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HYDROLOGIC SOIL GROUPING DETERMINATION FOR APPALACHIAN MINESOILS

Anthony Willard

Thesis submitted to the College of Agriculture, Plant and Soil Sciences
in partial fulfillment for the requirements for the degree of

Master of Science
In
Plant and Soil Science

Thesis Committee:
Eugenia Pena-Yewtukhiw, Chair
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Plant and Soil Sciences

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Abstract

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Anthony J. Willard

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 true 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. Site #1 was selected to study the effect of vegetative cover and slope on surface hydrology while Site #2 was selected to study the hydraulic properties of the most compacted layer present in the profile of reclaimed minesoils, the compacted backfill. The properties measured to determine the minesoils true hydrologic grouping included organic carbon, texture, bulk density, and saturated hydraulic conductivity. Site #1 exhibited high infiltration and low surface runoff and erosion. Results obtained in Site #1 showed that, although minimal, the effect of slope on hydraulic properties was greater than that of vegetative cover. The organic carbon in Site #1 was 46.1 ± 3.2 g/kg while that in Site #2 was 21.3 ± 2.8 g/kg. Site #1 had a higher fraction of rocks, more silt and more clay, while Site #2 had fewer rocks and a greater amount of sand. Bulk density values were higher in Site #2, with uncorrected bulk density values averaging 2.10 ± 0.18 Mg/m³, as compared to 1.54 ± 0.24 Mg/m³ in Site #1. Corrected bulk density values for Site #2 were 1.80 ± 0.24 Mg/m³ while Site #1 exhibited corrected bulk density values of 0.91 ± 0.17 Mg/m³. The saturated hydraulic conductivity values for Site #1 averaged 47.3 ± 26.2 μ m/s, while Site #2 had a much lower average of 3.0 ± 2.7 μ m/s. Higher bulk density values and lower Ks values confirm that the compacted backfill found in Site #2 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. Such work should also be conducted over a longer period of time to study how soil hydrologic properties may change as minesoils become more developed.

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CHAPTER 1. INTRODUCTION AND JUSTIFICATION

With growing environmental concerns related to surface coal mining, coal companies are being pushed harder than ever before to restore the land area which they have disturbed while mining for coal. Conventional surface mining is the process of excavating a large land area from the surface down to extract coal. Using large mining equipment, a pit is opened up removing any overburden from the coal seam found below. The depth of this pit is determined by the depth at which the coal seam is located. Careful planning is done by mining engineers to determine this depth. The coal may go to a preparation plant for processing, or it may go directly to power plants or other industries for burning.

Reclamation goes on during the mining process. Overburden is removed and placed back into adjacent mined out pits and graded. Although the exact pre-mined landscape is impossible to achieve, the coal company attempts to reclaim the site back to its approximate original contour, or AOC. In some places the topsoil is mostly lost during site preparation and logging operations, hence there is little to save and stockpile. Therefore, the use of soil has been allowed. Recent research has shown the importance of replacement of topsoil and weathered brown sandstone materials for reforestation so more effort is being done to save these materials for placement on the surface. As time passes, the materials placed on the surface begin to develop physical and chemical properties similar to soils. In order to correctly reclaim a site, it is important that coal companies plan out careful strategies to ensure that their reclamation efforts are put to best use in order to receive the full benefit that the land has to offer.

Minesoils are newly forming man-sculpted soils which develop on surface mined sites. Minesoils consist of a collection of blasted material which was removed during the mining process and are put into the taxonomic group known as Entisols. Like most Entisols, minesoils

show little to no sign of soil development and weak structure. Soils usually have a thin A horizon directly above a C horizon. There are some cases where older minesoils contain signs of a Bw horizon. Because of their lack of development, minesoils are considered to be unproductive and less fertile for plant growth and development than the soils that were found in the area before mining. The time frame for these young soils to become like the native soils may take thousands of years of weathering and development in order to be greatly productive again. Future land use of minesoils is greatly influenced by the way in which they were reclaimed which can alter the physical properties of a minesoil. It is important to carefully examine minesoils more closely to better understand and determine their actual properties and characteristics.

This research project will be conducted on a recently reclaimed surface mine in Webster County, West Virginia. Our long-term goal is to determine the hydrologic soil grouping of minesoils based upon infiltration and runoff plots. There is a critical need for such research to help aid in the understanding of minesoil hydrologic characteristics and properties in order to implement better reclamation plans. With limited information about the hydrologic processes and behavior of minesoils, the need for both short-term and long-term studies of minesoil hydrologic characterization is great. This particular research can be the building blocks of future studies which can either be repeated or modified in an effort to accommodate for changing environments, yet measure the same factors.

Once mining has been completed in an area and the reclamation process begins, the hydrologic properties of the area are completely reconstructed. Pre-mining hydrologic properties are no longer considered because of the large amount of destruction and reconfiguration of the landscape, which surface mining and reclamation brings to the area. The large overburden which was removed to get to the coal has now been blasted and shattered into numerous smaller

particles. When the overburden is placed back there are two ways in which it is deposited, compacted or non-compacted. The more traditional way is the compacted method. With this method the blasted rock material is dumped and tracked over by large equipment several times in an effort to make the land more stable and to reshape the landscape to AOC. A new approach is to reclaim the land with non-compacted overburden. With this type of reclamation, the overburden is placed without compaction or with only one or two passes of a bulldozer. The theory is that the fewer passes reduces the negative effects that compaction has on the hydrologic properties of reclaimed minesoils which lead to runoff and erosion properties. There is also the potential for a negative impact of the non-compacted approach where the loose material is not stable enough to sustain heavy rainfalls and remain in place. There is the possibility of this loose material to be more susceptible to sediment transportation and/or mudslides.

Better understanding of surface hydrology relating to the environment is important when considering both land stability and controlling harmful pollutants. Water which does not infiltrate can runoff leading to such problems as erosion and pollutant transport. Erosion can cause the land to be unstable and prone to environmental disasters such as mudslides which can have a large negative impact on the surrounding environment. Some soils may contain some harmful minerals close to the soil surface which, if not controlled adequately, can be transported by overland flow to the surrounding area. This may endanger the surrounding environment by polluting waterways or animals which come in contact with the tainted water. A thorough understanding of an areas surface hydrologic tendency can greatly reduce the potential of these problem factors.

This study seeks to identify the correct hydrologic soil grouping of minesoils, which as mentioned before has had very little definitive research. The findings of this study could have a

profound effect on our understanding of minesoil hydrology and provide us with information that can aid us in the development of future reclamation techniques. Upon completion of our studies, we believe we can define and establish the hydrologic grouping of minesoils. The successful completion of the studies is expected to show that the minesoils have a moderately low runoff potential which could greatly impact the way water is managed on the site and the sizing of ponds and retention structures.

CHAPTER 2. LITERATURE REVIEW

Surface Mining Process

Minesoils are a unique type of soils because their development is unlike any other type of natural developing soil, and their characteristics will depend on the methods used during the reclamation process (Sencindiver and Ammons, 2000). Several techniques are used in the surface mining process which include: contour stripping, mountain top removal, and area stripping. The common method found throughout West Virginia as well as other hill terrains in the Appalachian region is mountain top removal. Ramani and Grim (1978) described this surface mining technique as follows:

The Mountain Top-Removal method is an adaptation of the area mining method to contour mining. In this method, the entire mountain tops are removed down to the coal seam in a series of parallel cuts. Excess overburden that cannot be retained on the mined area is transported to Head-of-Hollow Fills, stored on ridges, or placed in natural depressions. In either case, the method produces plateaus of level, rolling land that may have great value in mountainous terrains.

Minesoils in the Appalachian region, are a combination of saved and replaced native topsoil substitute materials generated from blasted overburden (Paone et al., 1978). Where enough native topsoil material was saved, it may be placed at the surface after regading of the overburden. However, if topsoil is insufficient and must be supplemented, selected blasted rock overburden material can be used. The main purpose of these efforts is to restore the area to its future purpose (e.g. pasture land) and shape the landscape to an approximate original contour

(AOC). Pasture land had traditionally been the favored land use selected for reclamation, but future efforts are beginning to focus around forest reclamation.

SMCRA and Minesoil Reclamation

Early surface coal mining lacked any reclamation. Instead, after the coal was removed the land was left without regarding or reseeding. This led to environmental impact such as erosion and excess runoff water. In an effort to avoid major environmental damage, and to aid in reclamation efforts, the Surface Mining Control and Reclamation Act (SMCRA) was passed in 1977 (SMCRA, 1977). The act was put in place to regulate coal mining activities and to reclaim the land to a productive post-mining land use. The act also covers those sites which had been mined prior to its passage in 1977 (Zipper, 2000). Although there have been some revisions to the original act to accommodate for new mining techniques and technology advances, however, the purpose behind the act remains the same.

The first step in the reclamation process is placing back the overburden that was removed in order to extract the coal beneath it. The overburden placed back to rebuild the landscape is a mixture of rock fragments and partly weathered finer earth material (Rubel and Jenny, 1988). The way in which the land is replaced, contoured (AOC) and re-vegetated is determined by its future use after reclamation. Although the land must be returned to AOC, the reclamation process could alter the original topographic design in a way the landowner and regulators deem appropriate to ward against erosion (Toy et al., 2002). Landscape in a reclaimed minesite can vary from steeply to gently sloping hillslopes and north or south facing aspects. With water movement being an important factor in infiltration and erosion potential, preexisting (pre-mining) landscape and soil properties must be closely examined when implementing a reclamation project.

Minesoils are susceptible to erosion before a vegetative cover is established. In most cases, minesoils have poor structure and aggregation (higher amount of loose soil particles at the surface) and more time is needed for these physical properties to develop. Weathering proceeds in minesoils at a higher rate than that of an undisturbed natural soil because of the higher amount of primary (less stable) minerals available. Studies by Ciolkos et al. (1985) and Thomas et al. (2000) show that after geologic materials have been placed at the surface, they experience accelerated weathering, thus increasing soil development, and that the development of a biologic component (grass and tree vegetative cover) plays an important role in mineral weathering and erosion protection.

The specification of a hillslope gradient or slope, is one of the few regulations dealing with the specific landscape shape of a reclaimed mine land. Minimum hillslope gradient is typically specified between 3-5% and maximum hillslope gradients are typically specified between 33-50%. Landscape slope stability design considers that the minimum slope or gradients are directed to promote surface drainage, while maximum slope gradients are used to achieve or control for mass-stability and erosion (Toy and Black, 2000). Landscape form or shape also influences water flow and erosion. Water runoff and erosion on a convex hillslope will increase downslope while a concave hillslope will decrease downslope. There has been little research specifically directed toward the effect of hillslope shape or form on reclaimed mine lands. However a recent study by Buda et al. (2009) studied the influence of soil properties on surface runoff generated from two agricultural hillslopes (north and south hillslopes) in Pennsylvania. They found that runoff on the north hillslope was substantially greater than that of the south hillslope. They concluded that the presence of a compacted layer due to equipment during regrading likely played a role in their results.

The major energy sources acting to produce water erosion are raindrop impact and surface runoff. The main factors controlling the erosion process are climate, soil properties, topography, vegetation, and ground cover (Toy et al., 2002). Sub-factors related to climate include rainfall and temperature. Soil texture is one of the most important soil properties related to erosion, with finer particles being more susceptible to erosion. Topographic variables like slope length and steepness determine runoff. In general, vegetation and ground cover are important to the erosion process, because they protect the soil from direct raindrop impact and control the velocity at which the raindrop impacts the soils (canopy height), and influence runoff velocity. Revegetation is the most important practice when attempting to stabilize reshaped topography (Toy and Hadley, 1987). SMCRA (1977) requires that all reclaimed minesoils be planted with a permanent vegetative cover that will be effective in protecting and stabilizing the landscape to ensure acceptance (bond release) of the approved post mining land use. Vegetative cover increases a minesoil's resistance to erosion by impeding direct raindrop impact, increasing infiltration, and increasing aggregation of soil particles by root networks. However, while in most cases this is true, a study by DePloey (1981) resulted in contradicting results.

Minesoil Properties

Physical Properties

When mine sites are reclaimed, the reclamation planner must take into account the physical properties of the overburden being placed back. Physical properties are some of the most important minesoil characteristics to consider due to their effect in controlling the success of vegetative covers and hydrology. A study by Welch (1988) showed that minesoils would be less favorable for plant growth than native soils based solely upon morphological and physical

properties. The most limiting factor driving this conclusion was the minesoil's inability to provide sufficient water to sustain plant growth.

Some important physical properties to described minesoils are rock fragment percentage, texture, and water holding capacity (Sobek et al., 2000). Research by Thurman and Sencindiver (1986) has shown that Appalachian minesoils contain a high percentage of rock fragments ranging from 35 to $\geq 75\%$ and low clay content. The combination of high rock fragments and low clay content may help prevent against erosion, but may also be detrimental to vegetative growth due to the soil's low water holding capacity.

