeable cations, base saturation, and pH, and total clay of spoils 1 and 2.

Horizon	Lower Depth	NH_4OAc Extractable Cations				Total Bases	NH_4OAc CEC	Base Saturation	pH 1:1 H_2O	Total Clay
		Ca	Na	K	Mg					
	cm	$cmol_c\ kg^{-1}$						%		%
Spoil 1										
A	2	19.71	0.27	0.46	4.19	24.64	32.54	75.7	5.1	29.5
Bw1	30	0.43	0.04	0.22	0.67	1.36	12.48	10.9	4.3	45.3
Bw2	70	1.63	0.22	0.22	1.95	4.02	11.92	33.7	4.7	42.8
C	140	1.67	0.06	0.24	1.44	3.42	12.50	27.4	4.7	35.6
2Ab	160+	0.97	0.08	0.19	1.04	2.29	10.83	21.1	4.9	30.7
Spoil 2										
A	6	23.32	0.12	0.64	5.61	29.69	30.87	96.2	6.2	36.3
C1	41	5.73	0.07	0.53	3.30	9.63	14.22	67.7	5.7	53.5
C2	93	1.32	0.05	0.24	0.98	2.58	9.62	26.8	4.6	45.3
C3(R)	108	2.68	0.05	0.14	1.71	4.58	12.05	38.0	4.7	59.2
C3(L)	108+	1.64	0.04	0.19	1.35	3.22	10.54	30.6	4.5	49.8

material) prior to deposition in a spoil. Differences in clay content in spoil 1 compared to the paleosol material indicates that mixing with loess material had occurred during placement of the overburden material. Spoil 2 developed in backfill material that was less pre-weathered and originated from limestone material originally underlying the iron ore before mining occurred. It was abundant with cherty coarse fragments. Coarse fragments in the upper portion of spoil 2 appeared less weathered than fragments at lower depths, reversing the weathering sequence expected from pedogenic processes. This suggests that during the mining process the material was removed and backfilled from higher depths to lower depths, so that material originally at a lower depth (less weathered) was deposited at the upper portion of the spoil.

Bridging voids (packing voids), averaging 1 cm in diameter, were observed between rock fragments and soil material in the subsoil of both spoils. The voids were not present in either native pedon. Both spoils had a higher occurrence of color mottling not associated with anaerobic conditions than the native soils (Table 3). Presumably, these mottles resulted from contrasting materials mixed together during the spoil construction. Moderate medium granular structure was observed in the surface horizon of both spoils. Differences in thickness of the surface horizon between spoil 1 and 2 were a result of differences in landscape position. Spoil 1 was positioned at the shoulder of a hollow more susceptible to surface erosion than the more stable position of spoil 2 (in a drainageway).

Subsoil structure observed in spoil 1 was better described by the "man-made" structure termed "fritted" proposed by McSweeney and Jansen (1984) than the morphology structures outlined in Soil Taxonomy. Massive structure was observed throughout the subsoil of spoil 2. Subsoil horizonation differed between the spoils. A cambic horizon had developed in spoil 1 noted by change in color and fine clay movement (Table 4 and Fig. 6). Diagnostic subsurface horizons did

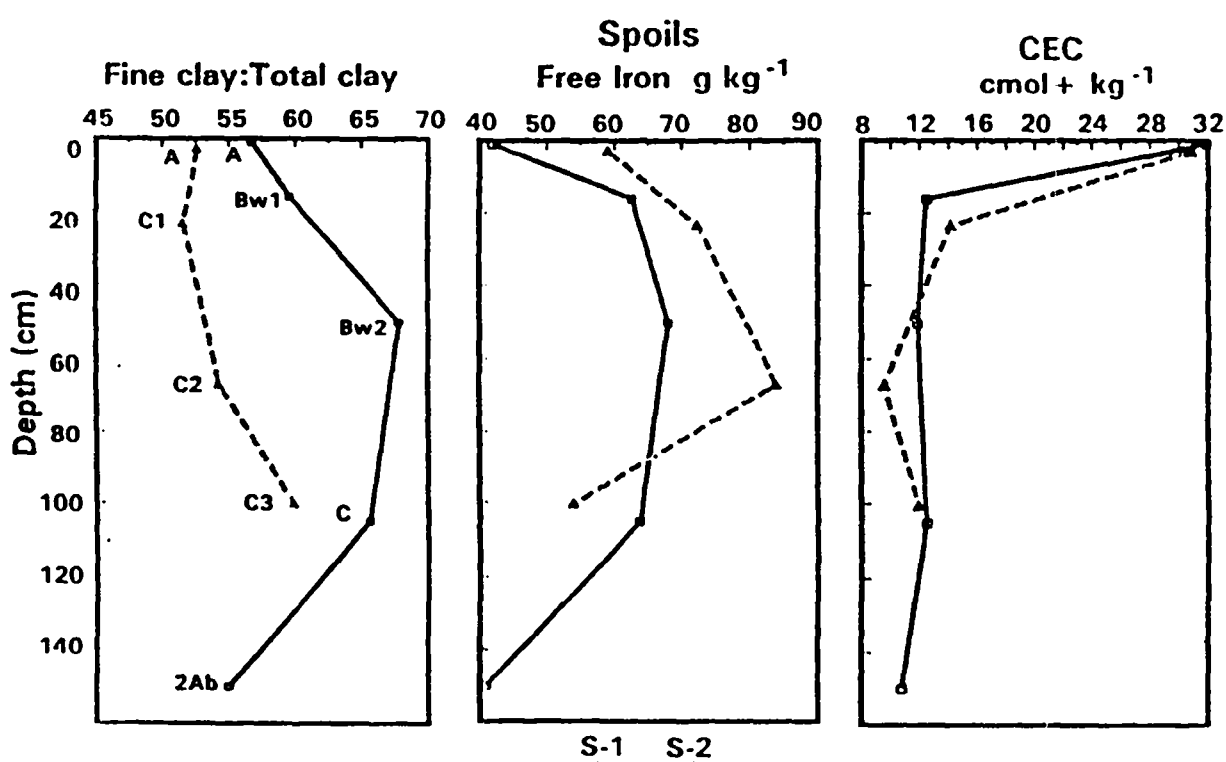

Figure 6. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in spoils 1 and 2.

not develop in spoil 2. Differences in soil structure and preweathered condition of parent material most likely accounts for the difference in subsoil development between them.

Total iron and free iron concentrations in both spoil profile's were approximately double that of the native pedons (Figs. 4 and 6; Table 5a and b). An "enrichment" of iron oxides was expected in the spoils due to their parent material source having been associated with the origin and mining of the iron ore. Total barium (Ba) was highest in the surface horizons of both native pedons and spoils except for the buried horizon in spoil 1 (Table 5a and b). Total barium almost doubled in the buried A horizon (from the overlying horizon) in spoil 1 but not in the buried A horizon of native pedon 2. Total manganese (Mn) concentrations were significantly highest (α 0.05) in the surface horizons of all four pedons and generally decreased with depth. In spoil 1, total manganese significantly increased in the buried A horizon from overlying horizons. Trace element concentrations in the buried A horizon in native pedon 2 did not tend to increase such as those in the buried A horizon of spoil 1. Lower clay content, lower total carbon content, differences in parent material, and higher coarse fragment contents in the buried horizon in native pedon 2 presumably reduced its ability to retain trace elements compared to the buried horizon in spoil 1. Total copper (Cu) was significantly higher in the surface horizon compared to subsurface horizons in native pedon 1 and both spoils. Distribution of sulfur by depth differed between the native pedons and the spoils. Total sulfur (S) was significantly highest in the surface horizons of the spoils.

Hartley's test indicated if variations of a selected element in row 3 (40 - 60cm) were significantly different between any two sites. Total carbon, total aluminum, barium, manganese, phosphorus, titanium, and zirconium were the elements compared between sites (Table 6). Variation of manganese and zirconium were not significantly different (α 0.05) between any two sites. Variances of total carbon, total aluminum, barium, phosphorus, and titanium were not consistently significantly different between the native pedons and the spoils.

Conclusions

1. The buried paleosols in the native pedons are the primary origin of overburden material in which spoil 1 formed. Mixing of this material with loess had occurred. Less preweathered cherty limestone material originally below the iron ore was the source of overburden material for spoil 2.

2. The differences in origin of overburden material and the degree of weathering prior to placement in a spoil accounted for morphologic differences such as subsoil development, color, carbon content, rock fragment content, and iron oxide concentration between spoil 1 and 2.

3. A cambic horizon developed in spoil 1. A diagnostic subsurface horizon did not develop in spoil 2. The "fritted" structure with a loose (noncoherent) consistence observed in spoil 1, not present in spoil 2, accelerated the rate of fine clay and free iron movement to the degree of forming a weakly developed cambic horizon within 140-170 years. The massive structure throughout spoil 2 did not allow as much water through the profile, limiting profile development.

4. Bridging voids, averaging about 1 cm in diameter, were observed in both soils (minesoils) but not in the native soils.

5. Moderate medium granular structure formed in the surface horizons of both spoils as well as the native pedons.

6. The association of the spoil material with the iron ore during the mining process enriched the spoil materials with iron oxides.

7. In general, trace elements were highest in the surface horizons of both minesoils and native soils and

Table 5a and b. Total elemental concentrations determined using an acid digestion technique for native pedons 1 and 2 and spoils 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm	g kg^{-1}			mg kg^{-1}				
Native 1									
A	16	27.2	17.7	9.3	420	4,510	50	30	70
EB	35	33.8	22.3	9.6	370	1,250	10	40	<2
Bt1	60	51.2	36.5	9.4	320	2,030	<3	70	<2
Bt2	78	61.4	38.9	10.4	280	1,190	20	70	10
BC	94	44.5	29.9	9.9	220	1,520	10	50	10
2Bt	116+	71.6	43.1	12.0	240	1,150	<3	80	<2
LSD*$_{05}$		2.6	2.2	1.5	90	750	30	10	5
Native 2									
A	21	29.6	23.3	11.2	500	1,240	30	30	20
BE	32	42.2	25.3	13.4	460	930	20	30	20
Bt	58	49.7	37.5	11.8	390	1,200	20	40	20
2Ab	95	32.8	29.4	8.9	290	890	20	30	10
3Bt	108+	71.1	59.1	11.9	260	1,000	10	90	5
LSD*$_{05}$		1.1	1.6	0.6	170	360	10	10	20

*LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm	mg kg^{-1}									
Native 1											
A	16	1,270	1,560	5,560	30	250	870	80	1,580	80	80
EB	35	1,480	600	1,910	30	190	120	30	2,340	40	100
Bt1	60	2,700	140	1,060	60	220	270	50	1,920	210	80
Bt2	78	3,080	160	620	50	230	270	60	2,020	200	80
BC	94	2,810	110	360	60	80	650	60	1,520	130	60
2Bt	116+	3,930	80	260	60	300	470	50	2,050	220	80
LSD$_{05}$		170	50	1,400	20	80	290	30	200	70	10
Native 2											
A	21	1,310	1,230	3,200	20	70	120	60	2,190	50	100
BE	32	1,940	620	2,840	20	50	100	50	2,600	160	110
Bt	58	2,680	510	2,040	20	<5	100	50	2,770	60	110
2Ab	95	1,670	480	1,440	20	<5	40	40	2,130	60	90
3Bt	108+	3,340	90	270	40	90	100	70	2,480	120	80
LSD$_{05}$		200	20	870	20	30	100	20	90	160	5

Table 5a and b. Total elemental concentrations determined using an acid digestion technique for native pedons 1 and 2 and spoils 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm	g kg^{-1}			mg kg^{-1}				
Spoil 1									
A	2	30.9	41.2	4.9	280	5,790	30	40	40
Bw1	30	66.3	66.4	8.6	250	750	10	60	5
Bw2	70	62.1	68.5	4.9	280	1,040	10	50	10
C	140	58.4	75.6	6.8	260	780	20	40	10
2Ab	160+	51.1	44.7	12.0	450	870	20	30	10
$LSD_{.05}$*		16.5	12.4	0.6	170	520	20	10	30
Spoil 2									
A	6	39.4	61.1	8.6	280	8,670	<3	60	30
C1	41	73.0	76.9	13.1	230	2,100	<3	100	<2
C2	93	72.0	94.0	9.0	280	810	20	60	<2
C3(L)	108+	92.6	65.9	11.6	360	1,200	10	120	10
C3(R)	108+	73.1	53.0	14.8	280	970	20	110	10
$LSD_{.05}$*		2.0	1.6	0.7	10	140	5	10	10

*LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm	mg kg^{-1}									
Spoil 1											
A	2	1,580	820	1,980	20	520	770	70	1,330	140	50
Bw1	30	2,400	380	990	40	110	150	40	2,660	150	90
Bw2	70	2,280	310	870	40	130	110	30	2,820	120	90
C	140	2,180	490	750	40	60	80	40	2,820	90	80
2Ab	160+	2,330	780	2,380	30	30	10	50	2,720	50	100
$LSD_{.05}$		230	120	1,090	20	140	70	30	170	60	10
Spoil 2											
A	6	2,930	1,510	3,890	40	700	1,130	60	980	240	40
C1	41	4,290	790	400	60	580	30	70	2,610	290	70
C2	93	2,180	630	1,040	30	180	110	60	2,690	160	80
C3(L)	108+	3,580	180	360	70	750	180	150	2,650	260	100
C3(R)	108+	4,290	690	320	80	530	50	70	1,900	380	80
$LSD_{.05}$		70	100	90	20	100	90	5	970	70	10

Table 6. List of calculated F values, using Hartley's test of homogeneity of variances, between all sites.

Between Sites	% total carbon	Al	Ba	Mn	P	Ti	Zr
	F_c						
N1/N2	3.0	16.8*	1.8	2.8	3.2	8.8*	2.0
N1/S1	9.0*	27.1*	17.9*	3.7	1.2	1.6	4.4
N1/S2	1.6	1.4	7.5*	5.7	3.3	1.7	1.0
N2/S1	2.9	1.6	9.9*	1.3	3.7	5.5	2.2
N2/S2	4.8	19.0*	4.2	2.0	10.6*	5.3	2.0
S1/S2	14.0*	30.0*	2.4	1.5	2.9	1.0	4.4

*Calculated F value exceeded tabular F value at a 95% confidence level ($F_{\alpha=0.05\ df\ 4,4} = 6.4$) indicating a significant difference between the variations for the two sites for that elemental concentration.

the buried surface horizon in minesoil 1. Of the trace elements, total barium and manganese best identified the buried A horizons.

8. Variations for seven selected chemical analyses at a depth of 40-60cm were not consistently significantly different between spoils and native pedons at a 0.05 alpha level.

Literature Cited

Ammons, J.T. and J.C. Sencindiver. 1990. Minesoil mapping at the family level using a proposed classification system. J. of Soil and Water Cons. 45:566-571.

Ammons, J.T., M.E. Essington, R.J. Lewis, A.O. Gallagher, and G.M. Lessman. 1995. An application of a modified microwave total dissolution technique for soils. Commun. Soil Sci. Plant Anal. 26:831-842.

Baker, D.E., and N.H. Suhr. 1982. Atomic absorption and flame emission spectrometry. p 13-27. *In* A.L. Page (ed.). Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr. 9. ASA. Madison, WI.

Bell, J.C., R.L. Cunningham, and C.T. Anthony. 1994. Morphological characteristics of reconstructed prime farmland soils in Western Pennsylvania. J. Environ. Qual. 23:515-520.

Burchard, E.F. 1934. Brown iron ore of the Western Highland Rim, Tennessee. US Geological Survey Bull. 39. Division of Geology. Nashville, TN.

Gallagher, A.O. 1993. A modified method of total elemental analysis for determining background metals in Tennessee. M.S. thesis. University of Tennessee.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. p. 383-411. *In* A. Klute (ed.). Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA, Madison, WI.

Haering, K.C., W.L. Daniels, and J.A. Roberts. 1993. Changes in mine soil properties resulting from overburden weathering. J.Environ.Qual. 22:194-200.

Hammer, R.D., and R.J. Lewis. 1987. Extraction time requirements for determination of exchangeable bases with a mechanical vacuum extractor. Soil Sci. Soc. Am. J. 51: 828-831.

Hershey, R.E. and S.W. Maher. 1963. Limestone and dolomite resource of Tennessee. Division of Geology. 65 Nashville, TN.

Indorante, S.J. and I.J. Jansen. 1984. Perceiving and defining soils on disturbed land. Soil Sci. Soc. Am. J. 48:1334-1337.

Jackson, M.L. 1958. Soil chemistry: A first course. 6th ed. Madison, WI.

Killebrew, J.B. 1874. Tennessee: Its agricultural and mineral wealth. Trave and Howell printers. Nashville, TN.

Kilmer, V.J. and L.T. Alexander. 1949. Methods of making mechanical analysis of soils. Soil Science. 68:15-24.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. *In* A.L. Page, et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9, ASA, Madison, WI.

McSweeney, K. and I.J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. Soil Sci. Soc. Am. J. 48:607-612.

Nadkarni, R.A. 1984. Applications of microwave oven sample dissolution. Analysis-Analytical Chemistry. 56: 2233-2237.

Olsen, R.V., and R. Ellis. 1982. Free iron oxides. p 301-312. *In* A.L. Page et al. (ed.). Methods of soil analysis. Part 2. 2nd ed.

Agron. Monogr. 9. ASA. Madison, WI.

Ott, R.L. 1993. An introduction to statistical methods and data analysis. Duxbury Press. Belmont, CA. pp. 785-788.

Potter, K.N., F.S. Carter, and E.C. Doll. 1988. Physical properties of constructed and undisturbed soils. Soil Sci. Soc. Am. J. 52:1435-1438.

Rhoades, J.D. 1982. Cation exchange capacity. p. 149-157. *In* A.L. Page (ed.). Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr. 9. ASA. Madison, WI.

Safford, J.P. 1856. A geological reconnaissance of the state of Tennessee. 1st biennial report. G.C. Torbett. Nashville, TN.

Schafer, W.M. 1979. Variability of minesoils and natural soils in Southeastern Montana. Soil Sci. Soc. Am. J. 43:1207-1212.

Schafer, W.M., G.A. Nielson, and W.D. Nettleton. 1980. Minesoil genesis and morphology in a spoil chronosequence in Montana. Soil Sci. Soc. Am. J. 44:802-807.

Smith, D., C. Stripling, and J. Brannon. 1988. Tennessee's western highland rim iron industry a cultural survey. Dept. of Cons. Division of Archaeology. Series no. 8. TN.

Smith, R.M., E. Tryon, and E. Tyner. 1971. Soil development on mine spoil. West Virginia University. Agri. Exper. Stat. Morgantown.

Snedecor, G.W. 1956. Statistical methods applied to experiments in agriculture and biology. 5th ed. Iowa State Univ. Press. Ames. IA. p. 96.

Soil Survey Staff. 1984. Soil survey investigations report no. 1. USDA-SCS. U.S. Gov. Print Office, Washington, D.C.

Soil Survey Staff. 1993. Soil survey manual. USDA Handb. 18. U.S. Gov. Print Office, Washington, D.C.

Springer, M.E. and J.A. Elder. 1980. Soils of Tennessee. University of Tennessee Agri. Exper. Stat. Bull. 596. Knoxville, TN.

Thurman, N.C. and J.C. Sencindiver. 1986. Properties, classification, and interpretations of minesoils at two sites in West Virginia. Soil Sci. Soc. Am. J. 50:181-185.

CROP AND SOIL RESPONSES TO SEWAGE SLUDGE APPLIED TO RECLAIMED PRIME FARMLAND[1]

BY

Qiang Zhai and Richard I. Barnhisel[2]

Abstract. Improvements in reclamation of surface mined prime farmland may be abtained by adding sewage sludge to topsoil and subsoil. This prime farmland reclamation study was done in western Kentucky. The experiment was conducted to investigate effects of the sludge amendment to topsoil and subsoil on soil and crop responses. The experiment showed, in most cases at highest application rates, that the sludge addition significantly increased the soil organic matter, total N content, and available P levels. However, water holding capacity, CEC, and exchangeable cations were not significantly affected. Higher microbial populations and activites were also obtained. The wheat biomass, tiller number, tissue N, grain N, grain yield, and N removal in grain were well correlated with application rates of sewage sludge. Corn also responded positively to additions of sewage sludge. The corn ear-leaf N concentration, grain yield, and grain N removal increased with application rates of sewage sludge. Experiments indicated that topsoil and subsoil sewage sludge addition was beneficial practices in terms of increasing crop yield and improving some soil properties.

Additional Key Words: organic matter, reclamation, sewage sludge, soil properties, wheat and corn yields.

Introduction

The original soil ecosystem, structure, horizons, microbial community, and fertility may be drastically affected by surface mining (Barnhisel et al., 1987). Return of the productivity of mined prime farmland to conditions equal to or greater than those of the original soil prior to mining is a requirement of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

In the past 10 years, several projects have been reported on the use of inorganic fertilizer to meet the requirements of recovery of soil properties and crop yield for reclaimed prime farmlands, but few have included organic amendments. Organic materials, such as sewage sludge, peat, and wood residue have been extremely successful only for spoil reclamation compared to inorganic fertilizers (Fresquez and Lindemann, 1982). The high organic matter of waste amendments largely ameliorates the physical conditions of mine spoil. Soil properties that benefit from sludge incorporation includes water holding capacity, bulk density, water-stable aggregates and hydraulic conductivity. (Sopper, 1992).

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Chemical properties of mine spoils affected by organic amendments include raising acidic spoil pH, and increasing CEC, N and P nutrients, but effect on K, Ca, and Mg levels varies depending on the characteristics of amendments (Sopper, 1992). Microbial population and activities are often stimulated by organic amendments (Sopper, 1992). However, few studies if any have quantitatively measured the effect of organic waste application on physical, chemical, and biological properties as well as on crop yield of disturbed prime farmland.

The objectives of this study were to determine the effects of sewage sludge applied to either topsoil and/or subsoil on soil physical, chemical, and biological properties, as well as wheat and corn responses seeded to a reclaimed prime farmland soil following surface mining. The hypotheses were that adding sewage sludge in topsoil or subsoil may significantly improve soil physical, chemical, and biological properties and increase crop yields.

Materials and Methods

Field procedures

The mine is located in Henderson County, western Kentucky. The replacement of spoil and subsoil was completed in 1989 and seeded to cover crops including wheat and tall fescue. The reconstruction of topsoil was done in the summer of 1992 following sewage sludge additions. The original soil disturbed by surface mining activities was the Grenada (fine-silty, mixed, thermic Glossic Fragiudalfs) silt loam soils. The topsoil and subsoil were separately stockpiled and were mixed during the soil removing and replacing processes.

Two sewage sludge experiments were initiated, one in which sewage sludge was applied only to the subsoil (Zhai, 1995), and the other in which sewage sludge was applied to both subsoil and topsoil. Only the results from the latter experiment will be reported here. The sewage sludge was from the Henderson Water and Sewage Utilities. Characteristics of the sludge are shown in Table 1. The experiment design was completely randomized block with three replications.

Table 1. Physical and chemcal properties of sewage sludge.

