SOIL ORDINATION: IMPLICATIONS FOR POST-MINING DISTURBANCE LAND-USES

by

Jon Bryan Burley and Don Gray

Abstract. Reclamation specialists are often faced with reconstructing landscapes suitable for numerous post-mining disturbance land-uses. Sometimes by creating landscapes suitable for one type of use may render options for other types of use difficult to facilitate. For example, constructing soils suitable for buildings and roads often means that the soils would not be suitable for vegetation. In our study, we examined the soils of the North Dakota coal fields determining their suitability for supporting structures and supporting vegetation. We developed a site suitability equation by employing principal component analysis (PCA) across soil suitability variables to support shallow excavations, dwelling foundations, roadway foundations, septic tanks, and absorption fields and we selected a vegetation productivity equation from a previous investigation we had conducted. There was no correlation between the results from the two equations when employing the dataset and PCA indicated that the two equations were somewhat independent and orthogonal. We then plotted the results of the site suitability equation with the results of the vegetation productivity equation. The plotted results (ordination) indicated zones where soils were unsuitable for either building sites and vegetation, zones that were suitable for vegetation or building sites, and zones suitable for both. We discovered that sandy loams placed in middle topographic positions, and relatively gentle slopes were most suitable for both land-uses. We suggest that in the reconstruction of soils intended for a variety of land-uses, these sandy loams may be the most flexible soils adaptable to post-disturbance landscapes.

Additional Key Words: soil science, landscape architecture, landscape planning, soil mechanics, agronomy, forestry, environmental planning

Introduction

While developing soil productivity equations at the University of Michigan (Burley 1995), there was one ancillary topic related to vegetation productivity equations that Jon Burley wanted to address. The idea for the topic emerged when he was an undergraduate student at the University of Minnesota (1973-1978). At that time he took an introductory course in soils for agronomic, horticultural, and forestry applications as well as a civil engineering course in soil mechanics. It seemed to Jon that the properties associated with productive agronomic soils and structurally sound engineered soils were on opposing ends of an axis (dimension). Not only were the properties different, textbooks focused upon only one subject, but not both. For example, today one can examine publications which addresses the construction of fills yet does not address the relationship of constructed fills to vegetation and so to Jon Burley the work seems incomplete. Even a recent book titled Urban Soil in Landscape Design by Craul (1992) focuses effectively upon only one part of the topic, soil properties for vegetation. In another example, Steiner et al. (1994) review the U.S. Soil Conservation Service land evaluation and site assessment system. Despite the name of the program, the purpose of this system is to identify landscapes with productive soils and does not appear to be considering other important resources of the landscape specifically pertinent to soils, such as preserving sand and gravel resources. Nor does the program seem to be concerned with assessing the

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landscape for land-uses such as housing and commercial development. In contrast, Hausmann (1990) and Sowers and Sowers (1970) present issues and techniques associated with stabilizing soils for structures without consideration for vegetation. These publications illustrate the perspective that there often appear to be experts on either subject, but rarely individuals who know and integrate both. Documents written by Gray and Leiser (1982), and Schiechtl (1980) are three of the few exceptions. They attempt, in part, to integrate the relationship between structural stability and vegetation growth.

As a practicing landscape architect, Jon encountered building site conditions in urban areas where the construction process had destroyed the soil capacity to support healthy vegetation. Vegetation drowned in some parking lot planting islands; yet vegetation in an adjacent island suffered from lack of moisture. He observed vegetation dying after installation in confined planting boxes, where the vegetation was starving to death as the roots could not develop beyond a certain capacity to support the growth and development of above ground biomass. In contrast, he participated in the development of numerous building sites where organic soils were removed or buildings were placed on pilings to provide a suitable stable foundation to support structures. He also observed some contractors who would not faithfully execute construction instructions, with the result that poured slab-on-grade floors sunk several feet downwards from their installed location, large structures slid downhill, and substantial cracks developed in building walls and floors which were attributed to differential settling and changes in moisture conditions of the subsoils. As a result of observing these phenomena, Jon Burley developed the opinion that the two requirements for engineered soils and vegetation seemed incompatible.

Burley and Thomsen (1987) describe the diversity of reclamation land-uses that may commonly occur on a mining site. Landscapes for recreation, housing, and industrial production are post-mining land-use examples where buildings are required. Therefore, post-mining landscapes may often require soils suitable for both vegetation and buildings. Then, in 1988, while working on a research project for the Federal Highway Administration, Jon Burley read a report by Bloomquist (1953) that indicated a special mixture of a gravelly substrate employed on roadside shoulders was capable of supporting turf grasses, resulting in a grassed shoulder. Based upon this report, Jon wondered whether there was indeed an opportunity to further investigate a soil mixture that was suitable for both structures and vegetation and to develop a predictive reclamation equation that could indicate both adequate vegetation productivity and suitability for building site development. While many investigators are interested in the ability of reclaimed sites to support vegetation, there should also be a concern for the ability of reclaimed sites to support small structures.

