# COMPARISON OF POTENTIAL SOIL PRODUCTIVITY PRIOR TO AND FOLLOWING MINING[1]

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**Abstract:** In most reclamation operations the productivity of the reclaimed land is controlled by the soil material in the topmost portion of the mined profile. By examining the composition, layering, potential behavior, and properties of the profile prior to mining, or by referring to a county soil survey, it should in theory be possible to reconstitute a similar, or improved profile following reclamation. This however, is not always the case, because soil properties vary greatly over area and in time and when disturbed and reconstituted, are not likely to correspond exactly to the properties of the original profile. An alternative approach is examined which attempts to evaluate potential changes in productivity due to mining on a scale of a watershed, or drainage basin in a regional context. The approach utilizes a productivity index model in a GIS format and three regional databases to simulate distributions of the productivity index and biomass on nine contiguous watersheds within a 12,000 sq.km area in Pennsylvania. Simulations show that a regional map of PI can be constructed based on STATSGO data and that GIS overlays reflecting profile properties may be used to monitor progress of reclamation and status of soil biomass productivity.

**Additional Key Words**: Variability, GIS, Geostatistics.

## Introduction

Profitable recovery of a deposit is usually the primary goal of a mining operation. However, it is equally important that following mining, the disturbed land be reclaimed to previous or better use. The productivity controlling zone in most mining operations is the soil. The soil consists of a relatively thin upper crust of a regolith formed by weathering of the underlying rock mantle, sedimentary, or alluvial deposit. By examining the composition, layering, behavior and properties of soil prior to mining, it may be possible to predict the potential environmental impact of mining and to develop a defensible reclamation plan.

Even though one purpose of reclamation is successful revegetation of a disturbed area, the relative impact of soil disturbance on biomass production can seldom be fully evaluated. Equipment used to spread topsoil tends to compact soil layers unevenly, increasing bulk density, decreasing aeration and sealing the surface if moisture contents are high. Overabundance of coarse fragments near soil surface, so often the case on reclaimed areas in central Pennsylvania, makes cultivation and seeding difficult. To minimize recharge, operators construct compacted high density layers below the topsoiled zone. Although these layers slow down percolation and can be effective in controlling acid mine drainage, they will also hinder root growth and development. Most importantly however, original soil has developed in place over time in response to climate, hydrologic controls, landscape position and other factors. When disturbed, repositioned and reclaimed, freshly laid topsoil requires time to reach a new state of equilibrium. Because soil properties can vary over area and in time, (Rogowski and Wolf, 1994) examining and sampling of the profile in place at one or more locations prior to mining, or even referring to soil information in a county soil survey does not necessarily guarantee a similarly behaving profile following reclamation.

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To evaluate soil productivity Kiniry et al. (1983) proposed a simple index relating corn growth to soil properties. Pierce et al. (1983) have used it to estimate crop yields while Rogowski and Weinrich (1987) have adapted and modified the original index to estimate relative biomass productivity of different mined and reclaimed areas.

In this study the index is applied in a Geographical Information Systems (GIS) context. Various GIS methods have been applied recently to display, model and simulate environmental impacts of different activities (Burrough 1986). Standard environmental assessments are usually concerned with an impact of a single activity at a point, or over a small area. GIS applications are more regional in scope and can deal with much larger areas. In this study, GIS was used to evaluate potential impact of mining on nine contiguous watersheds within a 12,000 sq.km area in western Pennsylvania. The objective was to show how a simple model, GIS technology, and available data can be combined to evaluate large scale impacts of mining on regional biomass production.

## Materials and Methods

### Productivity Index Model (PI)

Relative productivity (Rogowski and Weinrich, 1987) of a soil can be written,

$$PI_{ij} = \sum_{i=1}^{m} W_i \prod_{j=1}^{n} x_{ij} \qquad (1)$$

where,

$PI_{ij}$ = productivity index (dimensionless 0 to 1)
$\Sigma$ = summation operator over i=1,2,...m horizons
$\Pi$ = product operator over j=1,2,...n factors
$W_i$ = relative root distribution function
$x_{ij}$ = productivity factors (0 to 1), such as available water, bulk density, aeration porosity and pH

The model assumes that biomass production is a function of root growth modified by certain productivity factors, which depend on soil properties. Root growth density is described by a relative root distribution function (between 0 and 1), subsequently corrected by a product of growth limiting factors, such as lack of available water, poor aeration, high bulk density and low pH, (Rogowski and Weinrich, 1987). All growth limiting productivity factors are scaled between 0 and 1 based on potential impact. For example, relative impact of different levels of the productivity factor pH is shown in Fig. 1.