Water content	(%)	42.9
Total N	(g kg^{-1})	26.3
NH_4-N	(mg kg^{-1})	536
NO_3-N	(mg kg^{-1})	330
Cd	(mg kg^{-1})	0.16
Cr	(mg kg^{-1})	0.64
Cu	(mg kg^{-1})	2.23
Pb	(mg kg^{-1})	0.16
Ni	(mg kg^{-1})	0.80
Zn	(mg kg^{-1})	0.16

Sewage sludge at rate 22.4 Mg ha^{-1} was uniformly applied to the subsoil prior to the topsoil replacement. Then 0, 11.2, and 22.4 Mg ha^{-1} sewage sludge were applied to the topsoil. All sewage sludge was applied as described above and incorporated to a 15 cm depth in both the topsoil and subsoil with a chisel plow.

The topsoil (0-15 cm) was sampled after sludge application on September 6, 1992. Every soil sample from each plot was taken by a hand sampler and was made up of by ten cores taken throughout the study period.

On October 16, 1992, the entire area received a broadcast application of N fertilizer (NH_4NO_3) at a rate of 70 kg N ha^{-1} and planted to wheat (*Triticum aestivum*, L.) at seeding rates of 136 kg ha^{-1}. On May 11, 1993, this experiment site was divided into two parts. One part was retained for wheat yield measurements. For the other part, the wheat was killed with a mixture of atrazine (4WDL) and "Roundup" at a rate of 3.0 and 1.8 L ha^{-1}, respectively.

Corn (Zea mays L.) was planted at a seeding rate of 59,000 kernels ha^{-1} using a Kinze no-till planter.

Topsoil (0-15 cm) was sampled again on September 1993 for biological analyses. The soil sampling procedure was the same as described above.

Wheat tiller numbers were counted from 20 randomly selected plants from each plot and their above-ground plant tissue was sampled on May 5 for biomass determination and chemical analyses. Wheat grain was harvested on July 3, 1993 with a plot combine. Yields were measured based on the standard 12.5% moisture. A wheat grain sample (200 g) was collected from each plot at harvest for chemical analyses.

Corn ear-leaves were taken during late silking growth stage on July 29, 1993, from six randomly selected corn plants in each plot. Corn grain was harvested on October 2, 1993 with the same plot combine. Yields were measured and based on the standard 15.5% moisture content. A corn grain sample (200 g) was collected at harvest from each plot for chemical analyses.

Soil analyses

Soil bulk density was determined by Blake and Hartge, except that the core size was 4.5 cm (1986). Water-holding capacity was determined using the method developed by Klute (1986). The soil samples for chemical analyses were air-dried, and ground to pass a 2-mm sieve. Soil pH was determined with a pH meter on a 1:1 deionized water to soil mixture (McLean, 1982). Exchangeable Ca, Mg, K, and Na and CEC were determined with the neutral M NH_4OAc method (Thomas, 1982). Available P was determined using the Bray-I (Bray and Kurtz, 1945). Organic matter (Nelson and Sommers, 1982) and total nitrogen (Bremner and Mulvaney, 1982) were performed by the University of Kentucky Soil Testing Laboratory, Division of Regulatory Services.

Soil microbiological analyses were performed using moist soils. Total heterotrophic and facultative anaerobic organisms were enumerated by the Most Probable Number method (Alexander, 1982). The numbers of organisms were calculated based on oven-dry soil. Microbial biomass (C) was determined using a chloroform fumigation procedure (Parkinson and Paul, 1982). Soil respiration rate (CO_2 evolution rate) in the laboratory was measured by gas chromatography on a Varian 3700 gas chromatograph equipped with Porapak Q column operated at 80°C (Rice and Smith, 1982).

Plant analyses

Wheat tissue and corn ear-leaf samples were dried and ground to pass a 0.425 mm sieve. The samples were then analyzed for N, P, K, Ca, and Mg which were all determined based on Jones and Case (1990).

Statistical analyses

Statistical analyses were performed using the Statistical Analysis System (SAS Institute, 1985). General linear Models (GLM) procedure was used to obtain the analyses of variance based on the experiment design.

Results and Discussion

Soil responses

The effects of sewage sludge application on soil physical, chemical, and biological properties are shown in Tables 2. The significant increase in soil organic matter, total N, and Bray I-P, is attributed to the sludge application. Soil water holding capacity, pH, CEC, and exchangeable Ca, Mg, K, and Na were not significantly altered. Sewage sludge application to subsoil had similar effects on soil physical and chemical properties as observed in the sludge applied to

Table 2. Physical and chemical properties of topsoil (0-15 cm) after sewage sludge application on August 25, 1992.

Sludge (Mg/ha)	WHC† (%)	PH	OM (%)	TN (-- mg/kg	Bray I-P -)	CEC (--------	Ca cmol(+)/kg	Mg ---------)	K	Na
0	25.2	5.0	0.82	1110	5.5	9.4	3.26	1.34	0.17	0.07
11.2	25.8	5.0	1.15	1470	6.8	9.8	4.04	1.35	0.19	0.07
22.4	25.2	4.9	1.11	1490	9.2	10.1	4.03	1.35	0.17	0.07
$LSD_{(0.1)}$	NS‡	NS	0.23	267	1.7	NS	NS	NS	NS	NS

† WHC, water holding capacity; OM, organic matter content; TN total nitrogen content.
‡ Not significantly different.

Table 3. Total heterotrophic and facultative anaerobic organisms, microbial biomass, and respiration rates after sewage sludge application to topsoil (0-15 cm) on 7 Sept., 1993.

Sludge Rate (Mg/ha)	Total Heterotrophs (10^7/g)	Facultative Anaerobs (10^7/g)	Microbial Biomass C (mg/kg)	Respiration Rate (mg CO_2/kg h)
0	0.31	0.12	224	30.0
11.2	4.49	0.56	267	39.7
22.4	10.9	1.19	331	55.3
$LSD_{0.1}$	4.25	0.31	58	9.6

topsoil. Significantly higher levels of organic matter, total N, and Bray I-P and pH were observed compared to the control, but other measured properties were not significantly affected.

These results were consistent with those that have been reported for spoil reclamation with sewage sludge. Sewage sludge has increased organic matter content, total N, and Bray I-P in reclaimed spoils according to Sopper (1992).

Total heterotrophic and facultative anaerobic organisms, microbial biomass C, and respiration rates of topsoil affected by sewage sludge application are shown in Table 3. Total heterotrophic and facultative anaerobic organisms increased. The significant increases were observed at the highest sludge application rate. Microbial respiration and biomass C also increased in response to increased sludge addition.

Sewage sludge addition stimulated microbial populations. This agrees with previous research that sewage sludge increases the microbial population of disturbed soils (Sopper, 1992). The enhancement of microbial activity in amended soil is primarily due to two factors. Sewage sludge has high microbial activity with the high bacterial numbers and large amounts of fungal hyphae as well as a nutrient-rich composition (Sopper, 1992).

Microbial activity usually increases as sludge application rate increased as observed in this study. However, this is not always consistent, particularly for sewage sludge. Inhibition of microbial activity was observed by others when heavy loading rates were used (Sopper, 1992). The

inhibition is usually caused by a high content of heavy metals and/or salt. Such an inhibition was not observed here, probably due to the lower contents of heavy metals and salt (Table 1), as well as the lower application rates used here as compared to the sludge studies conducted by other researchers.

Wheat response

Wheat response to sewage sludge were in Table 4. A significant increase in grain yield was observed as a result of sewage sludge addition. A significant difference was not observed between application rates of 11.2 and 22.4 Mg ha^{-1}. The application rates had significant linear and quadratic effects on yields. Grain N removal followed the same basic trend that was observed for grain yield. The amount of N removed significantly increased as the sludge application rate increased.

Plant biomass and tiller numbers are usually good indicators of wheat growth after improvement of soil nutrient status and other physical and chemical properties by organic amendment (D.A. Van Sanford, personal communication). Application of sewage sludge significantly increased wheat above-ground biomass and tiller numbers, but there was no significant difference between the 11.2 and 22.4 Mg ha^{-1} application rates. Significant linear and quadratic responses to application rates were obtained for both biomass and tillers.

Wheat tissue (flag leaf) or grain N concentrations can be used as indicators of N nutrition (Grove et al., 1984). In this study, greater wheat tissue and grain N concentrations were observed in sewage sludge treatments than in the control. Significant linear and quadratic responses of tissue and grain N concentrations to application rates were observed. Tissue and grain N concentrations were significantly correlated with each other (r=0.87***). Tissue and grain N concentration have been frequently used to evaluate crop N nutrition.

Forage crops, as well as others such as silage corn, have significantly responded to sewage sludge in undisturbed prime farmlands (Smith and Peterson, 1982). Winter wheat response to sewage sludge may not be the same as the forage crops because wheat growth is often more sensitive to available soil N. Wheat grain yield is often low due to either low levels of available soil N or too much N. Grove et al. (1984) reported that the lush growth and lodging of winter wheat was due to excessive available soil N. The results of tissue and grain N concentration, grain yield, N removal in the grain have been related to available soil N in studies of wheat response to N fertilizer (Grove et al., 1984). The response of tissue and grain N concentration, grain yield, grain N removal, and tiller numbers in this study indicates that the increase in each of those parameters is well correlated with the addition of sewage sludge.

The sludge addition did not significantly affect wheat tissue P, K, Ca, and Mg. The sewage sludge contribution to crop growth is probably due to supplying available N from the sludge mineralization. This is consistent with results reported by Smith and Peterson (1982) who demonstrated that crop response to sewage sludge is mainly due to available N supplied by the sludge, although sewage sludge may also provide other nutrients.

Corn response

Grain yields and grain N removal in 1993 are shown in Table 5. Grain yields were significantly increased as the results of sewage sludge addition. There was a linear and quadratic rsponse of yield to application rates.

Table 4. Wheat about-ground biomass, tillers, tissue composition, grain yield, and N removal as affected by sewage sludge applied to topsoil and subsoil.

Sludge†	Biomass	Tiller	Tissue Composition					Grain	Grain	N
			N	P	K	Ca	Mg	N	Yield	Removal
(Mg/ha)	(g/tiller)	(#/plant)	(g/kg)					(g/kg)	(Mg/ha)	(kg/ha)
0	2.37	4.30	8.43	1.26	15.5	2.11	0.93	15.1	3.31	49.7
11.2	2.84	5.90	10.2	1.18	17.5	2.01	1.05	17.4	4.24	73.0
22.4	3.38	6.40	11.1	1.25	15.7	1.97	1.09	19.6	4.65	89.9
$LSD_{(0.1)}$	0.64	0.82	0.55	NS‡	NS	NS	NS	16.8	0.52	13.3
C.V.	12.8	8.54	4.49	4.6	22.6	17.6	11.0	5.55	8.16	10.8
Linear	**	***	***					***	***	***
Quad.	**	**	***					***	**	***

† Rates of sewage sludge applied to topsoil were 0, 11.2, and 22.4 Mg ha^{-1}, respectively, and 22.4 Mg ha^{-1} was applied to the subsoil for the entire Experiment II. Linear, linear effect; Quad., quadratic effect.

‡ NS, not significantly different; *, significant at $p<0.1$; ** significant at $p<0.05$; ***significant at $p<0.01$.

Table 5. Ear-leaf composition, grain yield, and N removal in 1993 as affected by organic wast application to topsoil and subsoil.

Trt	Ear-leaf					Grain	N
	N	P	K	Ca	Mg	Yield	Removal
	(g/kg)					(Mg/ha)	(kg/ha)
0	24.7	2.27	19.2	4.02	2.02	4.03	49.5
11.2	25.7	2.33	23.9	4.36	1.87	5.25	73.1
22.4	26.8	2.47	22.4	4.37	2.24	6.22	85.6
$LSD_{0.1}$	0.7	NS†	NS	NS	NS	0.42	6.1
C.V.	2.0	9.7	9.3	6.7	15.7	2.3	4.3
Linear	*		*	*		***	***
Quad.						***	***

† linear effect; Quad., quadratic effect. NS, not significantly different; *, significant at $p<0.1$; ***significant at $p<0.01$.

Corn yields were measure again in 1994. Significantly higher yields were abserved in sludge rates of 5 Mg ha^{-1} (72.9 Mg ha^{-1}) and 10 Mg ha^{-1} (92.9 Mg ha^{-1}) than control plots (52.2 Mg ha^{-1})

Grain N removal followed the trend observed for grain yields. The sewage sludge addition significantly increased grain N removal.

The application of sewage sludge increased ear-leaf N concentrations. Significant sludge effects occurred between application rates. A significant linear relationship was found between ear-leaf N and application rates. The level of ear-leaf N seemed normal. It was between the critical values of 28.2 g kg^{-1} reported by Steele et al. (1982) and the 23 g kg^{-1} reported by Dirks and Bolton (1980).

Ear-leaf P concentration was not significantly affected by the application of sewage sludge, although there was a slight increase as application rates increased. This was probably due to the fact that sewage sludge also supplied available P. Ear-leaf K was significantly increased in both trials, but Ca and Mg was not significantly affected by sewage sludge amendments in either study.

The addition of sewage sludge to soil had apparently increased of ear-leaf N concentration, grain yield, and grain N removal. The N from sludge mineralization likely contributed to these responses. The response of corn to sewage sludge has been reported in

similar experiments on unmined lands. A single application of sewage sludge at rate 7.5 to 30 Mg ha^{-1} following sorghum-sudan significantly increased the corn dry-matter yield at all sludge application rates (Bouldin et al., 1984). Data for yield and N uptake indicate that mineralization of sludge N was supplying a significant amount of N for corn uptake. The amount of N recovered by crops reached 6 to 19 percent of the total N applied, and these values were generally lower than those found for conventional N fertilizer (Bouldin et al., 1984).

The experiment indicated that topsoil and subsoil sewage sludge amendments improved some soil physical, chemical, and biological properties, and crop N nutrition and yields.

Literature Cited

Alexander, M. 1982. Most probable number method for microbial populations. p.815-820. In Methods of soil analysis. A.L. Page et al. (eds.) Part 2. 2nd ed. Agron. Monogr. 9. ASA, Madison, WI.

Barnhisel, R.I., J.L. Powell, and D.H. Hines. 1987. Changes in chemical and physical properties of two soils in the process of surface mining. Am. Soc. Surface Mining and Reclamation 4:87-97.

Blake, G.R. and K.H. Hartge. 1986. Soil bulk density. p.363-376. In A. Klute (ed.) Methods of soil analysis. Part 1. Physical and mineralogical methods. Agron. mono. 9. ASA, Madison, WI.

Bouldin, D.R., S.D. Klausner, and W.S. Reid. 1984. Use of nitrogen from manures. p.221-243. In Nitrogen in crop production. R.D. Hauch (ed.). ASA, Madison, WI.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Bremner, J.M. and C.S. Mulvaney. 1982. Soil total nitrogen. p.595-622. In A.L. Page (ed.) Methods of Soil Analysis - part 2: Chemical and microbiological properties. Agronomy 9 .ASA, Madison, WI.

Dirks, V.A. and E.F. Bolton. 1980. Regression analyses of grain yield of corn, level of leaf nitrogen, phosphorus, potassium and soil conditions in a long-time rotation experiment on Brookston clay. Can. J. Soil Sci. 60:599-611.

Fresquez, P.R. and W.C. Lindemann. 1982. Soil and rhizosphere microorganisms in amended coal mine spoils. Soil Sci. Soc. Am. J. 46:751-755.

Grove, J.H., B.F. Hicks, and D.C. Ditsch. 1984. Tillage related nitrogen responses of soft red winter wheat grown in he corn-wheat-double crop soybean rotation. p.37-38. In M.T. Nielsen (comp.) Agron. Res. Report, Univ. of Kentucky, Coll. Agr., Exp. Sta., Dept. Agron. Lexington, KY.

Jones, J.B., Jr., and V.W. Case. 1990. Sampling and analyzing plant tissue samples. p.405-415. In R.L. Westerman (ed.) Soil testing and plant analysis. 3rd ed. SSSA. Madison, WI.

Klute, A. 1986. Water. holding capacity. p.876-898. In A. Klute (ed.) Methods of soil analysis. Part 1. Physical and mineralogical methods. Agron. mono. 9. ASA, Madison, WI.

McLean, E.O. 1982. Soil pH and lime requirement p.199-209. In A.L. Page (ed.). Methods of

soil analysis. Part 2. Chemical and microbiological properties. Agron. mono.9. ASA, Madison, WI.

Nelson, D.W. and .E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p.539- 577. In A.L. Page (ed.) Methods of Soil Analysis - part 2: Chemical and microbiological properties. Agronomy 9. ASA, Madison, WI.

Parkinson, D. and A. Paul. 1982. Microbial biomass. p.821-829. In A.L. Page (ed.) Methods of soil analysis. Agronomy No.9. Part 2. 2nd. Ed. Madison, WI.

Rice, C.W. and M.S. Smith. 1982. Denitrification in no-tilled and plowed soils. Soil Sci. Soc. Am. J. 46:1168-1173.

SAS Institute. 1985. SAS User's guide: Basics/Statistics Version 5 edition. SAS Inst., Inc., Cary, NC.

Seaker, E.M. and W.E. Sopper. 1988. Municipal sludge for minespoil reclamation: II. Effects on organic matter, J. Environ. Qual. 17:598-602.

Smith, J.H. and J.R. Peterson. 1982. Recycling of nitrogen through land application of agricultural, food processing, and municipal wastes. p.791-831. In Nitrogen in agricultural soils. Agronomy No. 22. ASA, Madison, WI.

Sopper, W.E. 1992. Reclamation..of mine land using municipal sludge. p.351-431. In R. Lal and B.A. Stewart (eds.). Soil restoration. Advances in soil science. Vol. 17. Springer-Verlag. NY.

Steele, K.W., D.M. Cooper, and C.B. Dyson. 1982. Estimating nitrogen fertilizer requirements in maize grain production. 2. Estimates based on ear leaf and grain nitrogen concentrations. N. Z. J. Agric. Res. 25:207-210.

Thomas, G.W. 1982. Exchangeable cations. p.159-165. In A.L. Page (eds.) Methods of soil analysis. Part 2. Chemical and microbiological methods. Agron. mono. 9. ASA, Madison, WI.

Zhai, Q. 1995. Nitrogen transformation and availability in organic waste amended prime farmland following surface mining. Dissertation. Univ. of Kentucky, Lexington, KY 40546.

Acid Mine Drainage and Minesite Salinity in Australia. D.J. Williams.

Abstract: Acid mine drainage and minesite salinity are, arguably, the most serious threats posed to the environment by open-cut mining and mineral processing. Acid mine drainage arises when sulphur, usually in pyrite form, contained in the ore and/or waste materials, is exposed to oxidation, the products of which are subsequently leached out by water as acid. As the pH of the system drops, bacteria begin to catalyse the chemical reactions, and any metals present go into solution. Open-cut mining and mineral processing activities also lead to the storage of water on the surface, where evaporation and leaching raise its salinity. At many mines in Australia in dry climates, soil covers over potentially acid generating waste rock dumps are being actively trialed. The aim is to maintain the soil cover in a saturated state by covering it with a sacrificial mulch of loose-dumped inert material. The mulch also serves to take up rainfall, preventing excessive runoff which may cause erosion of the soil cover. In the coalfields of Queensland, Australia, measured pH and salinity levels have been found to vary widely between minesites, within any given minesite, and with changing climatic conditions.
Additional Key Words: dissolved metals, open-cut mines, pyrite oxidation, soil cover.

Organic Matter and Nutrient Accumulation in Reclaimed Kaolin Mine Soils of Georgia.

R. B. Haddock, L. A. Morris, R. L. Hendrick, and E. A. Ogden

Abstract: Deficiencies in soil nutrients, particularly nitrogen, commonly result from replacement of natural soil profiles by overburden low in organic matter and essential elements. Reclamation success depends largely upon creating nutrient reserves, establishing adequate nutrient cycles, and developing a functional soil profile. Loblolly pine (*Pinus taeda* L.) stand productivity and soil characteristics of reclaimed kaolin mines in Georgia were evaluated along a chronosequence. Estimated site index (age 25) ranged from 11.3 m on poor sites to 24.1 m on productive sites. Projected volume at age 25 ranged from 119 m^3/ha on poor sites to 280 m^3/ha on productive sites. These values indicate that growth on many mined lands is comparable to growth on adjacent non-mined lands. Soil profile development below the surface soil was nonexistent on all sites and differences in soil texture and color did not adequately explain observed differences in site productivity. Foliar deficiencies in phosphorus, potassium and several micronutrients suggest that availability of nutrients and potential mineralization explain the observed differences in site productivity.

Plant Materials and Amendments for Controlling Wind and Water Erosion on a Fly Ash Disposal Area: TVA Colbert Fossil Plant, Alabama. Jimmy J. Maddox, David Behel, John M. Soileau, and Jimmie Kelsoe.

Abstract: Fly ash disposal sites adjacent to fossil fueled generating plants are subject to wind and water erosion which increases the operation and maintenance costs. Gullies and unstable areas in the disposal sites require expensive leveling and filling practices. Test evaluated both warm- and cool-season cover crops established by either sod or seed. Amendments to the ash consisted of composted poultry litter (CPL), soil, soil+CPL, fertilizer and beneficial soil microbes including mycorrhizal fungi. Turf sods (419 Bermuda, Emerald zoysia, and Raleigh St. Augustine) were compared in greenhouse and field studies. Six legumes and 12 grass species were tested in the greenhouse as seeded cover crops using similar amendments and raw poultry litter (PL). Legumes grew better with CPL and soil amendments and grasses grew better on PL and soil amendments possibly due to differences in N requirements and N supply. Cool season crops generally grew faster than warm season species in the greenhouse tests. Amendments should be mixed with the FA to ameliorate the effects of boron and salt toxicity and to increase the water holding capacity. Bermuda sod grew faster than either St. Augustine or Emerald zoysia,but requires more water. A microbial amendment increased dry matter yields of bermuda sod 2 to 3 times after 40 to 60 days over unamended controls. Microbial amendments may be justified on an economic and sustainable basis. A field study is assessing the environmental and cultural requirements to grow a cover crop on an annual basis.

Additional Key Words: restoration, ash ponds.

Reclamation of Acidic, Denuded Copper Basin Land: Revegetation Performance of Phosphate Rock VS Other Nutrient Sources. J. M. Soileau, F. J. Sikora, J. J. Maddox, and J. J. Kelsoe.

Abstract: Open pit smelting of Copper ore about 100 years ago resulted in approximately 9,300 ha of severely eroded, very acidic (pH 4.0 to 5.0) soils at Copper Basin, Tennessee. Along with other essential nutrients, phosphorus (P) amendments are critical for long-term productivity and sustainability of vegetation on this depleted soil. A field study was conducted (1992-1995) to compare revegetation from surface-applied North Carolina phosphate rock (PR) and triple superphosphate (TSP) at 20, 59, and 295 kg P ha^{-1}, and to determine benefits of starter NPK tree tablets. The experimental design consisted of 7.3 x 9.1 m replicated plots, each planted to 20 loblolly pine seedlings and aerially seeded with a mixture of grasses and legumes. Tree survivability was high from all treatments. Through the third year, tree height and diameter increased with increasing P to 59 kg P ha^{-1}, without fertilizer tablets. There were no pine growth differences between PR and TSP. Weeping lovegrass has been the dominant cover crop through 1995, with increased stimulation to tree tablets and surface P. Tall fescue (KY 31), sericea lespedeza, and black locust responded more to PR than to TSP. Surface soil pH increased, and 0.01 M $SrCl_2$ extractable Al decreased, with increasing rate of PR. For future loblolly pine plantings in the Copper Basin, this study suggests there is no benefit to applying both tree tablets and surface P at rates above 59 kg P ha^{-1}. For reclaiming land with high acidity and low P fertility, PR has significant benefits. In reclaiming steep, gullied land, there is great potential for aerial application of PR and/or pelletized liming agents.