Bulk density defined as mass per unit volume of soil. There is an abundance of literature on minesoil bulk density values being greater than those of native undisturbed areas (Bussler et al., 1984; Potter et al., 1988; Schafer et al., 1980; Smith et al., 1971; Thurman and Sencindiver, 1986). These studies report bulk density values that include rock fragments (rock uncorrected bulk density); while some of them adjust or correct for the amount of rock fragments (rock corrected bulk density). In areas with high amounts of gravel or rock fragments (particles greater than 2mm), the bulk density determination method selected should be able to include this characteristic, an example of such methods is the "excavation method" (Grossman and Reinsch, 2002). The rock fragments content must be taken into account to help separate between the space occupied by rock and gravel fragments from that occupied by fine soil particles (less than 2 mm diameter); this procedure will determine the soil's true or corrected bulk density (Grossman et al., 2001). Thurman and Sencindiver (1986) reported that the soil bulk density values at the surface of 25-year-old minesoils were higher than those for the native soils. However, when the bulk density was adjusted or gravel corrected, the bulk density values were similar to undisturbed soils.

Textural classes are classified using the amount of soil particle size fractions (sand, silt, and clay) present in a soil. Minesoil textures are highly variable not only from minesite to minesite, but also within a minesite (Galibrath, 2004). The method used to reclaim the site and the type of overburden placed back at the surface greatly affects soil texture. Minesoil texture can vary from sandy to clayey, but most minesoils in the eastern United States are loamy (Bussler et al., 1984; Ciolkosz et al., 1985; Daniels and Amos, 1981; Short et al., 1986; Sencindiver and Ammons, 2000).

Soil structure is the property that describes the arrangement of the solid particles of the soil and determines the pore space located between them. Minesoils have a weak to moderate structure that develops in the surface horizons (Sencindiver and Ammons, 2000). The structure is mostly granular or subangular blocky (Ciolkoz et al., 1985; Daniels and Amos, 1981; Roberts et al., 1988; Thomas and Jansen, 1985), but can also be platy due to minesoil compaction by machinery during the reclamation process (Bussler et al., 1984; Schafer et al., 1980). Subsurface horizon development have also been observed in older minesoils where more weathering has taken place. (Ciolkoz et al., 1985; Daniels and Amos, 1981; Schafer et al., 1980; Thomas and Jansen, 1985). Soil structure is related with several important soil properties such as bulk density and water movement (Haering et al., 2004).

The movement of water throughout the soil is dependent upon the previously discussed soil properties. Water movement measured as hydraulic conductivity in a saturated soil will be higher than an unsaturated soil due to the restrictive forces that arise as the soil gets drier. Hydraulic conductivity is higher when there is less air-filled voids with a sandy texture as compared to more air-filled voids and a clayey texture (Lal and Shukla, 2004). Water movement through minesoils has been assumed to be slower than that of native soils. This assumption

affects the hydrologic soil grouping in which minesoils are assigned. However, some research shows that the reclamation process helps to improve water movement compared to a soil that has been unreclaimed. Shukla et al. (2004) showed how soil properties and water movement varied in a reclaimed minesite compared to unreclaimed mine sites based upon fertility treatments. While no significant changes in soil properties were measured, there was an increase in water movement in the soils that had been reclaimed and fertilized. It's also very important to know the depth in the soil profile where the most restrictive layer lies because of its effect on soil hydrologic processes and behavior. The most restrictive layer is the soil horizon at which water begins to slow its movement inside the profile. The closer the restrictive layer is to the soil surface, the greater the risk for runoff and erosion to occur.

Chemical Properties

Minesoil chemical properties are determinant to vegetative cover establishment. Some important chemical properties to be considered in minesoils are pH, presence of high concentration of harmful elements (toxicity), and concentration of nutrient (deficiencies or excess).

Soil pH is an important chemical property of a minesoil due to its effect on plant growth success or failure. In the Appalachian region, minesoil pH is in general less than 7.0, although some values between 7.0 to 8.5 can be found (Vogel, 1981; Angel et al, 2008; Emerson et al., 2009). Sulfide minerals, such as iron sulfides like pyrite and marcasite, which are not commonly exposed to oxidizing conditions, become exposed during coal mining (Skousen et al., 2000). These oxidizing agents can lead to acid mine drainage (AMD) problems that directly affect the surrounding environment as it is transported to surrounding watersheds. Most minesoils lack an adequate supply of essential elements such as nitrogen and phosphorus (Mays et al., 2000).

Taylor et al. (1992) reported that N content of the spoils of three abandoned mines in central Alabama was very low ($<0.05 \text{ g kg}^{-1}$). Phosphorus supplies are often moderately to severely deficient on surface-mined sites. Plass and Vogel (1973) analyzed 10 samples from each of the 39 spoils from southern West Virginia and found that P concentrations were very low in 52%, low in 35%, and medium in 13% of the samples tested. The lack of these essential nutrients can impair plant growth. However with the application of fertilizers such as urea (45-0-0), triple superphosphate (TSP, 0-46-0), and lime, the area can support a healthy growth of vegetative cover (Welch, 1988).

Biological Properties

The biological properties of a minesoil play an important role in soil development and in determining soil characteristics that control vegetation establishment. Soil biological activity helps to build soil aggregates, to increase pore space, as well as to break down freshly added organic matter (Indorante, 1981). Surface mining alters the abundance and diversity of soil organisms by changing their native habitats (e.g. removing their food sources). Soil microorganisms such as bacteria, fungi, and actinomyces can still be found in bare minesoils, but as vegetation returns or is introduced these numbers will likely increase as well (Vogel, 1981). Unlike microorganisms (micro-fauna), soil meso-fauna (worms, beetles, etc.) are normally nonexistent in newly reclaimed minesoils; soil meso-fauna survive on established vegetative communities, which are not present in newly reclaimed areas. Therefore without the use of reintroduction of these vegetative species or native topsoil containing these habitat species to an area, it may be several years before natural colonies reestablish themselves (Vogel, 1981).

Minesoil Hydrology

Soil Hydrologic Grouping

Soils are classified into four hydrologic soil groups based on the soils potential for runoff (Neilson and Hjelmfelt, 1998). Water movement is the major factor when classifying soils for hydrologic grouping. The minesoil properties of interest for assessing their hydrologic groupings are: saturated hydraulic conductivity of the least transmissive layer in the profile, depth to water impermeable layer (least transmissive), depth to/or location of the water table, water permeability or movement, and amount of clay and sand.

Some important definitions are necessary:

- a) Saturated hydraulic conductivity of the least transmissive layer is the rate at which water moves through the soil profile at its slowest speed or rate.
- b) Soil depth to water impermeable layer is the depth at which water movement does not flow vertically, but begins to disperse horizontally.
- c) Depth to the water table is the depth where groundwater pressure is equal to atmospheric pressure.
- d) Water movement or permeability is defined as how easily the water moves throughout the profile either as more freely and less restricted or less freely and more restricted.

Other important factors affecting the hydraulic soil classes are: the intake of water under maximum yearly wetness, soil not frozen, bare soil surfaces, and maximum swelling of expansive clays (NRCS, 2007).

The soil properties required to classify the hydrologic group of a soil are listed in Tables 1a and 1b. The tables split the hydrologic group into four classes: A, B, C, or D. Hydrologic

group A is considered as having the lowest runoff potential conditions and D having the greatest runoff potential. The assignment of the hydrologic soil groups are separated into two different tables based on the water impermeable layer depth (NRCS, 2007). Table 1 is used when the depth of the water impermeable layer is deeper than 100 cm, and Table 2 is used when the depth of the water impermeable layer is between 50 and 100 cm. Minesoils are currently being placed into hydrologic soil group C, soils considered to have moderately high runoff potential because of the way overburden material is 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. There is one exception to the grouping of soils. The NRCS (2007) also states that those soils which are given textural classes of loamy sand, sandy loam, loam, or silt loam may be placed in a different group if they are well aggregated, have a low bulk density, or contain greater than 35% rock fragments.

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).

Soil Property	----- Hydrologic Soil Group -----			
	A	B	C	D
Saturated Hydraulic Conductivity of the Least Transmissive Layer	> 10 $\mu\text{m/s}$ (>1.42 in/h)	< 10 to > 4 $\mu\text{m/s}$ (< 1.42 to 0.57 in/h)	< 4 to > 0.4 $\mu\text{m/s}$ (< 0.57 to > 0.06 in/h)	< 0.40 $\mu\text{m/s}$ (< 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	Gravelly or Sandy	Loamy Sand or Sandy Loam	Loam, Silt Loam, Sandy Clay Loam, and Silty Clay Loam	Clayey

Table 2. Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth between 50 and 100 cm (20 and 40 in) (Modified from USDA, 2007).

Soil Property	----- Hydrologic Soil Group -----			
	A	B	C	D
Saturated Hydraulic Conductivity of the Least Transmissive Layer	> 40 $\mu\text{m/s}$ (>5.67 in/h)	< 40 to > 10 $\mu\text{m/s}$ (< 5.67 to > 1.42 in/h)	< 10 to > 1 $\mu\text{m/s}$ (< 1.42 to > 0.14 in/h)	< 1 $\mu\text{m/s}$ (< 0.14 in/h)
	and	and	and	and / or
Depth to Water Impermeable Layer	50 to 100cm (20 to 40 in)	50 to 100cm (20 to 40 in)	50 to 100cm (20 to 40 in)	< 50cm (< 20 in)
	and	and	and	and / or
Depth to High Water Table	60 to 100cm (24 to 40 in)	60 to 100cm (24 to 40 in)	60 to 100cm (24 to 40 in)	< 60cm (< 24 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	Gravelly or Sandy	Loamy Sand or Sandy Loam	Loam, Silt Loam, Sandy Clay Loam, and Silty Clay Loam	Clayey

Minesoil Hydrologic Processes and Minesoil Properties

Compaction

In mine soils, hydrologic processes are strongly affected by traditional reclamation practices. The major soil problem affecting hydrologic properties and processes in a minesoil is the high level of compaction as a consequence of the reclamation process (Barnhisel and Hower, 1997). Some examples of the direct influence of soil compaction on hydrologic processes include the decreases in water holding capacity and permeability (Bussler et al., 1984). Permeability is the ability of water to flow through a soil profile. A pervious soil will have a permeability rate range of approximately 10^{-5} to 10^{-8} m² while an impervious soil will have a permeability range of approximately 10^{-14} to 10^{-17} m².

After minesoil reclamation, soil particles are tightly packed due to the high compaction of the area. Increases in compaction decrease pore space and restrict water flow, causing slower permeability rates. When recontouring the land during the reclamation process, large/heavy equipment make multiple passes over the same area, increasing soil compaction, which leads to a decreased macropore system and decreased water movement and flow through the soil (Indorante et al., 1981). At the minesoil surface, water infiltration rate is reduced and overland flow and erosion is increased.

Another minesoil characteristic that affects hydrological properties is the amount of coarse fragments found at the soil surface and within the profile. Undisturbed soils typically have a lower content of clay sized particles and higher content of larger particles at the surface which favor infiltration (Thurman and Sencindiver, 1986; Brady and Weil, 2002). Due to the technique used to place the overburden back on reclaimed minesoils, finer particles may be found closer to the soils surface. Subsoil, located below the soil surface prior to mining and containing more

clay sized particles, may be replaced closer to the surface upon reclamation. The smaller particles clog pore space, reducing infiltration. This characteristic increases erosion and increases overland flow (Osterkamp and Joseph, 2000).

There is limited amount of published research that discusses runoff and erosion on reclaimed surface mined lands under natural rainfall conditions. For the most part, these processes have been studied through the use of simulated rainfall. McKenzie and Studlick (1979) estimated the erosion on a surface mined site based upon the factor of slope under natural rain. The authors expected to compare a bare pre-SMCRA minesoil (unreclaimed) site, with a post-SMCRA reclaimed site. However this comparison was hard to perform and the results were inconclusive. The most relevant study discussing runoff and erosion on a reclaimed mine site under natural conditions was performed by McIntosh and Barnhisel (1993). Their study site was located in western Kentucky, and was used to measure erosion and sediment yield under natural rainfall conditions for a natural soils versus three materials or substrates commonly exposed during mining operations: reconstructed topsoil, subsoil, and mine spoil. Results showed that the susceptibility to erosion of reconstructed topsoil was not significantly higher than that of natural soil, and that the subsoil substrate yielded the greatest amount of erosion. Mine spoil was found to produce more runoff than both the reconstructed topsoil and subsoil, with the topsoil producing the least amount of runoff. McIntosh and Barnhisel (1993) concluded that reconstructed topsoil is not inherently more erodible than an undisturbed site. The authors suggested that factors such as slope, vegetative cover, and management practices should be taken into account to determine their impact on erosion losses on reconstructed soils as compared to the area's pre-mining conditions.