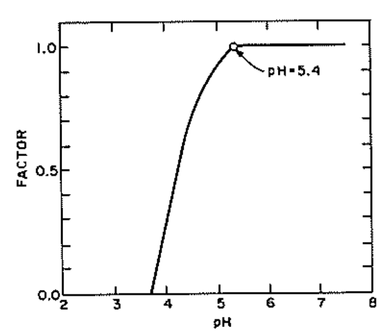


Figure 1. Distribution of the productivity factor pH.

Undisturbed field soil profiles usually consist of several distinct horizons which may be of different thickness. Plant root distributions, and rooting depths may vary. Some plants are shallow rooted, others have roots going down to a considerable depth. The PI model computes the root distribution function based on plant rooting depth and the depth of the soil horizon in the profile. In reconstituted profiles, the topsoil is composed, to a large extent, of the most fertile A-horizon material. In central Pennsylvania the amounts of

A-horizon material are limited and consequently topsoiled profiles are shallow. Therefore both the rooting depth and the depth of the topsoiled layer are the same and the root distribution function, at least initially, may be taken as equal to 1.0 for all reclaimed profiles.

## Available Data

To demonstrate the approach three sources of available data were utilized. The major data source was STATSGO, the Soil Conservation Service's 1:250,000 digital soil map of Pennsylvania and the soil interpretations record attribute (GIS term for "property", or "characteristic") data file. Each STATSGO soil unit is composed of different types and percentages of individual mapping units whose properties, descriptions and characteristics are listed in the attribute data file. The STATSGO coverage gives spatial polygon delineations of soil associations and their attribute values identified by a number at a centroid of each polygon. These provided spatial addresses and necessary coordinates for associated attribute values. Continuity and homogeneity of properties within a mapping unit is tacitly assumed. However, at each point within the map there exists a potential for error i.e. the mapping unit, or the percentage composition may not be as listed because of inherent soil variability, (Rogowski and Wolf, 1994).

The second data source was the Pennsylvania State University soil characterization laboratory database system (PSU database), (Ciolkosz and Thurman 1992). The PSU database provides detailed profile descriptions, and attribute information, for over 800 individual soil pedons, which are georeferenced with latitude and longitude identifiers. This data base provides positive identification of mapping units and their locations at a point but lacks information on their distribution and continuity. The data set may also be biased towards modal profiles and easier to reach locations.

The third data source consisted of the 1992-1993 Pennsylvania Soil Test database on land use, pH, acidity, selected nutrients and management recommendations. Land use classification was used to extract spatial locations of "disturbed" land. Disturbed land category, especially in western Pennsylvania, refers primarily to mined and reclaimed areas. The data were summarized by zip code and referenced at the centroid of each zip code zone. By screening zip codes for minimum pH and maximum recommended lime, potential problem areas were targeted. This data base represents user selected field samples extrapolated to the respective zip code areas. Attribute values are correct at a field size scale, but their spatial extent and interpretation of land use may be in error.

Originally the use of data covering much of Pennsylvania was anticipated. Because of the large size of the data bases the task proved beyond the scope of our computing facilities. Accordingly, a subset of nine contiguous watersheds within a 12,000 sq.km area in western Pennsylvania was "windowed out" to be used as a study area.

## Computation of PI

The STATSGO database was used to construct PI maps of the study area. Because each STATSGO unit is composed of many individual soil mapping units (Table 1) the PI model was run separately for each of the primary soils comprising a STATSGO map unit. The attribute data file, generally lists data for each soil as a range of values, i.e. pH for the A-horizon of Hazleton soil on 8-15% slope in Table 1 is given as 3.76 to 5.50 pH units. To introduce a degree of variability into STATSGO map, PI was calculated for the low (MIN) and high (MAX) value of each attribute

Table 1. Frequency of occurrence of soils in a STATSGO map unit (PA012) used in weighting.

| Soil Name | Slope | Composition |
|---|---|---|
| | % | % |
| Hazleton | 8 - 15 | 14 |
| Hazleton | 25 - 60 | 12 |
| Hazleton | 8 - 25 | 9 |
| Hazleton | 15 - 25 | 5 |
| Cookport | 8 - 25 | 10 |
| Cookport | 3 - 8 | 1 |
| Cookport | 0 - 3 | 9 |
| Cookport | 8 - 15 | 5 |
| Ernest | 8 - 25 | 9 |
| Ernest | 3 - 8 | 5 |
| Wharton | 3 - 8 | 3 |
| Wharton | 0 - 3 | 2 |
| Clymer | 8 - 15 | 6 |
| Udorthents | 0 - 50 | 1 |

separately and the actual PI assigned to that soil was picked by a random coin toss. The soils, weighted by the frequency of their occurrence were then averaged to give a PI for each STATSGO map unit such as for example PA012 in Table 1.The resulting distributions of the PI were made using ARC-INFO overlay coverage.