Additional Key Words: land restoration, P fertilization.

Improved Methods for Acid Base Accounting Utilizing Geospatial Modeling.

Michael DiMatteo(1),and Mark Gaylord(2), ((1)Pennsylvania Department of Environmental Protection, (2)Dynamic Graphics, Inc.).

Abstract: A comparison between the traditional mass averaging Acid Base Accounting (ABA) procedure and a geospatial ABA method is applied to a mine site in Fayette County, Pennsylvania. The traditional method for determining mass-weighted or volume-weighted acid base accounting (ABA) typically uses Theissen polygons and straight line interpolation to determine an area of influence for each overburden drill hole on a mine site. The traditional ABA method has been used to characterize overburden in terms of net neutralization potential (NNP) and to define the location of toxic strata. Recent developments in geospatial modeling, available as part of the Office of Surface Mining's TIPS system, allows significant improvement in the estimated property distribution, estimated concentration and mass and/or volume calculations. A geospatial approach, which includes better representation of topographic variability and incorporates stratigraphic and geologic structural features in a model, results in improved volumetric calculations, and ultimately, in a more precise site characterization. Improved site characterization provides the basis for integrating material handling and alkaline addition plans into an overall mine plan.

Additional Key Words: geospatial modeling, acid base accounting, alkaline addition, material handling

Age and Site-Related Patterns of Carbon Allocation to Wood, Foliage and Roots on Reclaimed Kaolin Mines in Georgia.

A. Legerski, R. Hendrick, E. Ogden.

Abstract: We quantified merchantable stand volume, leaf area indices (LAI), and root densities in twelve *Pinus taeda* L. forests growing on reclaimed kaolin mines in Georgia. Stands were 11 to 36 yrs old, and formed two productivity classes. Projected wood volume on the poor sites ranged from 104 to 142 m^3/ha and from 164 to 298 on the better sites. LAI was not related to age on either the good or poor sites. LAIs reach their maximal values early in stand development (<12 yrs). Fine roots (0-1 mm) within the upper 1 m were most abundant on the poorer sites. Roots were nearly absent at depths>50 cm in stands aged 14 or less, but nearly equal in density to surface roots in the older stands. Stand age was strongly and negatively related to fine root density on both site types. Densities of larger, more perennial roots (1-2 mm) decreased with stand age on poor sites and increased on good sites. Stand productivity is closely related to LAI, and root densities show that trees allocate more energy into fine, absorbing roots on the poorer sites. Deep fine root densities indicate that trees must explore progressively greater volumes of soil to meet water and nutritional needs in reclaimed soils.

Mycorrhizal Fungi + Trees -- Practical Beneficial Tools for Mineland Reclamation.

C.E. Cordell, D.H. Marx, and B. Jenkins.

Abstract: Successful consistent revegetation of drastically disturbed sites (ie., acid coal spoils and mineral waste dumps) throughout the U.S. and several foreign countries has been achieved by using the biological "tools" -- Mycor Tree™ seedlings and native shrub and grass species. These unique plants are custom-grown in bareroot and container nurseries with selected mycorrhizal fungi. On disturbed sites, specific mycorrhizal fungi such as Pisolithus tinctorius (PT) or VAM provide significant benefits to the plant symbionts through increased water and nutrient absorption, decreased toxic materials absorption, and overall plant stress reduction. During the past 15 years, the Ohio Division of Reclamation--Abandoned Minelands Project (AML) has utilized the combination of the PT fungus and reforestation to significantly improve the effectiveness and reduce the cost of AML projects. Since 1981, over 3.5 million PT-inoculated pine and oak seedlings have been planted on approximately 2,500 acres of unreclaimed AML sites. Tree survival has averaged over 85 percent in the PT-inoculated tree plantings with few failures as compared with less than 50% survival and over 75% failures in previous plantings with the same noninoculated tree species. From 1981 to 1995, the 2,348 acres reclaimed in Ohio have cost approximately $832,000.00. Traditional reclamation would have cost approximately $14 million and represents a 94% cost reduction. The total PT reforestation cost in 1995 was $354.00 per acre and the added cost of the PT-inoculated seedlings is approximately 13% ($45.00/acre) or $.03 per seedling. This is a minute expense when compared to conventional AML reclamation costs ($6,000/acre). Interest in the application of this natural environmentally-friendly technology to mineland reclamation programs throughout the U.S. and abroad is expanding.

COMPARATIVE ASSESSMENT OF GROUNDWATER CHEMISTRY EVOLUTION AT THREE ABANDONED MINES AND ITS PRACTICAL IMPLICATIONS

Jaroslav Šolc[1]

Abstract: The reclamation effort typically deals with consequences of mining activity instead of being planned well before the mining. Detailed assessment of principal hydro- and geochemical processes participating in pore and groundwater chemistry evolution was carried out at three surface mine localities in North Dakota—the Fritz mine, the Indian Head mine, and the Velva mine. The geochemical model MINTEQUA2 and advanced statistical analysis coupled with traditional interpretive techniques were used to determine site-specific environmental characteristics and to compare the differences between study sites. Multivariate statistical analysis indicates that sulfate, magnesium, calcium, the gypsum saturation index, and sodium contribute the most to overall differences in groundwater chemistry between study sites. Soil paste extract pH and EC measurements performed on over 3700 samples document extremely acidic soils at the Fritz mine. The number of samples with pH <5.5 reaches 80%-90% of total samples from discrete depth near the top of the soil profile at the Fritz mine. Soil samples from Indian Head and Velva do not indicate the acidity below the pH of 5.5 limit. The percentage of samples with EC > 3 mS cm^{-1} is between 20% and 40% at the Fritz mine and below 20% for samples from Indian Head and Velva. The results of geochemical modeling indicate an increased tendency for gypsum saturation within the vadose zone, particularly within the lands disturbed by mining activity. This trend is directly associated with increased concentrations of sulfate anions as a result of mineral oxidation. Geochemical modeling, statistical analysis, and soil extract pH and EC measurements proved to be reliable, fast, and relatively cost-effective tools for the assessment of soil acidity, the extent of the oxidation zone, and the potential for negative impact on pore and groundwater chemistry. Interpretive techniques used in this project can be used in premining environmental characterization to allow for better mining and reclamation design and reduce costs associated with improperly designed material deposition.

Additional key words: reclamation design, environmental impact

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Injection of Alkaline Ashes Into Underground Coal Mines for Acid Mine Drainage Abatement. William W. Aljoe.

Abstract: The injection of fly ash, scrubber sludge, fluidized-bed combustion (FBC) ash, and other alkaline waste materials into abandoned underground coal mines for acid mine drainage (AMD) abatement has obvious conceptual appeal. This report describes three ongoing projects -- one each in West Virginia, Maryland, and Ohio -- where field demonstrations of the technique are being pursued in cooperative efforts among State and Federal agencies and/or private companies. The West Virginia site produces AMD that is causing the State to incur very high treatment costs and operational problems, especially in the storage and disposal of metal hydroxide sludges that result from treatment. In an attempt to achieve a more cost-effective long-term remediation scheme, the State is working with local coal companies and power generators on a plan to fill part or all of the mine voids with slurries of fly ash and/or FBC ash. At the Maryland site, the goal is to demonstrate the feasibility of completely filling a very small underground mine with an FBC ash slurry. The information gained here will determine whether large-scale AMD remediation can be achieved if deep mine disposal of ash is incorporated into the design of a new FBC power plant. In Ohio, it is believed that sealing and complete flooding of a relatively small mine will be able to curtail its AMD production. In order to accelerate the flooding process and insure that alkaline conditions will prevail in the mine, a waste slurry of calcium hydroxide from a nearby source will be injected into the mine voids in conjunction with mine sealing.

Additional Key Words: mine hydrology, site characterization

Closure of the Brewer Gold Mine by Pit Backfilling. Anne Lewis-Russ (1), John F. Lupo (1), Jon M. Bronson (2), Joe M. Flynn (2) and B. G. "Bud" Long (3). [(1)Titan Environmental Corporation, Englewood, CO, USA; (2) Titan Environmental Corporation, Tempe, AZ, USA; (3) Brewer Gold Company, Jefferson, SC, USA].

Abstract: Brewer Gold Mine, located in north-central South Carolina, is implementing an innovative reclamation plan that includes backfilling the main Brewer open pit with mine waste. The primary goals of the closure are to reduce acid rock drainage and minimize or eliminate long-term operation and maintenance requirements by restoring the site property to approximate pre-mining topography. The plan calls for consolidation of approximately 200 acres of waste into approximately 20 hectares (50 acres). Much of the material to be backfilled into the pit, including spent heap leach material and waste rock, has acid-generating potential. Therefore, the backfill design integrated geochemical properties of the backfill materials with expected post-closure conditions. A prime consideration was the final position of the water table. Since mining at the site started in the early 1800's, no records exist of the original groundwater levels. Therefore, the design incorporates a large anoxic limestone drain to control the final groundwater level. Additional amendments are to be placed in targeted areas of the backfill to maximize their utilization. A low-permeability cap system that includes a geosynthetic clay liner has been designed to limit infiltration into the backfill.

LEACHATE GENERATION, QUALITATIVE TRENDS AND GROUNDWATER CONTAMINATION POTENTIAL IN DRY DEPOSITS OF FLY ASH

Jaroslav Šolc[1]

Abstract: Globally, coal conversion solid residues (CCSRs) currently pose a potentially serious environmental problem due to the increasingly large volumes to be disposed of and the complexity of chemical and physical behavior. During the past 5 years, several experimental field test cells were designed and constructed under the sponsorship of the U.S. Department of Energy using conventional industrial landfill practices as guidelines. Two 2.5-m-thick cells containing approximately 700-1000 tons each of waste were emplaced. Advanced process residues from Ohio (LIMB combustion process) were used in this study. The experiments focused on 1) engineering behavior, 2) diagenesis of buried advanced process residues, and 3) long-term impact of natural leaching processes on the surrounding environment. An intensive monitoring effort generated a substantial project database consisting of baseline chemical characterizations of initial and buried fly ash; x-ray diffraction (XRD), x-ray fluorescence (XRF), and scanning electron microscopy (SEM) analysis of mineral composition and transformations within the cells; American Society of Testing and Materials (ASTM) leachate chemistry; physical properties of soil and ash drill cores; water chemistry of runoff; and pore waters from soil vacuum pressure lysimeters and groundwater in surrounding monitoring wells. On-site meteorological, borehole permeameter, and moisture density data also support quantification of the extent of percolation and flushing. Although permeabilities of $X.10^{-7}$ ms^{-1} initially slowed downward migration of strongly alkaline pore waters (pH of 10 to 12), with time, sufficient water was collected in the vacuum pressure lysimeters. A time-dependent decrease of Na, K, SO_4, and Cl concentration, with an attendant decline in pH and EC, indicates intensive leaching near the top of the ash profile and downward displacement toward the cell base. Monitoring wells used to assess leachate transport to the saturated zone did not indicate significant change in groundwater chemistry; however, pore-water chemistry in base soils beneath the cells reflects an impact from cell leachate.

Additional key words: contaminant migration, mobility, environment

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Backfill Hydrologic Characteristics in a Tennessee Area Surface Coal Mine

by
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The hydrologic characteristics of backfill in a Tennessee area surface coal mine provide useful information concerning the aqueous environment in a recovering water table within a reclaimed surface coal mine. Chemical analyses of water samples from observation wells emplaced in a reclaimed surface coal mine provide a measure to evaluate the overall effectiveness of post-mining reclamation activities. Graphs of chemical parameters including Total and Dissolved Fe, Total and Dissolved Mn, Alkalinity, Sulfate and Specific Conductance reveal that reclamation efforts can be effective in reducing adverse chemical impacts. Trends for Total and Dissolved Fe in water from several observation wells indicate that following an initial increase in Fe concentrations, there was a general decreasing trend to levels below the standard for concentrations permitted for discharge in natural streams. Graphs of chemical parameters also reveal that many traditional rules of aquatic chemistry are not always followed during water table recovery in a reclaimed surface mine. This is most evident in the case of metal concentrations. Increases or decreases in metal concentrations have no apparent correlation with pH levels. Metal concentrations fluctuate as pH remains relatively constant. Total alkalinity levels also fluctuate as pH remains relatively constant. Graphing water quality over time provides valuable information on observation well water quality which can be useful in regards to maintaining enforced water quality standards and as a tool in understanding the chemistry within a surface mine hydrologic regime.

Erosion Control on Tailings Dams Using Soil Bioengineering. Moreen Miller.

Abstract: Increased awareness of the complexity of ecosystems has generated the need to integrate all facets of mining into the development of sustainable environmental management plans. Environmental management goals that may previously have concentrated on final closure of the mine are now becoming part of the preliminary planning and day-to-day activities of new mines, and are being integrated into planning goals of established operations. These management goals must address all components of a mining operation, including those relating to long-term maintenance of tailings areas. The long-term maintenance of tailings dams presents a challenge to the operations and reclamation divisions of minesites. Reducing, and eventually eliminating long-term maintenance and monitoring of surface slope stability on tailings dams has been identified as a cost-effective measure that can lead to the diversification of natural systems. An application of bioengineering techniques on a tailings dam at the INCO Limited Copper Cliff tailings complex is the focus of this poster. Soil bioengineering is a slope stabilization technique that uses dormant live plant material as the major engineering component. Unrooted live vegetation is installed on the slope, which provides immediate stabilization. Roots and shoots then develop to form a permanent vegetative cover and root reinforcing matrix. Bioengineered slopes strengthen over time as the root matrix develops, and provide a microclimate for the invasion of natural species, thus encouraging biodiversity and successional development. Live fascines were installed in the fall of 1994 on the face of the dam to slow the velocity of surface water runoff and to facilitate subsurface water movement in saturated conditions. The structures performed extremely well during their first growing season, and are currently being monitored to assess long-term performance.

Additional Key Words: soil bioengineering, erosion control, fascine, biodiversity, live construction, slope stabilization

WQEP - A COMPUTER SPREADSHEET PROGRAM TO EVALUATE WATER QUALITY DATA [1]

by

ROBERT G. LIDDLE [2]

A flexible spreadsheet Water Quality Evaluation Program (WQEP) has been developed for mining companies, consultants, and regulators to interpret the results of water quality sampling. In order properly to evaluate hydrologic data, unit conversions and chemical calculations are done, quality control checks are needed, and a complete and up-to-date listing of water quality standards is necessary. This process is time consuming and tends not to be done for every sample. This program speeds the process by allowing the input of up to 115 chemical parameters from one sample. WQEP compares concentrations with EPA primary and secondary drinking water MCLs or MCLG, EPA warmwater and coldwater acute and chronic aquatic life criteria, irrigation criteria, livestock criteria, EPA human health criteria, and several other categories of criteria. The spreadsheet allows the input of State or local water standards of interest. Water quality checks include: anion/cations, TDS_m/TDS_c (where m=measured and c=calculated), EC_m/EC_c, EC_m/ion sums, TDS_c/EC ratio, TDS_m/EC, EC vs. alkalinity, two hardness values, and EC vs. Σ cations. WQEP computes the dissolved transport index of 23 parameters, computes ratios of 26 species for trend analysis, calculates non-carbonate alkalinity to adjust the bicarbonate concentration, and calculates 35 interpretive formulas (pE, SAR, S.I., unionized ammonia, ionized sulfide HS-, pK_x values, etc.). Fingerprinting is conducted by automatic generation of stiff diagrams and ion histograms. Mass loading calculations, mass balance calculations, conversions of concentrations, ionic strength, and the activity coefficient and chemical activity of 33 parameters is calculated. This program allows a speedy and thorough evaluation of water quality data from metal mines, coal mining, and natural surface water systems and has been tested against hand calculations.

Key Words: Water Quality, Computer Programs, Chemistry, Coal mining, Mining

Introduction

The evaluation of water quality data can be just as tedious and time consuming as collecting the data itself. Poor interpretation of data may lead to erroneous decision making. The science of hydrologic data interpretation is a complex and ever changing. New techniques are constantly being developed to evaluate the data.

Some evaluation methods work better for certain types of water characteristics, but not all (See Hem, 1992, and Hounslow, 1995). Other methods may work well but either do not catch on or fall out of favor. Often, the methods of interpretation exist but we do not have the time to apply them to all our analyses. The hydrologist must also possess a diversity of skills to be a good evaluator of data. The task requires one to be an organic chemist, an inorganic chemist, a mathematician, a computer specialist, a statistician, knowledgeable in regulatory standards, experienced with data interpretation and methodology, and possessing good intuition. Unfortunately few of us are this diverse.

A computer program was developed to aid in water data interpretation of single samples. The program is geared toward inorganic constituents with

[1] Paper presented at the 1996 Annual Meeting of the American Society for Surface Mining and Reclamation, Knoxville, Tennessee, May 19-25, 1996.

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some water quantity calculations included. The program is designed to be flexible, easily expanded, and receptive to modification. It does not handle large sets of data; rather, it is designed to look at one or two samples at a time and provide a thorough interpretation. A full suite of chemical analyses is necessary to optimize the program's capability.

Methods

A Water Quality Evaluation Program called WQEP has been developed. The program is based on a water quality evaluation program developed in OSM's Kansas City Field Office in 1989 (Liddle, 1989). The program has been continually modified and debugged and has been used in-house on hundreds of sites. The program results were frequently compared with those obtained by hand calculation or other software programs such as Wateq4F (Ball, 1991) and HC-GRAM (McIntosh, 1986). The program was developed for Lotus 1,2,3 spreadsheets and can be converted to other spreadsheet platforms such as Excel.

Lotus was chosen because the program could be easily changed by inexperienced programmers to tailor the model to different regions and ever changing water quality criteria. Lotus can handle small databases depending on the computer's memory and has data transfer capabilities with many other databases such as dBase, FoxPro, Oracle, ParLens, and SQL Server (Bradley, 1994, p. 1028). From a practical standpoint, since the program is designed to analyze full suite water chemistry, the cost of data collection usually limits the number of samples to be analyzed. This makes most databases of full suite water chemistry manageable.

Tedious hydro-chemical calculations were programmed to allow the user to concentrate on the results not the calculations. Data interpretation methods were obtained from numerous publications. Greenberg (1992), Hem (1985), and Minear (1982) provides good discussions about the interpretation techniques. General water quality references showing examples include Benefield (1982), Stumm (1996), Novotny (1994), Manahan (1991), and Bodek (1988). General chemistry calculations can be found in Sawyer (1967). Statistical methods for water resources can be found in Helsel (1992), Koch (1970), Barnes (1994), and Haan (1977). Soil, rock, and water chemistry interrelations are discussed in Loeppert (1995), Stumm (1995), Bohn (1985), and Garrels (1965). The pH concept is explained by Westcott (1978). Case studies, water quality summaries, and hydrologic investigation reports were used to find additional ideas. Examples include Likens (1995) and USGS (1993). Being an avid reader of USGS Water Resources Investigations and Open-File Reports is beneficial in seeing a variety of interpretation techniques and illustrations from many hydrologists.

Model Components

The program conducts several types of quality assurance checks, comparisons with water quality standards, data manipulations, calculation of other parameters, and graphical presentations. WQEP allows the importation of 115 chemical parameters including dissolved and total species; metals and trace elements; conventional pollutants; and physical parameters. They include the following:

acidity	carbonate	lead	phosphate	sulfate
alkalinity	cesium	lithium	potassium	sulfide
aluminum	chloride	magnesium	radium	TDS
ammonia	chromium	manganese	radon	Temp.
antimony	cobalt	mercury	scandium	thallium
arsenic	conduct.	molybdenum	selenium	titanium
barium	copper	nickel	SS	TSS
beryllium	cyanide	nitrate	silica	uranium
bicarb.	fluoride	nitrite	silver	vanadium
boron	gallium	ORP	sodium	yttrium
cadmium	hardness	DO	strontium	zinc
calcium	iron	pH	sulfate	zirconium

The model immediately conducts calculations to predict the value of other species such as un-ionized ammonia, ionized sulfide HS, sulfide (S2-), bicarbonate, hardness, etc.

WQEP runs more than 10 different quality assurance checks to evaluate the quality of the data. Water quality checks include: anion/cations, TDS_m/TDS_c, EC_m/EC_c, EC_m/ion sums, TDS_c/EC ratio, TDS_m/EC, EC vs. alkalinity, two hardness values, EC vs. Σ cations, and ionic strength comparisons.

The program contains the latest water quality criteria, standards, and threshold values cited in the

literature. Federal Register notices were compiled on each parameter to understand the latest regulatory requirements rather than rely on outdated water quality tables.

The program automatically compares each of the 115 chemical parameters to up to 16 categories of criteria and standards. These include:

- EPA Drinking Water MCL
- EPA Drinking Water MCLG
- EPA Secondary Drinking Water MCL
- EPA Warmwater Aquatic Criteria
  - Chronic
  - Acute
- EPA Coldwater Aquatic Criteria
  - Chronic
  - Acute
- Irrigation Criteria (various sources)
- Livestock Criteria (various sources)
- EPA Human Health Criteria
  - Water and Organisms
  - Organisms Only
- National Ambient Levels (Bodek)
- State Sediment Criteria
- Other State Criteria
- Optional Criteria

The program displays a "WARNING!" note beside each parameter that exceeds some water quality criteria and shows which column the parameter exceeded.

Several aquatic life criteria for metals vary depending on the hardness or alkalinity of the receiving stream. The values are derived from regression equations relating the two parameters. The program allows the user to enter a hardness value and the criteria are automatically calculated. The parameters calculated are as follows:

CHRONIC CONCENTRATIONS SHOULD NOT EXCEED:

$$\mu g/l\ Cd = e^{(0.7852\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -3.490}$$

$$\mu g/l\ Cr(III) = e^{(0.8190\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +1.561}$$

$$\mu g/l\ Cu = e^{(0.8545\ [\ 1\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -1.465}$$

$$\mu g/l\ Pb = e^{(1.266\ [\ 1\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -4.661}$$

$$\mu g/l\ Ni = e^{(0.8460\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +1.1645}$$

$$\mu g/l\ Ag = e^{(1.72\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -6.52}$$

$$\mu g/l\ Zn = e^{(0.8473\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +\ 0.7614}$$

more than once every three years on average.

ACUTE CONCENTRATIONS SHOULD NOT EXCEED:

$$\mu g/l\ Cd = e^{(1.128\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -3.828}$$

$$\mu g/l\ Cr(III) = e^{(0.8190\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +3.688}$$

$$\mu g/l\ Cu = e^{(0.9422\ [\ 1\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -1.464}$$

$$\mu g/l\ Pb = e^{(1.266\ [\ 1\ Ln\ (\ Hardness\ mg/l\ )\ ]\ -1.416)}$$

$$\mu g/l\ Ni = e^{(0.8460\ [\ 1\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +3.3612)}$$

$$\mu g/l\ Zn = e^{(0.8473\ [\ Ln\ (\ Hardness\ mg/l\ )\ ]\ +\ 0.8604)}$$

more than once every three years on average.

The program also calculates bicarbonate alkalinity, carbonate, alkalinity, hydroxide alkalinity, free carbon dioxide, and total carbon dioxide, and noncarbonate alkalinity. The dissolved transport index (DTI) (Horowitz, 1991) is calculated for 23 parameters based on the dissolved and total species present in the water. More than 25 different ionic ratios are calculated such as sulfate/TDS, Cu/Mo, Ca/SO_4, etc. The program allows user defined ratios to be calculated.

