FOREST ESTABLISHMENT AND WATER QUALITY CHARACTERISTICS AS INFLUENCED BY SPOIL TYPE ON A LOOSE-GRADED SURFACE MINE IN EASTERN KENTUCKY

Patrick N. Angel[2], Christopher D. Barton, Richard C. Warner, Carmen Agouridis, Tim Taylor, and Sarah L. Hall

Abstract: Six research plots were established on a surface mine for the purpose of evaluating the forest productivity potential and hydrological and water quality characteristics of three different loose-graded spoil types. The three spoil types were: (1) predominately brown, weathered sandstone (BROWN); (2) predominately gray, un-weathered sandstone (GRAY); and (3) mixed weathered and un-weathered sandstones and shale material (MIXED). The average area of the six plots was approximately 3,658 m^2. The physical and chemical soil characteristics that gave the BROWN spoil type a predictably higher productivity potential and natural regeneration than the GRAY and MIXED spoil were its finer soil texture, higher CEC and P concentration, and a pH that was more suitable for native hardwood trees.

Four species of tree seedlings were planted into the spoils. Growth and survival of the planted trees were evaluated for three years. As an indicator of natural succession potential, percentage ground cover of volunteer vegetation on the three spoil types was also evaluated. By the third year (2007) after planting, the BROWN spoil type had a significantly higher average tree volume index than the MIXED spoil and MIXED was significantly higher than GRAY. Ground cover from natural regeneration was found to be 66.4% on the BROWN spoil (61 different species), 5.8% on the MIXED spoil (35 different species), and less than 2.0% on the GRAY spoil (12 different species).

Results showed that the loose-graded spoil in this experiment was characterized by low discharge volumes, small peak discharges, and long durations of discharge and had hydrologic characteristics of a forested watershed, even at this early stage of development. Generally, concentrations of Ca, Mg, and SO_4^{2-} decreased over time in GRAY and MIXED and increased in BROWN. The pH of the water discharge from all three spoil types has increased from about 7.5 to 8.5. Although the average electrical conductivity (EC) in water discharged from the BROWN spoil remained relatively level during the study period, the GRAY and MIXED appears to be on a downward trajectory from about 1500 µS cm^{-1} to about 500 µS cm^{-1}. The latter value of EC has been reported as the apparent threshold at which the benthic invertebrate community returns to drastically disturbed headwater streams of eastern Kentucky and adjacent coal-producing Appalachian states.

Additional Key Words: tree performance, compacted spoil, infiltration, coal, stream.

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[2] Patrick N. Angel, Forester/Soil Scientist, Office of Surface Mining, United States Department of Interior, London, KY 40741 and Doctoral Candidate in Soil Science, University of Kentucky (UK), Lexington, KY 40506. Christopher D. Barton, Assistant Professor, Department of Forestry, UK. Richard C. Warner, Extension Professor, Biosystems and Agricultural Engineering (BAE), UK. Carmen Agouridis, Assistant Research Professor, BAE, UK. Tim Taylor, Fuller, Mossbarger, Scott and May Engineers, Inc. 1409 N. Forbes Rd., Lexington, KY. 40511. Sarah L. Hall, Doctoral Candidate in Plant Sciences, UK.

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Introduction

The biggest impediment to the establishment of productive forests as a post-mining land use on surface mines in the eastern United States is excessive compaction (Ashby et al., 1984; Burger et al., 1997; Graves et al., 2000). Other potential obstacles include lack of careful selection of a rooting medium for tree roots, creation of an aggressive herbaceous cover that is too competitive for young tree seedlings, selection of tree species that are not suited to site conditions, and improper tree planting techniques. These problems and others contributed to significant forest fragmentation across Appalachia since the implementation of the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA).

In the 1950's and 1960's, a regulatory requirement of surface mining performed in the gently rolling terrain of the Midwestern states was referred to as "strike-off" reclamation. This requirement consisted of making one or two bulldozer passes down the length of each parallel ridge of spoil, pushing it into the parallel valleys on both sides. If viewed from the air, the result of "strike-off" reclamation would look like the rough surface of a giant washboard. Trees were then planted at the rate of 1500 to 2000 per hectare into this loosely graded spoil bank. The growth of those trees in this non-compacted spoil over the past 40 to 50 years has been very good relative to typical mine spoils (Ashby, 2006).

Stability of mine sites was a prominent concern among regulators and mine operators in the years immediately following the implementation of SMCRA. These concerns resulted in the highly compacted and consequently unproductive spoils of the early post-SMCRA era. However, there is nothing in the regulations that requires mine sites to be overly compacted as long as stability is achieved. Mostly cultural barriers, and not regulatory barriers, have contributed to the failure of reforestation efforts under the federal law over the past 30 years. Efforts are being made to change the perception that the federal law and regulations impede effective reforestation techniques and interfere with bond release (OSMRE, 2006).

The United States Department of Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) and the seven state regulatory authorities in the Appalachian Region have embarked on a campaign to 1) plant more high-value hardwood trees on reclaimed coal mined lands in Appalachia; 2) increase the survival rates and growth rates of planted trees; and 3) expedite the establishment of forest habitat through natural succession. Drawing on the recommendations generated by surface mine reclamation research over the past 40 years, OSMRE and the state regulatory authorities advocate the following Forestry Reclamation Approach (FRA): (1) Create a suitable rooting medium for good tree growth that is no less than 1.2 meters deep and comprised of topsoil, weathered sandstone and/or the best available material; (2) Loosely grade the topsoil or topsoil substitutes placed on the surface to create a non-compacted growth medium; (3) Use native and non-competitive ground covers that are compatible with growing trees; (4) Plant two types of trees – early succession species for wildlife and soil stability, and commercially valuable crop trees; and, (5) Use proper tree planting techniques (OSMRE, 2006).

The FRA is extensively supported by research with the exception of the first recommendation involving the selection of a suitable spoil type as the rooting medium. Mine soil development from different rock types is complex, and different rock types can have vastly different physical and chemical properties. The wording, "best available material" is ambiguous and has generated significant controversy and confusion. Clear definitions of good forest mine soils based on mine soil analyses and tree growth responses are needed.

Researchers have reported on the attributes of loose-graded brown weathered sandstone spoil compared to un-weathered fine-textured rocks (Torbert et al., 1990). Other studies have identified certain types of loose-graded mixed un-weathered sandstone and shale (mine run) spoil as being highly productive (Conrad et al., 2002; Angel et al., 2006). A recent study compared the response of three native hardwoods to weathered and un-weathered sandstone materials in a greenhouse study (Showalter et al., 2006); however, no operational-scale side-by-side comparisons of these two spoil types have been made on the same mine site. Although these studies do not conflict in regards to their findings, they show that several different mine spoils may serve as topsoil substitutes suitable for tree growth while others are unsuitable. The economic considerations implied by each of these studies are significant and may prompt coal operators to favor one spoil type over another regardless of suitability for trees. Mine spoil suitability for trees must be established so coal operators and regulators can make informed cost-benefit decisions. Furthermore, several gaps exist in the scientific literature concerning the selection of a suitable spoil type as the rooting medium.

