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SOIL PROPERTIES IMPORTANT TO STREAM DEVELOPMENT ON MINED LANDS[1]

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Abstract: Fluvial processes and channel development on landscapes have recently received more attention as designers attempt to establish or replace natural streams on disturbed or degraded sites. Several approaches using similar parameters have been developed to evaluate stream development and erosion processes on natural soils and landscapes. Such approaches include the Manning's and stream power equations for stream development, and the Universal Soil Loss Equation (USLE) and the Bank Erosion Hazard Index (BEHI) for erosion. Soil properties used in these methods to evaluate erosion potential include texture (clay, silt and sand contents), bulk density, aggregate stability, rock fragments, soil horizons, rooting density and vegetation cover. Soil scientists have developed a well-known descriptive system for identifying and classifying disturbed soils and this information should be used to more fully evaluate the process of channel development on new landscapes. Therefore, the soil properties used in classification can be evaluated in designing channels and streams on disturbed lands, and refinements on interpreting these physical properties in the context of stream design need to be made.

Additional Key Words: minesoil properties, minesoil classification, reclamation, rehabilitation, stream restoration,

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Introduction

Channels form on landscapes due to slope, precipitation, and erosive forces. In the classic sense, erosion and sediment movement begin on evenly sloping planes as sheet erosion, where enough energy is applied by moving water to dislodge and move soil particles. With continued water flow, this sheet erosion rapidly changes to rill erosion as water naturally converges to less restrictive paths because of slight differences in elevation on the land surface, thereby cutting small channels. As water continues to flow, gullies may form as flowing energy cuts the channels deeper and moves sediments further down slope. The erosion process from sheet to rill to gulley development therefore forms deeper and wider channels, which in turn drives landscape development.

Stream Principles

The form of a channel and the rate at which it develops are functions of the kinetic energy in flowing water and of the resisting forces to water flow. Kinetic energy in water channels is controlled by gravity, channel slope, water quantities (watershed boundaries), and flow rates (velocity). Gravity continuously tends to accelerate the flow downstream and steeper slopes accentuate the energy in the water flow. Higher water quantities can potentially generate more erosive forces, and higher velocity provides opportunities for greater sediment movement downstream.

Resisting forces are defined by the fluid’s properties, friction among particles within the fluid, friction between the fluid and channel boundaries, turbulence, and channel configuration and composition. Many attempts have been made to quantify these resisting factors. For example, researchers recognized centuries ago that water flowed in distinct ways and described these as laminar and turbulent flow. In laminar flow, water flows in straight paths without interruption or disruption from surrounding influences. Therefore, most resistance in laminar flow results from viscosity of the fluid, which is largely controlled by temperature and suspended solids. Turbulent flow is water in a channel that continuously fluctuates in all directions based on adjacent zones of flow, suspended particles, and channel boundaries and impediments in the channel. Therefore, flowing water in streams and channels is dominated by turbulent flow.

To quantify these types of flows, the Reynolds number (Re) was developed, which represents a ratio between driving forces and resisting forces:

$$Re = VR\rho/\upsilon \qquad (1)$$

where V is the mean velocity, R is the hydraulic radius, ρ is the density of the fluid, and υ is the molecular viscosity. R in the equation is determined by channel configuration and the wetted perimeter of the channel. As a result, the Re can predict laminar or turbulent flow, with values of 500 or less representing laminar flow and values 750 or greater representing turbulent flow. Those values between 500 and 750 are a mixture of the two types of flow.

Other flow and resistance equations have been developed. An important equation was developed by Manning in 1889:

$$V = \frac{1.49}{N} R^{2/3} S^{1/2} \qquad (2)$$

where V is velocity, n is the Manning roughness coefficient, R is the channel hydraulic radius, S is the channel slope. Roughness coefficients such as Manning's (Table 1) are presumed to be a constant for any particular channel framework and therefore they have been used extensively for ditches, canals, streams and rivers.

Although resistance coefficients are defined generally by characteristics such as slope of the channel, hydraulic radius of the channel, and channel configuration, these characteristics are not independent of other factors, such as soil physical properties. For example, channel configuration can vary dramatically within short distances. Bottoms and sides of channels can be irregular because of bars, riffles, and bends. Bottom sediments in the streambed can change drastically within short distances based on erosion and deposition processes. Particle size of bed materials can also affect roughness values, with combinations of large and small particles causing much complexity to flow prediction. Indeed, channel configuration, boundary conditions, and particle size generate a large amount of resistance in streams. Some of these factors produce turbulence and form eddies and secondary circulation patterns, all of which increase resistance to flow. Surprisingly, sediment-laden water tends to flow at higher velocity than clear water because an increase in suspended sediment tends to lower resistance.

