Determination of Soil Hydrologic Group for Minesoils in Appalachia

FINAL REPORT

Submitted by:
Eugenia Pena-Yewtukhiw and Jeff Skousen
Division of Plant and Soil Sciences
West Virginia University
Morgantown, WV 26506

In Fulfillment of the Project
DETERMINATION OF SOIL HYDROLOGIC GROUP FOR MINESOILS USING THE FORESTRY RECLAMATION APPROACH IN APPALACHIA

To:
Mike Bower and Brad Edwards
Office of Surface Mining
Three Parkway Center
Pittsburgh, PA 15220

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Abstract

The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting. This classification system separates soils into four hydrologic groups (A, B, C, and D), based upon the intake and transmission of water under conditions of maximum yearly wetness. Group A has the lowest runoff potential and D the highest. Several soil properties are used to determine the hydrologic soil groupings. In the study of the hydrologic soil nature, soil properties that affect infiltration, such as bulk density, porosity and texture, should be considered. Associated factors that affect infiltration in the field are slope and vegetation. Surface coal mining is a common practice for extracting coal in West Virginia. This practice destroys soil where mining takes place unless it is saved for later use. Surface grading for stability during minesoil reclamation often causes high compaction and, as a consequence, high bulk density and low porosity. Therefore, it has been assumed that minesoils are somewhat poorly drained with low infiltration rates and high runoff potential. This assumption results in minesoils being classified in hydrologic soil group C. The objectives of this study were to determine the hydrologic soil grouping of a minesoil and the minesoils hydrologic behavior, as affected by slope and cover. Two study areas were selected on a reclaimed surface mine in Webster County, WV. Starting in May of 2009, and until August 2011, research was performed to determine the surface runoff, and soil hydrologic group classification of reclaimed minesoils on forestry post-mining land uses. Under natural rainfall conditions, field measured runoff coefficient was between 0.01 and 0.13, and slightly higher for tree than for grass cover. Regardless of grass or tree cover, the soil surface saturated hydraulic conductivity values averaged 47.3 ± 26.2 μm/s, while the most limiting subsurface layer (compacted backfill) had a much lower average of 3.0 ± 2.7 μm/s. Higher bulk density values and lower Ks values confirm that the compacted backfill found in the study area was the most limiting layer in the minesoil profile. The study findings lead to the conclusion that the hydrologic soil grouping for this minesoil should be hydrologic soil group A. In order to ensure that other minesoils are placed into the correct hydrologic soil grouping, future work should be done on more mine sites to determine whether similar hydrologic behavior may change an assumed hydrologic soil grouping.

Introduction

With growing environmental concerns related to surface coal mining, coal companies are being pushed harder than ever before to restore the land area disturbed while mining for coal. Conventional surface mining is the process of excavating a large area land from the surface down to extract coal, using large mining equipment to remove overburden from the coal seam found below.

The process of reclamation occurs at both ends of the extraction operation. Overburden is removed and placed into separate areas depending on their future use in reclamation process upon completion of the coal removal. Although the exact pre-mined landscape is impossible to achieve, the coal company will attempt to reclaim the site back to its approximate original contour (AOC). Because most of the volume of the overburden is composed of solid rock fragments, there is little soil being placed back, and the use of soil substitutes is commonly implemented. It is not until several years later when these reclaimed areas begin to develop soil through the physical and chemical weathering processes. In order to correctly reclaim a site, it is important that coal companies plan careful strategies to ensure that their reclamation efforts are effective in order to receive the full benefit that the land has to offer.

Minesoils are newly forming man-sculpted soils which are developed after a mining operation has seized production (Schaller, 1978). Minesoils consist of a collection of blasted material which was removed during the mining process and are classified into the taxonomic group known as entisols. Like most entisols, minesoils show little sign of soil development, and usually have a thin A horizon directly above a C horizon; older minesoils might show signs of a more developed profile with a Bw horizon. However, future land use of minesoils greatly influences physical properties of a minesoil based on the way they are reclaimed (Rubel and Jenny 1988).