Index parameters such as ESP, SAR, Morphoedaphic index (Brocksen, 1992), Langelier saturation index, etc. are also calculated. Conversions into equivalents and moles are conducted. Dissociation constants, dielectric constant, pE from eH, and other tedious calculations are automatically done.

The model provides some rough dual species solubility calculations but is not intended to replace hydro geochemical models such as WATEQ4F (Ball, 1991) or Solmineq.88 (Kharaka, 1988). Chemical activities are calculated using the Debye-Huckel ionic strength method. Ion solubility product constants K_{sp} and activity product constants K_{iap} are printed for 56 species.

One additional feature allows the input of a flow measurement in cfs or gpm. This value is used for the mass balance mixing model calculations. Downstream water chemistry can be predicted based on baseline data and the addition of one or more discharges knowing the flow rates.

Mass loading calculations are also calculated in several ways. The program takes the concentration of the constituent such as iron, adjusts for the flow rate, and calculates loading in pounds per day, pounds per year, tons per day, and tons per year. By entering a sediment density value into the program, the potential sediment accumulation is calculated in cubic feet per month and cubic feet per year. This is beneficial for dam and reservoir siltation estimations.

WQEP automatically produces a histogram of major ions and a STIFF diagram for water quality fingerprinting. These graphics along with the normal graphing features of a spreadsheet program allow a quick and effective illustration of data. The nature of a spreadsheet allows additional water evaluation techniques to be added to the program as they are developed with little effort.

Conclusions

A Water Quality Evaluation Program (WQEP) was developed for special use in situations where full suites of major ions, metals, trace elements, and field parameters are collected for individual samples. The program does many water interpretation calculations that are generally too tedious and time consuming to do for every sample. The program enables quality assurance and detailed evaluations to be quickly conducted so that the hydrologist can concentrate on the other aspects of the data.

References

Ball, J.W. and Nordstrom, D.K. 1991. User's Manual For WATEQ4F, With Revised Thermodynamic Data Base and Test Cases For Calculating Speciation of Major, Trace, And Redox Elements in Natural Waters. USGS Open File Report 91-183, Menlo Park, CA

Barnes, W.J. 1994. Statistical Analysis for Engineers and Scientists - A Computer-Based Approach. McGraw-Hill Publishers, New York. 396 p.

Benefield, L.D., Judkins, J.F., and Weand, B.L. 1982. Process Chemistry For Water and Wastewater Treatment. Prentice-Hall, Inc. New Jersey. 510 p.

Bodek, I., et. al. 1988. Environmental Inorganic Chemistry, A Publication of SETAC, Pergamon Press, New York

Bohn, H.L, et. al. 1985. Soil Chemistry. John Wiley and Sons, New York, 341 p..

Bradley, D.; 1994. Using 1-2-3 Release 4 for DOS. Que Publishers, Indianapolis, IN. 1099 p.

Clark, J.W., Viessman, W., and Hammer, M.J.; 1977. Water Supply and Pollution Control. Harper & Row, New York. 857 p.

Garrels, R.M. and Christ, C.L., 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper & Company, San Francisco, CA., 450 p.

Greenberg, A.E., et. al., editors. 1992. Standard Methods for the Examination of Water and Wastewater. Joint publication of the APHS, AWWA, WEF. American Public Health Association, Washington, D.C.

Haan, C.T. 1977 Statistical Methods in Hydrology. Iowa State University Press, Ames, IA.

Hem, John D. 1992. Study and Interpretation of the Chemical Characteristics of Natural Water. USGS Water-Supply Paper 2254. US Government Printing Office, Washington, D.C. 263 p..

Helsel, D.R., and Hirsh, R.M. 1992. Statistical Methods in Water Resources. Elsevier Science Publishers, New York. 522 p.

Horowitz, A.J. 1991. A Primer on Sediment-Trace Element Chemistry. Lewis Publishers, Chelsea, Michigan. 136 p.

Hounslow, A. W., 1995. Water Quality Data: Analysis and Interpretation. CRC Press, Boca Raton, Florida. 397 p.

Kharaka, Y.K., et. al. 1988. SOLMINEQ.88: A Computer Program For Geochemical Modeling of Water-Rock Interactions. USGS Water-Resources Investigations Report 88-4227. Menlo Park, CA

Koch, G.S., and Link, R.F., 1971. Statistical Analysis of Geological Data. Volume 1 pp. 375; Volume II 438 p.

Liddle, R.G. 1989. EZQual and OWEP. Spreadsheet programs for evaluating water quality. Unpublished internal programs for Office of Surface Mining, Kansas City, Mo.

Likens, G.E and Bormann, F.H. 1995. Biogeochemistry of a Forested Ecosystem. Springer-Verlag Publishers, New York. 159 p.

Loeppert, R. H., et. al., Editors; 1995. Chemical Equilibrium and Reaction Models. Soil Science Society of America Special Publication No. 42; Madison, Wisconsin. 422 p.

McIntosh, Gary. 1986. HC-GRAM Hydro Geochemical Modelling Program. Office of Surface Mining, Denver, CO.

Manahan, S. E. 1991. Environmental Chemistry. Lewis Publishers, Inc., Chelsea, Michigan. 583 p.

Minear, R. A., and Keith, L.H. 1982. Water Analysis, Volume 1: Inorganic Species, Part 1. Academic Press, New York. 287 p.

Novotny, Vladimir and Olem, H. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York. 1054 p.

Saywer, C.N. and McCarty, P. L. 1967. Chemistry for Sanitary Engineers. McGraw-Hill, New York. 518 p.

USGS, 1993. National Water Summary 1990-1991: Hydrologic Events and Stream Water Quality. USGS Water Supply Paper 2400. US Government Printing Office, Washington, D.C. 590 pp.

Westcott, C.C. pH Measurements. Academic Press, New York. 172 p.

LIMESTONE DRAINS TO INCREASE pH AND REMOVE DISSOLVED METALS FROM AN ACIDIC COAL-MINE DISCHARGE IN PENNSYLVANIA[1]

Charles A. Cravotta III[2] and Mary Kay Trahan[3]

Extended Abstract

Limestone drains are used to increase pH and remove dissolved metals from acidic mine drainage (Hedin et al. 1994). However, the chemistry of mine drainage is variable and geochemical processes within these treatment systems are poorly understood. To resolve uncertainties about some of the factors affecting chemical reactions within limestone drains, three identical drains were constructed in parallel to treat acidic drainage from an abandoned coal mine in east-central Pennsylvania (fig. 1). A static mixer was installed to enable aeration of the inflow to one or all three drains. Samples of water were collected at the inflow to the drains, at points within the drains, and at the outflow from the drains. The samples were analyzed to evaluate the rate of dissolution of limestone and the extent of hydrolysis and precipitation of iron, aluminum, manganese, and other dissolved metals. The inflow rate was varied to determine any effects on the rates of dissolution and precipitation reactions and the transport of reaction products through the drains.

As the water flowed through the drains, pH and concentrations of alkalinity and calcium increased, and concentrations of acidity and of dissolved and suspended iron and aluminum decreased, and concentrations of sulfate, magnesium, manganese, nickel, and zinc did not change (figs. 2-4). These water-quality trends and computed saturation indices (table 1) indicate that throughout the drains, limestone ($CaCO_3$) can dissolve and neither calcium nor sulfate can precipitate as gypsum ($CaSO_4 \cdot 2H_2O$), because the water is undersaturated with respect to these solids. However, as pH increases, first iron, and then aluminum, rapidly undergoes hydrolysis and precipitates as hydroxide compounds within the drains. At slow flow rates, iron and aluminum hydroxides tend to settle out of suspension and do not adhere strongly to (armor) limestone surfaces. Concentrations of dissolved manganese, nickel, zinc, and other trace metals are not limited directly by precipitation or sorption reactions. Only minor amounts of the trace metals are removed from solution by sorption onto iron and aluminum hydroxides at pH < 5 (Coston et al. 1995) because protons compete for sorption sites under the relatively low-pH conditions at which iron- and aluminum-hydroxide solids precipitate. Under "closed system" conditions in which hydrolysis products including protons and carbon dioxide can not escape the drains and are retained as reactants, limestone surfaces rapidly dissolve and hence armoring is avoided, despite oxygenated conditions. Water quality changed most near the inflow (fig. 3), because the rate of limestone dissolution slows with increasing pH and increasing concentrations of calcium and bicarbonate (Plummer et al. 1979). Although the concentration of calcium added to treated effluent was greatest at slower flow rates (fig. 5), or increased residence time, the overall average rate of dissolution of limestone, 4.4 kg/day, was independent of residence time. If the rate of dissolution remains constant, the 40,000 kg of limestone used to fill the drains theoretically will last 25 years.

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Literature Cited

Coston, J.A., C.C. Fuller and J.A. Davis. 1995. Pb^{2+} and Zn^{2+} adsorption by a natural aluminum- and iron-bearing surface coating on an aquifer sand. Geochimica et Cosmochimica Acta, 59(17):3535-3547.

Hedin, R.S., R.W. Nairn and R.L.P. Kleinmann. 1994. Passive treatment of coal mine drainage. U.S. Bureau of Mines Information Circular IC-9389, 35 p.

Plummer, L.N., B.L. Jones and A.H. Truesdell. 1976. WATEQF--a FORTRAN IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters. U.S. Geological Survey Water Resources Investigations 76-13, 70 p.

Plummer, L.N., D.L Parkhurst and M.L. Wigley. 1979. Critical review of the kinetics of calcite dissolution and precipitation. p. 537-573. In Jenne, E.A., ed., Chemical modeling in aqueous systems--Speciation, sorption, solubility, and kinetics. American Chemical Society Symposium Series 93.

Table 1. Measured composition and calculated saturation indices for water samples[1]

[Water-quality constituents in milligrams per liter, except for pH; saturation index and $\log P_{CO_2}$, unitless; -- no data; < less than; > greater than]

Sample	Measured Water-Quality Constituent								Saturation Index[2]				
Dist-ance	pH	SO_4	Alka-linity $CaCO_3$	Ca	Mg	Fe	Mn	Al	Cal-cite	Gyp-sum	Fe-$(OH)_3$	Al-$(OH)_3$	log P_{CO2}
0 ft	3.50	210	0	28	26	1.70	3.0	0.79	--	-1.6	-0.8	-6.1	--
5 ft	4.30	210	0	36	26	.680	2.9	.64	--	-1.5	-.2	-3.8	--
10 ft	4.85	210	3	39	27	.240	3.0	.63	-4.7	-1.5	-.3	-2.2	-1.4
20 ft	5.95	210	24	49	26	.020	2.9	.27	-2.6	-1.4	-.1	-.4	-1.6
40 ft	6.40	200	70	70	26	.007	3.0	.08	-1.5	-1.3	-.1	-.4	-1.6
60 ft	6.70	200	110	81	26	.011	2.9	.05	-1.0	-1.2	.4	-.3	-1.7
80 ft	6.65	200	118	88	26	.007	2.9	.05	-1.0	-1.2	.1	-.3	-1.6

[1]Water-quality data for samples collected on April 25, 1995, from points at increasing distances downflow in drain 2; influent is at 0 ft and effluent is at 80 ft.

[2]Saturation index [SI = log (IAP/Ksp)] calculated with WATEQF (Plummer et al. 1976) and reported measured data (above), other constituents (silica, chloride, sodium, potassium, strontium, and zinc), temperature, and Eh. A value of zero ($-0.5 < SI < +0.5$) indicates the solution is in equilibrium with the solid; values that are negative ($SI < -0.5$) and positive ($SI > 0.5$) indicate the solution potentially can dissolve or precipitate the solid, respectively.

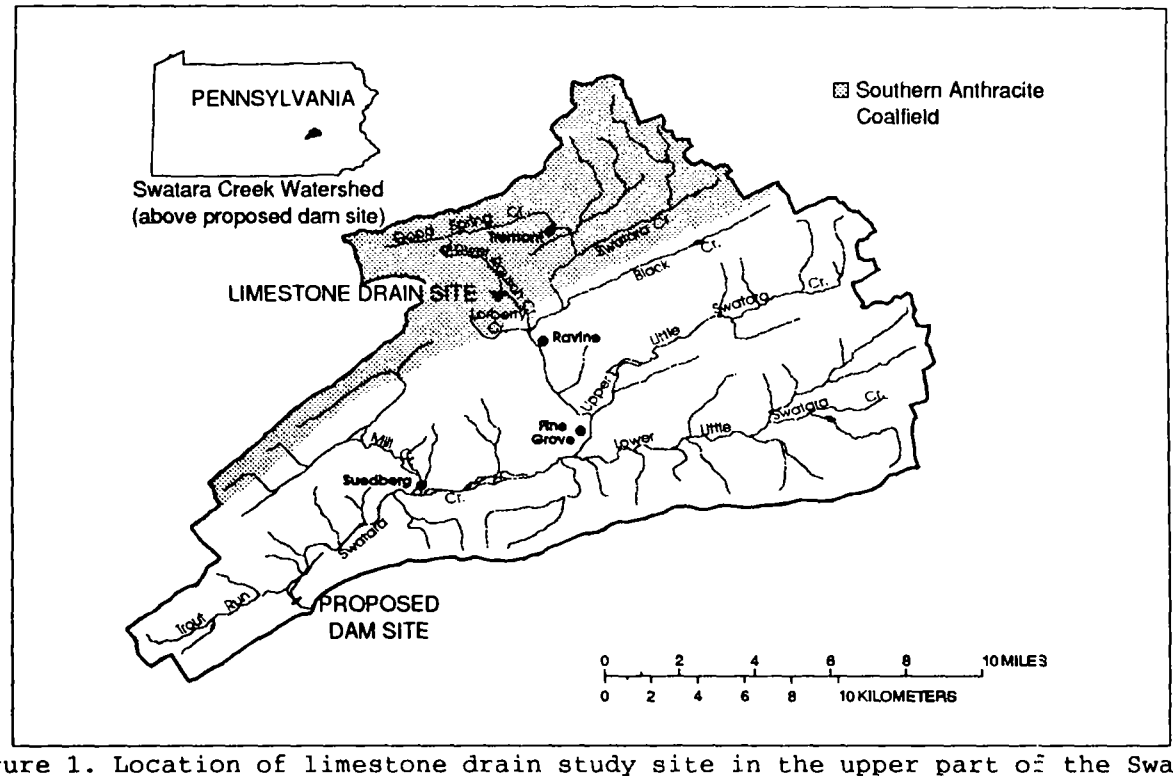


Figure 1. Location of limestone drain study site in the upper part of the Swatara Creek watershed, east-central Pennsylvania.

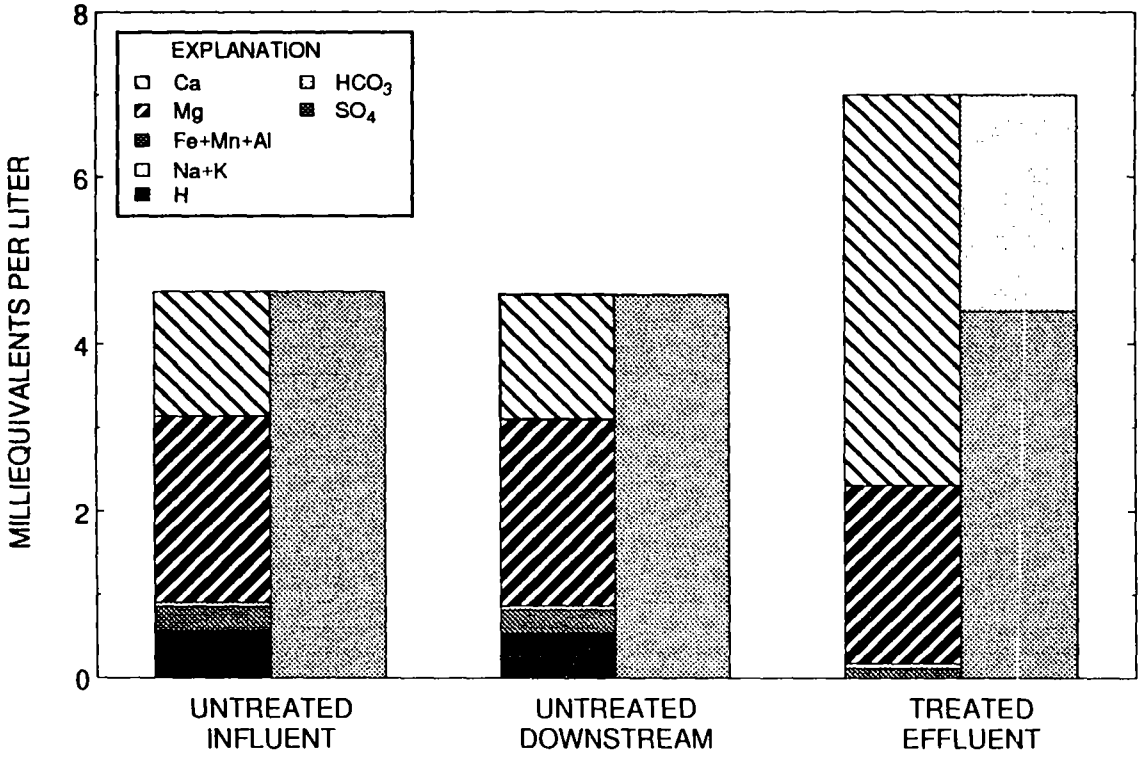
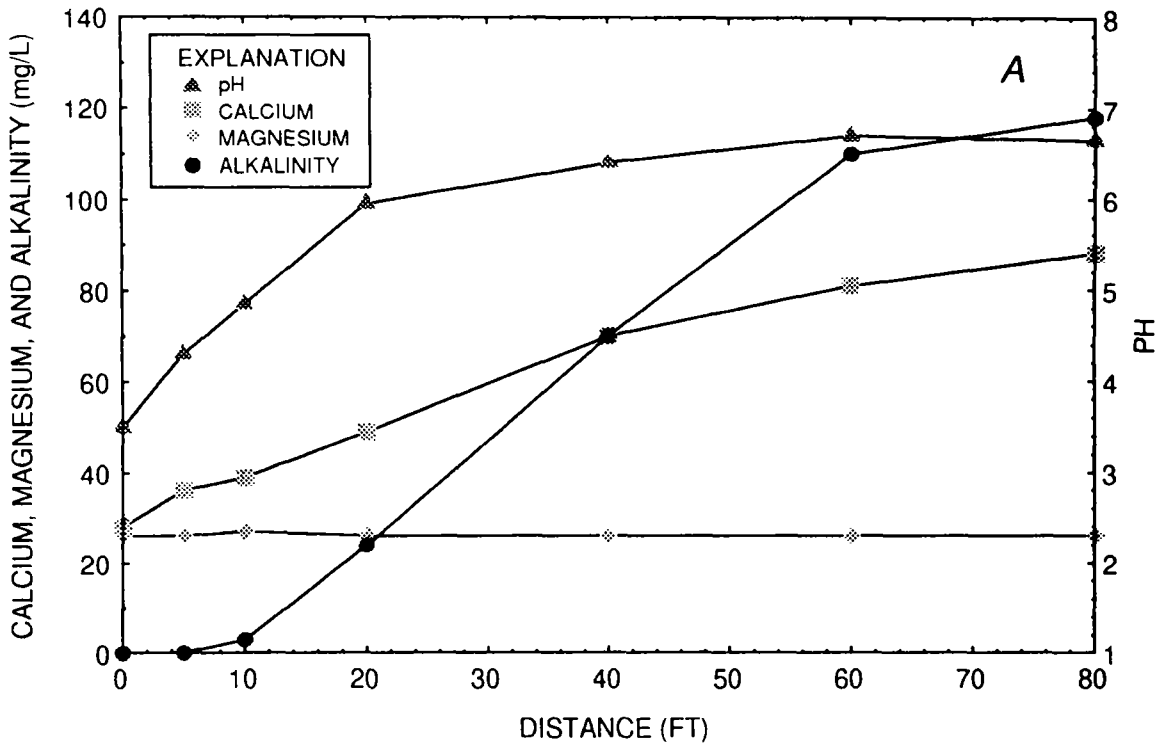


Figure 2. Major-ion composition of discharge before and after treatment by limestone drain 2. Data for samples collected March 23, 1995.



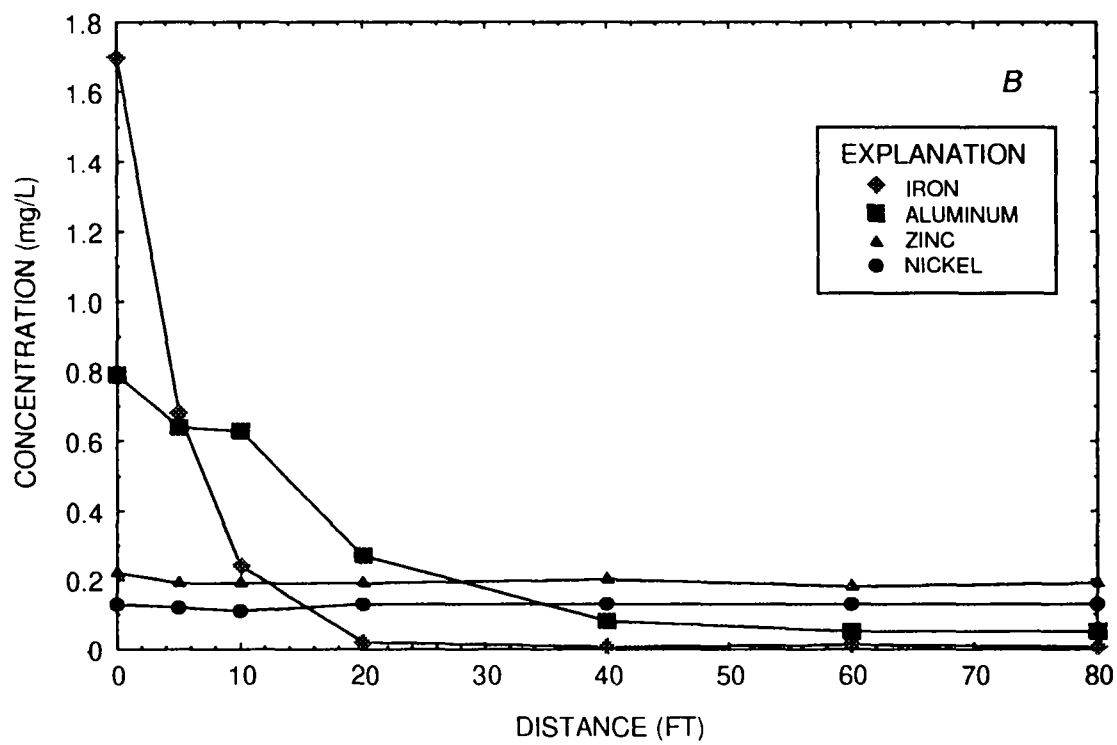


Figure 3. Sequential changes in water quality within a limestone drain: *A*, pH, and concentrations of alkalinity and dissolved calcium and magnesium; *B*, concentrations of dissolved iron, aluminum, zinc, and nickel. Data for samples collected April 25, 1995 from drain 2.