One investigator, James Urban, appears to be employing an approach which allows both stable soils and vegetation to co-exist, by constructing a structurally sound soil and then employing several construction techniques enabling vegetation to survive, surrounded by structural engineered soils (Goldstein et al. 1991, and Moll and Urban 1989). Urban (1992) explores the typology of soils across urban environments and their suitability for vegetation and illustrates the problems associated with some urban soils. Urban's approach is somewhat different than traditional practices which have placed vegetation into incompatible soils, causing the vegetation to die slowly. Alberty et al. (1984) present one of the few studies which examine woody plant response to construction sites, indicating that the typical compacted soil exhibited at construction sites inhibits the development of both *Forsythia ovata* and *Cornus sericea,* an issue that most reclamation specialists understand quite well for growing trees and agronomic crops on reclaimed landscapes. Without extensive site modifications many woody plants may not survive in these highly compacted soils. Craul (1994) describes several methods to reduce soil compaction for vegetation in urban areas. However, this interface between the requirements for vegetation and the need for structurally stable soils has not been vigorously investigated and reported in the literature.

Jon Burley was interested in using his soil productivity dataset for the North Dakota Coal Fields to search for soil types that were compatible for both building suitability and vegetation growth. While many urban sites are developed with existing *in situ* soils, because soil movement is a by-product of the mining activity, the act of surface mining can remove undesired existing soils and could build desired soils for a relatively minimal cost. It appears that most soil prescriptions in urban settings attempt to alter the physical state of the soil type, such as changing the void ratio by compacting the soil for roads, or altering the soil surface condition by aerating the soil to grow plants or covering the surface with mulch. However in urban areas, actually removing the soil and replacing it with a soil material that is more structurally sound, such as well graded substrate suitable for roadbeds, occurs only in relatively small quantities and only when absolutely essential to maintain a minimal level of stability. In most applications changing the soil type is costly and not typically conducted. Nevertheless, the act of surface mining may present the possibility to also change the soil type. Consequently, Jon Burley's vegetation productivity equation work appeared to present an opportunity for us to explore the potential for specifying large volumes of surface soil types and to define or search for soils that are compatible for both building suitability and vegetation growth.

Methods

For this study, we obtained ordinal data from the same sources concerning the soils examined in Burley (1995) for development suitability associated with ability to support embankments, dwelling foundations, roads, and septic tanks with absorption fields. The soils in this data source were rated in each category from slight limitations to moderate limitations to severe limitations. Jon Burley coded the data for analysis by assigning "1" for slight limitations, "2" for moderate limitations, and "3" for severe limitations. Since the dataset contains information that is not metric and is not continuous, the use of this dataset for parametric analysis is not suggested. However, this investigation is cursory and explorative in nature. As non-parametric multivariate procedures are developed, this type of analysis will require corroboration. For the moment, this study suspends the required assumptions for parametric multivariate analysis.

To begin the analysis we standardized the coded information with a mean of zero and a variance of 1 and then studied the four development suitability variables with Principal Component Analysis (PCA) to generate dimensions for site development. These dimensions would then be compared with predicted vegetation productivity derived from Burley (1995: Equation 8.1), by computing the Pearson product-moment correlations between the building suitability dimensions, predicted vegetation productivity, and actual vegetation productivity. If a strong relationship exists, then site development and vegetation productivity are related in some manner and one may employ vegetation productivity to predict building site suitability. If the variables are not correlated, then vegetation productivity and site development are not related and are relatively independent. This independence may suggest that there are at least two dimensions required to explain vegetation productivity and building site suitability, and that some soils could contain both adequate vegetation productivity and building site suitability, while other soils could contain adequate vegetation productivity but poor building site development potential. A plot of the soils along the identified dimensions would indicate soils suitable for both conditions. The characteristics of the suitable soils could then be examined.

Results

The four building site variables were positively associated with each other in the first principal component. The shallow excavation coefficient for the first dimension was over 50% smaller than the other three coefficients, meaning the shallow excavation variable may be a minor contributor in the first dimension. In contrast, shallow excavations comprised the major factor in the second component (Table 1). Only the first eigenvalue was considered significant. Therefore, a linear combination derived from the coefficients of the first eigenvectors was employed to create a variable representing building site suitability.