Much of the energy in a stream can be dissipated by turbulence and internal frictional force. A small part of this energy, however, is used in eroding and transporting sediment, a very important geomorphic process for streams and channels. Dislodging and transporting of sediments in streams is determined by the energy available in the water on that particular particle. Coarse particles are harder to dislodge and to keep in motion than smaller particles, and the large particles also tend to be quickly deposited and remain in the stream channel. Except for short bursts of energy during storm events, coarse particles usually move as bed load material (materials moving along the channel bottom by rolling, sliding, or bouncing) and move only short distances during high flow events. Therefore, the size, shape, and packing (density) of the particles, along with the flow characteristics of the stream, determine the amount of material suspended or in motion, and the location of its deposition.

Table 1. Manning roughness coefficients (n) for different boundary types in ditches, canals, streams, and rivers (Ritter et al. 2002).

Boundary Type	Manning n
Very smooth surfaces such as glass, plastic, or brass	0.010
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood surface	0.014
Vitrified smooth clay	0.015
Shot concrete, untroweled, and earth channels in good conditions	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition with some vegetation along side	0.025
Winding natural streams and canals in poor condition with much vegetation	0.035
Mountain streams with rocky beds and rivers with variable sections and vegetation	0.041-0.050

Entrainment is defined as the processes that initiate particle movement. Therefore, the amount of sediment entrained depends directly on the erosive power of the flow and on the nature of the particles in the streambed and their potential for erosion. So, two streams with identical flow conditions may have different bed loads or suspended sediment loads if one flows across a gravel bed versus a silt and fine-sand bottom.

Stream power was proposed as a different approach to relating stream energy to sediment transport in streams. Stream power is defined as:

$$\omega = \gamma QS \qquad (3)$$

where ω is stream power, γ is a specific weight of materials being dislodged and transported, Q is discharge rate, and S is the stream slope. The weight of materials suspended at a specific time (or storm event) can indicate the energy in the stream at that moment. If stream power is greater than that needed to transport sediment loads, then the energy can be used to scour the streambed causing greater cutting and stream development.

Fine-grained sediments (silt and clay) are often suspended quickly with storm events and transported with the supporting action of turbulence. The relationships among the amount of suspended sediment, streambed characteristics, and sediment yield are correlated but difficult to measure. Most estimates of sediment yield (sediment moved downstream for long distances) and bed load discharge (materials moved along the bottom) are made by equations relating flow parameters to different-sized sediments and their corresponding transport rates. While the equations have been developed, their accuracy is difficult to assess because reliable measurements of bed load discharge are scarce and small errors in the parameters translate into large differences in the computed rates. Therefore, better estimates of the amounts and types of materials moved with stream flow events are needed and better measurement techniques are necessary to allow accurate and reproducible values of sediment dislodging and transport. With better estimates and measurements, natural stream configuration and channel designs could be evaluated, and estimates of restoration rates for stream segments with specified streambed materials could be determined.

Much of this discussion has been focused on the processes involved in cutting channels or gulley formation downward into the soil or rock material, or in other words, erosion in a vertical direction. Once gullies or channels are formed, erosion also proceeds in a lateral direction. Much work has been done in describing bank erosion, and terms such as cantilevers (undercut sections along stream banks), tension cracks, soil fall, slab failure, shallow slips, and planar slides have all been used to describe the instability of banks along streams.

In the preceding sections, it is clear that the soil or rock substrate in which the stream is flowing has a dominant control on the configuration and the rate at which channels form. Therefore, it is important to better understand the factors involved in sediment movement, or the process of erosion.