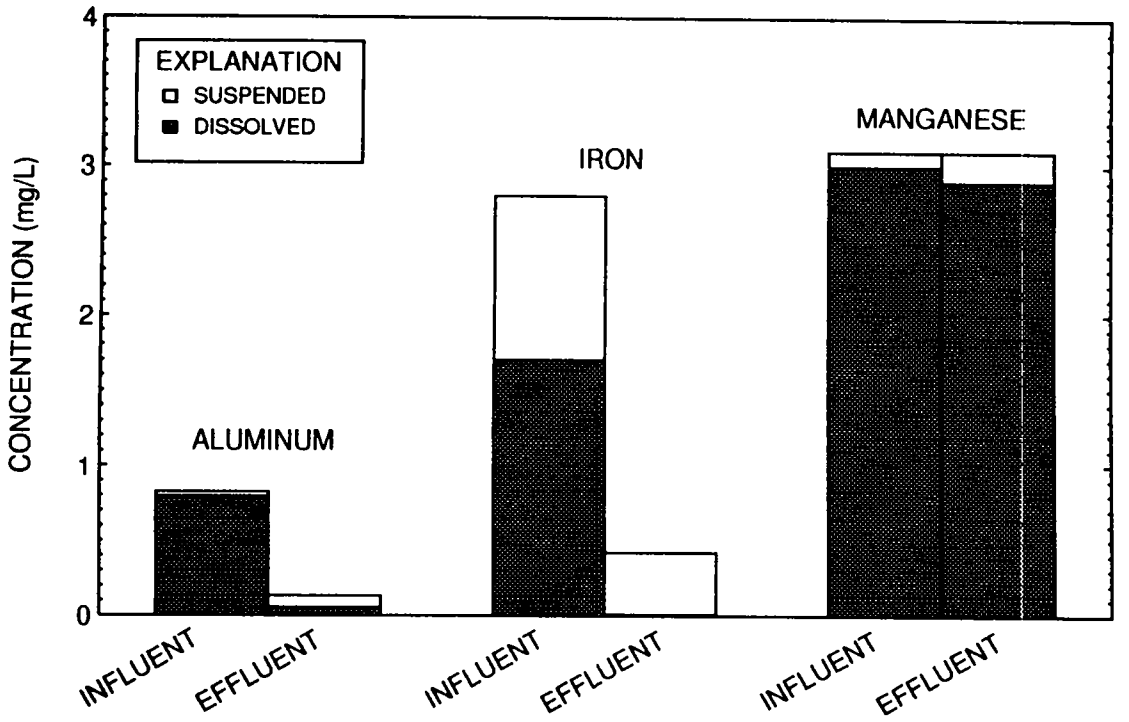


Figure 4. Concentrations of suspended and dissolved manganese, iron, and aluminum in discharge before (influent) and after (effluent) treatment by limestone drain. Data for samples collected April 25, 1995 from drain 2.

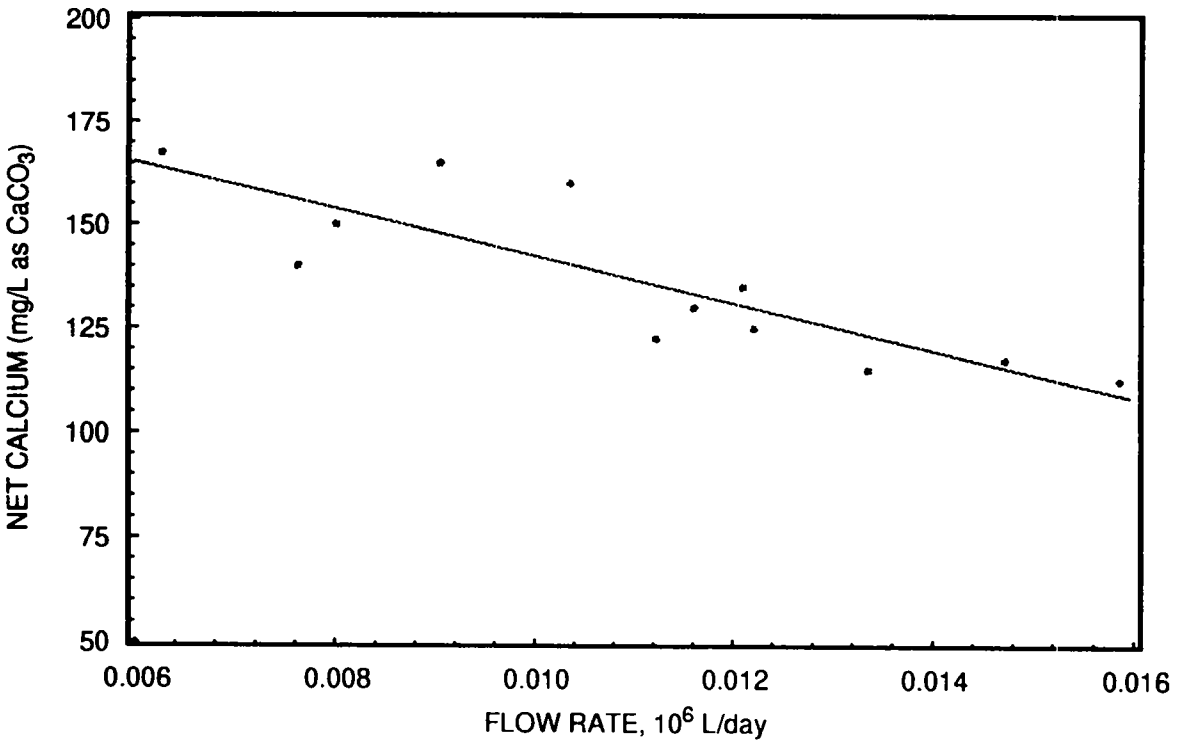


Figure 5. Concentrations of calcium added to effluent from limestone dissolution as a function of discharge rate. Data for samples collected March - August, 1995 from drains 1, 2, and 3.

CONTROLLING AND MONITORING FLOW IN TREATMENT WETLANDS USING WEIRS

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Abstract. Adjustable weirs can be used to control ponding depths and measure flows at constructed wetlands. This paper describes how to design, construct and operate weirs at wetlands.

Background

Constructed wetlands have been used successfully to treat acid mine drainage. Most constructed wetlands do not have a way to easily adjust flow into cells of a multiple cell wetland or to easily modify ponding depth in a wetland cell. In addition, accurate flow measurement to and from wetland cells is often difficult if not impossible. This paper presents practical guidance for using adjustable height V-notch (triangular) sharp crested weirs for flow control and flow measurement at wetland sites.

The paper will focus on practical tips on designing and constructing weirs including:

1. description of weirs,
2. flow equations,
3. using weirs for flow control,
4. using weirs for flow measurement,
5. sizing of weirs,
6. location of weirs,
7. materials,
8. range of adjustment,
9. preventing seepage around and under weir structure,
10. structural integrity,
11. operation of weirs.

In general, adjustable weirs are placed on the upstream end of wetlands to distribute flow between parallel cells, aerate water and measure inflow. Weirs are placed on the outlets of wetland cells to control water levels and measure outflows.

Description of Weirs

Weirs are defined as, "a notch of regular form through which water flows." (French, 1985) Outlet weirs can be thought of as the low spot in the dike around the wetland. Inlet weirs can be thought of as the end of the channel conveying water to the wetland. The top of the weir is called the "crest" and are classified according to the front view shape of the weir

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as rectangular, circular, V-notch (triangular) among others. They are also classified as to the thickness of the weir as broad, short or sharp crested.

For the combined purpose of measuring and controlling flow in constructed wetlands sharp crested, V-notch weirs are the easiest to work with and most accurate. Other types of weirs can be used and the rectangular sharp crested weir is also a suitable choice. For a weir to be considered sharp-crested, the thickness of the plate material from which the weir is made should be significantly less than the depth of water flowing over the weir.

Weir Flow Equation

Equations are available relating the flow rate over a weir to the head upstream of the weir from standard hydraulics references (French, 1985; Grant, 1989; SCS, 1956; Streeter, 1971). The equation for a triangular sharp crested weir can be given by

$$Q=\frac{8}{15}C_e\sqrt{2g}(\tan\frac{\theta}{2})h^{2.5} \qquad (1)$$

where
Q = flow, cfs (m^3/s)
C_e= discharge coefficient
g = acceleration due to gravity, ft/s^2 (m/s^2)
theta = angle of weir opening
h = effective head, ft (m)

Figure 1 defines some of the terms in equation (1). The discharge coefficient depends on the type of weir and the opening angle but is usually around 0.58 (Bos, 1976). A good angle is between 40 and 90 degrees.

The effective head is the height of the water surface above the tip of the V-notch. It should not be measured at the weir but at least several h's upstream of the weir (at least three). Do not measure h at the weir crest because the surface of the water has curved at that point and the potential energy upstream of the weir has already been converted into kinetic energy to some extent, thus violating the assumption under which equation 1 was derived.

Some other considerations regarding use of equation 1 are (see Fig 1 for definition)s:

1. P should be at least 0.3 ft (0.09 m),
2. h should be at least 0.16 ft (0.049 m),
3. T should be at least 2 ft (0.61 m),
4. h/P should be at least 1.2,
5. the depth of water downstream of the weir (tailwater elevation) should be below the vertex of the V-notch.

As one deviates from the above conditions, equation 1 becomes less accurate.

Using english units (g = 32 ft/s^2), equation (1) can be simplified to

$$Q=14.0\tan(\frac{\theta}{2})h^{2.5} \qquad (2)$$

For a 60 degree weir with a head of 4.2 in. (0.35 ft), the flow can be calculated as

$$Q = 14\tan\left(\frac{60}{2}\right) 0.35^{2.5} = 0.58 cfs$$

Using Weirs for Flow Control

If the wetland does not consist of more than one cell in parallel, then weirs cannot be used to control flow between or among cells because all of the water flowing into the wetland must go into the single cell. Raising the weir level for the influent to a single cell wetland, only can temporarily store water upstream as the upstream channel fills.

For wetlands with several parallel cells, the relative height of the weirs determines the relative flow through each cell. Lowering the level of an inlet weir relative to others will increase the fraction of the flow entering a given cell.

Weirs can be adjusted by trial-and-error to obtain the best flow distribution. Alternatively, the notch elevations for each weir can be determined mathematically by replacing the head (h) in equation 1 with

$$h_i = H_u - H_i \qquad (3)$$

where
H_u = upstream water level, ft
H_i = elevation of i-th weir notch, ft

for each of the n weirs. It is possible to set up a separate weir equation for each weir and solve the set of equations for the notch elevations that will give the desired flow distribution.

There are several alternative designs for adjustable outlet controls including telescoping valves and gates. These devices are quite expensive and are only justifiable where water level is changed frequently. For a constructed wetland, water level only needs to be changed occasionally. Therefore the authors have developed an adjustable weir as shown in Figure 2 which consists of three fixed plates (A, B and C) and one movable plate held in place by screws.

Using Weirs for Flow Measurement

Weirs are a very easy device to use for measuring flows over a wide range. The only field measurement is the head. The problem is that the head must be measured relative to the weir notch. For fixed (non-adjustable) weirs this can be done by placing a marked staff in the upstream water. For an adjustable weir the water surface elevation and the V-notch elevation (or the difference in elevation) must be known.

With acid mine drainage a staff placed in the water becomes stained and unreadable over time.

An alternative is a portable device that is attached to the weir and is placed in the water only when the flow is being measured. One such device, designed by

the authors, is shown in Figure 3. This device is attached to the weir such that the zero line on the ruler is at exactly the same elevation as the notch (bottom of V) of the weir. This can be done by installing anything that sticks out of the weir plate at the elevation of the notch.

Another device for measuring flow can be constructed from two carpenter's squares and a carpenter's level as shown in Figure 4. (US DOD, 1982)

In all measurements, the weir plate and the measuring staff must be vertical.

Sizing of Weirs

The two design parameters in weir design are the notch angle and the maximum height of the notch.

The notch angle determines the sensitivity of the weir. The more narrow the angle the greater the change in head for each change in flow. If the angle is too narrow, the head may vary more than desired in the wetland.

The maximum height is determined using the maximum flow rate expected over the weir. The height can be determined by solving equations 1 or 2 solved for h. Once the maximum height is determined the height at the minimum and average flow rates should be checked to make sure the values are not so small that h is insensitive to changes in Q.

For example, consider a weir where the maximum flow rate is 0.5 cfs, the average is 0.2 cfs and the minimum is 0.08 cfs. Equation 2 can be rearranged to give

$$h = \left(\frac{0.714Q}{\tan\left(\frac{\theta}{2}\right)}\right)^{0.4} \tag{4}$$

which yields maximum, average and minimum heads of 0.66, 0.46 and 0.32 respectively. If the heads were too small to measure accurately or below the minimum range for the weir equation, then the notch angle would need to be decreased.

The weir must not be placed in a shallow channel but in front of a pool area to insure that the distance from the bottom of the channel to the notch (P in Figure 1) is great enough to insure that the conditions described earlier with regard to P are satisfied.

The maximum range of adjustment is another design consideration for adjustable weirs. The maximum water level can be given by the value of H_A in Figure 2. The minimum level can be given as

$$H_A - h_D + h_v$$

in Figure 2. In addition

$$h_B > h_D - h_v$$

so that plate D can be slid behind plate B.

Location of Weirs

From the standpoint of measurement accuracy weirs can be placed virtually anywhere in a wetland. However, from a

water treatment standpoint, the wetland designer wants to maximize the average detention time of water molecules travelling through the wetland. This can be done by placing the inlets and outlets (weirs) at the opposite end of the wetland to achieve what process design engineers refer to as "plug flow." (Levenspiel, 1972; Viessman and Hammer, 1993) In some cases it may even be desirable to use several weirs. (Walski and Schroeder, 1978)

Ideal plug flow cannot be achieved in real wetlands due to turbulence and mixing but it can be approached by constructing wetland with a large length to width ratio. If the basin has a good length to width ratio as shown in Figure 5a, one need only insure that the inlet and outlet are on opposite sides. If on the other hand the location of inlet and outlet are constrained Figure 5b, the spur dikes (or baffles) can be introduced into the wetland as in Figure 5c to improve the length to width ratio and hence approach plug flow.

Constructed wetlands for AMD treatment have a great deal in common with dredged material containment areas and some of those references can be helpful for the hydraulics of constructed wetlands. (Shields, Thackston and Shroeder, 1987; Walski and Schroeder, 1978; US Army Corps of Engineers, 1987)

The next consideration is whether the weir should be constructed as a "drop inlet" with a pipe under the dike (embankment) or as part of the dike as shown in Figure 6. Drop inlets have the advantage of not interfering with the design and construction of the dike. However, because they are some distance away from the dike, it is more difficult to reach them to read water levels or make adjustments. On the other hand, weirs in the dike can lead to structural problems in the dike due to differential settlement. (Hammer and Blackburn, 1977)

Materials

Sharp-crested weirs should be constructed of material that is easy to work with, strong even if it is thin, durable and inexpensive. Galvanized sheet metal was selected by the authors. Wood could also be used but it would need to be fairly strong to resist the forces on it. For example plywood would need to be so thick, it might no longer be considered a sharp crested weir at low flow rates.

Where flow measurement is not a consideration and water depth need not be controlled exactly, weirs can be constructed of boards placed vertically inside a metal frame. (US Army Corps of Engineers, 1987)

Preventing Seepage

Seepage under and around weirs can be a serious problem in accurately measuring flow. By using very few parts, seepage through the weir can be minimized.

Seepage under and around the weir can be reduced by

grouting any joints between the weir and the dike or floor or the weir. Clay can be packed along the bottom of the weir to prevent seepage under the weir.

Structural Integrity

Weirs act as part of the dike and can be the weakest portion of the dike around the wetland. (Hammer and Blackburn, 1977) When the foundation material under the dike is a weak soil, the dike can settle faster than the weir structure. This can open up seepage paths between the weir and the rest of the dike. In addition, the material adjacent to the weir needs to be compacted well when it is placed so as not to allow seepage between the weir and the dike to start.

In the authors' weir, the weir plate was extended beyond the side wall into the dike to make it virtually impossible for water to seep around the weir as shown in Figure 7.

The weir acts as a dam and is therefore subject to significant forces due to the hydrostatic pressure of water upstream of the dam. The maximum force on a weir acts at the centroid and can be determined based on the maximum height of water behind the weir and the submerged area of the weir plate according to

$$F=\gamma h_c A \qquad (5)$$

where

F = force on weir, lbs
h_c= depth at centroid of weir, ft
A = cross sectional area, sq ft
gamma = specific weight of water, 62.4 lb/cu ft

The centroid is usually two thirds of the way down the weir. For a two foot wide three foot high weir, the force is

$$F=62.4(2)(2x3)=750\,lb$$

From the above it is clear that even a small weir has significant forces acting on it and must be well supported from the downstream side or else it can fail. The support can come from earth, masonry block or poured-in-place concrete.

Water flowing over the weir must not be allowed to erode or scour the channel leaving the weir and hence weaken the weir structure.

In cold climates where frost can penetrate to a significant depth, the weir structure should be placed on a deep footer to reduce the possible damage due to frost heaving.

Operation

Water level in constructed wetlands should not need to be adjusted frequently. Once the water level is set and flow distribution between cells is fixed they should stay roughly the same over time. However, adjustable weirs provide the

opportunity to experiment with relative ease with alternative flow distributions and ponding depths while knowing the flow and loadings in the wetland.

Adjustable weirs also provide the ability to shut off flow to a cell for a period to perform maintenance and study the cell in some detail. The ability to raise the weir level also provides the opportunity to raise the ponding elevation in the wetland to maintain the same depth even though the wetland begins to fill with sediment.

Summary

Properly designed and constructed adjustable weirs can be an effective way to control and measure flow in constructed wetlands.

Literature Cited

Bos, M.G., (Ed), 1976, Discharge Measurement Structures, International Institute for Land Reclamation and Improvement, Wagemingen, The Netherlands.

French, R.H., 1985, Open Channel Hydraulics, McGraw-Hill.

Grant, D.M., 1989, "Isco Open Channel Flow Measurement Handbook," Isco, Inc., Lincoln, Neb.

Hammer, D.P. and E.D. Blackburn, 1977, "Design and Construction of Retaining Dikes for Containment of Dredged Material," TR D-77-9, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Levenspiel, O., 1972, Chemical Reaction Engineering, Wiley.

Shields, F.D., E.L. Thackston and P.R. Shroeder, 1987, "Design and Management of Dredged material Containment Areas to Improve Hydraulic Performance," TR D-87-2, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Miss.

Streeter, V.L., 1971, Fluid Mechanics, McGraw-Hill.

US Army Corps of Engineers, 1987, Confined Disposal of Dredged Material, Engineering Manual 1110-2-5027.

US DOD, 1982, "Operation and Maintenance of Domestic and Industrial Wastewater Systems," Army TM 5-665, Washington, DC.

USDA Soil Conservation Service, 1956, National Engineering Handbook--Section 5, Hydraulics, SCS/ENG/NEH-5.

Viessman, W. and M.J. Hammer, 1993, Water Supply and Pollution Control, Harper Collins.

Walski, T.M. and P.R. Schroeder, 1978, "weir Design to maintain Effluent Quality from Dredged Material Containment Areas," TR D-78-18, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

Acknowledgement

This work was conducted under a demonstration project to construct wetlands for treatment of AMD managed by the Earth Conservancy, Ashley, Pa., and sponsored by the US

Environmental Protection Agency. CEO for Earth Conservancy is Michael Dziak; project manager is Thomas Chesnick; US EPA point of contact is Jeff Lapp; co-principal investigator for Wilkes is Kenneth Klemow; Willam Tarutis of Wilkes provided comments on the first draft.