Minesoils are considered to have moderately high runoff potential. With the minesoil development being in early stages, it is likely to be considered highly susceptible to erosion due to its lack of a strong structure and specially a weak surface structure; with water infiltration being such an important factor in surface runoff and erosion potential these landscape and soil properties must be closely examined after implementing a reclamation project. However, soil hydrologic characteristics of these soils are highly variable. Skousen et al. (1998) demonstrated that Ksat for the surface horizon of two reclaimed minesoils could show as much as two orders of magnitude differences. Other studies have shown similar values for saturated hydraulic conductivity of reclaimed and unreclaimed mine sites (Pedersen et al., 1980; Skousen et al., 1998; Gorman and Sencindiver, 1999; Barnhisel and Gray, 2000; Thomas et al., 2001; and Shukla et al., 2004). Unreclaimed mine sites close to reclaimed mine sites had saturated hydraulic conductivity values around 0.34 ± 0.21cm/min, while reclaimed mine sites had saturated hydraulic conductivity values around 0.15 ± 0.17 cm/min. Shukla (2004) suggested that these similarities showed a need for a better understanding on water storage within soil pores to make improvements in reclamation plans.

Soil hydrologic groups are based on the assumption that runoff from the surface after a storm event is a function of climatic conditions, and similarities in hydrologic properties, soil depths to restrictive layers or water tables, water movement characteristics, texture, structure, and degree of swelling (when saturated). To determine the hydrologic classes of a soil, it is necessary to consider the infiltration and transmission of water under the conditions of maximum wetness (thoroughly wet) in a soil that is not frozen, the surface is bare, and if expansive layers are present and wetted. Additionally, the saturated hydraulic conductivity of the least transmissive soil layer (soil horizon) should be measured, the depth to any layer that is more or less water impermeable (e.g. fragipan or compacted layer) should be recorded and/or the depth to a water table (if present) should be determined. In cases in which soil hydraulic conductivity data are not available or its measurement is not possible, other soil properties that affect water movement into the soil (infiltration) and in the soil profile can be used to estimate this variable. These properties are texture, bulk density, strength of soil structure (aggregate stability), porosity, clay mineralogy, and organic matter. Soil landscape characteristics (landscape position, slope) are not considered in defining the hydrologic group of a soil. Minesoils are currently being placed into hydrologic soil group C, soils considered to have moderately high runoff potential because of the way overburden material in replaced and compacted. Due to the regulations of SMCRA (1977), post-mining soil is to be reclaimed to as similar as possible to pre-mining soil types. Although the soil may be greatly changed, pre-mining soil hydrologic grouping is still considered for the post-mining hydrologic group. Table 1 was used to determine the Hydrologic Soil Grouping, since in our study site based on the forestry reclamation approach

(Buger at al. 2005), the depth of the water impermeable layer is below 100 cm (> 4 ft) (USDA, NRCS 2007).

The objective of this study was to determine the true hydrologic soil grouping of a minesoil and the minesoils hydrologic behavior, as affected by slope and cover. This is a long term project which hopes to aid in the knowledge about minesoil hydrology and future reclamation design and management practices.

Study Area

The ICG Eastern Birch River surface mining operation was located near Cowen, West Virginia in Webster County. This mining operation was extracting coal from five different coalbeds: Freeport, Upper Kittanning, Middle Kittanning, Upper Clarion, and Lower Clarion.

The study area was located within this Birch River located mining operation site. The site was reclaimed thirteen years ago using conventional reclamation practices enforced by the Surface Mining Control and Regulation Act (SMCRA) of 1977. Large dozers using a method known as tracking were used to contour the land. Grass along with a variety of fast growing trees was used to revegetate this area.

Methods

A total of twelve research runoff/infiltration plots were built at the reclaimed mine site with two changing factors: soil cover (grassland or trees) and slope (3-5% or 10-15%). Four different scenarios/treatments with three repetitions were tested (Table 2).

Collection of the runoff and eroded sediments was done according to the magnitude of rainfall events remotely recorded via the internet connection to a logging weather station located next to the experimental area. Collection times were established to be every week or earlier when a significant cumulative amount of rainfall had occurred (10 mm =0.4 in). The measured variables were runoff, infiltration, bulk density (surface 10 cm) by the excavation method (Jacob, 2002), percentage of rock fragments (surface 10 cm), particle size analysis (pipette method by Gee and Or, (2002), single ring saturated hydraulic conductivity (Wooding, 1986).

ANOVA (analysis of variance) was used to statistically assess if runoff/infiltration and saturated hydraulic conductivity are affected by vegetative cover and slope. This analysis allowed observing under which circumstances slope and cover will have a significant impact on the hydrologic properties of the minesoils.

Results and Discussion

The most common surface textural classes for the runoff/erosion plots was 'silt loam' classification (Table 3). There appeared to be an effect of slopes degree on soil texture (Table 4). Therefore the relationship among the three factors is very evident. Slope appeared to have a greater effect on soil texture than soil cover, erosion of finer particles leave a higher proportion of sand.