According to the results presented by Burley (1995), vegetation productivity per soil profile can be expressed by one variable and it appears that building site suitability can be expressed with one variable. When these two variables are examined using statistical software, the correlations between them are rather weak, suggesting independence between the two variables (Table 2). The two variables are not at the opposite end of an axis or dimension, but are actually composed to two independent dimensions.

Table 1. Principal Component Analysis of the building site suitability variables.

	Prin1	Prin2	Prin3	Prin4
Eigenvalue	2.428	0.921	0.483	0.167
Shallow Excavation Coefficients	0.240	0.965	0.006	0.104
Dwelling Foundation Coefficients	0.591	-0.067	-0.360	-0.719
Road Suitability Coefficients	0.576	-0.215	-0.387	0.687
Septic Tank and Absorption Field Coefficients	0.512	-0.133	0.859	0.008

Table 2. Correlations between vegetation productivity and building site suitability.

	Actual Vegetation Productivity	Building Site Suitability Dimension	Predicted Vegetation Productivity
Actual Vegetation Productivity	1.000		
Building Site Suitability Dimension	-0.036	1.000	
Predicted Vegetation Productivity	0.794	-0.074	1.000

Discussion

We interpret the results of this study to indicate that vegetation productivity and building site suitability are dimensions that are relatively orthogonal to each other. Therefore, in a PCA examination of the two variables (soil productivity and building suitability) we would expect two eigenvalues. The vegetation productivity variable, which has a larger range of values, would be associated with the first principal component, and would expect the building site variable to be associated with the second principal component. Table 3 presents actual results similar to what we might expect.

A plot of the two linear combinations associated with Table 3 would indicate those soils with characteristics suitable for both vegetation and building sites (Figure 1). Negative values for the site development suitability axis indicate conditions with slight limitations, and positive values for vegetation productivity indicate good plant growth potential. Therefore, soils in the upper left-hand corner of the plot indicate soils with few building site limitations and reasonable vegetation productivity. The letters in the plot indicate the number of soils within the same region of the plot.

Table 3. Principal Component Analysis of the vegetation and building site suitability variables.

	Prin1	Prin2
Eigenvalue	4.536	2.400
Predicted Vegetation Productivity	0.993	0.115
Building Site Suitability Dimension	-0.115	0.993

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  5 +
    |                  AA      B A
    |  B  B A B    A  GB B  AD AA EDBCCBA A CBAAGA  A A DD KDA
  0 +   A ADA A      CA  A     A AAA CF   B AE    A EJ ADG
    |  A  B               A B C   A A     AAA CCB
    |         A        A   B     A     A  BB
 -5 +  B      A        AAA B  A          A ACB
    |                              BA
    |
-10 +
    |
   -+----------+----------+----------+----------+----------+----------+
   -4         -3         -2         -1          0          1          2
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Figure 1. This figure plots the dimensions from Table 1. The x-axis represents site development suitability and the y-axis represents predicted vegetation productivity.

Soils in the upper left-hand corner of Figure 1 are typically sandy loams in middle topographic positions, and with relatively gentle slopes, such as the Manning soil series. These soils do not have the highest vegetation productivity potential but the potential is still fairly good. The surface layers of these soils must be removed before one encounters suitable soils for building site development; however, since such development usually requires excavation for basements and foundations, and earthworks to build ditches and roadbeds for roads, the initial three or four feet of surface soil with soils less suitable for building sites do not pose much of a problem. However, we believe that the results are somewhat tentative, due to the nature of the analysis.

Nevertheless, we do believe that this small study suggests that if one is concerned with maintaining vegetation productivity and ensuring building site development potential, subsurface soils would be composed of material suitable for septic tanks, absorption fields, building foundations, and for shallow embankments. This means that in the reclamation and earth moving processes, sandy soils with some rock fragments and no organic matter should be placed in this zone. If appropriate material exists during the mining process, we would suggest that this material could be placed in a zone four feet from the surface to approximately 20 feet below the surface and placed in a compacted state, providing the potential to support building site development.

We believe that this small study also indicates that one may develop a highly productive landscape for vegetation and yet create a site unsuitable for building site development. We suspect that in the future as the vegetation productivity issue in reclaiming sites is resolved, multiple functions such as vegetation productivity and building site development may become a focus for investigation. We also believe that this small investigation is a sub-study within the larger context of landscape stability for engineering purposes and for vegetation sustainability. We hope to address this issue future research.

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