Infiltration

The infiltration rate in minesoils characterizes soil profile water distribution and dynamic, and erosion potential. The infiltration rate, also known as infiltrability, is the rate at which water enters at the soils surface, and it is expressed in units of cm/min (Shukla et al., 2004). The infiltration rate is not always constant, it increases and decreases with the amount of rainfall, rainfall intensity and soil moisture. In a dry soil at the beginning of a storm event, the air filled pore space (meso and micropores) in the soil profile is high and conducts water easier, and as a consequence the infiltration rate observed is at its highest. The water holding capacity (WHC) is the ability of the soil to absorb and hold water. WHC is dependent upon the percentage of sand, silt, or clay found in the soil. Soil particles such as clay and silt have a larger surface area than sand sized particles and therefore can increase WHC (Brady and Weil, 2002). The term porosity is the void spaces filled with air or water found in the profile. As the storm continues, the initially empty voids are filled with water and the infiltration rate decreases (Brady and Weil, 2002). Minesoil properties such as compaction decrease the macropores and porosity available for transporting or holding water, reducing water infiltration rate. A study by Guebert and Gardner (2001) used dyes to document the importance of macropore networks on a reclaimed surface mine. They found that decreased macropore networks had a direct effect on surface storm runoff by decreasing infiltration and producing an excess overland flow. The authors stressed a need for a better understanding of macropore flow to develop new reclamation techniques to optimize long-term effluent ground water quality and minimize short-term erosion problems cause by mining and reclamation.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity is a measurement of the ability of a soil under saturated conditions to transmit water when exposed to a hydraulic gradient; it is measured in unit length over time (m/s, cm/s). Saturated hydraulic conductivity can be described as the ease with which pores of a saturated soil allow for water flow and movement. Ankey et al. (1991) suggested using a tension infiltrometer to measure saturated hydraulic conductivity in the field rather than using previous techniques which only used tension infiltrometers in laboratory settings. In past studies where saturated hydraulic conductivity was measured on surfaced mined sites, a double-ring infiltrometer was the most commonly used instrument (Barnhisel and Hower, 1997; Negley and Eshleman, 2006). The abundance of rocks in minesoils sometimes does not allow for the ring to be driven into the ground, therefore another type tension infiltrometer, “the Wooding Infiltrator,” can be used in its place. The Wooding Infiltrator working principle can be described as follows:

With the Wooding infiltrometer, water at atmospheric pressure is allowed to infiltrate into soil. Water is held inside a 15 cm diameter soil ring, pushed less than 0.5 cm deep into the soil. The infiltrometer is placed on top of the ring, and used to maintain a head of water of 1 cm inside the soil ring. As water infiltrates the soil, the water level in the infiltrometer tower decreases. This decrease in water level with time is recorded, either with a pressure transducer connected to a data logger or manually. From these data the depth of water entering the soil in a given time is calculated. This information is then used to compute the saturated hydraulic conductivity of the soil (Wooding, 1986).

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 ± 0.21 cm/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.

The objectives of the present study are to:

- (i.) Identify the appropriate soil hydrologic group of the particular minesoil within the study area.
- (ii.) Compare the effects of varying landscape and cover properties on the infiltration of water and sediment transportation on minesoils.

CHAPTER 3. MATERIALS AND METHODS

Site Description

The ICG Eastern Birch River, N 38°25.840' W 080°35.772', surface mining operation is located near Cowen, West Virginia in Webster County (Fig. 1.). ICG Eastern Birch River is extracting coal from five different coalbeds: Freeport, Upper Kittanning, Middle Kittanning, Upper Clarion, and Lower Clarion. Average daily temperature throughout the year is 11.8 °C (53.3 °F) with an average daily minimum temperature of 4.9 °C (40.9 °F) and an average daily maximum temperature of 18.7 °C (65.6 °F). Average total rainfall throughout the year is 123.11 cm (48.47 in) with an average number of days with 0.25 cm (0.10 in) or more rainfall totaling 105 days. Average yearly snowfall is approximately 110.74 cm (43.60 in) (Delp, 1998).

Figure 1. ICG Eastern Birch River, West Virginia identified by star.

Two study areas or “Sites” were selected to conduct the experiments designed to study minesoil hydrology:

- a) The first area or Site #1 was used to conduct experiment #1. The characteristics of the selected area allowed studying the effect of slope and vegetative cover on runoff and

erosion. Site #1 was located on a 20 - ha (48 - acre) hill within the ICG Eastern Birch River mining operation site. The site was reclaimed in 1996 using conventional reclamation practices. Large dozers using a technique known as “tracking” were used to contour the land. Stages of the reclamation process are shown in Figures 2a through 2d. Grass along with a variety of fast growing trees was used to revegetate this area (Figure 3). The tree species selected for the area were poplars (*Populus*) and pines (*Pinus*).

Figure 2a. Stage I of the reclamation process.

Figure 2b. Stage II of the reclamation process.

Figure 2c. Stage III of the reclamation process.

Figure 2d. Stage IV of the reclamation process.

Figure 3. Aerial photo taken in 2008 of vegetated area after reclamation in 1996.

- b) The second study area (Site #2) was located in the same surface mining operation slightly to the north-east of the previously described Site #1. This area was used to

measure the effects of the highly compacted underlying minesoil layer on hydrologic properties known as compacted backfill (Figure 4).

Figure 4. Locations of Site #1 and Site #2 in ICG surface mining operation.

Site #2 was reclaimed in 2004 following the forest reclamation approach (Buger et al. 2005). The forest reclamation approach differs from that of conventional reclamation by the number of passes over an area and the type of vegetation planted. In this area, an effort was made to reduce erosion problems caused by compaction by only allowing a few passes by large dozers to recontour the land. The revegetative effort in the area focused on tree planting alone and no grass cover was added. Due to the abundance of large boulders at the soil surface, direct measurements within the reclaimed top-soil layer were not possible (Figures 5a and 5b).

a)

b)

Figure 5. a) General view of Site #2; b) Detail of the surface cover at Site #2.

For this study, direct sampling was not done in the forest reclaimed area, but outside of it (Figure 6).

Figure 6. Exposed highly compacted underlying minesoil layer, called compacted backfill in Site #2.

The fact that in Site #2 several areas of the compacted backfill were exposed next to the access road presented us with the opportunity to measure the hydrologic properties of what we considered the most limiting layer for water movement in the “minesoil profile.”

Experiment Descriptions.

Experiment # 1

Experiment #1 was performed in the Site #1. This experiment was designed to fulfill the objective of comparing the effects of varying landscape and cover properties on the infiltration of water and sediment transportation on minesoils.

Experimental Design

A total of twelve research runoff/infiltration plots were placed at the reclaimed mine Site #1. A completely randomized 2x2 factorial experiment with 3 replications was designed to study runoff and infiltration as affected by two factors, soil cover and terrain slope. Each factor had two levels or classes: slope was three to five percent (low) or ten to fifteen percent (high), vegetation cover was grass only (Grass) or a combination of grass and forest (Forest). Four different scenarios/treatments with three repetitions were tested. The plots were placed in the south aspect of the hill, in close proximity to the ridge top. The ridge top is located in the center of the study area, approximately N 38°25.840' W 080°35.772'. The distance between plots varied between several meters to 50 m away (Figure 7).

Figure 7. Spatial location of the infiltration/runoff plots at study Site #1.

The infiltration/runoff plot physical design was based on field erosion plot structures modified by Dr Pena-Yewtukhiw. Plot dimensions were one meter wide by one and a half meters long (Figures 8a and 8b). A similar design was used by Buda et al. (2009) in Pennsylvania.

Figure 8. a) Infiltration/runoff plot diagram; b) Infiltration/runoff plot with filled runoff collection bag.

Plots were hydrologically isolated using plastic house siding. At the lower end of the plot, runoff water was collected in a stainless pipe capped off by a PVC cap on one end, and an opening on the other end where a collection bag was placed. During a rainfall event, runoff water and detached sediment flowed into the collection pipe and down into the bag.

Data Collection.

Collection trips for runoff and eroded sediments were scheduled according to the magnitude of rainfall events. Rainfall was recorded/logged by a weather station located next to experimental Site #1, and transmitted and stored in an accessible online file. The rainfall and temperature data were downloaded via internet connection; the following link was used to retrieve the weather data: <http://afws.erh.noaa.gov/afws/county.php?type=precip&state=54>.

Collection times were initially scheduled every week or earlier when at least a minimum cumulative amount of rainfall had occurred, 10 mm (0.4 in). This amount of rainfall produced a runoff volume similar to the maximum collection capacity of the collection bag.

Routine checks for the structural conditions of the plots were conducted during each trip to ensure their functionality. Proper maintenance was performed when necessary to assure the validity of the data collected during the experiment.

During a collection trip, the water and sediment filled bags were removed from the plots and replaced by new bags. The removed bags and their contents were transported to the West Virginia University Soil Physics laboratory for further analysis. Runoff water volume was measured in the lab using calibrated equipment. The amount of water infiltrating the soil was measured by subtracting the runoff volume collected in the bags from the cumulative precipitation registered by the weather station.

Soil sediment removal was directly obtained from the collection bags installed in plots. A clean beaker was weighed, and filled with the mixture of sediment and runoff water. After 24 hours of settling the process of decantation was performed. The excess water was siphoned out of the beaker, and the beaker was placed in the oven for 48 hours (or until completely dry) at 90°C. The dry sediment and beaker were then weighed. The total sediment was calculated as concentration of sediment in runoff water (g/L), and as sediment produced/plot area (m³/ha).

Soil Characterization

Bulk density was determined in the first 10 cm of the soil surface using the excavation method. Bulk density was determined at two depths: 0-5 and 5-10 cm. The procedure used to determine bulk density was as followed: a square frame of 15 cm by 15 cm (approximately 6 inches) was placed at the soil surface. Soil was removed within the frame at the specified depths. At each increment depth, the soil volume was determined by lining the excavated hole with a layer of plastic and filling it with fine sand. This volume of sand used was used with the mass of soil for the bulk density determination equation.

$$\rho = M_s/V_t$$

where ρ is the bulk density, M_s is the dry mass of dry soil solid material, and V_t is total volume of the excavated soil (Grossman and Reinsch, 2002).

The percentage of rock fragments was measured in the upper 10 cm of soil (0-5 and 5-10 cm depths). The soil sample (rock fragments and fine) were collected in the field during the bulk density determination. The samples were brought back for laboratory analysis to separate the rock/gravel fragments from fine soil particles. Rock fragments were considered to be soil particles >2mm in diameter and were determined by use of a No. 10 sieve.

From the previous procedure, the $< 2\text{mm}$ soil particles were analyzed for soil organic carbon (SOC) and particle size (sand, silt, clay). After the sample was completely homogenized, approximately 0.1 g of minesoil was used for each analysis. At least two reps were run for each sample for a total of twelve samples at each depth, equaling 24 total samples for the 10 cm depth. The concentration of soil organic carbon (SOC) found in the upper 10 cm of soil (0-5 and 5-10 cm depths) was determined with the LECO TruSpec CHN carbon analyzer, which burns the samples at $950\text{ }^{\circ}\text{C}$ ($1,742\text{ }^{\circ}\text{F}$). An infrared detector inside the analyzer measures CO_2 coming out of the sample (as it burns) and then converts it back to soil carbon. The number then reported by the analyzer to the computer is the C (%) for that sample. Particle size analysis was done using the pipette method (Gee and Or, 2002).

Figure 9. Particle size analysis in lab procedure.

Hydrologic Properties of the surface soil layer:

To measure the saturated hydraulic conductivity of the minesoil surface, a Wooding Infiltrometer designed by Soil Moisture Systems (SMS) (Wooding, 1986) was used at each of the twelve plots. Two reps were run for each plot, for a total of twenty-four samples. The Wooding infiltrometer was run for a minimum of fifteen to thirty minutes until a constant infiltration rate in ml/60sec was observed. The time interval between 15 to 30 minutes was established after initial test runs conducted on site determined a trend in water infiltration rate. As part of the procedure to measure the saturated hydraulic conductivity, soil samples were taken in the upper 10 cm to determine two moisture contents. An initial soil sample to measure moisture before the test was started, and a final sample after the test was finished. With these samples, the moisture content change during the test was measured. Figure 10 shows the Wooding infiltrometer installed in the field.

Figure 10. Wooding infiltrometer installed in the field.

Data processing

Precipitation data were recorded in inches of rain and they were converted to volume of water received per plot. Collected runoff was measured (ml or liters) and the data were converted to volume/area. The equations used to convert the precipitation and runoff units are presented in Table 3. Infiltration was not measured directly in the field, but it was calculated from the difference between precipitation and runoff. Due to the limitation the weather data limitations (e.g. lack of wind speed and solar radiation for the study area), evapotranspiration was assumed to be negligible.

Table 3. Equations used to process collected precipitation, sediment and infiltration data.

Precipitation, runoff/infiltration and sediment data:	
inches rain to mm	rain (in) * (25.4 mm/1 in rain)
inches to m ³ of rain/ha	rain (in) * (2.54 cm/ 1 in rain) * (1 cm ³ * 0.000001m ³ /1 cm ³) / (cm ² plot * 1*10 ⁻⁸ ha)
Runoff	
mm runoff	(cm ³ runoff/ cm ² plot)*10
mL/m ²	mL runoff collected/1.5 m ²
m ³ /ha	runoff (in) * (2.54 cm/ 1 in runoff) * (1 cm ³ * 0.000001m ³ /1 cm ³) / (cm ² plot * 1*10 ⁻⁸ ha)
% runoff	(Volume Runoff / Volume Rain)*100
Infiltration	
infiltration	Infiltration = Precipitation - Runoff
mm runoff	(cm ³ runoff/ cm ² plot)*10
mL/m ²	mL runoff collected/1.5 m ²
m ³ /ha	runoff (in) * (2.54 cm/ 1 in runoff) * (1 cm ³ * 0.000001m ³ /1 cm ³) / (cm ² plot * 1*10 ⁻⁸ ha)
% infiltration	100% - % runoff
Sediment	
mg/ha	(g sediment / 1*10 ⁶ mg) / (cm ² plot * 1*10 ⁻⁸ ha)
g/m ²	depth= (g sediment)/(area * ρb)
mg/L	mg sediment / L Runoff

Saturated hydraulic conductivity was calculated using the following modified Wooding equation (Perroux and White, 1988):

$$K_s = if - 4bS^2 / (\pi R_s (T_f - T_i)),$$

where,

K_s is the saturated hydraulic conductivity; if is final or steady state infiltration rate (which is measured); b is a constant with the value of 0.55; S is the sorptivity factor, obtained by plotting cumulative infiltration versus square root of time; R_s is the radius of the ponded soil inside the ring for our instrument, which is 7.25 cm; T_i and T_f are related to laboratory measurements taking the final water content of the soil minus the initial water content of the soil. The above equation is then simplified to:

$$K_s = if - 0.0966S^2 / (T_f - T_i)$$

All parameters in this equation are known, except S and if .