## Computation of Biomass Productivity

Equation 1 gives relative values of PI based on simulated root distribution modified by soil properties. Rogowski and Weinrich (1987) used Lieth's (1975) Miami Model based on mean annual temperature, or precipitation to estimate biomass productivity. In this study, the temperature portion of the Miami Model was used with PI based on pH, available water, bulk density and aeration porosity to compute potential biomass productivity ($P_B$).

$$P_B = B \cdot PI_{ij} \tag{2}$$

where,

$P_B$ = biomass productivity (g/sq.m/yr) adjusted for the dimensionless (0-1) $PI_{ij}$

and

$$B = \frac{3000}{1 + e^{(1.315-0.119T)}} \tag{3}$$

where,

B = biomass productivity level (g/sq.m/yr)

and

T = mean annual soil temperature (°C)

Mean annual soil temperature in the PSU database (Carter and Ciolkosz, 1980) was used in lieu of mean annual air temperature of the original Lieth (1975) model. This was done because in Central Appalachians soil temperatures can differentiate among the soil temperature regimes, which vary with elevation.

Biomass productivity based on STATSGO database and mean annual temperature at Philipsburg, which is located centrally within the subset area, was compared with interpolated values of productivity using soil temperature and pH values from the PSU database. Spatial distribution of PI was evaluated based on the potential inclusion of soil material from other horizons and projected biomass productivity values.

## Comparisons

It was anticipated that two productivity limiting factors, pH and available water, would be common to the three data bases and that changes in the distribution of these factors may help identify locations that were undergoing reclamation. Consequently pH, available water and estimated soil temperature values were extracted from the PSU database and the spatial distribution of pH and biomass productivity was interpolated by kriging, (Isaaks and Srivastava, 1989). The distribution of pH was compared with the kriged distribution of minimum pH and maximum recommended lime obtained from the 1992-1993 Soil Test database. In an effort to compare biomass production based on field sampled A-horizon values with profile based estimates, kriged distribution of biomass productivity from the PSU database was compared with the kriged distribution of biomass productivity based on the STATSGO data. The comparisons consisted of subtracting the respective overlays from one another pixel-by-pixel and analyzing the difference relative to the location of disturbed areas.

## Results and Discussion

### Disturbed Land

Figure 2a shows the disturbed land areas in Pennsylvania based on 1992-1993 Soil Test data land use classification and indicates the boundaries of the subset area. The delineations of disturbed lands are somewhat larger than their actual extent, because each is referenced to a zip code centroid and encompasses the entire zip code area from which soil test samples came. Figure 2a shows that disturbed land is likely to be present through much of the State. Figure 2b shows the "windowed out" subset of the study area in greater detail, including the boundaries of contiguous watersheds.

In western Pennsylvania, the disturbed land consists mainly of stripmined areas, or areas undergoing reclamation. In 1992-93, according to the Soil Test data these areas appeared to be located mainly in the upper half of the study area (Fig.2b). However, particularly elsewhere in the State, disturbed land may also include construction, landfills, and other mining operations, (stone, sand and gravel). This emphasizes the fact that mines are not the only land in need of reclamation and that other areas may need to receive equal attention and scrutiny.

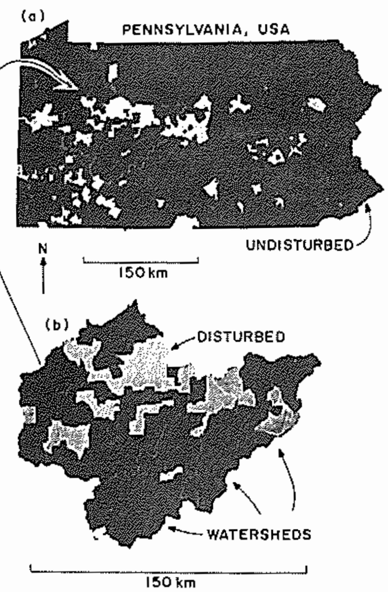


Figure 2. Distribution of disturbed land (a), and location of the windowed out (b) subset used in analysis.