Table 5 shows the average uncorrected and rock corrected bulk density for the surface soil. Lower corrected bulk density values, compared to uncorrected bulk density values, are likely due to the abundance of root mass found at the soil surface. Due to the way in which the area was reclaimed, high compaction acts against root growth leaving little room for plants to root except for the soil surface. Because sampling was done within the top 10 cm of the surface, a large concentration of root mass was found here. When corrections for particles with a diameter >2 mm, many of these root masses were discarded. The uncorrected and corrected bulk density values were common among published research conducted on reclaimed minesoils. Uncorrected bulk density values averaged 1.54 g/cm^3 with values ranging from 1.17 to 2.04 g/cm^3. Corrected bulk density values averaged 0.91 g/cm^3 with values ranging from 0.68 to 1.41 g/cm^3. Uncorrected bulk density were similar to those found by Pederson et al. (1980) and corrected bulk density values were similar to those found by Thomas et al. (2000).

The frequency of runoff/infiltration data collection was variable, depending on the quantity of precipitation over a given time period (sufficient cumulative precipitation). Runoff/Infiltration was measured to understand how slope and vegetative cover, influenced these variables. Table 6 summarizes the overall average of the % runoff and % infiltration by cover and slope class.

Saturated hydraulic conductivity (K_s) was measured at each of the twelve infiltration plots. The overall average saturated hydraulic conductivity was 47.3 µm/s with a standard deviation of ± 26.2. This value is higher than previously reported values published on minesoils by Pederson et al. (1980) and Guebert and Gardner (2001). High correlation coefficient (r=0.52) was observe between rock fragment content and saturated hydraulic conductivity. It has been previously reported that as the amount of rock increases, pore size also increases, helping more water flow more freely (Lal and Shukla, 2004).

Surface and subsurface soil properties.

Table 7 shows the overall average rock content (percentage of sample total weight) for a sampling depth of 0-10 cm. The mass based rock percentage value of 52.4% with a ± 7.3 standard deviation was slightly lower in the subsoil as compared soil surface which had an average percentage of rock value of 57.3% with a ± 8.6 standard deviation. This result may be explained due to the high compact forces applied to create the impermeable, and the smaller compaction forces used to “sculpt” the reclaimed minesoil surfaces. When compared to soil surface, the soil impermeable layer had higher sand and lower silt content. No statistical differences were observed for clay. The effect of weathering and biological activity may have decreased the bigger sand size particles increasing silt and clay particles (Table 8).

It was observed that with the higher levels of compaction applied to subsurface layer (compacted backfill), uncorrected and corrected mean bulk density values rose as compared to the soil surface (Table 5). Uncorrected bulk density increased from 1.54 Mg/m^3 ± 0.24 at the soil surface to 2.10 Mg/m^3 ± 0.18 at the subsurface. Corrected bulk density values rose from 0.91 Mg/m^3 ± 0.17 (soil surface) to 1.80 Mg/m^3 ± 0.24 (soil subsurface).

Average saturated hydraulic conductivity (K_s) values were much lower at the soil surface as compared to soil subsurface. Table 9 presents the average K_s values obtained for the soil surface and the compacted soil subsurface. The overall average saturated hydraulic conductivity for subsurface was 3.0 µm/s with a standard deviation of ± 2.7, and 47.3 ± 26.2 µm/s for the soil surface. This was expected because of the high level of compaction of the backfill.

Hydrologic Soil Grouping.

Minesoils are considered to have moderately high to high runoff potential because of the way overburden material is replaced and compacted. Compaction generated when recontouring the land to the approximate original contour (AOC) also alters the hydrologic properties and as a consequence processes in the soil. It is important for both environmental and economic factors to carefully examine minesoils to better understand and determine their actual properties and characteristics. Improper hydrologic soil group classification can lead to incorrect runoff structure designs, which could have a negative impact on the surrounding environment. From an economic standpoint, a misclassified soil may require higher investment to meet federal standards in safety and water management practices. Table 1 listed the criteria to evaluate when hydrologic soil grouping is to be determined. To characterize the hydrologic soil grouping of the minesoils in this study, Table 1 was selected over because the estimated depth to water impermeable layer and depth to high water table was greater than 100 cm. For the soil surface, Ks and water movement was almost always classified in hydrologic soil group A, while texture and textural class was almost always hydrologic soil group C. For the limiting layer, Ks and water movement was considered very limiting, while texture size and textural class was not as fine as for the surface. To determine the final hydrologic soil grouping for the minesoil in this study, it is necessary to consider that due to the low bulk density and abundance in rocks found at the soil surface (> 35%) (NRCS, 2007), and since the textural classes were predominantly medium, the hydrologic grouping should be A or in the worst case scenario B.