To obtain a value for S , the cumulative infiltration (I) in cm was plotted on the y-axis, and the square root of time in minutes on the x-axis. The next step, was to fit a straight line through the first 4 or 5 data points, and the slope of this line was calculated. This slope value is S ($\text{cm}/\text{min}^{0.5}$)

To obtain a value for if , the cumulative infiltration was plotted against time in min. A straight line was fitted through the first 7 or 8 data points and the slope of this line was calculated. The slope is the average final infiltration rate, if .

The values of S and if were fit into the above equation, to calculate K_s .

Statistical Analysis

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). Simple correlation analysis was performed among measured soil properties using PROC CORR, and correlation coefficients and significance were recorded.

The experimental design was a completely randomized 2x2 factorial. To analyze the data a two way ANOVA (PROC GLM, SAS) was performed. Runoff/infiltration, and sediment data, response variables, and slope and cover and collection data were the independent variables. Minesoil properties were used as explanatory variables. Using Proc GLM means statement, Fisher's t-tests were applied to test for differences in treatment means for the measured variables (runoff, sediment, infiltration). ANOVA analysis statistically assessed if runoff/infiltration and sediments were affected by vegetative cover and slope. This analysis allowed observing under which circumstances slope and cover had a significant impact on the hydrologic properties of the minesoils. An alpha level of 0.10 was considered significant.

Experiment #2

Experiment #2 was performed in Site #2. The objective was to compare saturated hydrology conductivities and related properties of the surface 0-10 cm measured at the first site with the same properties measured at an underlying restrictive layer or compacted backfill.

Rationale

The most compacted restrictive layer (or compacted backfill), is a consequence of the reclamation process, and it is found exposed at Site #2 (Figure 6). After compacting this subsurface layer (Figures 2a, b, c, and d), the area is later covered by soil that was found in the area originally or by a soil substitute, which is a mixture of unearthed soil particles and rock fragments. The compacted layer exposed at Site #2 is identical to the subsurface layer found in

the first study area, thereby making hydrologic grouping assumptions possible. Although this layer is currently exposed in Site #2, the reclamation process will cover the area with at least four foot of blasted overburden rock material and soil.

Experimental Design.

The depth of soil placed over the „minesoil pavement’ (or the depth of the limiting most layer) is one of the criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth greater than 100 cm (40 in). Measuring water movement in this subsurface layer, and that of the soil surface found at the first study area, allowed us to classify the hydrologic group. Because we believed that this is the most limiting layer (highest compaction), we determined this would be the best method to test the original hypothesis that the minesoil’s hydrologic grouping C is a misclassification with important consequences.

Measurements were taken between the access road and the forested reclaimed surface, allowing us to sample the surface found underneath the forested reclaimed area, and which is very similar to that area underneath the surface of Site #1 (Figure 6).

Data Collection

Soil Characterization

Bulk density was measured between 0-10 cm depth, and was performed using the excavation method previously explained. Visual assessment indicated that there seemed to be little to no difference in physical minesoil properties from the depths of 0-5 cm and 5-10 cm. There were a total of twelve sites randomly chosen at Site #2 to allow for statistical comparisons with the twelve sampling locations in Site #1.

Rock fragment percentage and infiltration was measured in the same manner. Soil samples collected during the bulk density determination were brought back to the lab, and soil particles and rock fragments were separated by the use of a No. 10 sieve with a screen mesh size of 2 mm. Particle size analysis was done using the pipette method (Gee and Or, 2002).

Saturated Hydraulic conductivity

Two repetitions of the saturated hydraulic conductivity were conducted at each of the twelve points for a total of twenty-four measurements. The procedure used to measure the Saturated Conductivity was explained in experiment #1.

Data processing

Bulk density and hydraulic conductivity calculations were explained in the previous section for experiment #1.

Statistical Analysis

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). Using Proc GLM means statement Fisher's t-tests were applied to test for differences in saturated hydraulic conductivity within point samples in Site #2 (compacted layer), and between points sampled in Site #2 and those sampled in Site #1 (surface vs compacted layer). This analysis allowed comparisons of the hydraulic conductivity of the surface and the most limiting layer localized approximately 1.5 m deep (four to five meters feet below surface). An alpha level of 0.10 was considered significant.

Soil hydrologic grouping was determined for each of the 12 infiltration plots. Using Table 1 limitations were followed and a final hydrologic grouping was determined for each plot. Results were compared with the generalized assumption that all minesoils are hydrologic group C.

CHAPTER 4. RESULTS AND DISCUSSION

EXPERIMENT 1 (Site #1)

Soil organic carbon (SOC)

Carbon is found in soils as organic and inorganic forms. In most soils the majority of C is held as soil organic carbon (SOC). The term soil organic matter (SOM) describes the organic material found in the soil such as tissues from dead plants and animals, products produced as these tissues decompose, and soil microbial biomass. SOC refers to the C found in the SOM. In this study the overall average SOC in Site #1 between 0 and 10 cm depth was 46.1 g/kg with a standard deviation of ± 3.2 . These values were slightly higher than those reported in minesoils by Shukla et al. (2004) and Ganjegunte et al. (2009). The SOC content was consistently higher at shallower depths (0-5 cm) as compared to the deeper depths of 5-10 cm (Table 4). The SOC content for each individual plot by treatment (slope and cover) and for two depths (0-5 and 5-10 cm) is presented in Appendix A Tables A1a-b through A2a-b; SOC between 0 and 10 cm depth for each individual plot by treatment is presented in Tables A3a-b and A4a-b (see Appendix A). Table 5 shows the average effect and statistical significance of the two treatments, cover and slope, on SOC content at depth of 0-5 and 5-10 cm. It was observed that the mean SOC between 0-5 cm depths for higher slopes was 60.3 g/kg and 54.7 g/kg for lower slopes; however, this difference was not statistically significant (Table 5). SOC between 5-10 cm depth was also higher for the highest slope, 39.4 vs 30.1 g/kg for the lowest slope, the difference was statistically significant (Table 5). For forest cover the average SOC between 0-5 cm depth was 62.6 g/kg and 52.4 g/kg for grass (Table 5, and Appendix Tables A2a-b), the difference was statistically significant. However between 5-10 cm depth, grass showed higher SOC content than forested plots, but the difference was not significant (Table 5).

Table 4. Overall average soil organic carbon content (SOC, g/kg) different soil depths.

Depth cm	SOC g/kg				
	Mean	Median	Standard Deviation	Minimum	Maximum
0 to 5	57.5	58.1	3.2	38.9	84.3
5 to 10	34.8	34.7	3.4	18.0	61.8
0 to 10	46.1	44.2	3.2	18.0	84.3

In summary, SOC was always higher in the upper 0-5 cm than in the lower 5-10 cm for both slope and cover. The t-test only showed a statistically significant difference for cover 0-5 cm and slope 5-10 cm implying that there was an effect of slope and cover on the SOC (Table 5). Figure 11 shows a positive trend between SOC at two different depths; there is a positive weak relationship between SOC at the surface (0-5 cm) and below the surface (5-10 cm); higher SOC at the surface translates in higher SOC at deeper depths.

Figure 11. Relationship between soil organic carbon (SOC) at depths of 0-5 cm versus 5-10 cm.

Table 5. Effect of soil cover and slope on soil surface organic carbon (SOC in g/kg) at 0-5 and 5-10 cm depth.

Property	Cover		Slope	
	Grass	Forested	Low	High
SOC 0to5	52.5b	62.6a	54.7a	60.3a
SOC 5to10	36.3a	33.2a	30.1b	39.4a

† 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.

The decrease in SOC as soil depth increases is probably due to the influence of decreased plant roots and microbial activity. In minesoils, documented compaction and high rock content restricts the movement and abundance of roots to deeper depths (less moisture and air availability) (Shukla, 2004). Higher amounts of roots close to the surface allowed for soil particles to attach and form aggregates, therefore increasing biological activity and increasing SOC storage (Brady and Weil, 2002).

Soil particle size

Fines and Rock size particles

Rock sized particles were considered those particles greater than 2mm and fines were less than 2mm. The amount of rocks size particles were important to measure due to the effect that rock fragment content has on runoff/infiltration. The more rocks in an area, the more likely infiltration will increase, and the opposite is expected when rock content decreases. In the case of the amount of fines, they have a direct effect on sediment production and the amount of particles being transported (Gee and Or, 2002).

Table 6 indicates that between 0 and 10 cm depth almost 60 % of the soil mass is above 2 mm (above gravel size) diameter and the rock content by mass increased with depth.

Table 6. Percentage of rock by weight at 0-5 and 5-10 cm depths.

	<u>0-5 cm</u>	<u>5-10 cm</u>	<u>0-10 cm</u>
	%Rock	%Rock	%Rock
Mean	53.7	60.8	57.3
Median	49.9	63.2	58.0
Standard Deviation	7.9	8.1	8.6
Minimum	45.2	46.1	45.2
Maximum	71.4	74.6	74.6

Soil Texture

Table 7 shows the overall average proportion of sand, silt, and clay for 0 to 10 cm depth.

Sand was found in the lower amounts compared to silt with an average of $274 \text{ g/kg} \pm 141$. Silt was found in higher amount with silt having an average of $481 \text{ g/kg} \pm 108$. Clay had an average amount of $245 \text{ g/kg} \pm 46$. These results do not support Bussler et al. (1984) and Short et al. (1986) observations. These authors indicate an increase in sand after the reclamation process. The higher shale content observed at Site# 1 could explain the higher silt and clay content observed.

Table 7. Overall average soil fine particles for 0-10 cm depth.

	Sand	Silt	Clay
		g/kg	
Mean	274	481	245
Median	250	519	248
Standard Deviation	141	108	46
Minimum	94	225	176
Maximum	599	613	352

In a previous section, SOC content was discussed, but the possible relationship between soil texture and SOC was not. The decrease in SOC with increasing depth was presumed to be related to the potential decrease in biological activity, but it could also be related to the amount of clay sized particles present. Clay sized particles could block pore spaces decreasing air and

water exchange and thereby making SOM less abundant in deeper depths. Micro-organisms may not reach available SOM that may be present due to pore blockage (Ganjegunte et al., 2009). Soil texture affects SOC due to the stabilizing properties that clay has on organic matter. Organic matter can be trapped in the very small spaces between clay particles making them inaccessible to micro-organisms and therefore slowing decomposition. In addition, clay offers physical protection to organic matter through adsorption onto clay surfaces, which again prevents organic matter from being decomposed by bacteria (Brady and Weil, 2002).

The following table lists the textural classifications for each sampled plot (Table 8), Appendix B Table B1 shows the sand silt and clay content by plot. Classes were determined by the use of a textural triangle (Gee and Or, 2002). The most common textural classes for the high slope plots (numbers 1-6) between 0-5 cm was „silt loam’ classification. At depths between 5-10 cm, the soil textural classes become finer and were represented mostly by „silty clay loam.’ The most common textural classes (0-5 and 5-10 cm depth) for the low slope plots (numbers 7-12) were „loam.’ It was observed during the construction and establishment of the runoff plots that there was more sandstone observed in the lower slopes, and more shale in the higher slopes. This observation could explain the textural classes determined for each slope classes. There appeared to be no effect of cover on soil texture.

Table 8. Runoff plots textural classes for 0-5 and 5-10 cm depths.

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

The greater the amount of fines, the more water that will be available for plants to uptake. Kirkham (2005) established that increase in finer particles blocks and decreases pore space for water retention and roots to develop and grow.

Figures 12a-c shows the relationship between percentage of rock content and fine's texture at 0-5 cm and 5-10 cm depth.

Figure 12a. Regression between percentage rock and sand content at 0-5 and 5-10 cm depth.

Figure 12b. Regression between percentage rock and silt content at 0-5 and 5-10 cm depth.

Figure 12c. Regression between percentage rock and clay content at 0-5 and 5-10 cm depth.

Figures 12a to c show that as rock volume increases, the content of sand decreases (Fig. 12a) and silt increases (Fig. 12b) at both depths. However, for the 0-5 cm depth, as rock percentage increases, clay content in the fines decreases; for the 5-10 cm depth, as rock content increases clay content increases (Fig. 12c). In all cases the regression coefficient (R^2) improves as depth increases, this may be a consequence of the surface processes (erosion, deposition) that occur at the soil surface.