### Distribution of the PI

Figure 3 shows the spatial distribution of the PI on the study area and Table 2 gives weighted MIN and MAX values of PI for STATSGO map units and lists contributions by horizon. The PI values are specific to each map unit and the delineations in Fig. 3 will also correspond to soil boundaries. In the light colored areas PI values will generally be <33% of possible values, while dark areas are expected to exceed 66%. Mid-range hues signify areas that are likely to have PI equal to about 50%. Some areas included in this analysis contain old minesoils, or soils that may naturally below in productivity.

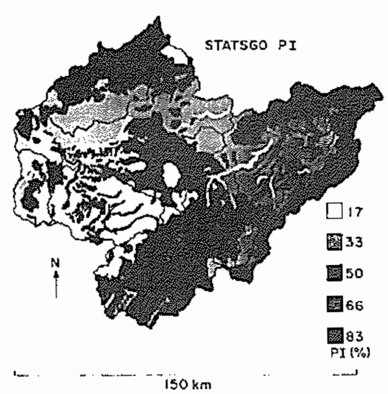


Figure 3. Distribution of the productivity index (PI) on the study area.

A more detailed scrutiny of individual PI calculations (not shown) indicates that differences in PI within the study area result primarily from differences in pH and available water while bulk density and aeration appear adequate, and constant.

**Productivity Status**

Figure 4 compares the distribution of pH values in the PSU database with distributions of the minimum pH (Fig. 4a) and the maximum lime requirement (Fig. 4b) based on the 1992-93 PSU Soil Test data. All distributions were kriged and scaled to the same number of "equivalent" classes, and the GIS overlays of Soil Test derived values (minimum pH and maximum recommended lime) were subtracted from the PSU derived overlays (pH). The classes were "equivalent" in a sense that the range of values for the three distributions was divided into ten equal increments with numerical values of 1 through 10. Also, for the purpose of this comparison, the lime requirement values were ranked from highest to lowest. Thus the 1st comparison class (Fig. 4) consisted of all locations with the lowest pH and highest lime requirement. All distributions gave well behaved semivariograms (Isaaks and Srivastava, 1989) with approximately a 15 km range of continuity, although structural analysis indicated that the PSU database pH was more variable than Soil Test values.

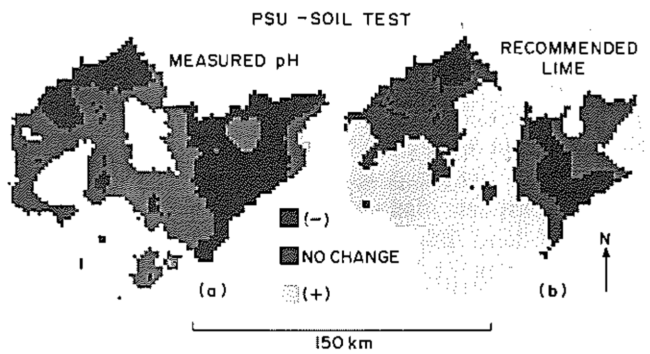


Figure 4. Relative change in pH (a) and lime requirement values (b), between interpolated PSU database values and 1992-93 Soil Test data.

Figure 4 shows locations within the study area where pH and/or lime requirement decreased, increased, or did not significantly differ from that for the original soil. Upper central part of the area designated as (+) in Fig. 4a, which corresponds to disturbed locations in Fig. 2b, may include areas that have undergone reclamation in 1992-93. Similarly, parts of the area (+) in Fig. 4b may also correspond to the area undergoing reclamation. This area is larger in Fig. 4b than in Fig. 4a and may also include soils with low productivity. It should be noted, that changes in pH reflect a comparison of actually measured values, while changes in lime requirement reflect management recommendations. Medium grey areas in Fig 4a and 4b identify locations with no significant change in either observed pH or lime requirement, while black areas (-), where pH of Soil Test data increased and lime requirement decreased, point to areas on which soil productivity has improved. The analysis illustrates a method of monitoring the regional productivity status and potentially, the progress of reclamation operations in time.

## Biomass Production

Figure 5 shows differences in the distribution of potential biomass productivity on the study area when an overlay based on STATSGO profile data is subtracted from the A-horizon PSU data based overlay. Black (-) areas indicate locations where profile (STATSGO) derived values were larger, medium grey zones show no change, while light grey areas (+) indicate areas where profile derived values were less than A-horizon derived (PSU data) values.