Erosion

The factors involved in soil erosion were developed over many decades of research. One of the better known methods of estimating soil erosion is the Universal Soil Loss Equation (USLE) and is written as:

$$T = R\ K\ LS\ CP \qquad (4)$$

where T is the tons/acre/year of soil lost, R is the rainfall factor, K is the soil erodibility factor, LS is the slope length and slope steepness factor, and CP is the vegetation and management practice factor. The rainfall factor has been assigned values for many parts of the world and is essentially a precipitation "energy" factor based on the frequency and intensity of rainfall in a particular region. The K factor is the inherent erodibility of a soil and is often called the most controversial factor in the equation. This relates to the soil's resistance to detachment, its infiltration capacity, and its structural stability. Every soil series has been assigned a K value, and this value is based on a specific soil's sand content, silt and very fine sand content (the most erodible particles), organic matter content, aggregate stability, and permeability. The LS factor reflects the influence of slope length and slope steepness on erosion. The CP factor provides a measure of the surface ameliorating effects due to vegetation (bare soil vs. crop, forage, or tree cover) and soil management practices (tillage, conservation practices).

These factors are very similar to those used in describing channel development and geomorphic processes involved in stream morphology. The USLE, however, was developed only as an estimate for sheet erosion and not for erosion in gullies, channels, or streams.

The soil properties involved in determining the K factor helps to assess the potential of soil and stream bank materials for erosion as related to stream development, and these properties may be especially important to determine erosion in disturbed soils, like those on mined areas. Therefore, soil texture (the relative proportion of sand, silt and clay) is critical because each texture class will have a different response to the energy contained in rainfall impact and flowing water. Silts and very fine sands are the most erosive particles; sand-sized particles are next, while clay-sized materials are the least erosive. While conventional wisdom might suggest that the small clay particles should be more erosive than silt and sand, the clay particles tend to be much more sticky and hard to detach from soil aggregates than the less sticky silt and sand particles. However, once clay particles are detached and suspended in water, very long time periods are required for these particles to settle out of stagnant water, and these particles may not settle out of flowing water at all.

The organic matter content is closely related to aggregate stability. Organic matter is sometimes fibrous in nature, which tends to bind soil particles together and make them less erosive. Organic matter also contains substances that “smear” or bridge soil particles together with molecules of long-chain carbohydrates. Organic matter also has high surface area and high electrical charge on the surface, which tends to attract and hold soil particles together. All of these processes influence the way soil peds are aggregated and held together. Soil aggregation is measured by dipping soil peds repeatedly in water and determining their disintegration over time.

Movement of water into the soil (infiltration) and through the soil (permeability) also are important to a soil’s erosion potential. Coarse-grained materials, like rocks, gravel and sand, allow high infiltration into the soil and thereby discourage overland flow of water that can detach soil particles for erosion. Small-sized soil particles like silts and clays can discourage infiltration and can cause more runoff and erosion. Therefore, a measure of the soil’s inherent capacity to take in water should be assessed.

Therefore, the factors that make up a soil’s inherent erodibility, or the K factor in USLE, are important soil properties to evaluate in terms of stream development.

Rosen (2001) used a Bank Erosion Hazard Index (BEHI) to evaluate erosion rates in and around streams. The BEHI rating includes stream bank variables such as bank height ratio (stream bank height / maximum bank full depth), ratio of rooting depth / bank height, rooting density, % surface area of bank protected by vegetation or other debris, bank angle, number and location of soil horizons in the bank, and bank material composition. Values were calculated for each of these variables and summed for a Total BEHI value, with higher values representing a higher erosion hazard. Value adjustments were made for varying bank material compositions. For example, banks composed of bedrock were rated “very low,” and those with boulders and cobbles were “low.” Banks composed of gravel material were given an extra 5 to 10 points if the sand content of the soil material was >50%. Sand (if greater than 50% of the texture) also added 10 points to the value. Surprisingly, there was no adjustment for silt or clay sized materials in the bank. For practical purposes, a relationship or curve was plotted for each of these stream bank variables to give a risk rating from “Very Low” to “Extreme.”

Properties of Disturbed Soils Important to Erosion

Based on the USLE and the BEHI, there are some paramount soil properties that should be measured to develop erosion ratings for streams. In every instance, texture is a determining and critical factor. The relative amount of sand and silt are important to erosion since they are the most erodible particles, while rock fragments including cobbles, flags, and boulders are not generally erodible with most storm events. In disturbed sites, rock fragments can make up a significant portion of the soil matrix, thereby reducing the erosion potential.