Table 9 shows the fines composition, sand, silt, and clay content by treatments. The general trend indicates that regardless of slope, depths of 0-5 cm and 5-10 cm had similar

particle size composition. Regardless of depth, lower amounts of sand and higher amounts of silt and clay are observed for the higher slopes (10 – 15%). This trend reversed for the lower slopes (3 – 5%), higher amounts of sand and lower amounts of silt and clay were observed regardless of soil depth between 0-10 cm. The differences observed were statistically significant (Table 9).

Cover type showed no relationship with soil particle composition, the relationship remains the same between depths of 0-5 and 5-10 cm. It could be possible for future experiments to sample deeper into the profile to prove if the trend persists.

Table 9. Textural composition of fines and percentage of rock by depth and treatment.

Particle Size	Cover		Slope	
	Grass	Forested	Low	High
Sand 0 to 5 cm (g/kg)	301.5a	276.3a	368.5a	209.3b
Silt 0 to 5 cm (g/kg)	477.2a	487.8a	414.3b	550.7a
Clay 0 to 5 cm (g/kg)	221.3a	236.0a	217.3a	240.0a
Sand 5 to 10 cm (g/kg)	242.7a	275.0a	381.5a	136.2b
Silt 5 to 10 cm (g/kg)	496.0a	463.7a	397.2b	562.5a
Clay 5 to 10 cm (g/kg)	261.3a	261.3a	221.3b	301.3a
Rocks 0 to 5 (%)	56.3a	51.0a	52.5a	54.9a
Rocks 5 to 10 (%)	65.1a	56.6b	56.8b	64.9a

† 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.

In summary, there appeared to be a relationship between slopes on soil texture (Table 9). It may be possible that the increase in smaller soil particles clogged the pores and decreased microbial movement and activity, lowering the amount of SOM and SOC present in the soil. Therefore the relationship among the three factors is very evident. Slope appeared to have a greater effect on soil texture rather than cover. There seemed to be no cover relationship with texture.

Rocks appeared to be affected by both slope and cover at 0-5 and 5-10cm depths. Low amounts of rock were found under the forested cover in both 0-5 and 5-10 cm. High amounts of rock were found under the grass cover in both 0-5 and 5-10 cm. There appeared to be no

difference between slopes and the amount of rock in 0-5 cm, but there was a difference in 5-10 cm. High slopes had a greater amount of rock than low slopes at 5-10 cm. The difference was proven significantly different according to a t-test.

The results obtained in this study were similar to those reported by other authors working on reclaimed minesoils. The observed sand values averaged 273.88 g/kg and clay values averaged 245.00. g/kg. Bussler et al. (1980), Ciolosz et al. (1985), and Shukla et al. (2004) reported similar values of fines texture and gravel sized particles in their samples. Bussler et al. (1980) also classified their soils in similar textural classes as the one reported in this thesis.

Bulk Density

Bulk density (BD), rock uncorrected and rock corrected, were measured with the objective of evaluating the effect of this soil property on runoff/infiltration and sediment production. BD values were recorded at two depths, 0-5 cm and 5-10 cm. Table 10 shows the uncorrected and rock corrected bulk density between each of the two depth increments.

Table 10. Bulk density values for the depths of 0-5 and 5-10 cm.

	Uncorrected Bulk Density		Corrected Bulk Density	
	(Mg/m³)		(Mg/m³)	
	(0-5 cm)	(5-10 cm)	(0-5 cm)	(5-10 cm)
Mean	1.42	1.67	0.94	0.89
Median	1.43	1.7	0.86	0.87
Standard Deviation	0.21	0.20	0.20	0.14
Minimum	1.17	1.35	0.73	0.68
Maximum	1.86	2.04	1.41	1.14

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/cm³ with values ranging from 1.17 to 2.04 g/cm³. Corrected bulk density values averaged 0.91 g/cm³ with values ranging from 0.68 to 1.41 g/cm³. 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).

Figure 13 shows the relationship between uncorrected and corrected bulk density, at 0-5 and 5-10 cm depths. Although both depths showed a similar positive trend, there was a stronger correlation between uncorrected bulk density and corrected bulk density at the surface (0-5 cm) depth; this may be caused by the smaller amount of rocks at the surface 0-5 cm.

Figure 13. Relationship between rock uncorrected and rock corrected bulk density for two soil depth (0-5 and 5-10 cm).

Soil bulk density values are affected by rock content, texture, and SOC. To study this relationship, the following figures (Fig. 14, Fig 15) will be discussed. As SOC decreases at depths of 0-5 cm, the corresponding rock uncorrected and rock corrected bulk density values

increases (Fig. 14a and 14b). However, for the 5-10 cm depth, although an inverse trend between SOC and BD is observed, the relationship is weak. Related to soil particle size distribution, finer particles may increase soil bulk density by decreasing pore space. This decrease in pore space limits water and air movement. Because of this, microbial movement and activity decreases lowering the amount of SOM.

Soil bulk density changed with soil depth. In this study as soil depth increased, rock uncorrected and corrected BD increased and SOC decreased

Figure 14a. Regression between uncorrected bulk density and soil organic carbon.

Figure 14b. Regression between corrected bulk density and soil organic carbon.

There is a better correlation with corrected bulk density and SOC at a depth of 0-5 cm, but no significant correlation at a depth of 5-10 cm.

Figures 15a-c show the relationship between rock uncorrected bulk density on texture size, while figures 16a-c show the effect of corrected bulk density on texture size for the depths of 0-5cm and 5-10 cm. In both cases, sand decreased while silt and clay increased as uncorrected and corrected bulk density increased.

Figure 15a. Regression between rock uncorrected bulk density and sand content (g/kg).

Figure 15b. Regression between rock uncorrected bulk density and silt content (g/kg).

Figure 15c. Regression between rock uncorrected bulk density and clay content (g/kg).

Figure 16a. Regression between rock corrected bulk density and sand content (g/kg).

Figure 16b. Regression between rock corrected bulk density and silt content (g/kg).

Figure 16c. Regression between rock corrected bulk density and clay content (g/kg).

Figure 17a. Regression between rock uncorrected bulk density and percentage rock (g/kg).

Figure 17b. Regression between rock corrected bulk density and percentage rock (g/kg).

The effect between treatments and soil bulk density is presented in Table 11. There appeared to be no effect of slope or cover on either uncorrected or corrected bulk density. No

trend or statistical significance was calculated. A small change in BD with depth was observed.

In all cases uncorrected BD were higher at deeper depth, but the opposite was observed for corrected BD; the increase in gravel content with depth explains this observation.

Table 11. Average rock uncorrected and rock corrected bulk density (Mg/m³) by treatment and depth.

Bulk Density Mg/m³	Cover		Slope	
	Grass	Forested	Low	High
Uncorrected 0to5	1.42a	1.42a	1.43a	1.40a
Corrected 0to5	0.91a	0.96a	0.94a	0.93a
Uncorrected 5to10	1.66a	1.67a	1.61a	1.73a
Corrected 5to10	0.83a	0.95a	0.87a	0.91a

† 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.

Rainfall

A total of 22 rain event collections occurred during the duration of the experiment, however only 20 produced enough experimental information. Table 12 shows the rainfall data collected by the rain gauge for each of the collections. These data show a similar amount of precipitation trends listed by the soil survey of Webster County, compiled by the Natural Resource Conservation Center (Delp, 1998).

Table 12. Rainfall data for each collection period.

Collection #	Collection Date	Duration (Days)	# days with Rain	Rainfall (in)	Average Rainfall Per Rain Event (in.)	Number of Rain Events Above Average	% Rainstorm Greater Than Average
1	4/10/2009	26	16	4.2	0.3	6	37.5
2	4/23/2009	13	9	2.3	0.3	3	33.3
3	5/7/2009	14	8	2.2	0.3	2	25.0
4	5/15/2009	8	5	1.0	0.2	1	20.0
5	5/28/2009	13	5	1.2	0.2	2	40.0
6	6/5/2009	8	6	1.6	0.3	3	50.0
7	7/15/2009	40	16	4.5	0.3	5	31.3
8	7/27/2009	12	3	1.4	0.5	1	33.3
9	8/4/2009	8	6	3.2	0.5	3	50.0
10	8/13/2009	9	3	0.8	0.3	2	66.7
11	8/27/2009	14	5	1.2	0.2	2	40.0
12	9/19/2009	23	5	1.9	0.4	1	20.0
13	10/5/2009	16	8	2.0	0.3	1	12.5
14	11/4/2009	30	15	4.8	0.3	5	33.3
15	1/27/2010	6	0	0.0	0.0	0	0.0
16	3/19/2010	51	22	3.8	0.2	6	27.3
17	3/29/2010	10	5	1.5	0.3	4	80.0
18	4/28/2010	30	10	3.1	0.3	3	30.0
19	5/11/2010	13	7	1.8	0.3	2	28.6
20	5/21/2010	10	5	1.7	0.3	1	20.0
21	6/15/2010	25	9	1.4	0.2	2	22.2
22	7/20/2010	35	12	2.9	0.2	4	33.3
AVERAGE		19	8	2.2	0.3	3	33.4
TOTAL		414	180	48.7	6.0	59	

Table 12 includes the rainfall information for each collection date, total days of rain, total rainfall, average rainfall, and above average rainfall. This information is important in that it shows the rainfall events that were broadcast over a long period of time and those which were very short. Although some collections had a total greater rainfall it appeared not to affect the amount of runoff and sediment produced, because average rainfall for each event was very similar.

Sediment production

Sediment production was studied to understand the effect of slope and vegetative cover on this variable. Table 13a shows the amount of sediment produced for each collection event by cover class, while Table 13b shows the amount of sediment produced for each collection event slope class.

Plots 1, 3, 4, 5, 6, 7 were on average the highest producers of sediment, while plots 2, 8, 9, 10, 11, and 12 produced the lowest amounts. As the percentage of sand size particles decreased and silt and clay sized particles increased, sediment production increased. The relationship remains the same for all treatments.

Table 13a. Sediment collected by date and vegetative cover class for the length of the experiment.

Collection Date	Grass	Forested	Grass	Forested
	Sediment (g/m ²)		Sediment Concentration (g/L)	
Apr-10-09	0.7b	2.4a	0.5a	34.4a
Apr-23-09	0.3a	0.5a	0.1a	0.2a
May-07-09	5.0a	13.8a	3.0a	7.1a
May-15-09	4.8a	6.8a	3.2a	8.1a
May-28-09	3.9a	4.4a	3.3a	5.6a
Jun-05-09	2.9a	2.5a	2.0a	5.7a
Jul-15-09	9.0a	10.7a	7.7a	5.8a
Jul-27-09	2.2a	4.9a	1.0a	2.1a
Aug-04-09	4.6a	3.6a	1.6a	0.7a
Aug-13-09	2.5a	2.2a	2.3a	1.2a
Aug-27-09	1.5a	4.7a	2.1a	3.5a
Nov-4-09	0.7a	6.8a	0.2a	1.0a
Jan-22-10	0.4a	0.4a	0.3a	0.2a
Mar-19-10	3.0a	9.9a	2.0a	2.3a
Mar-29-10	2.3a	6.2a	2.0a	2.6a
Apr-28-10	1.0a	8.0a	0.5a	1.7a
May-11-10	0.8a	1.9a	0.4a	0.6a
May-21-10	0.8b	1.8a	0.2a	0.5a
Jun-15-10	0.8a	4.4a	0.3b	1.8a
Jul-20-10	0.7a	2.8a	1.2a	1.2a

† Values followed by the same letter within rows and date are not significantly different at $p = 0.10$ level

Table 13b. Sediment collected by date and by slope class for the length of the experiment.

Collection Date	Low	High	Low	High
	Sediment (g/m ²)		Sediment Concentration (g/L)	
Apr-10-09	1.5a	1.6a	33.8a	1.1a
Apr-23-09	0.2b	0.6a	0.1a	0.2a
May-07-09	3.0a	15.4a	5.9a	4.7a
May-15-09	4.0a	8.2a	3.3a	9.0a
May-28-09	0.9b	7.0a	4.8a	4.3a
Jun-05-09	0.4b	5.1a	0.6a	7.1a
Jul-15-09	2.3b	16.3a	7.8a	5.8a
Jul-27-09	1.1a	5.8a	0.5a	2.5a
Aug-04-09	0.8a	7.4a	0.2a	2.2a
Aug-13-09	0.3a	4.9a	0.4b	3.2a
Aug-27-09	0.2a	4.3a	0.7a	3.7a
Nov-4-09	0.7a	5.7a	0.2a	0.9a
Jan-22-10	0.4a	0.4a	0.1a	0.4a
Mar-19-10	0.9a	10.2a	0.4a	3.6a
Mar-29-10	0.3b	7.2a	0.3b	3.9a
Apr-28-10	0.5a	7.2a	0.5a	1.5a
May-11-10	0.2b	2.5a	0.1b	0.8a
May-21-10	0.8b	3.1a	0.2a	0.6a
Jun-15-10	0.9a	5.2a	0.7a	1.7a
Jul-20-10	0.3a	2.2a	1.1a	1.2a

† Values followed by the same letter within rows and date are not significantly different at $p = 0.10$ level

Of the twenty collection dates, sediment production (g/m²) and concentration (g/L) was significantly affected by slope seven out of twenty times, while sediment was only affected by cover one time. Therefore, it would be believed that slope had more of an effect on sediment production than cover. Table 14 summarizes the previous two tables by presenting the overall average of sediment variables by treatment. Correlation analysis indicated a significant correlation between sediment and measured variables (Appendix Table 1C).