The objective of this paper is to evaluate reforestation success, natural regeneration, water quality, and hydrology as influenced by the following three types of loose-graded spoil on a surface mine in eastern Kentucky: (1) predominantly brown, weathered sandstone; (2)

predominantly gray, un-weathered sandstone; and, (3) a mixture of both sandstones and shale. This is part of a larger multi-year study that is designed to evaluate the influence of surface mineralogy (or geology) of differing types of loose-graded spoil on reforestation success and hydrologic attributes.

Methods

Study area

Since late 2003, the University of Kentucky has been engaged in the on-going installation of a reforestation research complex on an active mountaintop removal operation located on Bent Mountain on Brushy Fork near the community of Meta in Pike County, Kentucky (latitude N 37° 35′ 49″, longitude W 82° 24′ 19″) (Fig. 1).

Figure 1. Aerial photograph of the surface mine and reforestation research complex at Bent Mountain in Pike County, Kentucky taken in October 2007.

The operator of the mountaintop removal operation is Appalachian Fuels. This mine is located in Kentucky's eastern coalfield in the Cumberland Plateau physiographic region and is predominately forested. Climate is temperate humid continental with average annual precipitation of 114 cm, and an average monthly precipitation of 10 cm, which ranges from

6-12 cm. Average temperature is 13°C, with a mean daily maximum and minimum of 31° and 18° in July and 8° and -4° in January (Hill, 1976). The mine is within the Hazard Coal Reserve District as delineated by the U.S. Geological Survey (Huddle et al., 1963). Ultisols are the predominant soil order in the area (USDA, 1998). The soil series at the study site is Dekalb, which are typically on upper side slopes and ridges (Hayes, 1982).

The geologic unit that is affected by surface mining in the Bent Mountain area is the Lower and Middle Pennsylvanian (Carboniferous, 318.1-306.5 Ma) Breathitt Formation. The formation consists of interbedded sandstone, siltstone, shale and coal. Sandstone, shale and siltstone, in that order, are the most abundant rock types. In general, the sandstone is light gray, massive, fine to medium grained, and weathers to a yellowish or reddish brown. The shale is dominantly medium gray, silty, and contains siderite nodules (Wolcott and Jenkins, 1966). Strata exposed in the area rise 3 degrees southeast due to the Pine Mountain Fault, located to the southeast. To the northwest the same strata and coal seams may be 60 meters lower due to the overthrust. The formation contains over seven coal seams that are being mined.

Plot Installation

Spoil Placement. A set of research plots were established in March 2005 on Bent Mountain for the purpose of evaluating tree performance, natural regeneration, hydrologic characteristics, and determining the mineralogical, chemical and physical characteristics of three different types of loose-graded spoils. Three spoil types involved are: (1) predominately brown weathered sandstone; (2) predominately gray un-weathered sandstone; and (3) equally mixed brown weathered sandstone, gray un-weathered sandstone, and shale material (mine-run spoil). The Munsell (1975) color name and notation of color for the predominate color in the brown weathered sandstone spoil type was "light yellowish brown", 10YR 6/4. For the spoil type that was gray un-weathered sandstone, the predominate color was "light gray", 10YR 7/1. The third spoil type composed of mixed brown/gray sandstones and shale material was mottled one-third each of the above colors and one-third "gray", 2.5YR 5/0. The three spoil types will henceforth be referred to as "BROWN", "GRAY", and "MIXED". A small amount of coarse woody debris and root propagules were observed in the BROWN plots soon after installation, but not in the GRAY and MIXED plots. No effort was made to quantify the woody debris and root propagules.

The three loose-graded spoil types are the three treatments in this experiment. These treatments are randomly assigned to six square plots, each of which measures approximately 64 meters on each side. The three treatments were replicated once, across the six plots or experimental units, creating two BROWN plots, two GRAY plots and two MIXED plots Each of the six plots was physically separated and isolated from each other by a 2.5-meter buffer zone where no loose spoil was dumped. The buffer zones also served as an access to drain pipes and instrumentation installed in the six plots.

A rectangular foundation for the six plots was prepared with spoil material from the mountaintop removal operation. The foundation, which is about 3.5 hectares in size, was orientated along the long axis in a northwest-southeast direction on a 2% slope with the highest elevation occurring on the southeast edge. The foundation was then divided in half along the short axis and graded on a 2% slope so that the center line of each plot is at a lower elevation than the northeast and southwest edges (forming a "bathtub" configuration to facilitate the flow of water to the center and then to the exit point of each plot). The spoil in the foundation was then highly compacted by repeated passes of both rubber tired and tracked heavy equipment to prevent infiltration.

The three different spoil types were transported directly from the working surface mine and dumped out onto the compacted foundation into tightly placed piles to form the final configuration of the six plots (Fig. 2). The BROWN, GRAY and MIXED spoil was hauled to the plot sites in separate loads by large dump trucks. From northwest to southeast, the six plots are arranged and identified as:

(1) **1 BR** - predominately brown weathered sandstone;
(2) **2 GR** - predominately gray un-weathered sandstone;
(3) **3 BR** - predominately brown weathered sandstone;
(4) **4 MX** - equally mixed brown weathered sandstones, gray un-weathered sandstones, and shale material (mine-run spoil);
(5) **5 MX** - equally mixed brown weathered sandstones, gray un-weathered sandstones, and shale material (mine-run spoil); and,
(6) **6 GR** - predominately gray un-weathered sandstone.

Figure 2. Aerial photograph of the six research plots at the Bent Mountain surface mine in Pike County, Kentucky taken in March 2005. Plot 1 BR is in the foreground at the bottom of the photograph and Plot 6 GR is at the top of the photograph.

The make and model of the dump trucks that were used to haul and dump the spoil piles was Caterpillar Off-Highway Trucks, Model 785 which has a maximum load rating (capacity) of 136 metric tons (78 bank m^3). The spoil was dumped out of the end of the dump trucks ("end-dumped") into piles that averaged about 3.5 m in height. The piles were placed in parallel rows in such a way that they closely abutted one another across each of the six plots. The tops of the spoil piles were then "struck-off" with one pass of a small bulldozer (Caterpillar D5H, straight blade) down the length of each parallel ridge of spoil, pushing it into the parallel valleys on both sides. The one pass with the bulldozer cut the piles down in elevation by about 1 m, which resulted in the final average height of the piles to be about 2.5 meters. The spoil was dumped in the six plots and struck-off as specified in Reclamation Advisory Memorandum Number 124 (RAM 124) issued by the Kentucky regulatory authority (KDSMRE, 1997). The final grade configuration of the spoil resembles many natural forest sites in the area with a hummocky microtopography that is characterized by small mounds, depressions, rocks, and boulders, which create a surface more amenable to recruitment, establishment, and survival of diverse, native forest species, both flora and fauna. No fertilizer or soil amendments were added.

Lysimeter, Drainage Pipe, and Sampling Station Installation. Prior to the placement of the three spoil types on the foundation of the six plots, a system of drainage pipes and pan lysimeters were installed on the surface of the compacted foundation (Fig. 3).