Figure 5 shows that there was little, or no difference between A-horizon and profile derived biomass productivity over most of the area (medium grey). Areas with negative (black) differences may indicate soils where contribution to PI from deeper parts of the profile may be important. In contrast on areas with positive differences (light grey) suggest sites where contributions to PI from A-horizons appear to predominate. The analysis suggests a method of screening on a regional scale profiles that may be suitable for topsoiling.

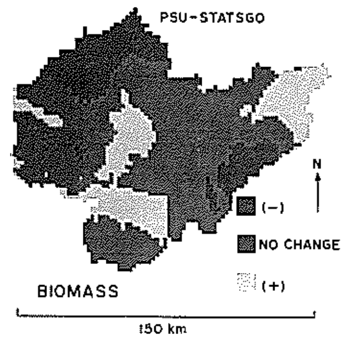


Figure 5. Differences in the distribution of biomass productivity based on the PSU database compared with the STATSGO profile data.

## Reclamation Potential

Table 2 shows percent of the area occupied by the soil mapping units, PI values based on MIN and MAX values of input parameters, and the respective contributions (percent) of the A, B and C-horizon materials to the soil PI value. Conventional wisdom holds that if soil horizons other than A are used in the reclamation operation, deterioration of land productivity will ensue. That however, is not always the case. Simulations show that for some map units in Table 2, B-horizon material can contribute much towards the overall productivity of the profile. Since the depth of A-horizons in the study area seldom exceeds 0.30 m and for some soils is between 0.15 and 0.20 m, B-horizon material may at times have to be used in topsoiling. The PI values in Table 2 suggest that for some soils the quality of the B-horizon material may be as good or better than of the topmost layer.

Table 2. Proportion of study area occupied by STATSGO map units, minimum and maximum values of PI, and proportion of PI contributed by different horizons.

| Soil Map Unit | PI | | | Contribution to PI | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AREA | MIN | MAX | MIN | | | | MAX | | | |
| | | | | A | B | B | C | A | B | B | C |
| | | | | % | | | | | | | |
| Hazleton/Dekalb/Laidig | 23 | 0.9 | 52.1 | 42 | 50 | 0 | 8 | 42 | 50 | 0 | 8 |
| Gilpin/Wharton/Ernest | 16 | 20.1 | 70.6 | 60 | 15 | 23 | 2 | 56 | 39 | 3 | 2 |
| Gilpin/Cavode/Ernest | 15 | 20.4 | 70.5 | 51 | 25 | 20 | 4 | 59 | 36 | 2 | 3 |
| Gilpin/Weikert/Ernest | 14 | 16.4 | 70.4 | 66 | 1 | 32 | 1 | 63 | 32 | 4 | 2 |
| Hazleton/Cookport | 13 | 17.3 | 58.7 | 76 | 15 | 8 | 2 | 54 | 40 | 1 | 5 |
| Udorthents/Gilpin/Ernest | 6 | 23.0 | 47.4 | 36 | 37 | 20 | 6 | 50 | 41 | 3 | 6 |
| Monongahela/Philo/Atkins | 5 | 39.0 | 76.9 | 57 | 25 | 16 | 2 | 53 | 36 | 8 | 3 |
| Cavode/Brinkerton/Gilpin | 4 | 39.9 | 68.3 | 57 | 21 | 15 | 7 | 57 | 30 | 7 | 6 |
| Average | | 17.4 | 63.3 | 56 | 25 | 15 | 4 | 53 | 40 | 3 | 4 |

## Conclusions

Productivity index (PI) and biomass production distribution were examined on a 12,000 sq.km area in western Pennsylvania. The area was reasonably typical of the of the coal mining region where stripmining operations necessitate subsequent reclamation. Three separate sources of regional data were used to construct and manipulate regional GIS overlays of PI and biomass production. A regional PI map was constructed, based on STATSGO profile data. Data analysis indicated that low values of PI within the study area were due to low values of soil pH and available water, while both bulk density and aeration porosity appeared adequate. GIS overlays of PI based on differences between 1992-93 Soil Test and PSU data could be used to locate some ongoing reclamation operations and check on progress. The analysis also suggested a method of monitoring the productivity status of soil and the progress of reclamation operations in time. Differences in the distribution of biomass productivity when STATSGO overlay was subtracted from the PSU database overlay, suggested a method of screening potential contributions of soil profile to the productivity. A closer scrutiny of simulations showed that when PI values were calculated separately for different horizons, sometimes the quality of a deeper horizon material was as good or better than that of the topmost layer.

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