Table 14. Overall average sediment related variables by slope and cover class.

	Sediment (g/m ²)	Sediment Concentration (g/L)
Low	1.0a	3.1a
High	6.0b	2.9a
Grass	2.4a	1.7a
Forested	4.9a	4.3a

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

Figures 18a and 18b show the regression between uncorrected bulk density and sediment (g/m²) and sediment concentration (g/L) while figures 19a and 19b show the regression between corrected bulk density and sediment (g/m²) and sediment concentration (g/L). Although the regression coefficients for both BDs were low, as bulk density increased the sediment production (g/m²) increased. There was a difference relationship between bulk density and sediment concentration. As uncorrected bulk density increased there was no change in sediment concentration, while as corrected bulk density increased, so too did the sediment concentration. Rock corrected BD represented better the 'erodible' soil material than the uncorrected BD.

Figure 18a. Regression between uncorrected bulk density and sediment production (g/m²).

Figure 18b. Regression between uncorrected bulk density and sediment concentration (g/L).

Figure 19a. Regression between corrected bulk density and sediment production (g/m²).

Figure 19b. Regression between uncorrected bulk density and sediment concentration (g/L).

Runoff/Infiltration

Runoff/Infiltration was measured to understand how slope and vegetative cover, influenced these variables. Table 15a shows the amount of runoff produced for each collection period for cover class, and Table 15b the runoff generated for each collection period by slope class.

A previous study done by Wu et al. (1996) reported runoff values of 12.7 mm. This average is higher than the values reported in this study (2.9 mm). When comparing average rainfall amounts measured in this study with those reported by Wu et al (1996) in which the average rainfall was 27 mm/storm, it was observed they were less than half the average rainfall per storm event in this study (56 mm). This study resulted in a much higher infiltration rate per storm event.

Plots 1, 3, 7, 8, 9, and 10 showed on average the highest amount of runoff, while plots 2, 4, 5, 6, 11, and 12 produced the lowest amounts. There appears to a relationship among % fines and texture on runoff or infiltration production (Table 2C). It was expected that as the sand content increased, runoff would decrease, but this was not observed.

Typically as the percentage of rocks increases, runoff decreases and infiltration increases. The larger diameter of rock particles compared to fine soil particles increases pore size which favors infiltration. There was no relationship between slope or cover classes, and texture particles on runoff/infiltration production.

Table 15a. Runoff variables collected by date and cover class for the length of the experiment.

Collection Date	Grass	Forested	Grass	Forested	Grass	Forested
	Runoff (mm)		Runoff (%)		Infiltration (%)	
Apr-10-09	2.8a	1.8a	2.6a	1.6a	97.4a	98.4a
Apr-23-09	3.0a	4.1a	5.1a	7.0a	94.9a	93.0a
May-07-09	1.8a	2.5a	3.2a	4.5a	96.8a	95.5a
May-15-09	2.0a	1.9a	7.5a	7.2a	92.5a	92.8a
May-28-09	1.0a	1.2a	3.2a	3.9a	96.8a	96.1a
Jun-05-09	1.3a	1.2a	3.2a	3.0a	96.8a	97.0a
Jul-15-09	2.7a	2.8a	18.7a	2.5a	89.6a	97.5a
Jul-27-09	2.3a	3.2a	6.4a	9.1a	93.6a	90.9a
Aug-04-09	3.6b	6.6a	4.4b	8.2a	95.6a	91.8b
Aug-13-09	0.8a	1.3a	3.6a	6.0a	96.4a	94.0a
Aug-27-09	0.7b	1.4a	2.3b	4.9a	97.7a	95.1b
Nov-4-09	3.8b	7.2a	3.1b	5.8a	96.9a	94.2b
Jan-22-10	2.5a	3.5a	.	.	.	.
Mar-19-10	1.7a	3.9a	1.8a	4.0a	98.2a	96.0a
Mar-29-10	1.7a	1.6a	4.5a	4.2a	95.5a	95.8a
Apr-28-10	2.1a	3.2a	2.7a	4.0a	97.3a	96.0a
May-11-10	3.7a	4.1a	8.0a	9.0a	92.0a	91.0a
May-21-10	5.4a	5.4a	12.6a	12.8a	87.4a	87.2a
Jun-15-10	3.4a	3.4a	9.4a	9.2a	90.6a	90.8a
Jul-20-10	4.3a	3.0a	5.8a	4.0a	94.2a	96.0a

† Values followed by the same letter within rows and date are not significantly different at $p = 0.10$ level

Table 15b. Runoff variables collected by date and by slope class for the length of the experiment.

Collection Date	Low	High	Low	High	Low	High
	Runoff (mm)		Runoff (%)		Infiltration (%)	
Apr-10-09	1.3b	3.3a	1.2b	3.0a	98.8a	97.0b
Apr-23-09	3.9a	3.4a	6.6a	5.7a	93.4a	94.3a
May-07-09	1.5a	2.8a	2.6a	5.0a	97.4a	95.0a
May-15-09	2.8a	0.9a	10.6a	3.5a	89.4a	96.5a
May-28-09	0.6a	1.5a	2.0a	4.8a	98.0a	95.2a
Jun-05-09	1.0a	1.5a	2.5a	3.7a	97.5a	96.3a
Jul-15-09	2.5a	3.0a	18.5a	2.6a	89.7a	97.4a
Jul-27-09	2.7a	2.9a	7.6a	8.1a	92.4a	91.9a
Aug-04-09	6.0a	4.3a	7.4a	5.2a	92.6a	94.8a
Aug-13-09	0.9a	1.3a	4.1a	6.0a	95.9a	94.0a
Aug-27-09	0.9a	1.1a	3.2a	3.6a	96.8a	96.4a
Nov-4-09	6.6a	4.7a	5.4a	3.8a	94.6a	96.2a
Jan-22-10	4.6a	1.1b	.	.	.	.
Mar-19-10	2.9a	2.5a	3.0a	2.6a	97.0a	97.4a
Mar-29-10	1.6a	1.7a	4.3a	4.4a	95.7a	95.6a
Apr-28-10	1.7a	3.3a	2.2a	4.2a	97.8a	95.8a
May-11-10	5.2a	2.5b	11.5a	5.6b	88.5b	94.4a
May-21-10	5.7a	4.6a	13.4a	10.7a	86.6a	89.3a
Jun-15-10	3.9a	2.7a	10.8a	7.5a	89.2a	92.5a
Jul-20-10	4.2a	3.5a	5.6a	4.7a	94.4a	95.3a

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

Table 16 summarizes the previous two tables and shows the overall average of the variables by treatment class. Of the twenty collection dates used to measure runoff, there were no runoff values that were significantly affected by slope or vegetative cover.

Table 16. Average overall runoff values based upon the effect of each treatment.

	Runoff (mm)	Runoff (%)	Infiltration (%)
Low	3.0a	6.4a	94.0a
High	2.6a	5.0a	95.0a
Grass	2.5a	5.7a	94.7a
Forested	3.2a	5.8a	94.2a

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

Figures 20a-c show the relationship between uncorrected bulk density and runoff expressed in mm, runoff expressed in percentage (%), and infiltration (%). Figures 21a-c show the relationship between corrected bulk density and runoff expressed in mm, runoff expressed in percentage (%), and infiltration (%). It was observed that regardless of bulk density calculation (uncorrected or corrected), there was a weak positive trend between BD and runoff, as BD increased, runoff (mm) increased, however runoff (%) was not affected by the change in BD (Fig 20a-b and 21 a-b). The infiltration percentage was high, but no trend was observed between BD and this variable (Fig 20c and 21 c).

Table 20a. Regression between uncorrected bulk density (Mg/m^3) and runoff (mm).

Table 20b. Regression between uncorrected bulk density (Mg/m^3) and percentage runoff.

Table 20c. Regression between uncorrected bulk density (Mg/m^3) and percentage infiltration.

Table 21a. Regression between corrected bulk density (Mg/m^3) and runoff (mm).

Table 21b. Regression between corrected bulk density (Mg/m^3) and percentage runoff.

Table 21c. Regression between corrected bulk density (Mg/m^3) and percentage infiltration.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_s) was measured at each of the twelve infiltration plots. Table 17 shows the average values for each of the plots. The overall average saturated hydraulic conductivity was $47.3 \mu\text{m/s}$ 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).

Table 17. Average saturated hydraulic conductivity (K_s) for the infiltration plots.

Plot Identification	K_s ($\mu\text{m/s}$)
1	63.9 ± 19.6
2	81.9 ± 9.8
3	79.2 ± 9.8
4	38.9 ± 23.6
5	31.9 ± 9.8
6	76.4 ± 21.6
7	65.3 ± 17.7
8	22.2 ± 23.6
9	52.8 ± 27.5
10	34.7 ± 17.7
11	15.3 ± 13.7
12	5.6 ± 3.9

Figure 22 shows the relationship between saturated hydraulic conductivity and SOC at the depths of 0-5 and 5-10 cm. Although the two are not highly correlated a positive trend among the two can be seen.

Figure 22. Regression between saturated hydraulic conductivity and soil organic carbon (SOC, g/kg).

As percentage of rock increases, so too does the saturated hydraulic conductivity (Figure 23). Although the increase in saturated hydraulic conductivity is modest (small slope), the observed trend/relationship is expected. It has been reported that as the amount of rock increases, pore size also increases, helping more water flow more freely (Lal and Shukla, 2004).

Figure 23. Regression between saturated hydraulic conductivity and percentage rock.

As the amount of sand increased, saturated hydraulic conductivity decreased, while as the amount of silt and clay increased K_s increased. This relationship was observed for both depths studied (0-5 cm and 5-10 cm depths) (Figures 24a-c). The observed texture vs K_s relationship is not expected, but it may be related to how the area was reclaimed.

Figure 24a. Regression between saturated hydraulic conductivity and sand content.

Figure 24b. Regression between saturated hydraulic conductivity and silt content.

Figure 24c. Regression between saturated hydraulic conductivity and clay content.

Figures 25a and 25b show the relationship between both uncorrected and corrected bulk density (0-5 and 5-10 cm) and K_s . For both depths, saturated hydraulic conductivity (K_s) increased as rock uncorrected bulk density increased. For 0 to 5 cm depth, there was no change in K_s as corrected or uncorrected BD changed. However, at the 5-10 cm depths saturated hydraulic conductivity increased as uncorrected BD increased, this may be a consequence of the increase in rock content in depth (higher rock content implies higher uncorrected BD); for uncorrected BD, at the 5-10 cm depths, saturated hydraulic conductivity decreased as corrected bulk density increased, this is the expected behavior since the effective porosity decreases as BD increases.

Figure 25a. Regression between rock uncorrected bulk density and saturated hydraulic conductivity.

Figure 25b. Regression between rock corrected bulk density and saturated hydraulic conductivity.

Table 18 shows the each treatment on saturated hydraulic conductivity. Mean saturated hydraulic conductivity under the cover treatment showed no significant difference, while mean saturated hydraulic conductivity under the slope treatment showed to have a significant difference.

Table 18. Saturated hydraulic conductivity in $\mu\text{m/s}$ by treatment.

	Cover		Slope	
	Grass	Forested	Low	High
Mean	41.0a	53.7a	32.6b	62.0a
Median	36.1	56.9	29.2	66.7
Standard Deviation	27.3	29.8	25.9	24.1
Minimum	2.8	5.6	2.8	22.2
Maximum	88.9	91.7	77.8	91.7

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

EXPERIMENT 2 (Site #2)

The following sections will discuss the results of measured soil property relationships found in Site #2. For this experiment, one (1) soil sampling depth of 0-10 cm was performed, the reason for this sampling design was to study the effect of compacted backfill (high compacted layer) on water movement, pavement properties stratification was considered negligible (no change in physical properties with depth). Soil stratified data collected in Experiment 1 were averaged between 0-10 cm, and then compared to the data collected in Experiment 2. Infiltration plots were not installed in this area. Only soil organic carbon, soil particle size, bulk density, and saturated hydraulic conductivity were measured in this area.

Soil Organic Carbon (SOC)

Table 19 shows the 0-10 cm depth SOC (g/kg) C for twelve (12) sampling points with two repetitions. An overall average value of 21.3 g/kg with a ± 2.8 standard deviation measured at this site was considerably smaller than the average value of 46.1 g/kg with a ± 3.2 standard deviation measured in Site #1 for the same depth (Table 4). This is likely due to a lack of vegetative cover that is found in Site #2. There was virtually no vegetative cover in the area, only bare surface cover resulting in a decrease in microbial activity and carbon storage.

Table 19. Overall average SOC content in g/kg at a depth of 0-10 cm.

	SOC (g/kg) 0-10 cm
Mean	21.3
Median	15.3
Standard Deviation	2.8
Minimum	3.7
Maximum	60.4

The lower amount of SOC found in Site #2 as compared to Site #1 shows the importance of vegetative cover on carbon storage. The vegetative cover provides root growth, microbial activity, and improves soil structure throughout the soil profile.