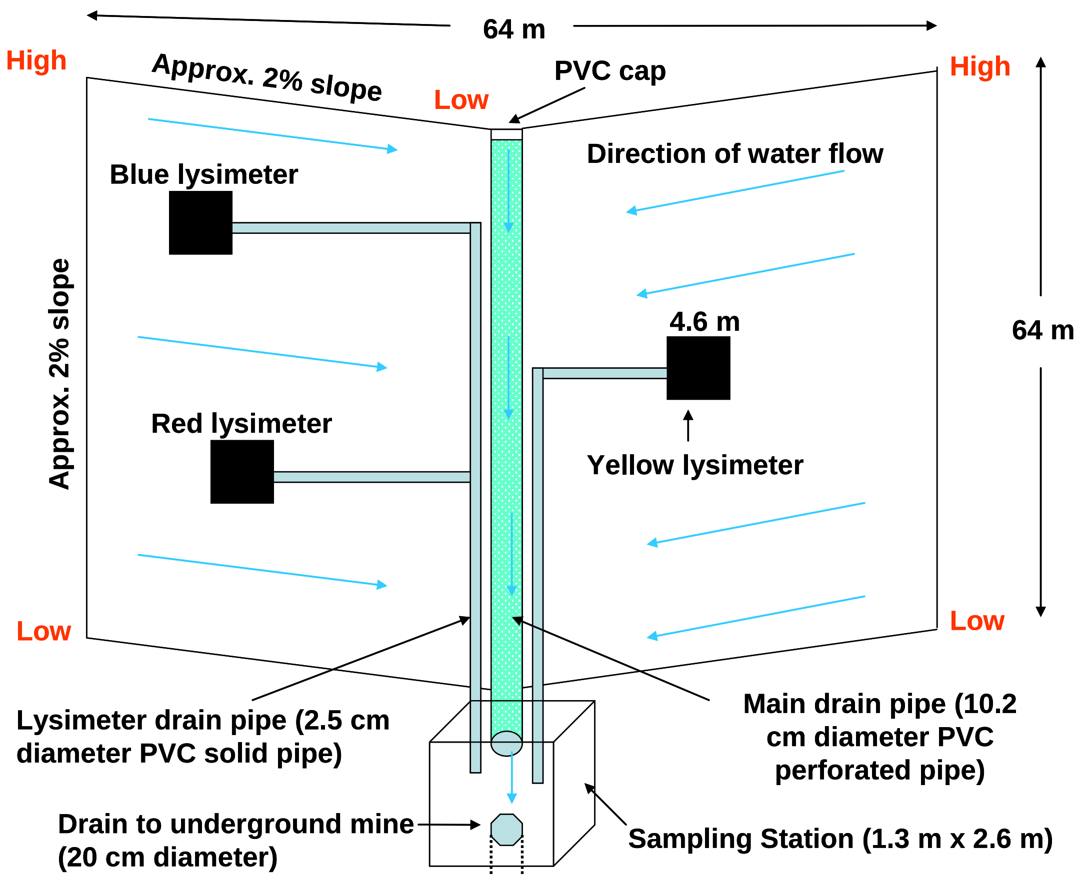

Figure 3. Conceptual internal view of loose-graded plots at the Bent Mountain surface mine in Pike County, Kentucky.

This system of pipes was designed to facilitate the internal drainage of the plots and to allow for the systematic sampling of the meteoric water that infiltrates into, percolates through and then exits each plot. Six 10.2 cm diameter perforated polyvinylchloride (PVC) pipes were installed on the foundation to serve as the "main drain pipes" for each of the six plots. The main drain pipes span the entire length of each plot down the center of the "bathtub" to the exit point of the plots. Three pan lysimeters were also installed on top of the compacted foundation of each of the six plots. The three lysimeters, which are each 4.6 meters square, were named "red", "blue", and "yellow" in accordance to the color of tape wrapped around the effluent point of each drain pipe. The lysimeters are drained to the effluent points by non-perforated PVC pipes that are 2.5 cm in diameter and henceforth referred to as "lysimeter drain pipes". The three lysimeter drain pipes, the one main drain pipe, and the three lysimeters of each plot were then carefully covered to a depth of approximately 1 m with the spoil type specific to each plot to protect them from the impact of the spoil and rocks that would be dumped on them.

A drainage system was installed to an underground mine below the plots to provide complete hydrologic isolation for each plot so that no drainage from one plot could mix with drainage from another. This was accomplished at the exit point of each plot and in the area of the buffer zones. At these six locations, a pit was dug into the compacted foundation that measured 2 m by 2 m by 1 m (deep). The floors of each of the six pits slope to a 20 cm diameter hole drilled through about 5 m of the compacted foundation and about 12 m of rock overburden to an abandoned underground mine in the Upper Peach Orchard coal seam below the plots. The underground mine is an abandoned conventional room and pillar operation on 6 m by 18 m centers.

Hydrologic sampling stations, covered by a 1.3 m x 2.6 m wood shelter, were constructed in each pit. Each station contains a large stainless steel tipping bucket, varying in capacity from 1400 ml per tip to over 3000 ml per tip. This was used to measure the discharge from the main drain pipes. The three lysimeters drain pipes empty into either a rain gauge (Davis Instruments Model No. 7852 Rain Gauge) or a smaller metal tipping bucket, according to the amount of water produced. The rain gauges act in the same way as the stainless steel tipping bucket. Each device was fitted with a HOBO Event Data Logger (HOBO), which recorded the time and date of each event (tip) experienced by the instrument. There are a total of 24 tipping devices for the entire experiment: one large tipping bucket per plot (for drainage from the main drain pipes) and three smaller tipping buckets per plot (for drainage from the lysimeter drain pipes). Plastic buckets (19 liter capacity) were placed underneath each tipping apparatus to collect the discharge.

Tree Seedling Establishment. Four species of tree seedlings were hand planted by a professional contract tree planter with a mattock type tool (hoedad) on a 1.8 m by 2.4 m spacing in the loose-graded spoil of the six plots on April 2, 2005. The four species were white oak *(Quercus alba)*, red oak *(Quercus rubra)*, yellow-poplar *(Liriodendron tulipifera)*, and green ash *(Fraxinus pennsylvanica)*. The tree seedlings were grown in one nursery bed for one year without being transplanted from one bed to another, then lifted and packaged for shipment without soil attached (1-0 bare-root stock).

Because of the hummocky microtopography and little relief no grasses or legumes were seeded to control erosion since it was anticipated that soil movement would be contained within the six plots. Furthermore, the presence of an aggressive herbaceous cover would serve as a confounding factor for tree growth and an impediment for natural regeneration (Groninger et al., 2007).

Data Collection

Water Data. The data recorded by the HOBOs were downloaded at intervals of every one to two weeks during the summer, fall and spring months. During the winter months, sampling was less frequent due to freezing conditions. Samples were taken from the 19 liter buckets each time the data from the HOBOs were downloaded. Upon sampling, the supernatant, or clear water above the sediment in the plastic buckets, was first collected and then the water and sediment in the buckets were mixed completely before a second sample was taken. Thus, two samples from each of the 24 discharge points were taken from the experiment for laboratory analysis. The supernatant was analyzed for Ca, Cl, K, Mg, Na, ammonium (NH_4^+-N), nitrate (NO_3^--N), sulfate (SO_4^{2-}), total carbon, total organic carbon (acidified), and dissolved organic carbon (filtered and acidified). The mixed water and sediment samples were analyzed for settleable solids, suspended solids, dissolved solids, and turbidity. Field measurements for electrical conductivity (EC) and pH were taken during each sampling event. A one time sampling event of the water being discharged from the main drain pipes on November 17, 2006 was conducted for the purpose of analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine elemental concentrations of Al, Ba, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, K, Si, Na, Sr and Zn. Data from each of the six plots was compiled and analyzed to determine total volume of infiltrated water, the rate at which it was discharged, the lag time for storm events, the quality of the discharge, and the progression over time of the hydrologic mechanisms and water chemistry associated with each plot.