Streams flowing upon bedrock and stream banks composed of bedrock erode slowly and are much slower to contribute particles to the water. This is due to the unweathered nature and density of the bedrock material (it is still cemented and not broken up) and less to its actual makeup and particle size. Therefore, compacted layers in disturbed soils may act like bedrock lenses and reduce erosion potential. Most disturbed soils, however, have been blasted or broken up and, as such, do not have bedrock-like materials (except for large boulders randomly intermixed among the broken materials). Our observations show that disturbed soils have the potential to erode very quickly, and erosion and channel development proceed at a rapid rate. This is due to the fairly coarse texture of most minesoils (having high amounts of sand and silt, and not much clay), low organic matter content and low aggregate stability, and sometimes low amounts of ground cover and rooting in the soil. Without armoring, grouting, or placing a liner in constructed channels, water conveyance channels across disturbed soils often incise to deep levels with continual erosion of the bank. Without vegetation, roots, and a confining layer (like bedrock), the loose, broken rock materials are ideal for intensive and excessive erosion.

The purpose of this paper is to compare the physical properties of disturbed and undisturbed soils in the Beaver Creek area and to evaluate their potential for erosion and stream incision.

Materials and Methods

The research area is located in Tucker County, WV, 5 km northeast of the town of Davis along State Route 93, which parallels Beaver Creek. The elevation of the soil sampling sites is approximately 975 m. Mean annual air temperature at Canaan Valley is 8^{o}C, and average annual precipitation is 136 cm.

Predominant vegetative species on these Upper Freeport coal mined sites was red pine (*Pinus resinosa* Ait.) with some miscellaneous scattered grasses and forbs underneath the pines.

Vegetation on the undisturbed sites varied from one site that had predominantly wetland species consisting of grasses, rushes, and sedges to forested sites consisting of predominantly black cherry (*Prunus serotina* Ehrh.).

Twelve soil pits were dug, described and sampled in this study: six on Upper Freeport minesoils, and six on undisturbed soils. All of the minesoils were located on sideslope positions. Each of the soil pits were excavated to at least 100 cm and described according to standard soil survey techniques (Soil Survey Division Staff, 1993). Bulk samples were collected from each described horizon, but only soil pH values are presented here. Some of the chemical data for the Upper Freeport minesoils and the undisturbed soils have been reported elsewhere (Jones et al., 2003).

Results and Discussion

A thin A-horizon of <10 cm was found that graded into slightly weathered C horizon material to a depth of 160+ cm on these Upper Freeport disturbed sites (Tables 2 and 3). Roots were found to a depth of 65 cm and rock fragments were found in all horizons (Fig. 1 and 2). Textures of these disturbed materials varied from loam and silt loam in the surface horizons to sandy loam to clay in subsurface horizons (Table 2).

Undisturbed profiles (Tables 2 and 4) had A-horizons that were slightly thicker than the disturbed profiles. The textures in the surface horizons of undisturbed soils were also loam and silt loam. In subsurface horizons, the textures were sandy loam to silty clay. Structure, moist consistence, and root abundance were similar for similar horizons of the disturbed and undisturbed soils (Fig. 3 and 4). Rock fragments were slightly higher in the disturbed soils compared to undisturbed soils.

Figure 1. Landscape and vegetation near a disturbed Upper Freeport coal minesoil pit along Beaver Creek in Tucker County, West Virginia.

Figure 2. Profile of a disturbed Upper Freeport coal minesoil along Beaver Creek, Tucker County, West Virginia.

Figure 3. Landscape and vegetation surrounding an undisturbed area near the Upper Freeport disturbed area along Beaver Creek, Tucker County, West Virginia.