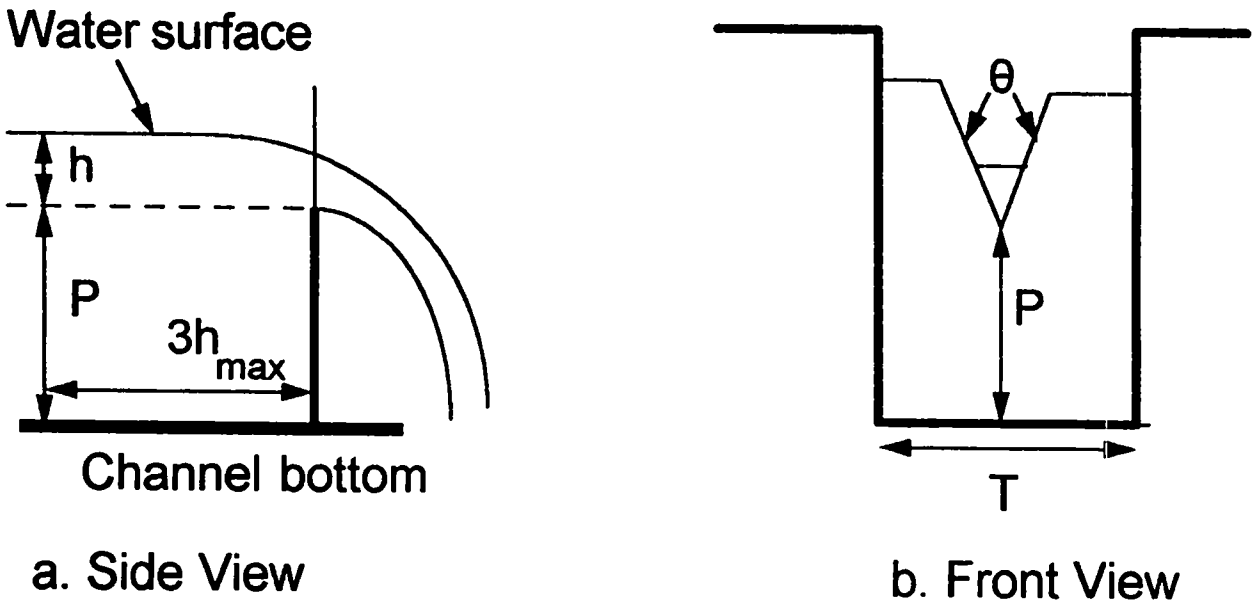

Figure 1. Definition Sketch for V-notch Weir

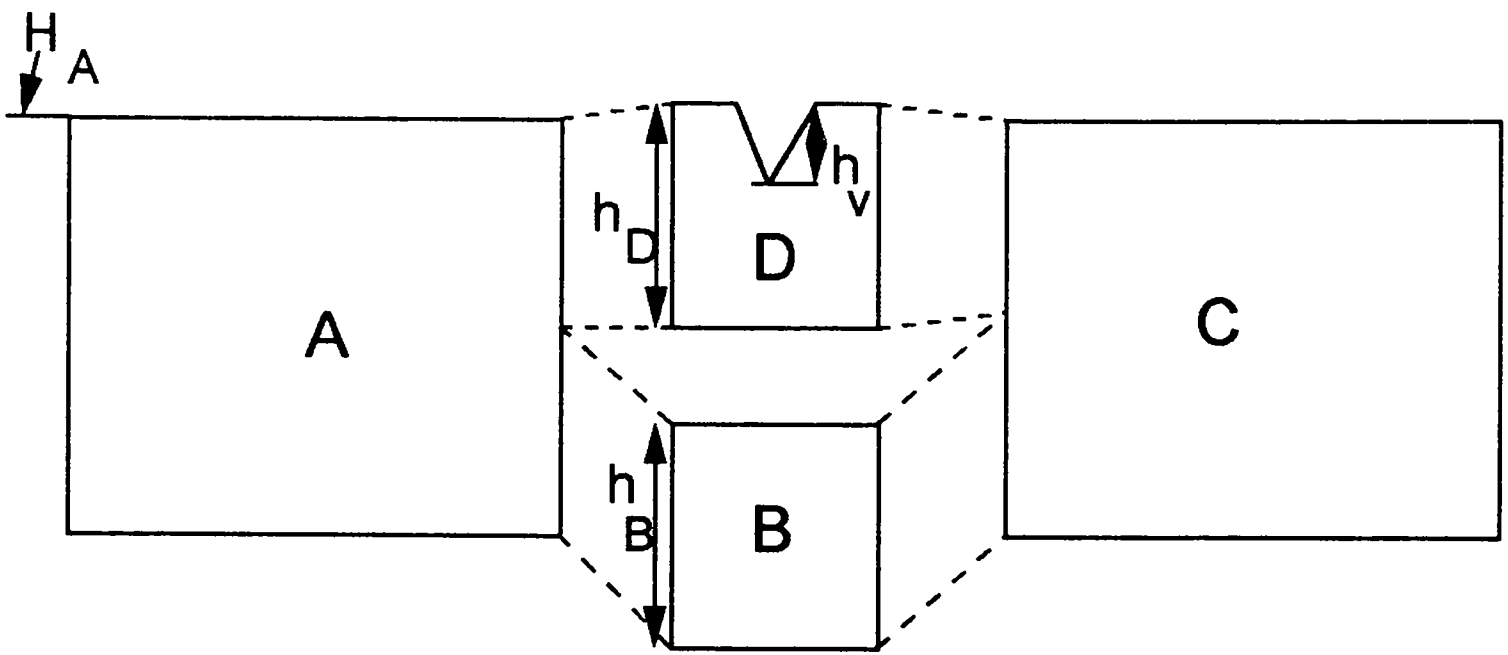

Figure 2. Plates Used in Weir Construction

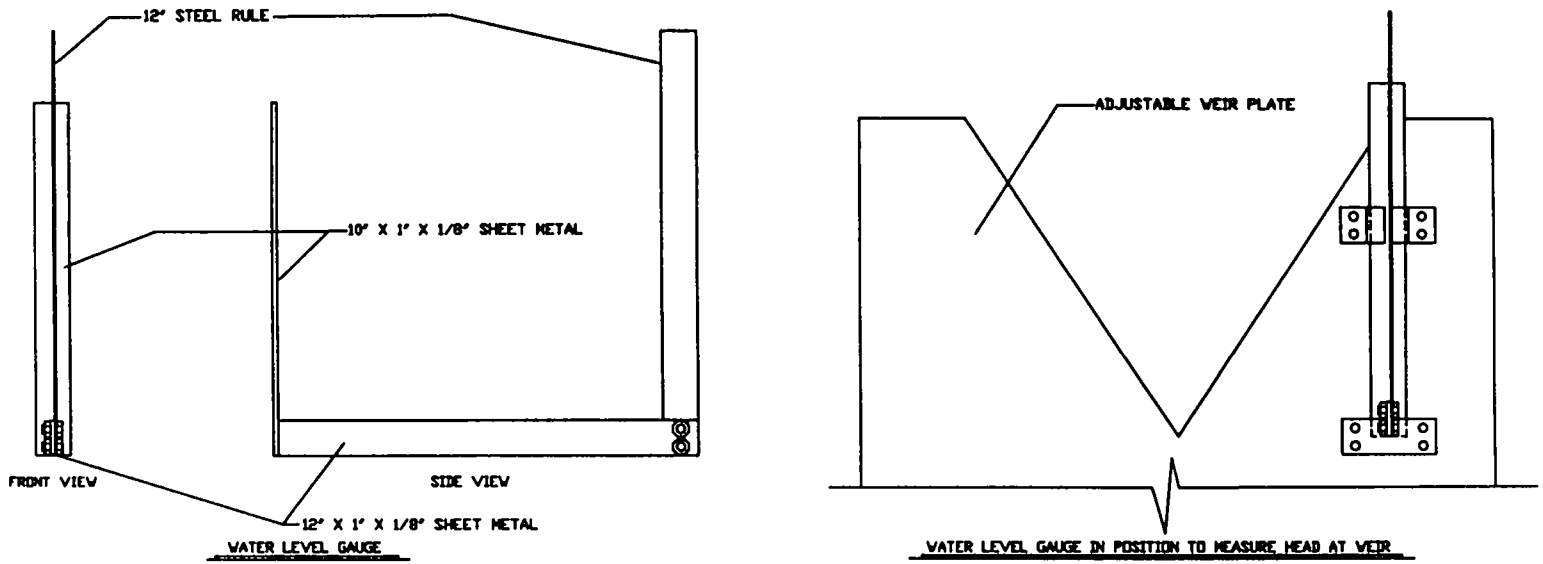

Figure 3. Depth Measuring Device

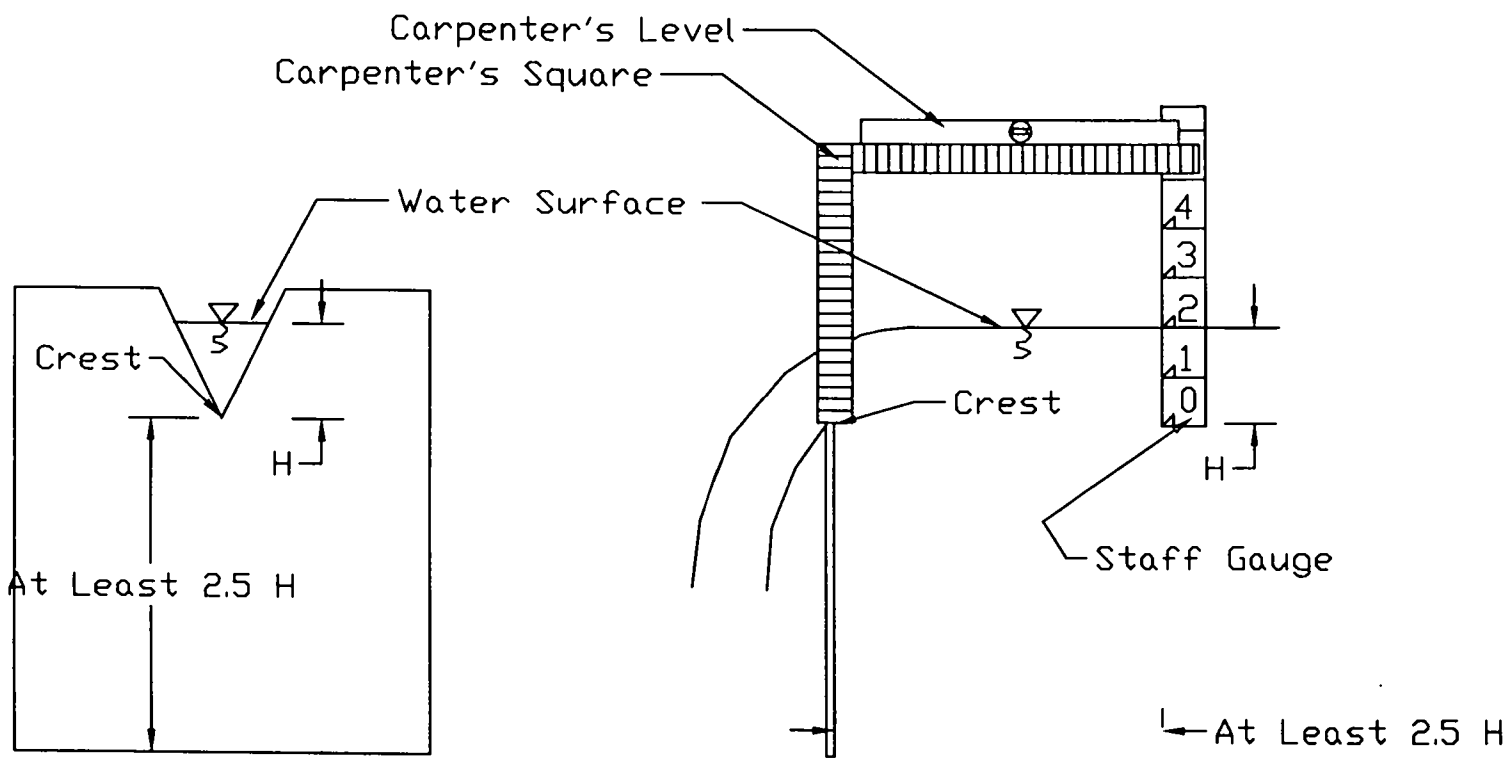

Figure 4. Alternative Method to Measusre Depth

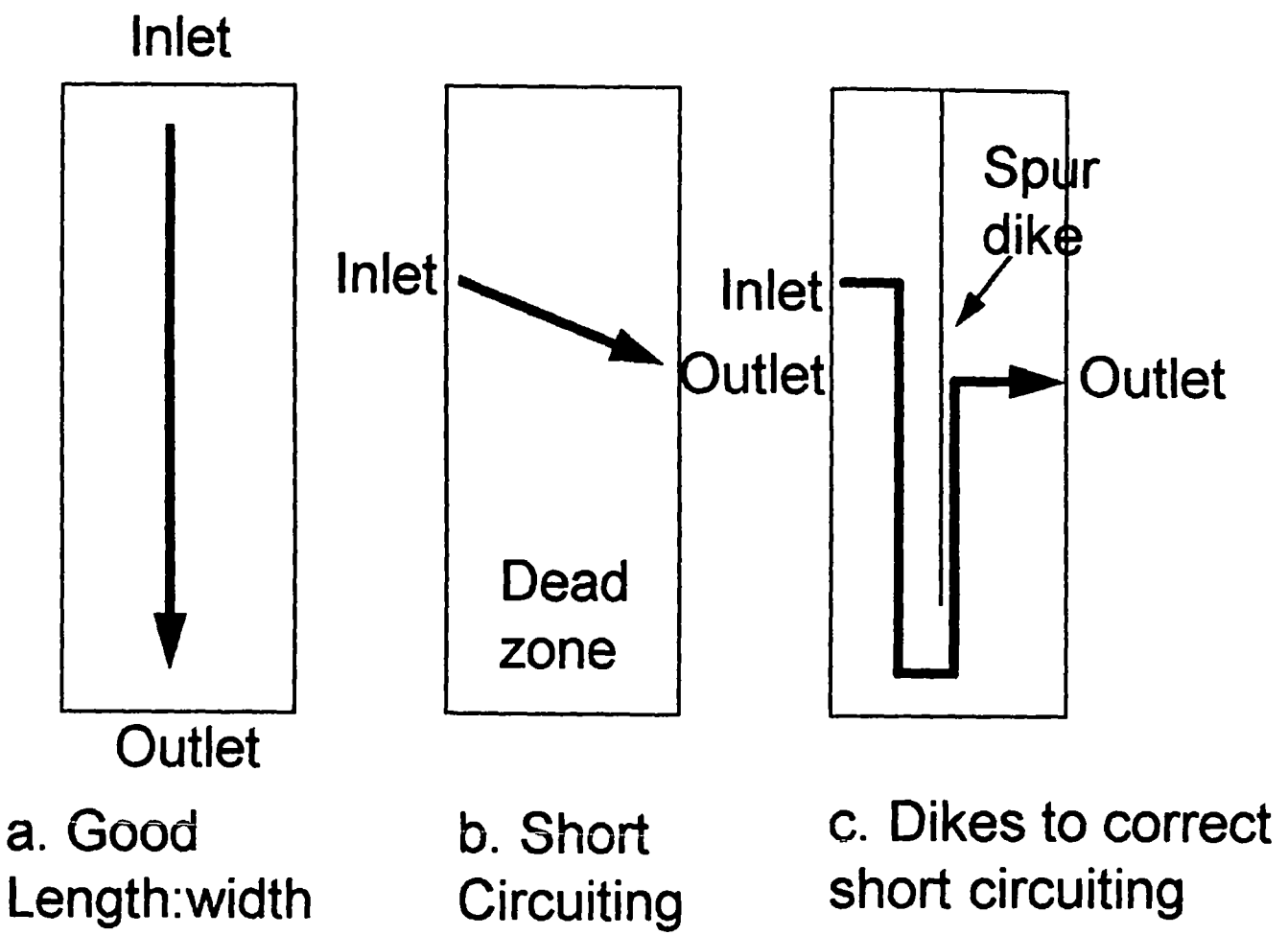

Figure 5. Alternative Flow Paths through Wetland

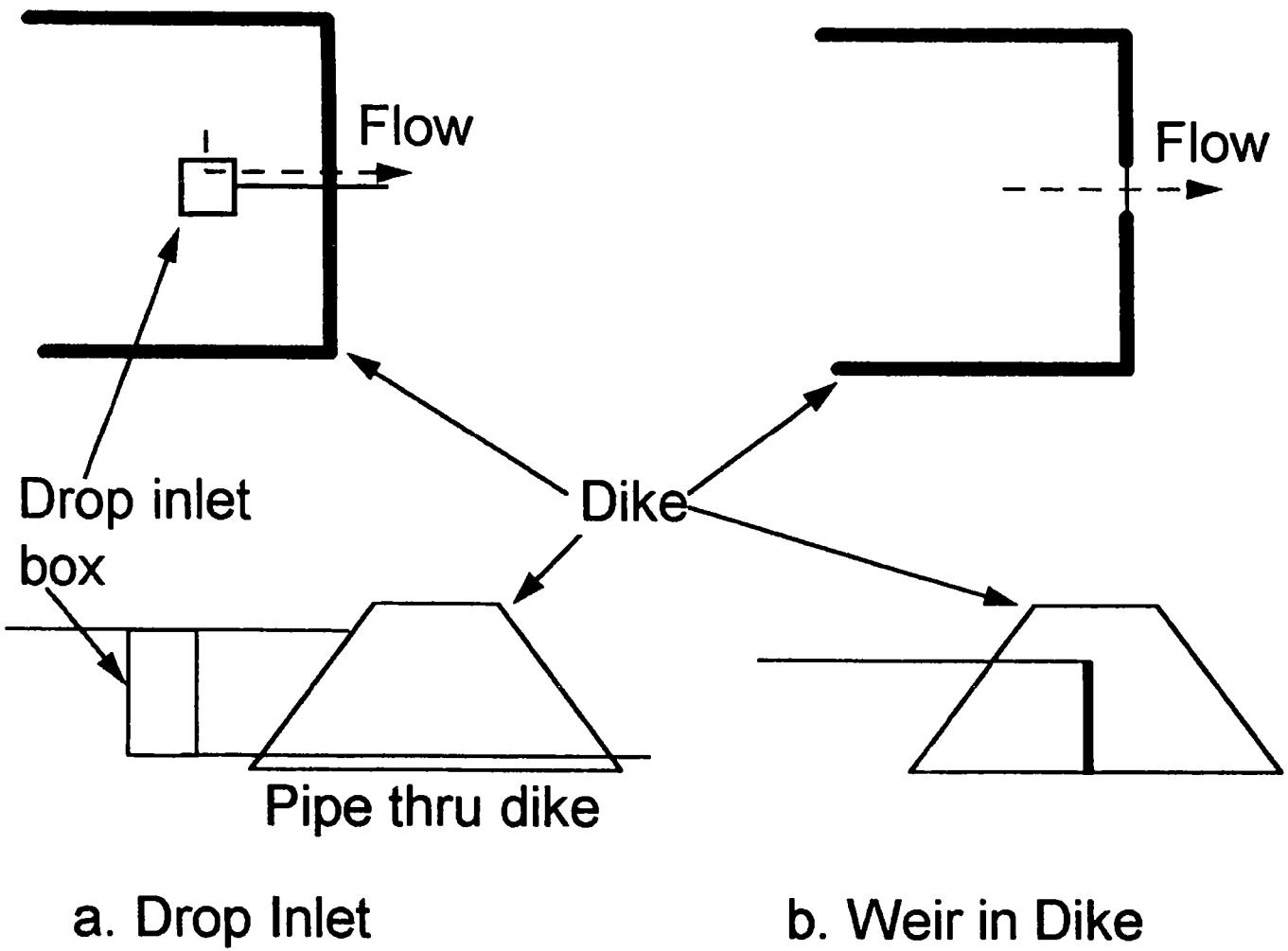

Figure 6. Alternative Location of Weir Structure

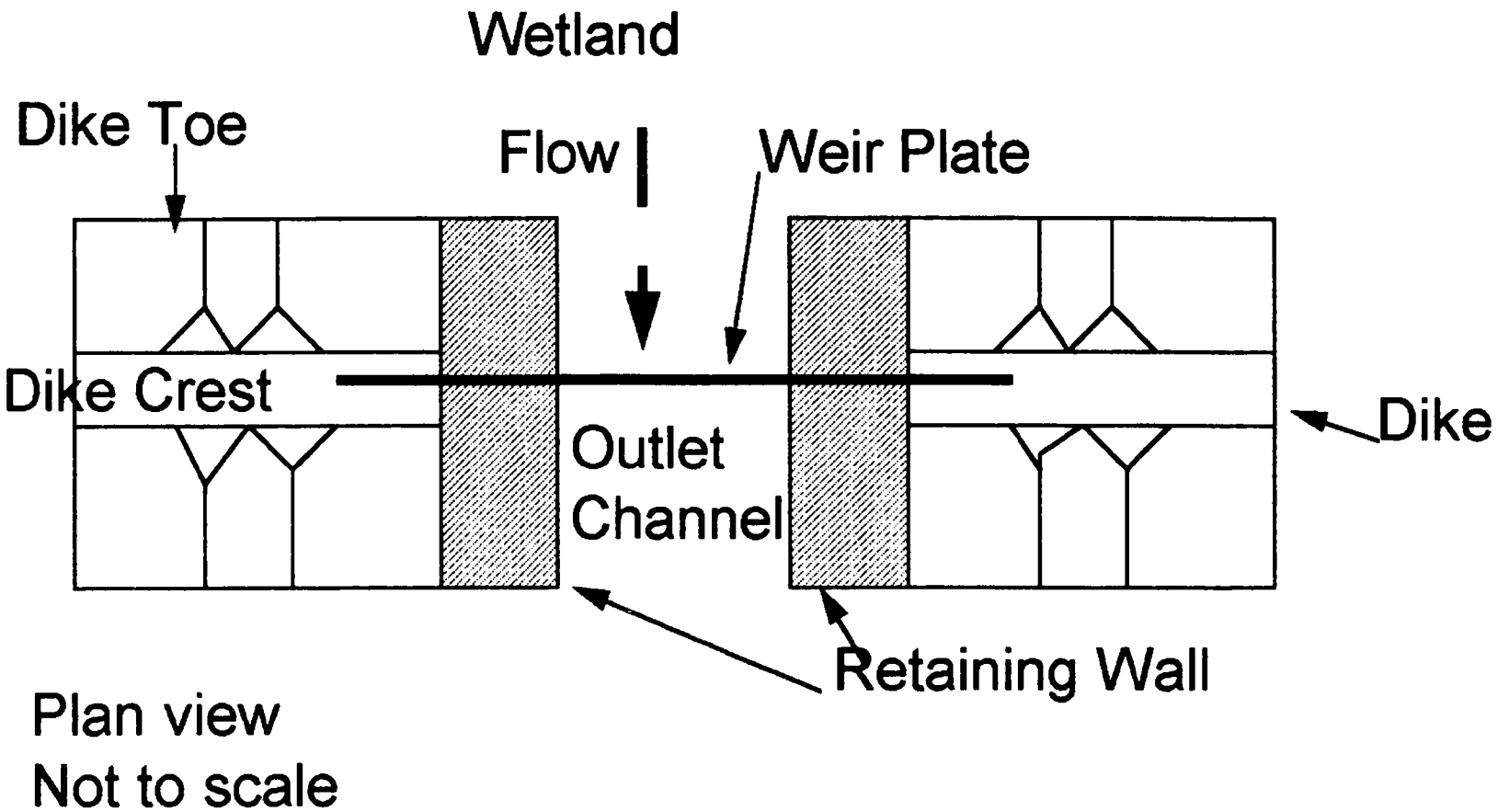

Figure 7. Plan View of Weir Structure

Sulfur Acidic Lakes in Germany: What Has to be Done?
Helmut Klapper, Walter Geller and Martin Schultze. UFZ Centre for Environmental Research Leipzig-Halle Department of Inland Water Research, Magdeburg, Germany. The problem: The rapid decline of brown coal mining, to about 30% in the new "*Länder*" of Germany, has produced many new lakes within a few years. These lakes filled with groundwater very often are affected by acidification from pyrite oxidation. Their water is dark red, the pH 2 to 4 with the consequence of high metal content and absence of bicarbonate. Depending on the base binding capacity of the oxidised rock layers, the acidic conditions may last for decades, and, therefore, countermeasures are needed. Decision criteria for an active water quality management are (1) the urgent demand for fish-waters and recreational areas, (2) the need of new jobs in the post-mining landscape, and (3) the desirability to conserve some of these limnologically unique lakes as objects for science. In nature are also examples of sustainable bacteriological sulfate reduction. One case study was performed on the meromictic lake *Waldsee*. The aerobic epilimnion is acidic, the anaerobic monimolimnion, however, is neutral. The preferred microhabitat is the boundary layer between the two main strata, where plankton synthesise the organic material, necessary for sulfate-reducing bacteria. In another case the carbon source stems from urban sewage. The 11km-long Lake *Laubusch*, serving as a drainage for sewage water, reduces sulfate in the heavy loaded hypolimnion and in the macrophyte stands. The good fish stock of this lake is the basis for sport fishing. The mining lake *Senftenberger See* is an example of neutralisation by river water. After 1.5 exchanges of the lake volume the pH shifted from acidic to neutral in the manner of a titration curve. Experience with anaerobic technology was gained during our development of an in-lake denitrification plant. In a reservoir with nitrate content above drinking water standard, a straw-filled steel cage 20 x 60 x 1.50 m was positioned on the bottom. Nitrate-rich water together with a carbon source was pumped through this *aufwuchs* reactor. After eight weeks the whole hypolimnion was free of dissolved oxygen and free of nitrate because of nitrate respiration. For the task at issue here, the long-term biological desulfurication in mining lakes,

research is likewise focused on the hypolimnion and the sediments as preferable places for sustainable treatment.

Conclusions

- Large lakes threatened with acidification should preferably be filled with surface water.
- In smaller and deeper lakes, conditions suitable for sulfate-reducing bacteria may be created by adding or producing degradable carbon sources.
- In too-shallow lakes, the stratification must be stabilised by installing barriers against wind-induced mixing.
- Besides this final in-lake treatment, all possible means of abating acidification at the sources should be implemented where applicable.

MANGANESE REMOVAL IN SATURATED GRAVEL BEDS: OBTAINING DESIGN CRITERIA.

F.J. Sikora, G.A. Brodie, and L.L. Behrends

Abstract: Manganese is difficult to remove in passive wetland systems due to high pH requirements for rapid Mn oxidation and solubilization of MnO_2 in the presence of Fe^{2+}. To achieve Mn removal below the federal requirement of 2 mg/L, gravel beds placed after wetlands that remove Fe has been proposed. Although some data is available on gravel beds, not enough is available to recommend design parameters for these systems under a range of operating conditions. A study is being conducted to obtain information on the required Mn loading rates and retention times for adequate Mn removal at the TVA constructed wetland research facility. Treatments consist of two Mn loading rates of 1.4 and 3.7 $g/m^2/d$ and two types of gravel, namely limestone and river gravel. The treatments are replicated 3 times resulting in 12 experimental units. After 3 months of operation, limestone is proving to be more effective at removing Mn than river gravel. Compilation of operating parameters for Mn removal in gravel beds will benefit power utility and surface mining industries by yielding information on a passive system that is inexpensive relative to caustic alkaline drip.