A Campbell Scientific weather station was also installed on site to measure precipitation, temperature, relative humidity, wind speed, wind direction, and solar radiation.

Soils Data. In the last week of July in 2005, 2006 and 2007, composite soil samples were collected in a systematic random fashion. Each plot was divided into sixteen square sampling subplots. The subplots were approximately 253 square meters and measured approximately sixteen meters on a side. Within each plot, eight subplots were randomly selected for sampling. Four sub-samples were taken with a sampling auger to a depth of approximately three cm from each subplot and mixed together to make a composite sample. Each year, a total of forty-eight composite samples were collected (eight from each of the six plots). The spoil samples were then analyzed for texture, percent soil moisture content, C (total and inorganic), and Mehlich III extractable soil P, K, Ca, Mg, and Zn. Ammonium, (NO_3^--N), cation exchange capacity (CEC), and exchangeable Ca, Mg, K and Na were also analyzed. Soil pH was determined in a slurry of 10 g of soil and 10 mL of water. EC was determined in a slurry of 10 g of soil and 30 mL of water using a Hanna EC meter. First year (2005) and third year soil samples (2007) were also subjected to ICP-MS analysis to determine elemental concentrations of Al, Ba, Ca, Cr, Co, Cu, Fe, Mg, Mn, Ni, K, Si, Na, Sr and Zn. Soil bulk density was measured in 2005, 2006, and 2007 with a nuclear density probe at 5, 15 and 30 cm.

Tree Performance Data and Natural Regeneration Analysis. Measurements of all the trees in each of the six loose-graded plots were conducted in the first week of August in 2005, 2006 and 2007. Tree species, height, and diameter at ground level were recorded and notes were taken in regards to plant health (vigor, dieback, herbivory). Percent survival in 2006 and 2007 was calculated by comparing the number of trees alive in those years with the number of trees measured in 2005. Tree volume index was calculated for each year by the formula: volume index = diameter^2 x height. In 2007, whole plant samples were taken of each tree species on each of the six plots to determine tree biomass and above-ground/below-ground ratio by spoil type.

An inventory and analysis of naturally regenerated species on all six plots was conducted in the second week of August 2006 and 2007 using the methodology developed by Farmer, et al (1981). Percent cover attributed to volunteer vegetation was calculated and native and non-native species were identified and categorized.

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Results

Soil

All of the soil, rock, plant, and water tests and measurements performed by this three-year study could not be reported in this paper due to space limitations. The following analyses and comparisons were selected from a wide array of data to best describe the field conditions and summarize tree performance, natural regeneration, and hydrological characteristics of the three loose-graded spoil types on the Bent Mountain surface mine.

Bulk density measurements are reported in Table 1. The average bulk density for all depths in all three types of spoil was 1.70 g cm^{-3} which is very close to the 1.67 g cm^{-3} average bulk density reported over a four year period in the loose-graded research plots at the University of Kentucky's Starfire reforestation research complex in Perry County, Kentucky (Angel et al., 2006). The data at Starfire definitively show that strike-off and loose-dump with no strike-off techniques improve seedling height and survival and that even a small amount of traffic (i.e., one or two passes per the strike-off method) may result in enough compaction to significantly reduce survival and growth in some species, such as yellow poplar *(Liriodendron tulipifera)* and white pine *(Pinus strobus)*. At Bent Mountain, the bulk density values between the three spoil types are very close and self compaction is apparent as the bulk density of all three spoil types increased with depth and time.

Table 1. Average dry soil bulk density in g cm^{-3} as measured in-situ by nuclear density probe at 5, 15 and 30 cm by spoil type in 2005, 2006 and 2007

SPOIL TYPE	5 cm	15 cm	30 cm
		2005	
BROWN	1.49	1.72	1.83
GRAY	1.52	1.73	1.83
MIXED	1.50	1.70	1.82
		2006	
BROWN	1.48	1.74	1.84
GRAY	1.48	1.74	1.86
MIXED	1.47	1.77	1.88
		2007	
BROWN	1.53	1.75	1.87
GRAY	1.57	1.77	1.89
MIXED	1.57	1.80	1.94

Although the average textural class of the three spoil types at Bent Mountain is the same, generally speaking there is a greater percentage of sand in the MIXED and GRAY spoil types and a larger percentage of fines (i.e. silt and clay) in the BROWN spoil types (Table 2). A slight shift in the average texture of each of the three spoil types was noticed from 2005 to 2007. The BROWN spoil appears to have increased in sand and decreased in clay, while both GRAY and MIXED exhibited a slight decrease in sand and increase in clay content. Between 2005 and 2007, GRAY actually changed textural classes from loamy sand to sandy loam. The directions of change in texture for all three spoil types suggest that they are moving towards a common point on the soil texture triangle. The average texture for all three types was sandy loam in the last two years of the experiment.

An explanation as to why the three spoil types are changing may be found in the results of tests performed on rock samples to determine their potential for weathering. Slake-durability and freeze-thaw tests indicated that the gray, un-weathered, sandstone rock was more durable and resistant to weathering than the brown, weathered sandstone rock and shale rock. Freeze-thaw tests showed that brown sandstone rock samples lost the most mass (64%) and gray sandstone rock samples lost the least mass (35%). Shale rock samples lost 45% of their mass. The tests also indicated that the brown rock samples turns into soil sized particles faster than the gray sandstone and shale rock. Approximately 58% of the initial mass of the brown sandstone was 2 mm or less after the freeze thaw test, compared to 29% for the gray and 17% for the shale.

This phenomenon has significant ramifications regarding the hydrologic characteristics of the BROWN spoil type compared to GRAY and MIXED. The water discharge from the BROWN spoil type was found to have significantly higher sediment levels than GRAY and MIXED. For example, the average suspended sediment in mg L^{-1} for BROWN, GRAY and MIXED were 1238, 381, and 215, respectively. This is believed to be associated with the presence of a greater amount of fines in the BROWN spoil type and a reflection of the propensity for the brown sandstone to weather faster. More fine fractions are available for water transport through and discharge from BROWN than in GRAY and MIXED. While the sediment levels in BROWN were elevated, these values displayed a notable decrease within approximately one year before reaching a more constant state. As for GRAY and MIXED, sediment levels remained steady over the study period.