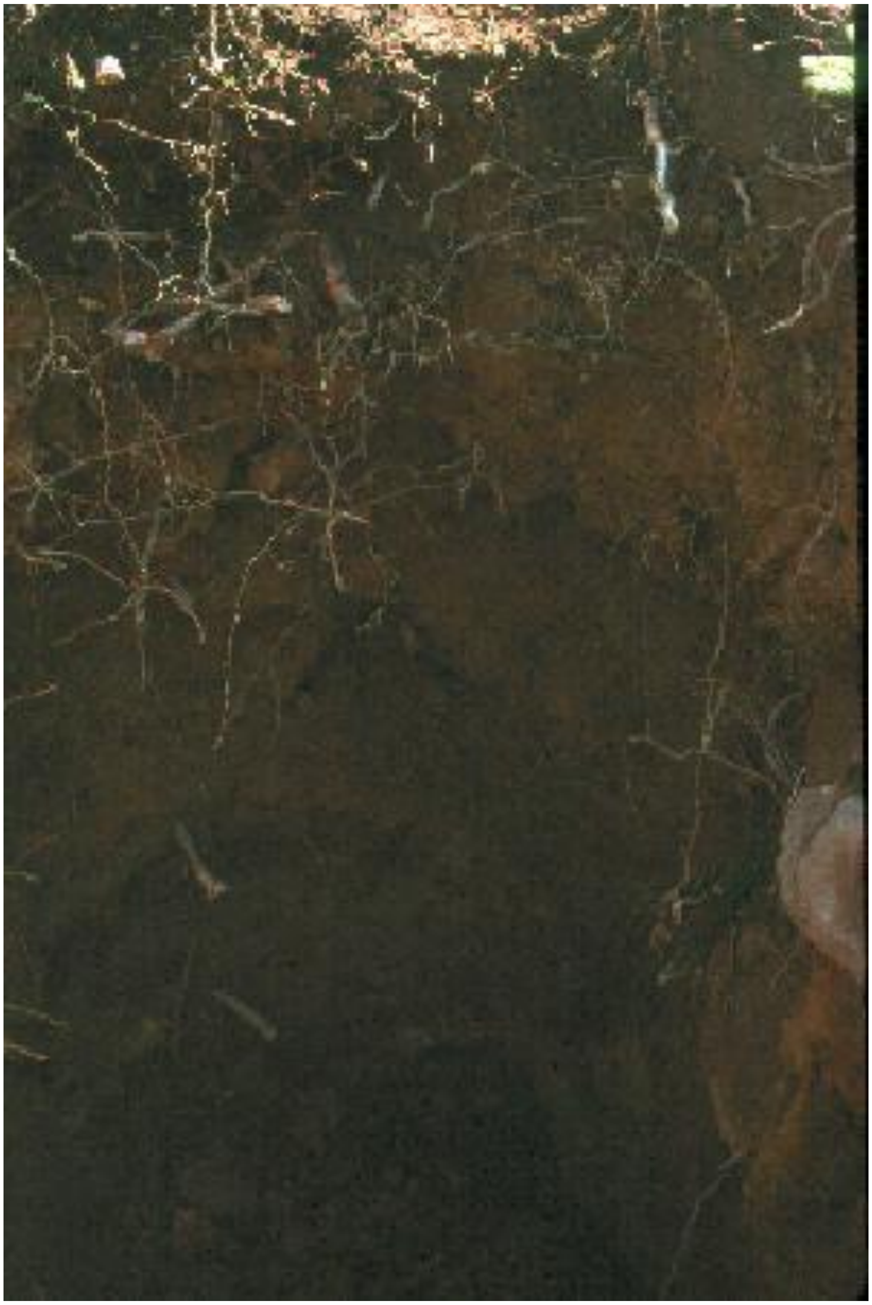

Figure 4. Profile of an undisturbed soil along Beaver Creek, Tucker County, West Virginia.

Table 2 . Description of minesoils and undisturbed soils in the Beaver Creek, West Virginia area (average of 6 sites each).

Layer[1]	**Average Thickness and Range (cm)**	**Texture**[3]	**Rock Frag. (%)**	**Structure**	**Consist.**	**Roots**
Minesoil 1	6 3-8	L, CHL, CHSIL	16 5-20	Weak or moderate granular	Very Friable or Friable	Many or common
2	33 5-91	CHSIL, CHSICL, CHCL, VCHCL	24 15-39	Weak Subangular Blocky	Very Friable to Firm	Many, common, few
3	121[2] 71-161	VCHCL, VCHC, VCHSICL, ECHSL, CHCL, CHSICL, CHC, C	44 24-70	Massive	Very Friable to Firm	Very few, few, none
Undist. 1	9 4-23	L, SIL	3 0-10	Weak or moderate granular	Very Friable or Friable	Many or common
2	71 56-91	L, SIL, SL, SCL, SIC, SC, CHL, CHSL, VCHL, VCHSL	13 0-25	Weak Subangular Blocky	Very Friable to Extremely Firm	Many, common, few, none
3	22[2] 0-45	L, SL, GL, VGL, VCHSL	14 0-50	Massive	Friable to Firm	Very few or none

[1] For both minesoils and the undisturbed soils, layer 1 = the surface mineral horizon. Layer 2 = all horizons below the surface mineral horizon that had structure development. Layer 3 = all C horizons.