Additional Key Words: iron, wetlands

Acidic Stream Mitigation by Limestone Sand Addition. David L. Brant[1], Anthony J. Marich Jr.[2], Keith L. Largent[3] (1-WVU National Research Center for Coal and Energy, Morgantown, WV, 2-PA Department of Environmental Protection, Markleton, PA, 3-Somerset Conservation District, Somerset, PA).

Abstract: The Town Line Run watershed comprises an area of 3,600 wooded acres. The tributaries feeding the stream consist of sandstone springs that do not contribute alkalinity to the watershed, leaving the stream susceptible to acid precipitation. This has a negative affect on Iser's Run, a native brook trout fishery above the confluence with Town Line Run. The objective in stream liming is to improve water chemistry by increasing pH, alkalinity, and reducing acidity, aluminum, and iron. Introducing crushed limestone directly into a stream from a dump truck is an inexpensive but temporary solution to accomplish this objective. In this type of liming operation, a bed of limestone is spread down the stream channel by the momentum of the stream from the introduction point, rather than manually. Water moving across this bed dissolves the limestone, increasing the pH, alkalinity, and calcium while decreasing the acidity, iron, and aluminum concentrations of the water. The size of the limestone particles is important for this purpose because particles that are too small (<150 microns) will carried away, while particles that are too large (>1000 microns) will remain at the introduction point. Our study placed 80 tons of sand-sized limestone (85% calcite) in the stream channel at a single point. Water samples were collected monthly at the following sites (1) directly upstream of the addition site, (2) 100 yards downstream of the site, and (3) 2500 yards downstream of the site. Other sample locations include (4) upstream and (5) downstream of the Town Line Run-Iser's Run confluence and the Casselman River upstream (6) and downstream (7) of Town Line Run. The samples were analyzed for pH, Specific conductivity, Alkalinity, Acidity, Iron, Manganese, Aluminum, and Sulfate. The first liming produced a pH of 6.6 that slowly declined to the baseline pH of 4.8 after 10 months. The alkalinity increased to 10 mg/l $CaCO_3$ eq. and also decreased to 6.0 mg/l $CaCO_3$ eq. after 10 months. The acidity was eliminated after the addition and gradually increased to 12.6 mg/l $CaCO_3$ eq. in the same time period. The second addition of 180 tons of the same limestone yielded similar initial results. The pH increased to 6.5, the alkalinity increased to 18.6 mg/l $CaCO_3$ eq., and the acidity was eliminated. In general, this low cost (<$2,000.00) project demonstrated that a single point application of limestone can increase the water quality of marginal acid sensitive streams for a limited time period. Careful selection of limestone particle size and amount of limestone can reduce the addition interval to annual or bi-annual additions.

Additional Key Words: Acid Rain, Lime-sand.

Performance of a Wetland/Anoxic Limestone Drain Treatment System at the Douglas Abandoned Mine Land Project. P.L. Sterner, J.B. Cliff, J.G. Skousen and A.J. Sexstone

Abstract. Acid Mine Drainage (AMD) exiting West Virginia's Abandoned Mine Land (AML) sites often is remediated using passive treatment systems. A new passive treatment technology which employs a combination wetland/anoxic limestone drain (WALD) is currently being evaluated at one AML site near Thomas, WV. The WALD utilizes a three cell design to complete treatment. Cell 1 (dimensions 365.8m x 2.5m x 1.8m- L x W x D) employs a 0.6m base of limestone overlain by 1.2m of organic material. Cell 2 (dimensions 457.2m x 9.1m x 2.4m) employs a 1.5m limestone base overlain by 0.9m of organic material. Cell 3 (dimensions 25m x 9.1m x 1.2m) is a sedimentation basin which allows deposition of precipitating metals. Thirteen polyvinyl chloride (PVC) cylinders with multiple ports were installed throughout the system so that water sampling at various locations and depths can be conducted. The working hypotheses to be tested is whether microbial iron reduction in organic sediments is sufficient to prevent limestone coating by iron oxyhydroxides, thus allowing continuous limestone dissolution and subsequent pH increase of the treated AMD. Influent water enters the system via surface flow at a rate of approximately 240 gpm from pipes draining an underground coal mine. Average influent AMD parameters over the study period were: pH= 3.0, total acidity= 426 mg/L, total alkalinity= 0 mg/L, total iron= 20 mg/L, total manganese= 6 mg/L and aluminum= 31 mg/L. Results based on effluent water quality indicate that AMD is being treated by the WALD. Average water quality parameters exiting the WALD over the course of the study period were: pH= 6.6, total acidity= 25 mg/L, total alkalinity= 152 mg/L, total iron= 0.1 mg/L, total manganese= 1.5 mg/L, and aluminum= 0.8 mg/L. Despite dramatic improvement in effluent water quality parameters, the organic matter in cells 1 and 2 does not currently function as desired. The organic matter has limited hydraulic conductivity so less AMD infiltration takes place than is desirable, resulting in surface rather than subsurface flow. Therefore minimal treatment occurs because of limited contact between AMD and the WALD. Dissolved oxygen values within the organic matter are not conducive to Fe^{3+} reduction, therefore Fe^{3+} is likely precipitating. Limestone is dissolving sufficiently to raise pH of the AMD allowing hydrolysis and precipitation of Fe^{3+} and Al^{3+} as shown by absence of total iron and aluminum and increased Ca^{2+} in the effluent water. Considering these results, the WALD treatment system may prove to be an effective retainer of metals that contaminate mine waters. However, retention of metals coats limestone, inhibiting dissolution, which leads to decreased functionality of the WALD. The pH of the effluent water has declined since AMD was introduced, accompanied by an increase in total acidity.

Additional Key Words: acid mine drainage and wetland/anoxic limestone drain.

Advanced Design and Construction Techniques for Staged Passive Wetland Treatment Systems for Coal Ash Leachate

by
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ABSTRACT. Passive wetland treatment systems represent a viable alternative for the chemical treatment of leachate waste waters from coal ash disposal. Ash resulting from the burning of coal commonly contains many trace metals. Leachate from active and closed disposal areas is often regulated as a solid waste discharge requiring the removal of trace elements to meet water quality standards in the receiving stream. For many of these sites, topographic constraints limit the availability of land for large passive systems. To meet these conditions, the Springdale Passive Wetland Treatment System represents a more engineered configuration with advanced design and construction techniques, with specific design considerations for future maintenance access. The Springdale facility is a passive wetland system designed to treat leachate from a closed fly ash disposal site near Pittsburgh, Pennsylvania. The project is jointly funded by the Electric Power Research Institute and Allegheny Power Service Corp. The project was developed to provide initial compliance with iron, pH and TSS under a current NPDES permit for a toe of fill discharge. To meet pending discharge criteria, the system was designed as a multiple stage system for research and development of passive design criteria for the removal of trace metals. Flows average 45 gpm, and the discharge is characterized by circumneutral pH, elevated iron, manganese, boron, and other trace metals typical of fly ash leachate. The leachate is collected at the toe and pumped to a flow equalization basin for initial iron oxidation and precipitation prior to entering a series of eight passive treatment units, each approximately 30 feet in width by 150 feet in length. The first four units are vegetated aerobic wetlands to remove residual iron. The fifth and sixth units are two rock drains for bacterial manganese removal. The seventh unit is a sulfide-generating organic upflow bed for trace element removal. System discharge occurs through a final algal and sand filter unit. Construction was completed in October 1995.

Performance of the system is monitored by water quality sample points located at the discharge of each type of passive treatment, so as to identify the most effective removal environment for each target parameter. The system is being monitored for 38 water quality parameters of interest on a semi-annual basis and monthly for selected parameters relating to current compliance objectives. Average removal efficiencies for Aluminum, Total Iron, Dissolved Iron and Manganese have been 99, 92, 96, and 66 percent respectively since the system was completed in 1995. A comprehensive monitoring program for water quality and substrate analyses will continue for at least 24 months. Detailed plant uptake and metal cycling studies will be undertaken with the University of California, Berkeley, through 1998. The ultimate goal of this work is to provide improved sizing and design standards for passive removal of trace metals.

Passive Treatment of Acid Mine Drainage in Systems Containing Compost and Limestone: Laboratory and Field Results. G. R. Watzlaf and D. M. Pappas.

Abstract: Passive, down-flow systems, consisting of compost and limestone layers, termed successive alkalinity producing systems (SAPS), may be well suited for treatment of mine drainage containing ferric iron and/or aluminum. A column, simulating a SAPS, has been operated in the laboratory for 52 weeks. The 0.16-m diameter column consisted of a 0.30-m thick layer of limestone, a 0.76-m thick layer of spent mushroom compost and 0.91 m of free standing water. Actual AMD (pH = 3.02, acidity = 218 mg/L (as $CaCO_3$), SO_4 = 600 mg/L, Fe = 16.0 mg/L, Mn = 12.1 mg/L, and Al = 17.1 mg/L) was applied to the column at a rate of 3.8 mL/min. Effluent pH has remained above 6.2 (6.2-7.9) in the column system. A SAPS located in Jefferson County, PA has been monitored for the past 4.5 years. The SAPS has an approximate area of 1000 m^2 and contains a 0.4-m thick layer of limestone, a 0.2-m thick layer of spent mushroom compost, and 1.5 m of free standing water. Mine water (acidity = 335 mg/L (as $CaCO_3$), SO_4 = 1270 mg/L, Fe = 246 mg/L, Mn = 38.4 mg/L, and Al = <0.2 mg/L) flowed into the SAPS at a rate of 140 L/min. Water samples from the field and laboratory systems have been collected at strategic locations on a regular basis and analyzed for pH, alkalinity, acidity, Fe^{2+}, total Fe, Mn, Al, SO_4, Ca, Mg, Na, Co, Ni, and Zn. Alkalinity has been generated in both field and laboratory systems by a combination of limestone dissolution and sulfate reduction. The column generated an average of 378 mg/L of alkalinity; 74% due to limestone dissolution and 26% due to bacterial reduction of sulfate. The field SAPS generated an average of 231 mg/L of alkalinity and exhibited seasonal trends. Sulfate reduction was responsible for 70% of the alkalinity production in the summer and decreased to as little as 30% of the alkalinity production in the winter.

Additional Key Words: compost wetlands, sulfate reduction.

EVALUATION OF SELECTED GRASSES FOR THE REVEGETATION OF A COAL SLURRY LAGOON IN WESTERN KENTUCKY BY DIRECT SEEDING.

by

T.P. Carter, R.I. Barnhisel, B. Gray and J.R. Nawrot

The research was conducted on the intermediate zone of a 23 ha slurry impoundment located on the Gibraltar Mine, near Central City, Kentucky. Two separate experiments were established. In the first, cultivation was carried out using a conventional disc and in the second, an 'Aer-way' attachment was used. The experimental plots, each measuring 4 m x 3 m, were prepared and seeded in June 1993. Percentage cover results were estimated by field observation in September 1995. In the experiment where cultivation was carried out using a conventional disc,. the greatest mean percentage cover levels with sideoats grama 'El Reno' (55%) being the best entry. For the second experiment, the highest percentage cover was obtained for switchgrass 'Alamo' (38%). These values reflect do not include weeds which averaged in the 40-50% ranged and most plots had 90-95% vegetation cover. Results for the cool-season species were generally disappointing and may have been due to late seeding-date. This study revealed that warm-season grasses, especially the tall-grass prairie species, produced reasonable stands on coal slurry after just two years.

KEY WORDS: direct seeding, coal slurry lagoon, warm season grasses, grass seed stratification

Constructed Wetland Treatment System for Upper Blackfoot Mining Complex. F. S. Sanders

Abstract: A combined passive oxidation/sedimentation (pre-treatment) and constructed wetland (polishing) system has been designed and installed to treat mine drainage at the inactive Upper Blackfoot River Mining Complex northeast of Lincoln, MT. The system is designed to treat up to 100 gpm flow with moderate heavy metal concentrations (25 to 95 mg/L Zn; lower concentrations of Pb, Cu, and As), moderate Fe concentrations (< 100 mg/L), and periodic high acidity (pH 2.6 to 3.5). The treatment scheme is flexible to accommodate a wide range of flows, metal concentrations, and acidity in order to gain cost-efficiencies and to meet restrictive discharge standards for the environmentally-sensitive Blackfoot River watershed. The wetland treatment system presently is undergoing start-up testing and initial tuning and will be operational during summer, 1996. Conceptual and engineering designs are presented along with preliminary data.

Additional Key Words: constructed wetland, acid mine drainage, metals

Reclamation of degraded areas in Eastern Amazonian: the potential of *Sclerolobium paniculatum* Vogel

by

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Abstract. *Sclerolobium paniculatum* Vogel (taxi-branco) is a legumenous tree native to the Brazilian Amazon region. It occurs in different types of soil and fix atmospheric nitrogen. The mechanical dormancy of the seeds may be overcome by immersing in boiling water and then removing them from the heat until the water cools to room temperature. The seed germination occurs in approximately 30 days. In greenhouse conditions, taxi-branco does not respond to the application of Ca and S. The critical levels in the soil of these two nutrients were 0.37 meq/100 cm^3 and 5.10 mg/cm^3, respectively. The silvicultural performance of taxi-branco may be considered satisfactory when compared to other native tree species of the Amazon. In homogenous plantations, taxi-branco trees produce about eight tons of litter per hectare. Its rapid growth accompanied by a high production of litter and its N fixation qualify this species as potentially suitable for the recuperation of degraded soils by human actions.

Additional Key Words: Amazon region, nutrients, critical levels, legume tree, etc

Introduction

The economic activities developed in the Brazilian Amazonian have caused different levels of degradation. From an environmental point of view, exist effects on biodiversity involving the losses or damages to the animal and/or plant populations, as well as alterations in the critical functions of the natural ecosystems, modifications in the carbon stores, quantities of water transpired and the retention of nutrients. Estimates shows 25 to 34 million hectares of native forest, have already been altered. (INPE, 1990; Skole & Tucker, 1993 and Feanrside, 1993).

The search of environmental conservation practices must be based upon more sustainable production systems, involving biological, social and economic aspects. Restoring the productivity of areas considered altered or degraded, must be the object of continuing research. The use of species more adapted and production systems more efficiently in the humid tropical areas are the key for sustainability.

Reforestation programs in the Brazilian Amazonian are limited to a few regions such of Para and Amapa States. The mainly species used in plantations programs are non-native, e.g. *Pinus caribea*, *Eucalyptus urophylla*, *E. deglupta*, *E. pellita* and *Gmelina arborea*. Despite the high production of the introduced species, the potential of native species has not been exploited and it is rarely considered in reforestation programs.

This paper presents and discusses a mineral nutrition experiments for seedlings of taxi-branco carried out in glass house and silvicultural field information obtained in the State of Para in Brazilian Amazonian.

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Material and Methods

- Mineral nutrition of seedlings

Sub-superficial (0.4 to 0.8 m depth) samples of an Alic Red yellow Latossoil with a clay texture were used from Viçosa, State of Minas Gerais, Brazil (Table 1). The samples were dried, ground to pass through a 4 mm sieve and divided into subsamples of 3.6 kg. The treatments composed by nine combinations of liming and N, P, K and S doses levels were compared to a control that did not receive any liming materials or fertilizers (Table 2). The levels of corrective material were based on soil liming demand (LD) (LD = 2 x Al^{3+} + 2 - (Ca^{2+} + Mg^{2+}).

Table 1. Physical and chemical properties of the an Alic Red yellow Latossoil used in the glass house experiment

Parameter	Unit	Value
pH (1)	-	4.60
Al^{3+}(2)	$cmol.kg^{-1}$	0.78
Ca^{2+} (2)	$cmol.kg^{-1}$	0.04
Mg^{2+} (2)	$cmol.kg^{-1}$	0.02
P (3)	$mg.kg^{-1}$	0.40
K (3)	$mg.kg^{-1}$	5.00
S (4)	$mg.kg^{-1}$	5.10
Organic carbon (5)	%	1.60
Sandy (6)	%	31.00
Silt (6)	%	14.00
Clay (6)	%	55.00
CEC (7)	$cmol.kg^{-1}$	6.57

1) water (1:2.5)
2) Extract. KCl 1.0 N
3) Extract. Mehlich-1
4) Extract. $Ca(H_2PO_4)_2$, 500 mg P kg^{-1} in HOAc 2N
5) Walkley & Black procedure
6) Granumetric fractions
7) Cation-exchange capacity

As a liming was used a mixture of commercial $MgCO_3$ and $CaCO_3$. The N, P and K were applied as salt solutions of $NH_4H_2PO_4$, NaH_2PO_4 H_2O, KH_2PO_4, KCl and NH_4NO_3. The S source was $CaSO_4$ $2H_2O$.

Table 2. Liming demand levels and doses of N, P, K and S applied to soil samples

Liming Demand	Doses Applied ($mg.Kg^{-1}$)			
	P	N	K	S
0.175	180	120	150	60
0.175	420	120	150	60
0.455	180	120	150	60
0.455	420	120	150	60
0.315	300	120	150	60
0.000	180	120	150	60
0.630	420	120	150	60
0.175	30	120	150	60
0.455	570	120	150	60
0.315	300	0	150	60
0.315	300	30	150	60
0.315	300	60	150	60
0.315	300	120	150	60
0.315	300	180	150	60
0.315	300	300	150	60
0.315	300	120	0	60
0.315	300	120	75	60
0.315	300	120	225	60
0.315	300	120	300	60
0.315	300	120	150	60
0.315	300	120	150	30
0.315	300	120	150	90
0.315	300	120	150	120
0	0	0	0	0

In the study of liming and P doses the plants received 80 mg $N.kg^{-1}$, 100 mg $K.kg^{-1}$, and 60 mg $S.kg^{-1}$, while in the study of the response to N, K and S the plants received 300 mg $P.kg^{-1}$ and 0.315 of the liming demand (Table 2).

After the application of the treatments, each experimental plot, consisting of six plastic bags containing 0.6 kg of treated soil, received 18 taxi-branco seeds. Forty-five days after

planting was done a pruning, leaving only one plant per bag.

The assays were carried out in a glass house with three replicates. After 190 days of planting the tops of the plants were harvested and the leaves separated from the branches and stems. Soil samples of each plot were taken to evaluate P and K (extraction with Mehlich-1), Ca and Mg (extraction with 1N KCl) and S (extraction with $Ca[H_2PO_4]_2$, 500 ppm of P in HOAc 2N). The plant samples were dried at 70°C, then weighed and ground. From the extract obtained by the nitre-perchloric digestion, K was determined by flame photometry (A.O.A.C., 1975), S by turbidimetry (Blanchar *et al.*, 1965), P by a colorimetric procedure (Braga and Defelipo, 1974), Ca and Mg by atomic absorption and N by Kjeldhal method (Bremner, 1965).

Regression analyses were carried out for leaves dry matter production (LDM), twigs + stems (SDM) and total (TDM) as a function of liming levels and P, N, K and S doses. With these equations, the necessary doses to reach 90% of maximum production were estimated. By substituting the necessary doses of P and K in the regression equation for the recovered P and K in relation to the added P and K doses were determined, the critical levels of these nutrients in the soil. The foliar N, P and K critical values were obtained by substitution of the necessary N, P and K doses in the regression equations adjusted to the foliar N, P and K content, as dependent variables of the doses added to the soil. To choice the equations by the regression analysis, were tested the linear, quadratic and root-quadratic models. The coefficients of the models were examined by F test, using the mean square error of the variance analysis of the experiment.

- Silvicultural information

Silvicultural information were taken from different places in State of Para under homogeneous plantations where the soil was recovered after mined of bauxite and in natural soil conditions.

Results and Discussion

- Mineral nutrition of seedlings

The fertilizers applied resulted in considerable growth gains to the taxi-branco plants and no response to the addition of lime (Table 3). The absence of response may be related to the fact that these treatments received 60 mg $S.kg^{-1}$ as gypsum. The Ca content in this salt (0.37 $cmol.kg^{-1}$) was sufficient for the requirements of taxi-branco and, as the soil used contained low levels of Ca (0.04 $cmol.kg^{-1}$), it follows that seedlings of taxi-branco have a low requirement for this nutrient.

Increments of P doses resulted in increments of P foliar contents (Table 4). The soil critical level of P was 26.06 $mg.kg^{-1}$ using the model adjusted for TDM, and 0.12% of the critical foliar P content with the model adjusted for LDM. These values were close to those observed by Novais *et al.* (1982) for *Eucalyptus* sp.

Table 3. Regression equations adjusted for the production of total dry matter ($g.pot^{-1}$) of the aerial parts (TDM) as dependent variables of levels of liming and P, N and K doses

Regression Equation	R^2
Response to liming and P applied	
$TMD = 3.71699 + 0.05134^{***} P - 0.000059^{*} P^2$	0.9444
Response to N applied	
$TMD = 9.40775 + 0.05735^{**} N - 0.000166^{*} N^2$	0.8390
Response to K applied	
$TMD = 9.92005 + 0.04669^{*} K - 0.000125^{*} K^2$	0.9088

° Significant at 0.1 probability level
* Significant at 0.05 probability level
** Significant at 0.01 probability level
*** Significant at 0.005 probability level

The positive response of N addition can be confirmed by the equation for TDM as variables dependent on the N doses added to the soil (Table 3). In accordance with this model, 90% of maximum production (12.92g) obtained can be

obtained by one dose dose around 79 mg of N kg^{-1} of soil.

Table 4. Regression equations adjusted for the P, Ca, Mg, N and K concentrations (%), in the dry matter of leaves and twigs + stems, as dependent variables of the applied doses of N and K

Regression Equation	R^2
$P= 0.05855 + 0.000335^{***} P - 0.00000042^{*} P^2$	0.8825
$Ca= 0.1745 + 0.00103^{*} P + 1.16715^{***} NC - 0.00000187^{*} P^2 - 0.95461^{*} NC^2$	0.9088
$Mg = 0.0802 - 0.00011^{***} P + 0.08953^{***} NC + + 0.00000016^{**} P^2 - 0.07326^{*} NC^2$	0.9725
$N= 1.41731 + 0.011643^{***} N - 0.0000213^{*} N^2$	0.9616
$K= 0.28103 + 0.004501^{***} K + 0.0000093^{***} K^2$	0.9582

° Significant at 0.1 probability level
* Significant at 0.05 probability level
** Significant at 0.01 probability level
*** Significant at 0.005 probability level

In spite of a quadratic response to the N addition, taxi-branco is regarded as a legume tree with the capacity to associate with atmospheric N_2-fixing bacteria. Therefore, if Rhizobium inoculated seeds were to be used, the plants may exhibit a different response to the addition of these nutrients.

According to the adjusted model for TDM as the dependent variable of K doses (Table 3), the soil critical level obtained for this nutrient was 27.4 $mg.kg^{-1}$. This value is close to that obtained by Barros *et al.* (1982) for *Eucalyptus grandis*.

The N and K contents in the tops of the plants increased with increasing doses of these nutrients (Table 4). On the other hand, this was not observed for the S contents in the aerial parts of the plants, since they did not alter significantly with the different S doses applied.

As the recommended N and K doses (79 mg $N.kg^{-1}$ and 80 mg $K.kg^{-1}$) are substituted in the adjusted equations for N and K foliar contents as dependent variables of the applied doses (Table 4), the critical foliar levels of 2.2% of N and 0.7% of K were obtained.