Table 2. Average soil texture by spoil type in 2005, 2006 and 2007

SPOIL TYPE	AVERAGE % SAND	AVERAGE % SILT	AVERAGE % CLAY	AVERAGE TEXTURAL CLASS
		2005		
BROWN	60.8	27.2	12.0	Sandy loam
GRAY	77.8	15.7	6.5	Loamy sand
MIXED	73.9	18.4	7.7	Sandy loam
		2006		
BROWN	61.0	27.9	11.1	Sandy loam
GRAY	75.5	17.5	7.0	Sandy loam
MIXED	69.0	22.8	8.2	Sandy loam
		2007		
BROWN	64.8 (+ 4.0)	26.0 (- 1.2)	9.2 (- 2.8)	Sandy loam
GRAY	73.6 (- 4.2)	18.9 (+ 3.2)	7.5 (+ 1.0)	Sandy loam
MIXED	67.9 (- 6.0)	24.1 (+ 5.7)	8.0 (+ 0.3)	Sandy loam

The numbers in parentheses represent the gain or loss in percent from 2005 to 2007

The average pH of the BROWN spoil in 2005 was 6.03 (Fig. 4). By comparison, the pH of the GRAY and MIXED plots was much higher at 8.07 for GRAY and 8.33 for MIXED. There were significant differences in pH between BROWN and the other two spoil types in all three years. GRAY and MIXED were similar in pH. The pH in all three types appears to be rising over time with BROWN increasing from 6.03 to 6.59, GRAY increasing from 8.07 to 8.59, and MIXED increasing from 8.33 to 8.54. The four tree species planted on the three spoil types prefer a rooting medium that is slightly acidic and the initial pH of the BROWN spoil was suitable. In just three years the pH has risen considerably in all three spoil types and is approaching an alkaline toxicity in the GRAY and MIXED plots for these species

Table 3 shows the average CEC in cmol kg^{-1}, and Mehlich III extractable P, Ca, and Zn in mg kg^{-1} by spoil type in 2005, 2006 and 2007. In all three years of this experiment, BROWN revealed a higher CEC and P concentration than GRAY and MIXED. However, no significant differences were noted among the three spoil types with respect to the levels of Ca and Zn. All three spoil types had statistically similar levels of K, Mg, (NH_4^+-N), and (NO_3^--N) in 2007. The level of soil K in mg kg^{-1} in 2007 was 63.3 for the BROWN spoil, 62.4 for the GRAY spoil, and 68.7 for the MIXED spoil. The level of soil Mn in mg kg^{-1} in 2007 was 315.8 for the BROWN spoil, 336.0 for the GRAY spoil, and 288.4 for the MIXED spoil. The level of soil (NH_4^+-N) in mg kg^{-1} in 2007 was 6.5 for the BROWN spoil, 6.7 for the GRAY spoil, and 5.4 for the MIXED spoil. The level of soil (NO_3^--N) in mg kg^{-1} in 2007 was 2.3 for the BROWN spoil, 2.3 for the GRAY spoil, and 2.8 for the MIXED spoil. The physical and chemical soil characteristics that give the BROWN spoil type a predictably higher productivity potential than the GRAY and MIXED spoil are its finer soil texture, higher CEC and P concentration, and a pH that is more suitable for native hardwood trees.

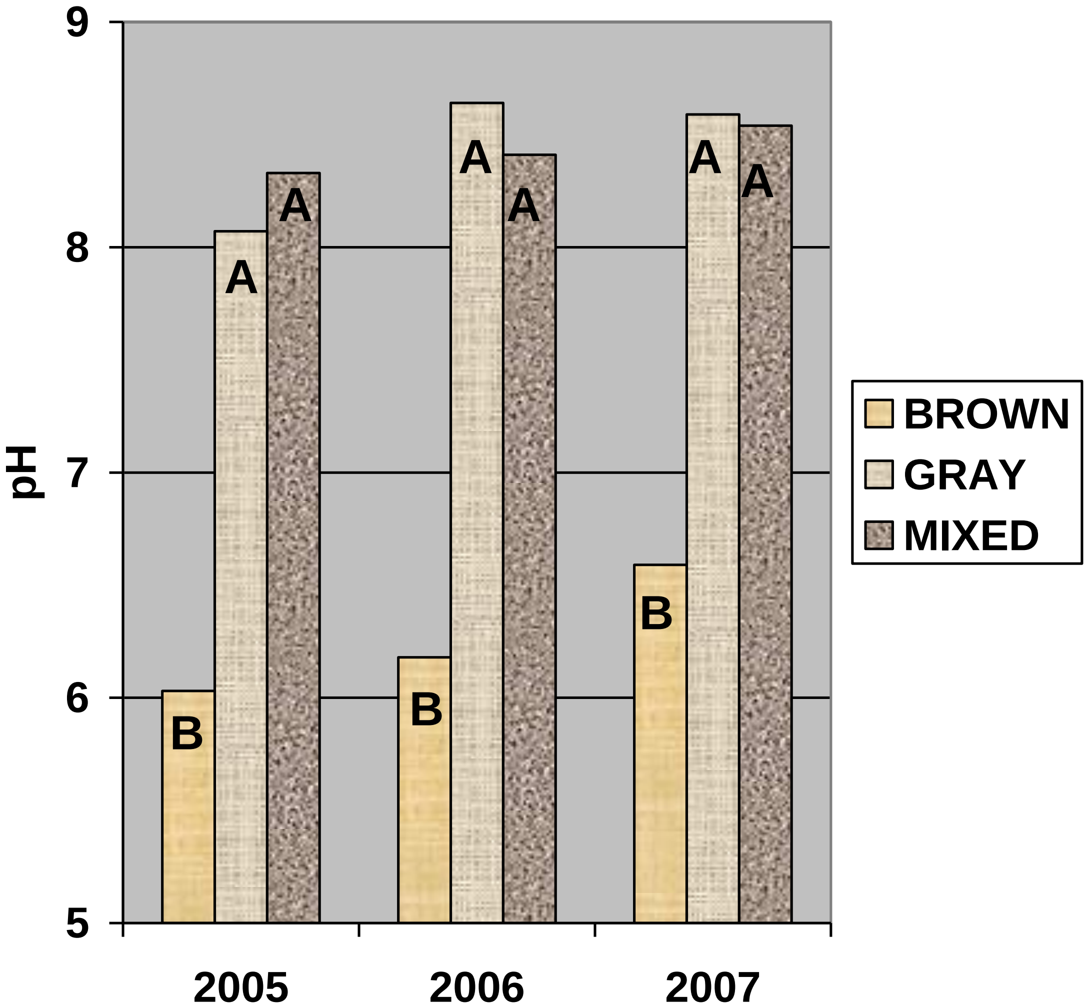

Figure 4. Average soil pH by spoil type in 2005, 2006, and 2007. Comparisons are made between spoil types in the same year (i.e., BROWN in 2005 vs. GRAY in 2005 vs. MIXED in 2005, etc). Spoil types with the same letter are not significantly different at $p = 0.05$ level.

Table 3. Average soil cation exchange capacity (CEC) in cmol kg^{-1}, and Mehlich III extractable soil phosphorus, calcium, and zinc in mg kg^{-1} by spoil type in 2005, 2006 and 2007. Comparisons are made between spoil types in the same year (i.e., BROWN in 2005 vs. GRAY in 2005 vs. MIXED in 2005, etc). Spoil types with the same letter are not significantly different at $p = 0.05$ level.