Conclusions

The results of this study give new insights into a better understanding of the effect of soil properties on the hydrology of minesoils. There are few studies that have measured the hydrological characteristics at the surface of minesoils to this extent. Although much was learned, there are still many other landscape, weather, and soil variables that could be studied, as well as continuing the work to evaluate how these properties change over time. As a consequence of the reclamation process, the percentage of rock found at the surface of minesoils was high (above 50%).

Soil bulk densities (rock uncorrected and rock corrected) measured in this study were similar to values previously reported for minesoils. The bulk density was low at the soil surface and extremely high at the soil subsurface. This is not a coincidence, it was designed and built by compaction with heavy equipment with the objective to protect the surrounding watersheds. At the soil surface, neither treatment of cover or slope at any depth had an effect on average bulk density values.

The values at the soil surface were higher than those previously reported on minesoils. However for the soil subsurface the measured values were similar to those reported by other studies. The comparison of the layers (surface and subsurface) gave a better understanding of the role that the compacted backfill plays in the reclamation process.

Based upon the results of this study, many reclaimed minesoils have been incorrectly classified as hydrologic soil group C. The study site had a depth to water impermeable layer and depth to high water table greater than 100 cm, and showed hydrologic characteristics more associated with hydrologic soil group A than to its currently assigned group C. The hydrologic properties of the impermeable layer were measured in the compacted backfill. These results supported the hypothesis that minesoils may be wrongly classified in the hydrologic soil grouping. It also demonstrated that even more compacted minesoils as measured in the compacted backfill, were not hydrologic soil group C, but would be class B. Although this study showed that the hydrologic soil grouping for this minesoil was initially incorrect, studies should continue on this mine site as well as other mine sites to evaluate how the soil properties and its variability change with time from site to site.

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Table 1. Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth greater than 100 cm (40 in) (Modified from USDA, 2007).

	- - - - - - - - - - - - - - - **Hydrologic Soil Group** - - - - - - - - - - - - - - -			
Soil Property	A	B	C	D
Saturated Hydraulic Conductivity of the Least Transmissive Layer	> 10 µm/s (>1.42 in/h)	< 10 to > 4µm/s (< 1.42 to 0.57 in/h)	< 4 to > 0.4 µm/s (< 0.57 to > 0.06 in/h)	< 0.40 µm/s (< 0.06 in/h)
	and	and	and	and / or
Depth to Water Impermeable Layer	> 100 cm (> 40 in)	> 100 cm (> 40 in)	> 100 cm (> 40 in)	> 100 cm (> 40 in)
	and	and	and	and / or
Depth to High Water Table	> 100 cm (> 40 in)	> 100 cm (> 40 in)	> 100 cm (> 40 in)	> 100 cm (> 40 in)
	and	and	and	and
Water Movement	Freely	Less Freely	Somewhat Restricted	Restricted or Very Restricted
	and	and	and	and
Amount of Clay and Sand	< 10% Clay > 90% Sand	10 - 20% Clay 50 - 90% Sand	20 - 40% Clay < 50% Sand	> 40% Clay < 50% Sand
	and	and	and	and
Textual Classes	Gravely or Sandy	Loamy Sand or Sandy Loam	Loam, Silt Loam, Sandy Clay Loam, and Silty Clay Loam	Clayey

Table 2. Slope and Vegetative Cover by Plot

	- - - - - Factors - - - - -	
Plot #	**Slope**	**Cover Type**
	- - - - - Levels - - - - -	
1	10 - 15 %	Forested
2	10 - 15 %	Grass
3	10 - 15 %	Forested
4	10 - 15 %	Grass
5	10 - 15 %	Grass
6	10 - 15 %	Forested
7	3 - 5 %	Forested
8	3 - 5 %	Forested
9	3 - 5 %	Grass
10	3 - 5 %	Grass
11	3 - 5 %	Forested
12	3 - 5 %	Grass

Table 3. Runoff plots textural classes for 0-5 and 5-10 cm depths.