[2] For layer 3, the actual thickness may be greater than indicated. Depths to the bottom of all pits were not the same.

[3] L = loam, SL = sandy loam, SIL = silt loam, CL = clay loam, SCL = sandy clay loam, SICL = silty clay loam, SIC = silty clay, C = clay, CH = channery, ECH = extremely channery, VCH = very channery, G = gravelly, VG = very gravelly.

Table 3. Profile description of an Upper Freeport disturbed soil in the Beaver Creek, West Virginia area.

General:

Vegetation: Red Pine Forest, grasses and forbs
Parent Material: Minesoil
Slope: 7%
Aspect: West

Profile Description:

A - 0-4 cm, dark grayish brown (10YR 4/2) loam; weak fine granular structure; very friable; many very fine and fine roots; 10% rock fragments; clear wavy boundary.

AC - 4-9 cm, mixed yellowish brown (10YR 5/4, 10YR 5/6, and 7.5YR 5/8), pinkish gray (7.5YR 6/2) channery silty clay loam; weak fine to medium subangular blocky structure; friable; many very fine to medium roots; 15% rock fragments; abrupt wavy boundary.

C1 - 9-65 cm, mixed black (N 2.5/0), strong brown (7.5YR 5/8), yellowish brown (10YR 5/4), and pinkish gray (7.5 YR 7/2) channery clay loam with few pockets of more clay and few pockets of more sand; massive; firm; very few fine and very fine roots; 20% rock fragments; gradual wavy boundary.

C2 - 65-88 cm, mixed black (N 2.5/0), strong brown (7.5YR 5/8), yellowish brown (10YR 5/4), and pinkish gray (7.5YR 7/2) channery clay with pockets of sandier material; massive; firm; 20% rock fragments; diffuse wavy boundary.

C3 - 88-170+ cm, mixed black (N 2.5/0), strong brown (7.5YR 5/8), yellowish brown (10YR 5/4), pinkish gray (7.5YR 7/2), and red (2.5YR 4/8) very channery clay; massive; firm; 35% rock fragments.

In comparing the data for these soils in Beaver Creek, properties of the surface horizons of minesoils and undisturbed soils are very similar. When textures and rock fragment contents of the three layers are compared, it appears that the undisturbed soils have a higher erodibility hazard, since less clay and fewer rock fragments are found in the undisturbed profiles. Soil pH ranges are slightly lower in disturbed soils versus undisturbed soils (Table 5).

While not part of the data in Table 2, bulk density or the compaction of materials in disturbed soils is important to potential erosion. Several investigators report that disturbed soil

Table 4. Profile description of an undisturbed soil in the Beaver Creek, West Virginia area (adjacent to Upper Freeport disturbed soils).

General:

Vegetation: Black cherry, quaking aspen, clubmoss, ground blackberry
Parent Material: Colluvium
Slope: 9%
Aspect: West

Profile Description:

A - 0-9 cm; very dark brown (10YR 2/2) silt loam; weak medium granular structure; very friable; many very fine and fine roots; clear wavy boundary.

BA - 9-25 cm; dark brown (7.5YR 3/4) silt loam/loam; weak fine and medium subangular blocky structure; very friable; many fine to coarse roots; clear wavy boundary.

Bw1 - 25-50cm;brown(10YR 4/3)gravelly loam; moderate medium and coarse subangular blocky structure; friable; few fine and medium grayish brown (10YR 5/2) depletions; many fine and medium roots; 30% rock fragments; clear wavy boundary.

Bw2 - 50-68 cm; dark yellowish brown (10YR 4/4) gravelly loam/clay loam; weak medium and coarse subangular blocky structure; friable; common medium and coarse dark gray (10YR 4/1) depletions and strong brown (7.5YR 5/6) concentrations; common fine and medium roots; 30% rock fragments; clear wavy boundary.

BC - 68-81cm; olive brown (2.5Y 4/3) gravelly loam; weak fine and medium subangular blocky structure; friable; many medium and coarse gray (10YR 5/1) depletions and strong brown (7.5YR 5/6) concentrations; common fine and medium roots; 20% rock fragments; abrupt wavy boundary.