Spoil Type	CEC	Phosphorus	Calcium	Zinc
			2005	
BROWN	8.3 (a)	6.1 (a)	573 (a)	2.3 (a)
GRAY	2.5 (b)	2.6 (b)	1080 (a)	3.8 (a)
MIXED	3.4 (b)	0.5 (b)	1595 (a)	3.1 (a)
			2006	
BROWN	6.4 (a)	6.3 (a)	520 (a)	2.1 (a)
GRAY	2.7 (b)	1.9 (b)	1103 (a)	5.6 (a)
MIXED	3.7 (b)	1.6 (b)	1310 (a)	4.7 (a)
			2007	
BROWN	6.2 (a)	7.5 (a)	500 (a)	3.1 (a)
GRAY	3.0 (b)	2.5 (b)	941 (a)	5.8 (a)
MIXED	3.6 (b)	1.6 (b)	1307 (a)	4.4 (a)

Vegetation

Figure 5 shows the percent tree survival by spoil type for all species combined in 2006 and 2007. Observations indicate that by the third year after planting, the GRAY spoil had an overall higher average survival (88%) than the BROWN spoil (86%), and the MIXED spoil (81%). The increase in survival exhibited by the BROWN spoil type is attributed to the re-sprouting of tree seedlings that were recorded as dead during the previous year. In 2007, no significant differences were observed in the survival between the BROWN spoil and GRAY spoil for all species combined, but both BROWN and GRAY were significantly different than MIXED. Across all spoil types, white oak survived the best (mean = 97.7%), followed by green ash (mean = 96.3%), and then by red oak (mean = 76.7%). The species that had the least survival across all three spoil types after three years was yellow poplar (mean = 69.0%).

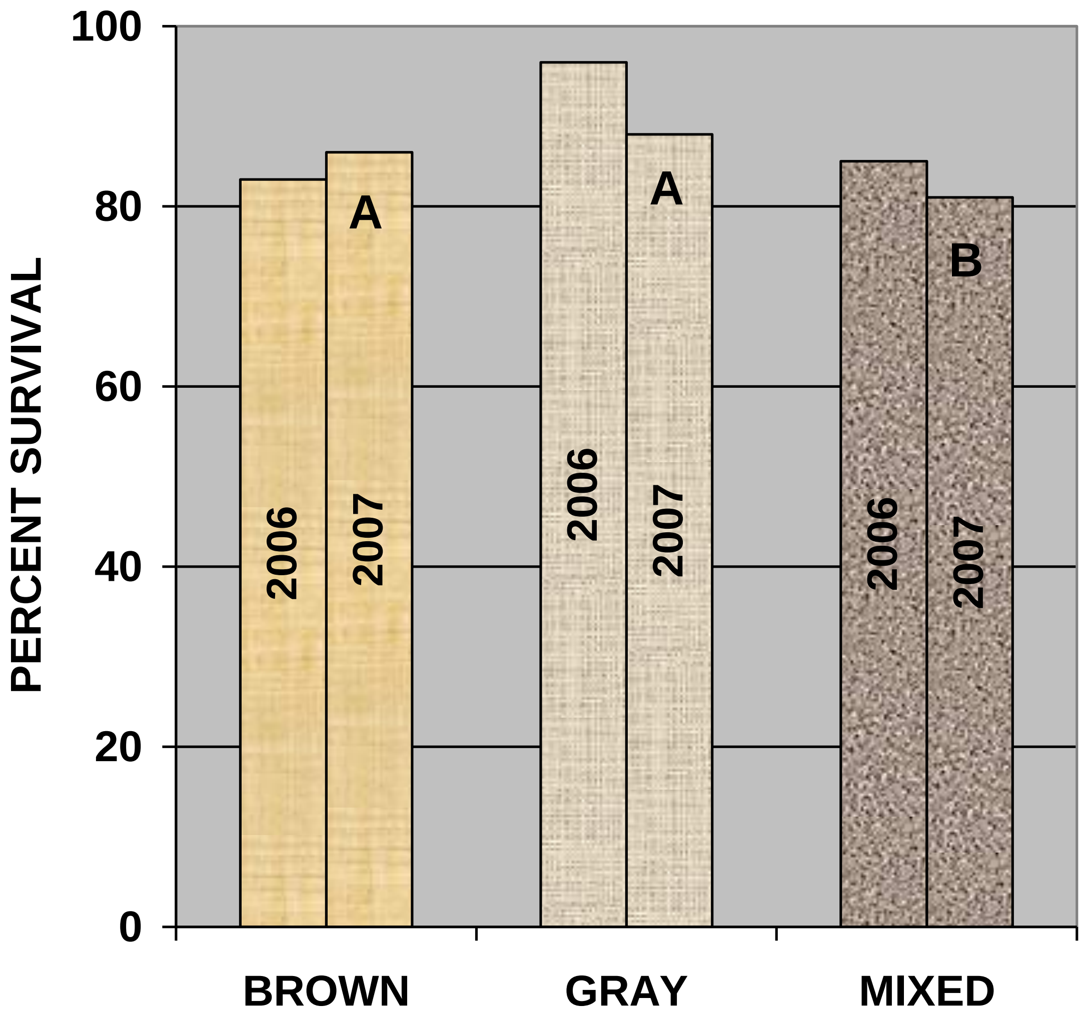

Figure 5. Percent survival of all trees by spoil type in 2006 and 2007. Spoil types with the same letter are not significantly different at $p = 0.05$ level.

Figure 6 shows the mean tree height in cm by spoil type for all species combined in 2005, 2006 and 2007. The BROWN spoil type had better average height than MIXED and MIXED had better height than GRAY in the last two years of growth. The average height in cm for BROWN was 65.8, MIXED was 44.7, and GRAY was 35.2. All three spoil types were significantly different in 2007. The bar for GRAY in 2007 shows a decrease in height from 2006 due to dieback and herbivory in that spoil type. The tree species that performed the best in terms of height growth on all three spoil types was yellow poplar.

The relative values for mean stem diameter at ground level for all species combined across the three spoil types reflected approximately the same trends observed for the relative values for mean height across the three spoil types. If we had created charts for mean stem diameter, the relative heights of the bars representing the three spoil types would have looked very similar to the three bars in the charts we created for mean tree height. The average diameter in mm for BROWN was 13.8, MIXED was 9.3, and GRAY was 7.7. Stem diameters between the three spoil types revealed similar statistical relationships as found for tree height.