Soil Particle Size

Fines and Rock size particles

Table 20 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 Site #2 as compared to Site #1 which had an average percentage of rock value of 57.3% with a ± 8.6 standard deviation (Table 6). This result may be explained due to the high compact forces applied to create the pavement, and the smaller compaction forces used to “sculpt” the reclaimed minesoil surfaces. The extreme high compaction of the backfill is compacted to add stability to the newly formed minesoil.

Table 20. Percentage of rock by mass at depths of 0-10 cm.

	<u>0-10 cm</u>
	<u>%Rock</u>
Mean	52.4
Median	53.1
Standard Deviation	7.3
Minimum	36.8
Maximum	64.8

Another explanation for the presence of fewer rocks could be the weathering processes in the area. With the lack of vegetative cover in the area, exposed rocks may be more susceptible to erodability and therefore total amount of rocks may be fewer although a larger amount of large sized rocks are in direct sight due to the forestry reclamation approach implementation.

Soil Texture

The average amounts of the three textural sizes that were found in the highest and lowest amounts in Site #1 were the exact opposite for Site #2. Table 21 shows the overall sand, silt, and clay in the „fines’ for depths of 0-10 cm.

Table 21. Overall average soil particle sizes measured in the „fines fraction’ for 0-10 cm depth.

	Sand	Silt	Clay
	g/kg		
Mean	558	234	208
Median	552	212	210
Standard Deviation	80	66	31
Minimum	416	150	178
Maximum	669	350	274

As compared to Site #1, sand which had been the lowest proportions in Site #1, was now the highest. The silt content in this area (Site #2) is smaller than that of Site #1. The amount of clay was not different between study areas (Table 22).

Table 22. Overall average sand, silt and clay for study site 1 and 2.

Textural Class	Site #1	Site #2
	g/kg	
Sand	274 ± 141	558 ± 80
Silt	481 ± 108	234 ± 66
Clay	245 ± 46	208 ± 31

When comparing the textural classes between study areas, the fluctuations in texture size showed to greatly alter the classes for each of the sites (Table 23). In summary, Site #2 had more of a sandy texture class, while study Site #1 had more silty textural classes.

Table 23. Proportion of fines and textural class for each sampling location at depths of 0-10 cm.

Sampling Identification	Sand g/kg	Silt g/kg	Clay g/kg	Textural Class
0 - 10 cm				
1	526	225	250	sandy clay loam
2	587	195	218	sandy clay loam
3	623	195	182	sandy loam
4	631	183	186	sandy loam
5	669	150	181	sandy loam
6	578	212	210	sandy clay loam
7	552	230	218	sandy clay loam
8	634	188	178	sandy loam
9	533	256	211	sandy clay loam
10	416	350	234	loam
11	494	322	184	loam
12	514	212	274	sandy clay loam

There was no relationship between percentage rock and sand, silt, or clay content for Site #2 (Figures 26a-c). This observation was different from the results obtained for Site #1, in which a decrease in sand percentage was observed as rock percentage increased, and an increase in silt and clay content was observed as rock percentage increased (Figures 12 a through 12 c). The high compaction of the pavement, resulting from the reclamation process could explain this observation. In the Site #2, the compacted mostly sandy particles are not as transportable as the less sandy and less compacted particles in the more pedological developed Site #1.

Figure 26a. Relationship between percentage rock and percentage sand content (0-10 cm depth).

Figure 26b. Relationship between percentage rock and percentage silt content (0-10 cm depth).

Figure 26c. Relationship between percentage rock and percentage clay content (0-10 cm depth).

Bulk Density

As expected with the higher levels of compaction applied to the pavement, uncorrected and corrected mean bulk density values rose in Site #2 (Table 24) as compared to Site #1.

Uncorrected bulk density increased from $1.54 \text{ Mg/m}^3 \pm 0.24$ in Site #1 to $2.10 \text{ Mg/m}^3 \pm 0.18$ in Site #2. Corrected bulk density values rose from $0.91 \text{ Mg/m}^3 \pm 0.17$ in Site #1 to $1.80 \text{ Mg/m}^3 \pm 0.24$ in Site #2.

Table 24. Overall average bulk density values for 0-10 cm depth.

	Uncorrected Bulk Density	Corrected Bulk Density
	Mg/m ³	
Mean	2.10	1.80
Median	2.14	1.87
Standard Deviation	0.18	0.24
Minimum	1.73	1.34
Maximum	2.29	2.05

Figure 27 shows the relationship between uncorrected and corrected bulk for Site #2. The relationship was better than that observed in study area one due to the higher sand content found in the pavement.

Figure 27. Relationship between rock uncorrected and rock corrected bulk density for 0-10 cm depth for Site #2.

Similar to Site #1, Site #2 showed a decrease in SOC as uncorrected or corrected bulk density increased (Figure 28). Since the biological activity was very limited in the pavement, the decrease in BD as SOC increases could be the result of the increase of „low density’ coal minerals.

Figure 28. Regression between uncorrected bulk density and soil organic carbon 0-10 cm.

Similarly to the weak or non existent relationship between rock content and sand, silt, or clay content, neither uncorrected or corrected bulk density were related to the amount of sand, silt, or clay (Figures 29a-c). Based on the observations made in Site #1, it would be expected that as the amount of sand decreased, and silt and clay increased, bulk density increased (Figures 15 a through 15c, and 16a through 16c). This trend observed in Site #1 was very weakly observed in Site #2

Figure 29a. Regression between bulk density and sand content (0-10 cm depth).

Figure 29b. Regression between bulk density and silt content (0-10 cm depth).

Figure 29c. Regression between bulk density and clay content (0-10 cm depth).

There was a small trend in the relationship between rock content and BD, as uncorrected bulk density increased the percentage of rock increased while as corrected bulk density increased the percentage of rock decreased (Figure 30). This observation supports the observations made for Site #1, however the strength of the relationship in Site #2 is even smaller than that in Site #1.

Figure 30. Relationship between bulk density and rock content (%) for 0-10 cm depth.

Saturated Hydraulic Conductivity

Average saturated hydraulic conductivity values were much lower in Site #2 as compared to Site #1. Table 25 lists the values obtained for Site #2. The overall average saturated hydraulic conductivity for Site #2 was $3.0 \mu\text{m/s}$ with a standard deviation of ± 2.7 . This was expected because of the high level of surface compaction of the pavement.

Table 25. Average saturated hydraulic conductivity (K_s) for each sampling location at Site #2.

Sampling Identification	K_s ($\mu\text{m/s}$)
1	0.5 ± 0.0
2	3.3 ± 0.7
3	1.4 ± 1.3
4	2.0 ± 1.1
5	0.0 ± 0.0
6	3.6 ± 1.6
7	0.3 ± 0.0
8	2.5 ± 2.0
9	9.4 ± 8.0
10	3.6 ± 2.5
11	2.5 ± 0.2
12	6.6 ± 3.0

A weak trend was observed between SOC and saturated hydraulic conductivity (K_s), as SOC increased, K_s increased (Figure 31). However, compared with Site #1, the ranges and values in SOC and K_s were much smaller. It is possible that the SOC measured in Site #2 has not the same origin as the SOC in Site #1. In Site #1 there is evident biological activity that will contribute to the SOC, and in Site #2 the biological activity is not evident.

Figure 31. Regression between saturated hydraulic conductivity and soil organic carbon.

Similar to study Site #1, as percentage of rock rose, so too did the saturated hydraulic conductivity (Figure 32).

Figure 32. Relationship between saturated hydraulic conductivity and percentage rock in Site #2.

Although as sand decreased, saturated hydraulic conductivity increased. The downward trend was weaker in Site #2 as compared to study Site #1 (Figure 33a). The same can be said for silt and clay which again showed an increase when saturated hydraulic conductivity increased, but the trend was as strong correlated as Site #1 (Figure 33b and Figure 33c).

Figure 33a. Relationship between saturated hydraulic conductivity and sand content (g/kg).

Figure 33b. Relationship between saturated hydraulic conductivity and silt content (g/kg).

Figure 33c. Relationship between saturated hydraulic conductivity and clay content (g/kg).

Similar to the relationship observed between bulk density and saturated hydraulic conductivity in Site #1, a positive trend as bulk density increases so does saturated hydraulic conductivity. This was the same for both uncorrected and corrected bulk density values (Figure 34a and Figure 34b.) Like other properties measured in Site #2 and Site #1, the regression coefficient among the two variables was weak.

Figure 34a. Regression between uncorrected bulk density saturated hydraulic conductivity.

Figure 34b. Regression between corrected bulk density and saturated hydraulic.

Hydrologic Soil Grouping

Minesoils are considered to have moderately high to high runoff potential because of the way overburden material is replaced and compacted. Minesoils consist of a collection of blasted material which was removed during the mining process and because of their young age are categorized into the soil taxonomic order known as Entisols. Like most Entisols, during early reclamation times, minesoils show little to no soil development and a weak structure. 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.

In order to define the minesoil's hydrologic soil grouping, field and laboratory determination of the criteria used to classify hydrologic soils groups were evaluated. Comparison between the field and laboratory measured data and the tabulated criteria will lead to a better understanding and more proper classification of minesoil hydrologic soil grouping.

Table 1 listed the criteria to evaluate when hydrologic soil grouping is to be determined. The criteria measured in the soils included in this study can be found in Appendix D (Table D1 and D2). To characterize the hydrologic soil grouping of the minesoils in this study, Table 1 was selected over Table 2 because the estimated depth to water impermeable layer and depth to high water table was greater than 100 cm. Two criteria evaluated in this study were not included in Tables D1 and D2: the depth to water impermeable layer and depth to high water table. Both criteria were not included because they were the same throughout the soils evaluated (depth to water impermeable layer and depth to high water table were bigger than 100 cm). Site #1 represented the soil surface, while Site #2 represented the exposed impermeable layer. For the soil surface (Site #1), 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 (Site #2), 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 (surface characterized in Site #1 and subsurface in Site #2), it is necessary to consider that due to the low bulk density and abundance in rocks found in Site #1 ($> 35\%$) (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.

The vegetative cover characterized in Site #1 affect the SOC content observed in that area. The SOC content in Site #1 averaged $46.1 \text{ g/kg} \pm 3.2$ and $21.3 \text{ g/kg} \pm 2.8$ in Site #2. Yet both sites reported higher values than those previously reported by earlier studies on minesoils. In Site #1, the relationship between experimental treatment and SOC content seemed to vary in depth. SOC was found to be statistically related to cover at the depths of 0-5 cm, but not to slope at the same depths. At depths of 5-10 cm, SOC was found to be statistically affected by slope but not by cover at the same depths.

As a consequence of the reclamation process, the percentage of rock found at the surface of minesoils was high. The percentage of rock by mass for both Sites #1 and #2 were greater than 50%. These values were similar to those reported in earlier papers. The relationship between rock content and soil properties could be observed with texture in Site #1, and saturated hydraulic conductivity in Sites #1 and #2. As the rock content increased, the amount of sand

tended to decrease, while silt and clay tended to increase. It was observed that as the rock content increased, so too did saturated hydraulic conductivity. In Site #1, the relationship of cover and slope treatment was found to be significant at the depths of 5-10 cm and not at the depths of 0-5 cm.

The amount of sand and silt sized particles showed a higher variation for Site #1 and clay sized particles the lowest. In Site #1 the average amount of sand was $274 \text{ g/kg} \pm 141$, silt was $481 \text{ g/kg} \pm 108$. In Site #2, average values for sand were $558 \text{ g/kg} \pm 80$ and $234 \text{ g/kg} \pm 66$ for silt. Average fines (particles less than 2mm) were similar to previous reported values. Related to the treatments, in Site #1, cover seemed to have no effect on particle size at any depths, while slope was shown to be statistically significant at both the depths of 0-5 and 5-10 cm.

Soil bulk densities (rock uncorrected and rock corrected) measured in this study were similar to values previously reported for minesoils, although the values in Site #2 (the pavement) were higher. Average uncorrected bulk density values in Site #1 were $1.54 \text{ Mg/m}^3 \pm 0.24$, and average corrected bulk density values were $0.91 \text{ Mg/m}^3 \pm 0.17$. Average uncorrected bulk density values in Site #2 were $2.10 \text{ Mg/m}^3 \pm 0.18$, and average corrected bulk density values were $1.80 \text{ Mg/m}^3 \pm 0.24$. The extremely high bulk density in Site #2, was not a coincidence. It was designed and built by compaction with heavy equipment with the objective to protect the surrounding watersheds. In Site #1, neither treatment of cover or slope at any depth had an effect on average bulk density values.

The measured saturated hydraulic conductivity varied greatly from Site #1 to Site #2 as expected. Site #1 had a saturated hydraulic conductivity of $47.3 \text{ } \mu\text{m/s} \pm 26.2$, while Site #2 had a saturated hydraulic conductivity value of $3.0 \text{ } \mu\text{m/s} \pm 2.7$. The values in Site #1 were higher than those previously reported on minesoils. Site #2 had similar values to those reported before. The

comparison of the two sites gave a better understanding of the role that the compacted backfill plays in the reclamation process. Because the reclamation was done in the same manner in the sampled mine site, and although measured at a different site, the exposed pavement in Site #2 is expected to have the same characteristics of the pavement below the reclaimed surface at Site #1.