C - 81-95 cm; brown (10YR 4/3) very gravelly loam; massive; firm; common medium strong brown (7.5YR 4/6) concentrations; 40% rock fragments; abrupt wavy boundary.

Cg - 95-105+cm; dark grayish brown (10YR 4/2) gravelly loam; massive; firm; few fine and medium strong brown (7.5YR 4/6) concentrations; 30% rock fragments.

Table 5. Range of pH values and slopes for minesoils and undisturbed soils in the Beaver Creek, West Virginia area.

Layer	**Minesoil**	**Undisturbed Soil**
1	3.4-4.5	3.5-5.0
2	3.3-4.9	4.0-4.6
3	3.0-4.7	4.2-4.6

bulk densities are higher than contiguous native soils. For example, undisturbed soils generally were found to have bulk densities of 1.3 to 1.5 Mg/m^3 compared to 1.6 to 1.8 Mg/m^3 for minesoils (Bussler et al. 1984, Skousen et al. 1998). Minimizing the amount of compaction on disturbed soils by reducing tracking by bulldozers can greatly improve the chances for vegetation and especially for the invasion of trees onto the site.

The one thing that is different and that may be slightly evident from the data is the amount of ground cover on the surface of these two soils. Less ground cover, and hence less organic matter, was found in the disturbed soils versus the undisturbed soils. Vegetation and the percent ground cover on disturbed soils, and any soil for that matter, are extremely important factors in the eventual erosion of a soil, regardless of its physical and chemical properties.

Therefore, one extremely important reclamation practice for disturbed soils is establishing vegetation on the site to minimize and control erosion. Much effort and time is spent in developing proper conditions in the disturbed soil to enhance vegetation establishment. Minimizing compaction of the surface soil, replacement of topsoil materials that were removed prior to mining, liming and fertilizing the soil materials, and seeding species known for rapid germination and quick growth are all practiced. Successful establishment of a vigorous herbaceous cover reduces rainfall impact, enhances infiltration of water and decreases runoff, and improves the stability of the soil to erosion.

Most reclamation activities for disturbed and abandoned surface mined sites use highly designed, engineered structures to channel water across the area. The most common techniques used to reduce erosion and stream incision are rip-rap channels (where large rocks maintain the channel and reduce erosion), grouting or cementing the channel so that no erosion occurs, or lining the channel with a synthetic material. All of these techniques are effective in controlling erosion and eliminating the possibility of channel development or incision. However, in a number of cases, the engineered structure fails due to slope failure or undercutting of the grouted channel by subsidence or settling, and water is then directed into underlying unconsolidated materials thereby generating further erosion. Therefore, natural erosion inhibitors like stable, vegetated banks are critical for controlling erosion on disturbed sites, and proper design is also paramount.

Liming and fertilizing of the surface minesoil during reclamation activities greatly enhance the vegetation on disturbed sites. These practices can improve the pH and lower the acidity in the soil, and supply necessary nutrients for plant growth. Without adding lime and fertilizer, the broken rocks may be unsuited for providing essential nutrients (particularly nitrogen and phosphorus) for vegetation development and growth. Therefore, understanding the pH and fertility status of disturbed soils can also aid in evaluating erosion potential.

In many cases, the disturbed soil materials need to be enhanced with topsoil that is removed prior to the disturbance activity or that is borrowed from another site. Applying a layer of topsoil may make the disturbed soil much more suitable to the growth of plants. However, emphasis should be placed on placing the right materials on the surface (even if not weathered) with the appropriate physical and chemical properties to establish and sustain vegetation.

A better understanding of the minesoil properties on disturbed lands can help to determine the rate and degree of erosion (aggrading vs. degrading sections, entrainment, etc.) and hence the ultimate development of channels and stream morphology. Research in this area should concentrate on determining the texture, rock fragment content and size of rocks in the disturbed materials, density of materials, layering and boundaries of horizons, land slope, and fertility of the soil. Having an understanding of the watershed boundaries and potential stream power, predictions of sediment movement and transport could be developed. Knowing these properties can help to balance the methods for designing streams on disturbed areas, and may help in determining the methods of helping the stream reach stability by the use of erosion inhibitors like stream bank vegetation, organic matter, and woody debris. In these ways, channel incision and eventual stream type may be predicted based on these properties and structures can be placed in strategic locations to enhance the development of the stream channel without damaging downstream lands.

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