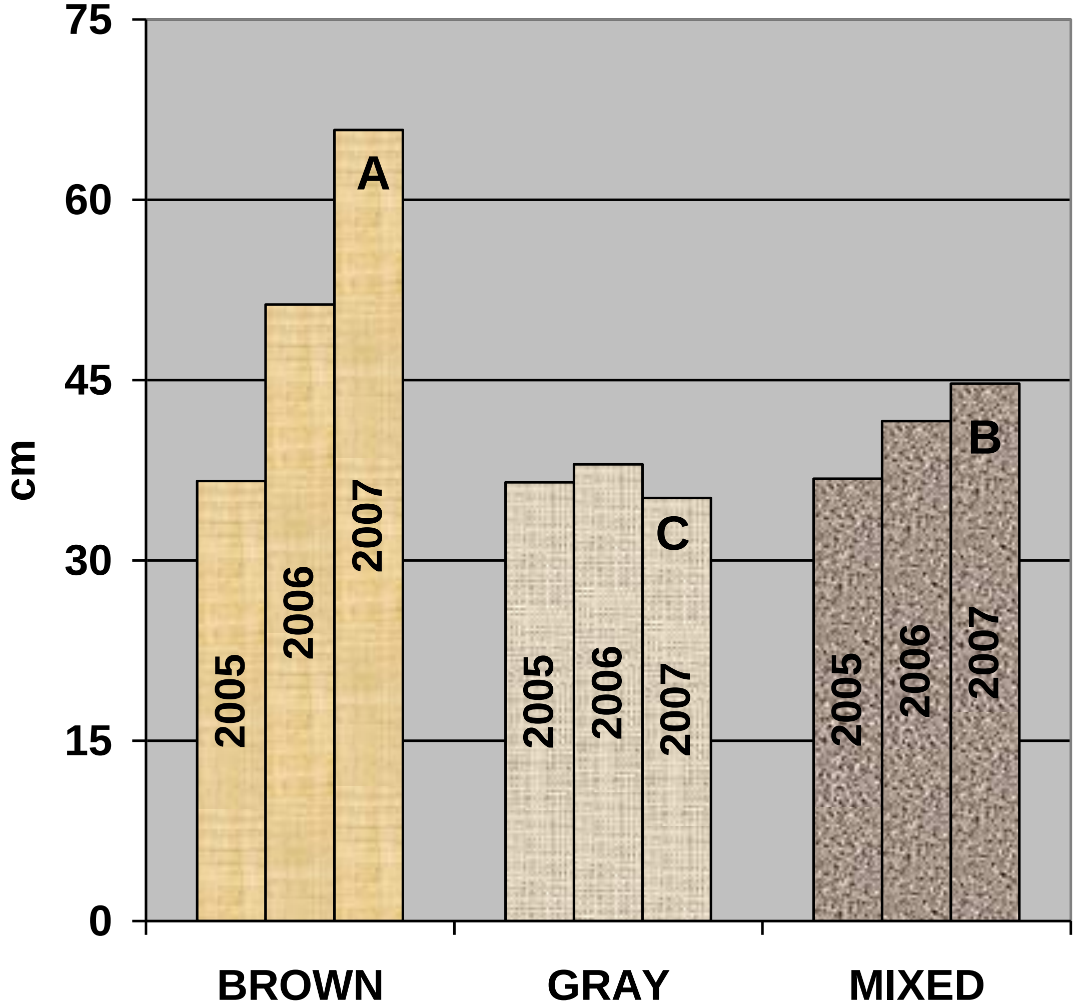

Figure 6. Average tree height (cm) of all trees by spoil type in 2005, 2006, and 2007. Spoil types with the same letter are not significantly different at p = 0.05 level.

Figure 7 shows the mean tree volume index in cm^3 by spoil type for all species combined in 2005, 2006 and 2007. The BROWN spoil type had better volume than MIXED and MIXED had better volume than GRAY in the last two years of growth. The average volume in cm^3 for BROWN, MIXED and GRAY was 235, 36, and 84, respectively. All three spoil types were significantly different in 2007. The tree species that performed the best in terms of tree volume index on all three spoil types was yellow poplar. By 2007 on the BROWN spoil type, yellow poplar grew over twice as much in volume than its closest planted tree competitor, green ash. Yellow poplar achieved the highest volume (mean = 466.3 cm^3), followed by green ash (mean = 228.8 cm^3), red oak (mean = 177.2 cm^3) and white oak (mean = 96.6 cm^3).

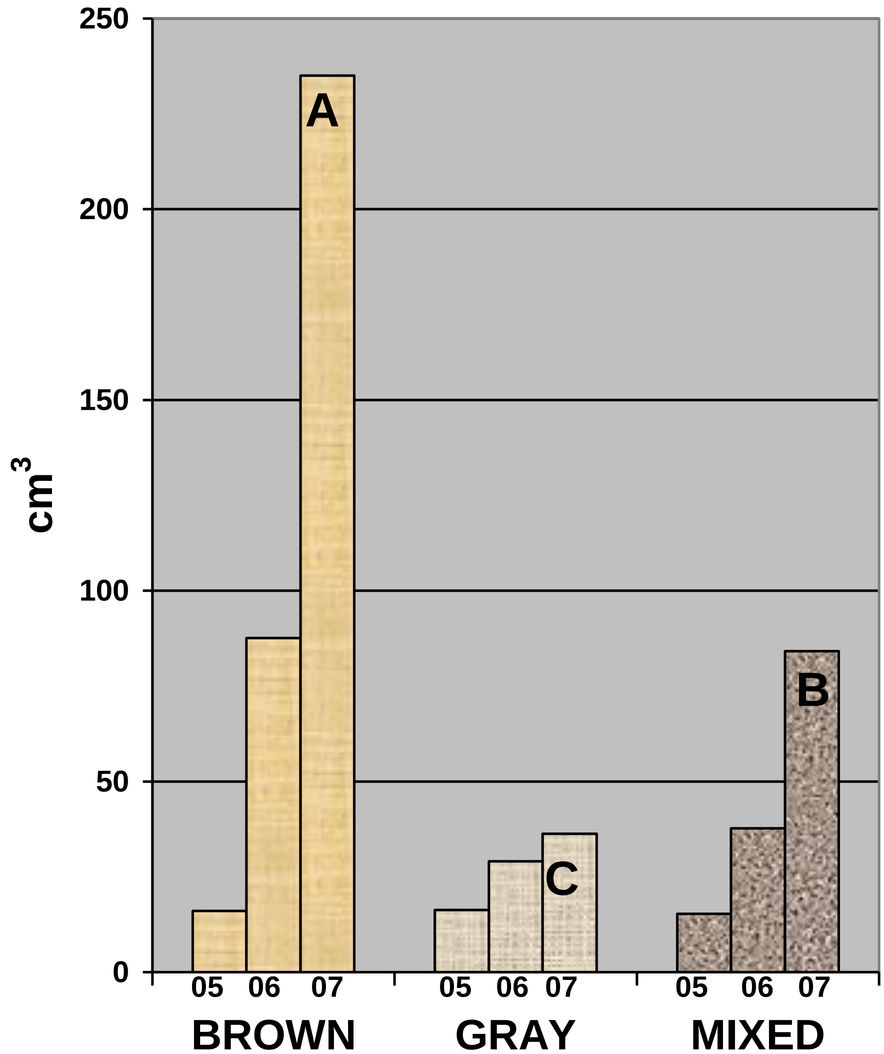

Figure 7. Average tree volume index (cm^3) of all trees by spoil type in 2005, 2006, and 2007. Spoil types with the same letter are not significantly different at $p = 0.05$ level.

Natural Regeneration

To avoid a competitive effect of an herbaceous cover on the trees, no grasses or legumes were seeded on the six plots. However, after the start of the second growing season, it was obvious that volunteer species were beginning to colonize two of the six plots. In August of 2006 and 2007, the Rennie-Farmer inventory system (Farmer et al., 1981) for evaluating revegetation on reclaimed surface mines was conducted on all six loose-graded research plots to provide an estimate of ground cover and to tabulate the composition of volunteer species. The sampling techniques for estimating ground cover provided by this methodology use a 90 percent statistical confidence interval (i.e., one-sided test with a 0.10 alpha error). To illustrate how natural succession is progressing across the three spoil types, the volunteer ground cover observed in the second year (2006) is described and compared with the ground cover observed in the third year (2007). After two growing seasons, the average percent ground cover of the volunteer vegetation on the three spoil types were found to be 42.3% on the BROWN spoil, 2.6% on the MIXED spoil, and less than 1% on the GRAY spoil. The volunteer vegetation on the whole experiment in the second year was composed of a total of 45 different species, with 40 of these found on the BROWN spoil, 6 on the GRAY spoil, and 21 on the MIXED spoil. On the BROWN spoil in 2006, the following three species made up the majority of the composition: *Tussilago farfara* (Coltsfoot), *Chenopodium album* (Lambsquarter), and *Phytolacca americana* (Pokeweed).