In Site #1, the amount of runoff and sediment produced was not statistically affected by slope or cover. However, slope was significantly significant on the amount of sediment (g/m^2) produced. Average sediment production on low slopes was 1.0 ± 1.0 while average sediment production on high slopes was 6.0 ± 4.3 . While it was hypothesized that slope and cover would have a great effect on both properties, this proved not to be the in Site #1.

Based upon the results of this study, many reclaimed minesoils have been incorrectly classified as hydrologic soil group C. Site #1 had a depth to water impermeable layer and depth to high water table greater than 100 cm (the pavement is below 1 meter or 5 feet), 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 Site #2 (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 was found at Site #2 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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APPENDIX

Appendix A

Table A1a. Surface organic carbon (SOC in g/kg) descriptive statistics for high slope at 0-5 and 5-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum	Mean	Median	Standard Deviation	Minimum	Maximum
	0-5 cm					5-10 cm				
1	53.8	54.7	7.9	44.5	61.4	38.6	38.6	3.9	35.8	41.3
2	57.4	57.4	4.1	54.5	60.2	42.6	41.7	5.8	36.4	51.0
3	73.8	73.8	14.8	63.3	84.3	40.2	39.0	5.0	35.7	48.7
4	58.9	58.9	5.8	54.8	62.9	41.5	38.9	7.5	32.8	51.5
5	54.3	54.3	8.3	48.4	60.2	36.9	36.7	2.8	33.0	41.3
6	63.7	63.7	5.2	60.0	67.4	36.5	36.9	3.9	30.2	41.9
AVERAGE	60.3	60.5	7.7	54.2	66.1	39.4	38.6	4.8	34.0	46.0

Table A1b. Surface organic carbon (SOC in g/kg) descriptive statistics for low slope at 0-5 and 5-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum	Mean	Median	Standard Deviation	Minimum	Maximum
	0-5 cm					5-10 cm				
7	62.8	62.8	7.0	57.9	67.8	29.1	26.6	7.4	23.5	43.2
8	62.4	62.4	8.5	56.4	68.4	33.5	32.6	4.7	28.1	42.2
9	49.2	49.2	3.5	46.8	51.7	23.9	23.5	3.3	20.3	28.5
10	46.6	46.6	3.0	44.5	48.7	34.0	31.9	5.8	27.5	41.2
11	59.0	59.2	7.8	45.6	69.9	21.5	21.5	4.9	18.0	24.9
12	48.3	48.4	8.0	38.9	58.4	38.8	32.2	15.4	29.2	61.8
AVERAGE	54.7	54.8	6.3	48.3	60.8	30.1	28.0	6.9	24.4	40.3

Table A2a. Surface organic carbon (SOC in g/kg) descriptive statistics for forest cover at 0-5 and 5-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum	Mean	Median	Standard Deviation	Minimum	Maximum
0-5 cm						5-10 cm				
1	53.8	54.7	7.9	44.5	61.4	38.6	38.6	3.9	35.8	41.3
3	73.8	73.8	14.8	63.3	84.3	40.2	39.0	5.0	35.7	48.7
6	63.7	63.7	5.2	60.0	67.4	36.5	36.9	3.9	30.2	41.9
7	62.8	62.8	7.0	57.9	67.8	29.1	26.6	7.4	23.5	43.2
8	62.4	62.4	8.5	56.4	68.4	33.5	32.6	4.7	28.1	42.2
11	59.0	59.2	7.8	45.6	69.9	21.5	21.5	4.9	18.0	24.9
AVERAGE	62.6	62.8	8.5	54.6	69.9	33.2	32.5	4.9	28.6	40.4

Table A2b. Surface organic carbon (SOC in g/kg) descriptive statistics for grass cover at 0-5 and 5-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum	Mean	Median	Standard Deviation	Minimum	Maximum
0-5 cm						5-10 cm				
2	57.4	57.4	4.1	54.5	60.2	42.6	41.7	5.8	36.4	51.0
4	58.9	58.9	5.8	54.8	62.9	41.5	38.9	7.5	32.8	51.5
5	54.3	54.3	8.3	48.4	60.2	36.9	36.7	2.8	33.0	41.3
9	49.2	49.2	3.5	46.8	51.7	23.9	23.5	3.3	20.3	28.5
10	46.6	46.6	3.0	44.5	48.7	34.0	31.9	5.8	27.5	41.2
12	48.3	48.4	8.0	38.9	58.4	38.8	32.2	15.4	29.2	61.8
AVERAGE	52.4	52.5	5.4	48.0	57.0	36.3	34.2	6.8	29.9	45.9

Table A3a. Surface organic carbon (SOC in g/kg) descriptive statistics for high slope at 0-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum
0-10 cm					
1	48.7	47.4	10.1	35.8	61.4
2	45.9	45.4	8.4	36.4	60.2
3	49.8	40.1	17.9	35.7	84.3
4	46.4	46.8	10.7	32.8	62.9
5	41.3	37.7	9.0	33.0	60.2
6	43.3	37.8	13.1	30.2	67.4
AVERAGE	45.9	42.5	11.5	34.0	66.1

Table A3b. Surface organic carbon (SOC in g/kg) descriptive statistics for low slope at 0-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum
0-10 cm					
7	37.5	29.0	17.0	23.5	67.8
8	39.9	34.7	13.7	28.1	68.4
9	30.3	25.9	12.1	20.3	51.7
10	37.6	39.1	7.9	27.5	48.7
11	49.6	58.9	18.7	18.0	69.9
12	44.5	42.6	11.8	29.2	61.8
AVERAGE	39.9	38.4	13.5	24.4	61.4

Table A4a. Surface organic carbon (SOC in g/kg) descriptive statistics for forest cover at 0-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum
0-10 cm					
1	48.7	47.4	10.1	35.8	61.4
3	49.8	40.1	17.9	35.7	84.3
6	43.3	37.8	13.1	30.2	67.4
7	37.5	29.0	17.0	23.5	67.8
8	39.9	34.7	13.7	28.1	68.4
11	49.6	58.9	18.7	18.0	69.9
AVERAGE	44.8	41.3	15.1	28.6	69.9

Table A4b. Surface organic carbon (SOC in g/kg) descriptive statistics for grass cover at 0-10 cm depth.

Plot #	Mean	Median	Standard Deviation	Minimum	Maximum
0-10 cm					
2	45.9	45.4	8.4	36.4	60.2
4	46.4	46.8	10.7	32.8	62.9
5	41.3	37.7	9.0	33.0	60.2
9	30.3	25.9	12.1	20.3	51.7
10	37.6	39.1	7.9	27.5	48.7
12	44.5	42.6	11.8	29.2	61.8
AVERAGE	41.0	39.6	10.0	29.9	57.6

Appendix B

Table B1. Textural classification at depths of 0-5 and 5-10 cm.

Plot Identification	Classification (0-5 cm)			Classification (5-10 cm)		
	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)
1	149	579	272	94	554	352
2	223	553	224	207	521	272
3	304	488	208	154	558	288
4	228	516	256	125	587	288
5	189	555	256	104	576	320
6	163	613	224	133	579	288
7	286	426	288	394	366	240
8	330	462	208	428	348	224
9	272	536	192	281	463	256
10	298	478	224	177	567	256
11	425	359	216	447	377	176
12	599	225	176	562	262	176

Appendix C

Table C1. Correlation coefficients for sediment and measured variables in Site #1.

	Sediment (g)		Sediment Concentration (g/L)	
	<u>Correlation Coefficient</u>	<u>P value</u>	<u>Correlation Coefficient</u>	<u>P value</u>
SOC 0 to 5 cm	0.00417	0.9521	0.90421	<0.0000
SOC 5 to 10 cm	0.23434	0.0006	-0.33214	<0.0001
Sand 0 to 5 cm	-0.32803	<0.0001	0.14679	0.0331
Sand 5 to 10 cm	-0.35452	<0.0001	0.0938	0.1746
Silt 0 to 5 cm	0.26601	<0.0001	-0.19871	0.0038
Silt 5 to 10 cm	0.26385	0.0001	-0.14549	0.0347
Clay 0 to 5 cm	0.37135	<0.0001	-0.36988	<0.0001
Clay 5 to 10 cm	0.50285	<0.0001	-0.30795	<0.0001
Rocks 0 to 5 cm	0.05214	0.4523	-0.42093	<0.0001
Rocks 5 to 10 cm	-0.04331	0.5325	-0.18368	0.0075
Uncorrected Bulk Density 0 to 5 cm	0.38880	<0.0001	-0.19531	0.0044
Uncorrected Bulk Density 5 to 10 cm	0.37206	<0.0001	-0.29123	<0.0001
Corrected Bulk Density 0 to 5 cm	0.48199	<0.0001	0.99906	<0.0001
Corrected Bulk Density 5 to 10 cm	0.40308	<0.0001	0.99958	<0.0001

Note: We considered significance when $P < 0.10$.

Table C2. Correlation coefficients for runoff/infiltration and measured variables in Site #1.

	Runoff (%)		Infiltration (%)	
	<u>Correlation Coefficient</u>	<u>P value</u>	<u>Correlation Coefficient</u>	<u>P value</u>
SOC 0 to 5 cm	0.77230	<0.0000	0.85320	<0.0001
SOC 5 to 10 cm	-0.31206	<0.0001	-0.30943	<0.0001
Sand 0 to 5 cm	0.10386	0.1423	0.16195	0.0216
Sand 5 to 10 cm	0.11619	0.1005	0.07500	0.2900
Silt 0 to 5 cm	-0.18433	0.0088	-0.18985	0.0069
Silt 5 to 10 cm	-0.18976	0.0070	-0.10642	0.1327
Clay 0 to 5 cm	-0.19880	0.0047	-0.43252	<0.0001
Clay 5 to 10 cm	-0.23660	0.0007	-0.32319	<0.0001
Rocks 0 to 5 cm	-0.37509	<0.0001	-0.40006	<0.0001
Rocks 5 to 10 cm	-0.24654	0.0004	-0.12321	0.0814
Uncorrected Bulk Density 0 to 5 cm	-0.06981	0.3247	-0.25345	0.0003
Uncorrected Bulk Density 5 to 10 cm	-0.21673	0.0020	-0.30782	<0.0001
Corrected Bulk Density 0 to 5 cm	0.84525	<0.0001	0.94311	<0.0001
Corrected Bulk Density 5 to 10 cm	0.84409	<0.0001	0.94465	<0.0001

Note: We considered significance when $P < 0.10$.

Appendix D

Table D1. Hydrologic grouping based upon soil properties measured in Site #1.

Plot #	Saturated Hydraulic conductivity of the least transmissive layer	Water movement	Amount of clay and sand		Textural Classes
	<u>µm/s</u>		<u>% Clay</u>	<u>% Sand</u>	
1	63.9 (A)	Freely (A)	31.2 (C)	12.2 (C)	silty clay loam (C)
2	81.9 (A)	Freely (A)	24.8 (C)	21.5 (C)	silt loam (C)
3	79.2 (A)	Freely (A)	24.8 (C)	22.9 (C)	silt loam (C)
4	38.9 (A)	Freely (A)	27.2 (C)	17.7 (C)	silty clay loam (C)
5	31.9 (A)	Freely (A)	28.8 (C)	14.7 (C)	silty clay loam (C)
6	76.4 (A)	Freely (A)	25.6 (C)	14.8 (C)	silt loam (C)
7	65.3 (A)	Freely (A)	26.4 (C)	34.0 (C)	loam (C)
8	22.2 (A)	Freely (A)	21.6 (C)	37.9 (C)	loam (C)
9	52.8 (A)	Freely (A)	22.4 (C)	27.7 (C)	silt loam (C)
10	34.7 (A)	Freely (A)	24.0 (C)	23.8 (C)	silt loam (C)
11	15.3 (A)	Freely (A)	19.6 (B)	50.0 (B)	loam (C)
12	5.6 (B)	Less Freely (B)	17.6 (B)	58.1 (B)	sandy loam (B)

Note: Letters in parenthesis represent the hydrologic soil grouping for that property based upon the Engineering Handbook, Chapter 7 Soil Hydrologic Grouping (NRCS, 2007).

Table D2. Hydrologic soil properties measured in Site #2.

Point #	Saturated Hydraulic conductivity of the least transmissive layer	Water movement	Amount of clay and sand		Textural Classes
	<u>um/s</u>		<u>% Clay</u>	<u>% Sand</u>	
1	0.5	Restricted or Very Restricted	25.0	52.6	sandy clay loam
2	3.3	Somewhat Restricted	21.8	58.7	sandy clay loam
3	1.4	Somewhat Restricted	18.2	62.3	sandy loam
4	2.0	Somewhat Restricted	18.6	63.1	sandy loam
5	0.0	Restricted or Very Restricted	18.1	66.9	sandy loam
6	3.6	Somewhat Restricted	21.0	57.8	sandy clay loam
7	0.3	Restricted or Very Restricted	21.8	55.2	sandy clay loam
8	2.5	Somewhat Restricted	17.8	63.4	sandy loam
9	9.4	Somewhat Restricted	21.1	53.3	sandy clay loam
10	3.6	Somewhat Restricted	23.4	41.6	loam
11	2.5	Somewhat Restricted	18.4	49.4	loam
12	6.6	Somewhat Restricted	27.4	51.4	sandy clay loam

HYDROLOGIC SOIL GROUPING DETERMINATION FOR APPALACHIAN MINESOILS

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