Plot Identification	**Classification (0-10 cm)**
1	silt loam
2	silt loam
3	silt loam
4	silt loam
5	silt loam
6	silt loam
7	loam
8	loam
9	silt loam
10	loam
11	loam
12	sandy loam

Table 4. Textural composition of fines and percentage of rock and treatment (0-10 cm depth).

	Cover		**Slope**	
Particle Size	**Grass**	**Forested**	**Low**	**High**
Sand (g/kg)	272.1a	275.7a	375.0a	172.8b
Silt (g/kg)	486.6a	475.8a	405.8b	556.6a
Clay (g/kg)	241.3a	248.7a	219.3b	270.7a
Rocks (%)	60.7a	53.8b	54.7b	59.9a

† Values followed by the same letter within rows are not significantly different at *p* = 0.10 level
Note: Letters compare two levels of the same factor for a single variable.

Table 5. Soil Surface bulk density values (0-10 cm) and subsurface layer.

	Soil Surface (0-10 cm)		Soil Subsurface	
	Uncorrected Bulk Density	**Rock Corrected Bulk Density**	**Uncorrected Bulk Density**	**Rock Corrected Bulk Density**
	Mg/m³			
Mean	1.55	0.92	2.10	1.80
Median	1.57	0.87	2.14	1.87
Standard Deviation	0.21	0.17	0.18	0.24
Minimum	1.26	0.71	1.73	1.34
Maximum	1.95	1.28	2.29	2.05

Table 6. Average overall runoff values based upon the effect of each treatment.

	Runoff (%)	**Infiltration (%)**
Low	6.4a	94.0a
High	5.0a	95.0a
Grass	5.7a	94.7a
Forested	5.8a	94.2a

† Values followed by the same letter within rows are not significantly different at *p* = 0.10 level.

Table 7. Percentage of rock by weight at soil surface (0-10 cm) and impermeable subsurface layer.

	Surface Soil %Rock	Subsurface Soil %Rock
Mean	57.3	52.4
Median	58.0	53.1
Standard Deviation	8.6	7.3
Minimum	45.2	36.8
Maximum	74.6	64.8

Table 8. Overall average sand, silt and clay for study site.

Textural Class	Soil Surface (0-10 cm)	Subsurface Layer
	g/kg	
Sand	274 ± 141	558 ± 80
Silt	481 ± 108	234 ± 66
Clay	245 ± 46	208 ± 31

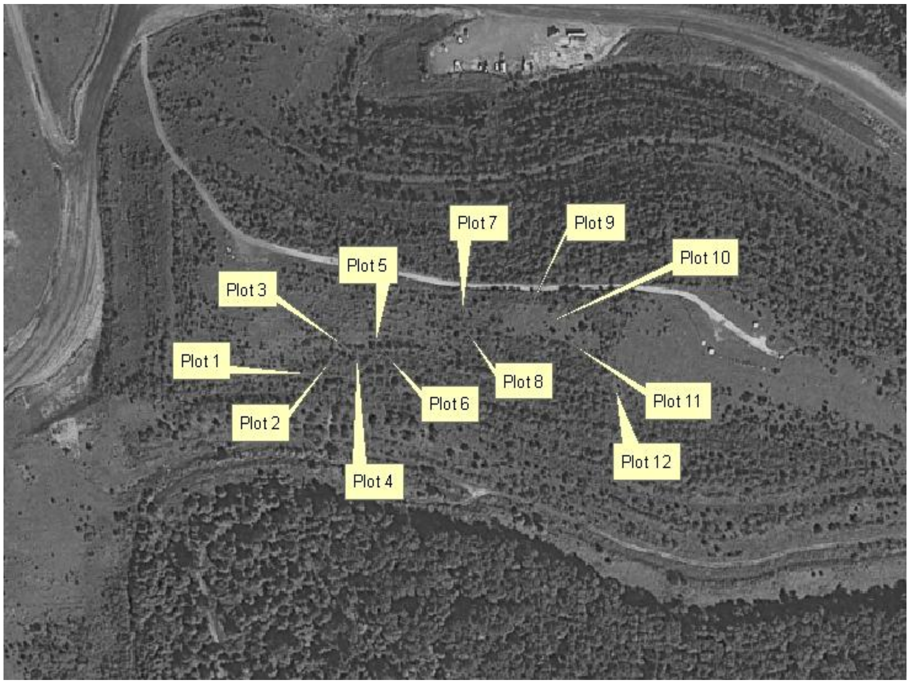

Fig 1. Spatial location of the infiltration/runoff plots at study site.