The absence of response to the S doses can be seen by the lack of adjustment of significant mathematical models for the different analyses of variables. This indicates that the original S content in the soil was higher than the critical level for taxi-branco. On the other hand, the adjusted equation for the S recovered from the soil by the extractant, as a function of the applied doses (Table 5), shows an increase of the availability of this nutrient with the doses. Therefore, it can be suggested that the critical S level for taxi-branco is lower than 5.1 $mg.kg^{-1}$ of soil.

With the same extractant from a soil with a clay content similar to that used in the present study (53%), Alvarez *et al.* (1983) obtained a critical S level of 5.3 $mg.kg^{-1}$ of soil for 90% of maximum production of *Eucalyptus grandis* seedlings.

Table 5. Regression equations adjusted for the P, Ca, Mg, K and S recovered from the soil by the extractants, as dependent variables of the applied levels of liming and P, K and S doses

Regression Equation	R^2
$P= - 5.62804 + 0.114598^{***} P$	0.9198
$Ca= 0.24512 + 1.51045^{***} NC$	0.9899
$Mg= - 0.023941 + 0.46401^{***} NC$	0.9590
$K= 4.4099 + 0.2362^{***} K + 0.00064^{**} K^2$	0.9986
$S= 4.5943 + 0.0680^{*} S + 0.00058^{*} S^2$	0.9899

* Significant at 0.05 probability level
** Significant at 0.01 probability level
*** Significant at 0.005 probability level

- Silvicultural information

Sclerolobium paniculatum Vogel has four varieties (paniculatum, subvelutinum, rubinosum, and peruvianum) with the difference found mainly in the characteristics of the leaflets. The States of Pará and Amazonas in Brazil are the main regions where the paniculatum variety occurs (Pereira, 1990).

In homogenous plantations taxi-branco has an architecture similar to eucalyptus plantations. The adult trees

found near Santarem, possess heights varying between 20 m and 30 m and a Diameter at Breast Height (DBH) of 70 to 100 cm. In secondary succession occupies open spaces and is characterised as a light demanding species, with a great capacity for adaptation in unfavourable soil conditions (Carpanezzi et al., 1983; Erfurth & Rusche, 1976; Lemeé, 1956; Ducke, 1949 and Correa, 1931).

Phenology observations in Trombetas National Forestry indicated that flowering occours between may throught july and frut production in August until November (Mineração Rio do Norte, sn). In Santarem region, near Trombetas National Forestry, fruit matures and the dissemination of the seeds occurs from January to March.

The taxi-branco seeds are small and hard. It was observed about 15,000 seeds per kilo (Mineração Rio do Norte, sn).

The mechanical dormancy of seeds can be overcome with the application of adequate technologies (Carpanezzi et al., 1983 and Carvalho & Figueiredo, 1991) and its germination occurs in approximately 30 days.

Field experimentation has shown good silvicultural performance in relation to other species considered pioneers in secondary succession (Tables 6 and 7). The analysis of the performance of taxi-branco with other native species must consider the fact that, seeds from mother trees, chosen in locals of natural occurrence were used and therefore there is a low index for genetic selection. So, the development of studies for genetic improvement to the determination of better provenance and adequate silvicultural practises, may improve, even further, the performance of taxi-branco.

Taxi-branco has showed its potential for reclamation of degraded land in a trial held in abandoned pasture in Paragominas (Table 8). This behavior can be due to its capacity to fix nitrogen and to associate to endomicorizal fungi (Table 9).

Table 6. Increments average values of plant height (m) and Diameter at Breast height (DBH) (cm) for taxi-branco at different ages (months) planted in Belterra

Age	Plant height	Plant DBH
24	1.00	2.80
60	2.40	3.70
72	1.90	3.80
108	1.80	2.80
180	1.10	2.50

Adapted from Matos (1993)

Table 7. Average values for survival (%), height (m), DBH (cm) and volume (m^3/ha) in different ages for some native and exotic species of rapid growth planted with a 3 m x 2 m spacing at Belterra, State of Para

Species	Age	Survival	Height	Dbh	Volume
*Vismia*sp	66	91,7	8,6	7,6	31,9
Laetia procera	66	96,7	7,6	8,6	36,9
Acacia mangium	30	97,0	7,4	10,7	58,2
S. paniculatum	66	94,7	12,2	9,1	105,7
E.urophylla	78	85,5	13,4	13,2	167,2
Jacaranda copaia	78	94,7	12,4	14,5	175,2
Eucalyptus grandis	78	74,7	16,0	16,0	257,2

Adapted from Yared et al. (1988)

Table 8. Growing of height (m), DBH (cm) and dossel area projection (m^2) of eight forestry species planted directly in abandoned pasture in Paragominas

Specie	Height	DBH
*Tabebuia serratifolia**	2.80	1.80
*Bertholletia excelsa**	3.30	5.10
*Dipteryx odorata**	3.60	3.30
*Cedrela odorata**	4.00	4.70
*Swietenia macrophylla**	6.30	6.30
*Sclerolobium paniculatum***	6.40	8.70

* plants with five years old

** plants with three years old

Adapted from Pereira & Uhl, in press

Table 9. Root infection of endomicorize fungi of fast growth tree species planted in abandoned pasture in Paragominas

Specie	Root infection (%)
Swietenia macrophyla	90.0
Cecropia palmata	86.0
Cordia multispicata	82.0
Solanum crinitum	80.2
Anacardium occidentale	80.8
Bertholletia excelsa	79.8
Dipterix odorata	74.2
Acacia mangium	65.7
Sclerolobium paniculatum	58.3
Stryphenodendrum pulcherrimun	57.8
Cariocar vilosum	56.2
Dydimopanax morototoni	56.0
Schyzolobium amazonicum	49.7

Adapted from Oliveira Júnior (unpublished data)

The biomass of taxi-branco trees is proportionally greater for the trunk (247.01 kg), branches (97.81 kg) and leaves (22.13 kg). The greatest concentrations of nutrients were found in the leaves followed by the branches and trunk. Nitrogen was the nutrient observed in the greatest proportion in the different parts of the plant (Matos, 1993).

In homogenous plantation at the Experimental Station in Belterra, the litter production of taxi-branco was about 2.7 times greater than *Eucalyptus citriodora* (Table 10). Besides this, the chemical composition of the litter incorporated to the soil is another important characteristic to be considered. This has immediate implications in relation to its ability for decomposition and augmentation of organic material to the soil, especially when one is dealing with recuperating degraded soils. In this context, when comparing the chemical composition of the litter of taxi-branco with that of *E. citriodora*, one can verify the advantage of using a leguminous specie for the recuperation of soil fertility (Table 10). Although taxi-branco has low ratio of C/N, that facilitates decomposition, the high quantities of N, P, K, Ca and Mg on litter that reach the soil are superior to those of eucalyptus (Table 10).

Table 10. Production of litter ($t.ha^{-1}.yr^{-1}$), C/N ratio in litter and quantities ($t.ha^{-1}.yr^{-1}$) of N, P, K, Ca and Mg in litter of homogenous plantations of taxi-branco and *E. citriodora* at Belterra, State of Para

Parameter	Species	
	Taxi-branco	E. citriodora
Production of litter	7.7	3.3
C/N ratio	40.0	69.0
N	32.0	28.0
P	2.3	1.0
K	3.9	2.3
Ca	13.9	13.7
Mg	5.4	3.3

Brienza & Yared (unpublished data)

The potential of taxi-branco for the recuperation of degraded soils has been confirmed with plantations in areas where bauxite has been mined by Mineração Rio do Norte, in Porto Trombetas. Among the different native species used, taxi-branco has been prominent (Table 11). The rapid formation of litter may provide favourable conditions for establishment of other pioneer species in order to promote the increase of biodiversity in an imitation of the natural succession process.

Table 11. Growth in height (m) and diameter at breast height-Dbh (cm) at seventy month of different native tree species planted in area with superficial top soil after buxite mined

Specie	Height	Dbh
Himenolobium excelsum	5.20	8.0
Miconia longifolia	9.40	11.0
Bowdichia sp	6.50	8.0
Sclerolobium racemosa	10.60	26.6

Adapted from Knowles (1994)

A study of undisturbed soil samples, collected under different vegetation after the exploitation of bauxite in Porto Trombetas, using *Acacia auriculiformis* as an plant indicator, suggest that the *A. auriculiformis* growth was probably favoured by the better soil conditions promoted by taxi-branco (Table 12).

Table 12. Height, roduction of dry matter of roots and aerial parts of *Acacia auriculiformis* planted in no-modified soil collected under: natural regeneration (NR); homogeneous stands of taxi-branco; mixed plantings of native species (MPN); mixed plantings with exotic species (MPE) and homogeneous stand of *Acacia mangium*, at the Mineração Rio do Norte in Porto-Trombetas

Soil type	Height (cm)	Aerial dry matter (g)	Root dry matter (g)
NR	17.3	2.6	0.6
Taxi-branco	16.5	2.5	0.4
MPN	14.3	2.2	0.3
MPE	13.6	2.2	0.3
Acacia mangium	8.7	1.5	0.1

Conclusion

The results of this work permitted the determination of the critical levels of P and K in the soil for taxi-branco, as being 26.1 and 27.4 $mg.kg^{-1}$ of soil respectively. The N dose required to obtain 90% of maximum production of total dry matter was 79 mg kg^{-1} of soil. The N, P and K critical foliar contents were 2.20%, 0.12% and 0.70% respectively. Because of the absence of response to liming and S addition, the Ca and S critical levels were estimated as being lower than 0.37 $cmol.kg^{-1}$ and 5.1 $mg.kg^{-1}$ of soil respectively.

The low Ca requirements of taxi-branco, its tolerance for exchangeable Al in the order of 1 meq/100 cm^3 of soil, its capacity fix N and associate with micorizal fungi are certainly factors which contribute to its success as a pioneer in secondary succession, especially in conditions of low soil fertility, as was confirmed based on Trombetas, Belterra and Paragominas plantations and experimentations.

Literature Cited

A.O.A.C. 1975. Association of official analytical chemists. Official methods of analysis. 12ª ed. Washington DC. 1094 pp.

Barros, N.F.; Novais, R.F.; Neves, J.C.L.; Gomes, J.M. 1982. Interpretação de analises do solo para *Eucalyptus grandis*. Rev. Árv. 6:38-44.

Blanchar, R.W; Rehm, G.; Caldwell, A.C. 1965. Sulfur in plant material by digestion with nitric and perchloric acids. Soil Sci. Soc. Am. Proc. 29 71-72.

Braga, J.M.; Defelipo, B.V. 1974. Determinação espectrofotométrica do fósforo em extrato de solo e plantas. Rev. Ceres, 21:73-85.

Bremner, J.M. 1965. Total nitrogen. In: Black C A, ed. Methods of soil analysis - Part 2 - Chemical and microbiological properties. Madison, Am. Soc. Agron. Inc Publisher pp. 1149-1178.

Carpanezzi, A.A; Marques, L.C.T.; Kanashiro, M. 1983. Aspectos ecológicos e silviculturais de taxi-branco-da-terra-firme (*Sclerolobium paniculatum*). Curitiba, EMBRAPA/URFCS, 10 p. (Circular técnica 8).

Carvalho, J.E.U. de & Figueiredo, F.J.C. 1991. Biometria e métodos para superação da dormência de sementes de taxi-branco, *Sclerolobium paniculatum* Vogel. Belém: EMBRAPA-CPATU, 18p. (EMBRAPA-CPATU. Boletim de Pesquisa, 114).

Correa, M.P. 1931. Dicionário de plantas úteis do Brasil e das exóticas cultivadas. Rio de Janeiro, Serviço de Informação Agrícola, v2. 707p.

Ducke, A. 1949. Notas sobre a flora neotrópica - II. As leguminosas da Amazônia brasileira. Boletim Técnico do Instituto Agronômico do Norte, Belém, (18):1-248.

Erfurth, T. & Rusche, H. 1976. The marketing of tropical wood. B. wood species from South American tropical moist forest. Roma, FAO. 32p.

Fearnside, P. M. 1993. Deforestation in brasilian Amazonia: the effect of population and land tenure. Ambio 22. pp.537-545.

Instituto Nacional de Pesquisas Espaciais. 1990. Avaliação da alteração da cobertura florestal na Amazônia Legal utilizando sensoriamento remoto

orbital. São Paulo. Instituto Nacional de Pesquisas Espaciais.

Knowles, O. H. 1994. Estudo exploratório sobre a influência do solo vegetal no desenvolvimento do reflorestamento realizado mina Saraca no período 1979-1987. Anais. I Simpósio Sul-Americano e II Simpósio Nacional de Recuperação de Áreas Degradadas. Foz de Iguaçu-PR. Brasil. 14p.

Lemeé, A. 1956. Végétaux utiles de la Guyane française. In: Flore de la Guyane française. Paris, P. Lechevalier, p 53.

Matos, A. de O. 1993. Biomassa, concentração e conteúdo de nutrientes em taxi (*Sclerolobium paniculatum* Vogel) de diferentes idades, em Belterra, Para. Piracicaba. São Paulo. ESALQ. Tese Doutorado. 110p.

Mineração Rio do Norte. Calendário frutícola de espécies vegetais. Mineração Rio do Norte. Porto Trombetas, Pará, Brasil.

Novais, R.F; Barros, N.F.; Neves, J.C.L.; Couto, C. 1982. Níveis críticos de fósforo para eucalipto. Rev Árv. 6:29-37.

Oliveira Júnior., V. M, Nepstad, D. C., Pereira, C. A. 1994. Ocorrência natural de endomicorriza vesicular-arbuscular em plantas de rápido crescimento em área de pastagem abandonada na região de Paragominas. 6p. Trabalho apresentado na V Reunião Brasileira sobre Micorriza. Florianópolis-SC, 10-14 de outubro.

Pereira, B.A. da S. 1990. Estudo morfo-anatômico da madeira, casca e folha de duas variedades vicariantes de *Sclerolobium paniculatum* Vogel (Leguminosa, Caesalpinioideae) de mata e cerrado. Piracicaba, São Paulo. ESALQ. Tese Mestrado. 192p.

Pereira, C. A. & Uhl, C. Crescimento de arvores de valor econômico em áreas de pastagens abandonadas de Paragominas-PA, Amazonia, Brasil. In: Regeneração florestal na Amazonia. INPA/PDBFF. Manaus, Amazonas, Brasil. In press.

Skole, D. & Tucker, C. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite dat from 1988 to 1988. Science 260.pp.1905-1910.

Yared, J.A.G.; Kanashiro, M.; Conceição, J.G.L. 1988. Espécies florestais nativas e exóticas: comportamento silvicultural no planalto do Tapajós-Pará. Belém, EMBRAPA-CPATU Documentos 49, 29p.

Field Inoculation Rates of Mycorrhizal Fungi in Revegetation of Abandoned Coal Mine Lands. Robert K. Noyd and F. L. Pfleger, Department of Plant Pathology, University of Minnesota, St. Paul, MN 55108

Abstract: Abandoned coal mine land (AML) sites in southern Illinois and western North Dakota contain areas that are difficult to revegetate due to low fertility (1-3 mg kg-1 N and P), little organic matter, and acidic (3-4, Illinois) or alkaline (~8, North Dakota) pH. Areas such as these may benefit from inoculation with arbuscular mycorrhizal (AM) fungi to assist in the establishment of vegetative cover. Potential sources of adapted mycorrhizal inoculum were found in reclaimed overburden sites with large AM fungal spore densities (100 and 33 spores g^{-1} Illinois and North Dakota, respectively). Soils from these locations were used to determine an infective inoculation rate by a mycorrhizal inoculum potential (MIP) bioassay. Inoculum, consisting of rhizosphere soil and dried roots, was mixed into overburden in proportions of 0, 1, 2.5, 25, 50 and 100% (w/w), placed into containers, and sown with a single 12-day-old seedling of *Andropogon gerardii* Vitm. (big bluestem), a native prairie species known to respond favorably to AM fungi. After 14 days, shoots were dried and weighed and the root system was collected, cleared, stained, and assessed for percent root length colonized by AM fungi. An inoculum proportion of 1% in Illinois and 2.5% in North Dakota overburden produced moderate (16%) root colonization. These inoculum proportions were selected for rates of field inoculation because they were the lowest proportions that were both infective and effective in increasing shoot biomass of *A. gerardii*. In both soils, this level of root colonization was about one-third of the maximum colonization (50%) obtained with 25, 50, and 100% proportions of inoculum. Using adapted AM fungi and *A. gerardii*, MIP bioassays can be used to determine a field inoculation rate that has the potential to establish populations of beneficial mycorrhizal fungi and enhance chances of successful revegetation.

Additional Key Words: arbuscular mycorrhizal fungi, mineland reclamation, native prairie grasses, mycorrhizal inoculum potential, *Andropogon gerardii*

Lateral Thinking on Minesite Rehabilitation in Australia. D.J. Williams

Abstract: The Australian mining industry has disturbed less than 0.03 % of the land mass in 200 years, compared with 65 % used for agricultural activity (mostly for sparse grazing). About 0.1 % of Australia's land is cleared every year, removing native habitat. The rehabilitation of mined land conventionally involves smoothing of the disturbed land, followed by revegetation. The end land use is typically designated as cattle grazing, even though this is unsustainable in the more arid climates. Open-cut mining results in an elevated land form. Smoothing generates a mounded final land form of enlarged area, which tends to direct increased rainfall runoff, erosion products, and any contamination offsite. An alternative strategy is to minimise the area of disturbance and to contain any potential offsite impacts within the mined area. This can be achieved with far less earthworks than is required for smoothing, and reduces offsite impacts. A dished plateau land form allows grazing, while retaining steeper slopes is compatible with native habitat re-construction, reflecting the sharp relief which often dominates in nature. These alternative strategies are being trialed at a number of operating Australian mines.

Additional Key Words: cattle grazing, erosion, rainfall runoff.

Reclamation of the Wahsatch Gathering System Pipeline in southwestern Wyoming and northeastern Utah. D. Strickland, G. Dern, G. Johnson and W. Erickson.

Abstract: The Union Pacific Resources Company (UPRC) constructed a 40.4 mile pipeline in 1993 in Summit and Rich Counties, Utah and Uinta County, Wyoming. The pipeline collects and delivers natural gas from six existing wells to the Whitney Canyon Processing Plant north of Evanston, Wyoming. We describe reclamation of the pipeline, the cooperation received from landowners along the right-of-way, and mitigation measures implemented by UPRC to minimize impacts to wildlife. The reclamation procedure combines a 2 step topsoil separation, mulching with natural vegetation, native seed mixes, and measures designed to reduce the visual impacts of the pipeline. Topsoil is separated into the top 4 inches of soil material mixed with ground up vegetation and the remaining 8 inches of soil material, when present. The resulting top dressing is rich in native seed and rhizomes allowing a reduced seeding rate. The borders of the right-of-way are mowed in a curvilinear pattern to reduce the straight line effect of the pipeline. Monitoring of reclamation success illustrates the effects of landowner cooperation on revegetation. Specifically, following 2 years of monitoring, significant differences in plant cover ($0.01<P<0.05$) exist among regions of the pipeline. Observations suggest that revegetation may be heavily influenced by grazing management by individual landowners. Observations also suggest that growth of sagebrush plants from seed germination is exceeding growth from sagebrush plants planted as tublings.

Additional Key Words: erosion potential, grazing, stratified sampling.

Case Studies of Ecosystem-Based Approaches To Remediation. K. Trimble.

Abstract: Applications of the ecological sciences to site remediation have becoming increasingly common, as objectives have expanded from surface stabilization and aesthetic improvement to actual ecosystem reconstruction. In the fields of surface mining reclamation, specific techniques are often applied to common problems such as slope instability and erosion. The influence of larger scale physical and biological pressures on a site from the surrounding ecosystem, such as vegetation succession, is usually ignored. These processes affect the success of reclamation techniques, the management effort required to achieve success, the appropriateness of choices where alternative techniques exist, and the long term ecosystem sustainability. We stress a need for design approaches that examine the broad ecological context of site specific projects. Using cases study examples, we discuss cost-effective considerations including successional trajectory, bioregional wildlife and vegetation management criteria, and large scale biodiversity targets. Such considerations are used in establishing goals for site specific projects, and as tools in choosing appropriate techniques. In one example, the rehabilitation design for a limestone quarry in southern Ontario addressed regional aquatic habitat requirements, wildlife and forest community targets, and bioregional populations of internationally significant species, while at the same time minimizing approval and maintenance issues.
Additional Key Words: ecosystem restoration, biodiversity.

Abandoned Mined Land Impacts on Water and Sediment Quality, and Invertebrate Assemblages in Two Virginia Watersheds. J.L. Yeager, J. R. Bidwell, D. S. Cherry and C. E. Zipper. The constituents of abandoned mined land (AML) discharges (acidic pH, metals, dissolved solids, total suspended solids) can be toxic to aquatic life. Studies were undertaken to determine environmental impacts of acid mine drainage(AMD), a component of AML, in the Black Creek and Ely Creek watersheds, Wise and Lee Counties, Virginia. Conductivity and pH in the stream were measured to survey the magnitude of AMD discharge within each system. Water, sediment and water/sediment mixtures that simulate storm events were analyzed for metal content (Al, Fe, Mn, Zn, Cu, Mg). Benthic macroinvertebrates were collected seasonally using D-framed nets to determine AMD effects on relative abundance and taxon richness. Acidic pH ranged from 2.15-3.30 at three AMD-influenced seeps and varied from 6.40-8.00 at reference stations. Conductivity (µmhos/cm) ranged from 32-278 at reference sites and from 245 to >6000 at AMD-impact sites. Benthic macroinvertebrate abundance and taxon richness were notably lower in the seeps having only 1-3 taxa totalling < 10 organisms as compared to reference areas where richness values were 12-17 and comprised 300-977 organisms. Sediments from selected areas within Black Creek caused significant reductions in Daphnia magna reproduction relative to reference site sediments in 10 day chronic toxicity test. Concentrations of Fe, Al, Mg, Cu, and Zn were highest in the AMD influenced stations with low pH and high conductivity.

Additional Key Words: Acid Mine Drainage, Metals

Revegetation Standards for Floodplain Forest Ecosystems in Western Washington, USA. B. Zamora (Natural Resource Sciences, Washington State University, Pullman, WA 99164-6410).

Abstract. Mining activity within floodplain landforms of western Washington, USA, presents unique problems in terms of approaches to revegetation and the success standards to be use to quantitatively evaluate revegetation success. Persistent historical disturbance of floodplain areas of the region has left little undisturbed natural vegetation to use as reference sites for development of success standards. A strategy is proposed for use of an ecological model of succession within floodplain vegetation to both identify revegetation options and provide a quantifiable and ecologically dynamic framework of success standards for revegetation evaluation. The floodplain forest mosaic of mined lands in western Washington is a combination of (1) aquatic sites of open surface, impounded or flowing waters, (2) minerotrophic wetlands, and (3) xeroriparian sites between wetlands and uplands. Seven distinct and persistent plant communities of three physiognomic types (herb-dominated, shrub-dominated, and tree dominated community types) are present are common. These physiognomic groupings are strongly related to the degree of seasonal flooding and are successionally linked as habitats change from one flooding regime to another. Remnant stands of floodplain vegetation were used to construct a successional model which will provide for revegetation guidelines and a framework of success standards.

Additional Keywords: ecological classification, wetlands