By the third growing season, the average percent ground cover of the volunteer vegetation on the three spoil types was found to be 66.4% on the BROWN spoil, 5.8% on the MIXED spoil, and 2.0% on the GRAY spoil. The BROWN spoil was found to contain 61 different species, whereas 12 different species were observed on the GRAY spoil and 35 different species were found on the MIXED spoil. In 2007, fifty-eight percent of the volunteers were native species. By 2007, the two most common volunteer species were coltsfoot and pokeweed, but lambsquarter was replaced with *Lespedeza cuneata* (Sericea lespedeza) (a non-native species) on the BROWN spoil. A list of the volunteer species observed in 2007 per spoil type and their contribution towards the volunteer ground cover is presented in Table 4. It is suspected that the primary source of the volunteer vegetation on the BROWN plots was the coarse woody debris and root propagules that were observed in the BROWN plots soon after installation. No coarse woody debris or root propagules were observed in the GRAY and MIXED plots. However, it is uncertain how much of the volunteer vegetation was in place when the spoil was end-dumped or how much was blown in by the wind or carried in by birds and other animals. Conversely, an inhospitable surface chemistry (high pH) may also have limited natural succession on the GRAY and MIXED plots.

Table 4. Naturally regenerated species by spoil type in 2007

Species	Common Name	Type†	Native‡	Spoil Type		
				BROWN	**GRAY**	**MIXED**
Acer negundo	Boxelder	T	Yes	+	-	-
Acer rubrum	Red maple	T	Yes	+	+	2%
Ageratina altissima	White snakeroot	H	Yes	<1%*	-	-
Ailanthus altissima	Tree of heaven	T	No	<1%	-	1%
Ambrosia artemisiifolia	Common ragweed	H	Yes	<1%	-	+
Andropogon virginicus	Broom-sedge	G	Yes	+	-	-
Betula lenta	Sweet birch	T	Yes	+	-	-
Cercis canadensis	Eastern redbud	T	Yes	+	-	-
Chenopodium album	Lambsquarter	H	No	<1%*	18%	+
Clematis virginiana	Virgin's-bower	V	Yes	+	-	-
Conyza canadensis	Horseweed	H	Yes	9%	5%	8%
Cornus florida	Flowering dogwood	T	Yes	+	-	-
Cyperus esculentus	Yellow nutsedge	G	Yes	<1%	-	-
Dactylis glomerata	Orchardgrass	G	No	+	-	+
Danthonia spicata	Poverty oat grass	G	Yes	<1%	-	+
Daucus carota	Wild carrot	H	No	1%	-	-
Digitaria sp.	Crabgrass	G	**	1%	-	<1%
Echinochloa crus-galli	Barnyard grass	G	No	<1%	-	5%
Elaeagnus umbellata	Autumn-olive	T	No	+	-	-
Epilobium coloratum	Purple-leaved willow-herb	H	Yes	+	-	-
Erechtites hieraciifolia	Fireweed	H	Yes	<1%	-	2%
Erigeron annuus	Annual fleabane	H	Yes	+	-	-
Festuca arundinacea	Kentucky 31 fescue	G	No	<1%	-	4%
Gnaphalium purpureum	Purple cudweed	H	Yes	+	-	-
Heuchera sp.	Alum-root	H	Yes	<1%	-	-
Ipomoea sp.	Morning glory	H	**	<1%	-	+
Lactuca saligna	Willow-leaf lettuce	H	No	1%	-	2%
Lactuca serriola	Prickly lettuce	H	No	<1%	-	3%
Lamiaceae	Mint family	**	**	+	-	+
Lespedeza cuneata	Sericea lespedeza	H	No	17%	19%	10%
Lespedeza striata	Kobe lespedeza	H	No	+	-	2%
Lotus corniculatus	Birdsfoot trefoil	H	No	7%	3%	+
Melilotus officinalis	Yellow sweetclover	H	No	+	-	+
Microstegium vimineum	Japanese stiltgrass	G	No	1%	-	1%
Oxalis sp.	Sorrel	H	**	<1%	-	3%
Panicum capillare	Witchgrass	G	Yes	<1%	-	-
Parthenocissus quinquefolia	Virginia creeper	V	Yes	<1%	+	1%
Paulownia tomentosa	Royal Paulownia	T	No	3%	+	2%
Phytolacca americana	Pokeweed	H	Yes	18%	15%	10%
Pinus virginiana	Virginia pine	T	Yes	+	-	1%
Plantago major	Common plantain	H	No	+	-	<1%
Platanus occidentalis	American sycamore	T	Yes	+	-	+
Polygonum caespitosum	Oriental ladysthumb	H	No	<1%	-	-
Populus deltoides	Eastern Cottonwood	T	Yes	+	-	-
Potentilla sp.	Cinquefoil	H	**	+	-	-
Robinia pseudoacacia	Black locust	T	Yes	3%	+	5%

Species	Common Name	Type†	Native‡	Spoil Type		
				BROWN	GRAY	MIXED
Rubus sp.	Blackberry	**	**	3%	+	1%
Salix nigra	Black willow	T	Yes	+	-	-
Sassafras albidum	Sassafras	T	Yes	+	-	-
Solanum ptycanthum	E. black nightshade	H	No	2%	-	<1%
Solidago gigantea	Smooth goldenrod	H	Yes	+	-	-
Sonchus asper	Prickly sow thistle	H	No	<1%	-	-
Symphyotrichum sp.	Aster	H	Yes	<1%	-	-
Trifolium pretense	Red clover	H	No	+	-	-
Trifolium repens	Ladino clover	H	No	+	-	<1%
Tussilago farfara	Coltsfoot	H	No	30%	41%	30%
Ulmus alata	Winged elm	T	Yes	+	-	<1%
Verbascum thapsus	Common mullein	H	No	2%	+	<1
Verbena urticifolia	White vervain	H	Yes	+	-	-
Viola sp.	Violet	H	Yes	<1%	-	-
Vitis sp.	Wild grape	V	Yes	<1%	-	1%
Total number of species	**61**	(Natives = 58% of total)		**61**	**12**	**35**
Percent cover				**66.4%**	**2.0%**	**5.8%**

†H = herbs; G = grass, sedge or rush; T = trees and shrubs; V = woody vine; + = species observed on indicated spoil type but not detected by Rennie-Farmer inventory system; - = species not observed on indicated spoil type. *Percentages reflect amount of naturally regenerated cover on indicated spoil type attributed to indicated species. ‡Native species status taken from Jones (2005). **Not enough information to determine status.

Hydrology

Several similarities between the three spoil types regarding the average pH of the water collected from the main drain pipes can be pointed out. The pH has increased for all three spoil types over time (Fig. 8). In the beginning of the experiment, all three spoil types were discharging water that was approximately pH 7.5 and by the end of the experiment, the pH for all three was approximately 8.5. Given that the average soil pH of the GRAY spoil type was 8.07 and the average soil pH of the MIXED spoil type was 8.33 in 2005 (Fig. 4), the alkalinity of the water discharge for those types is no surprise. However, with an average soil pH of 6.03, one would expect that the water discharging from the BROWN spoil type would be acidic in nature. Instead, the average pH has risen to approximately 8.5. One possible explanation is that carbonates in the BROWN spoil are weathering and contributing alkalinity to infiltrating water.

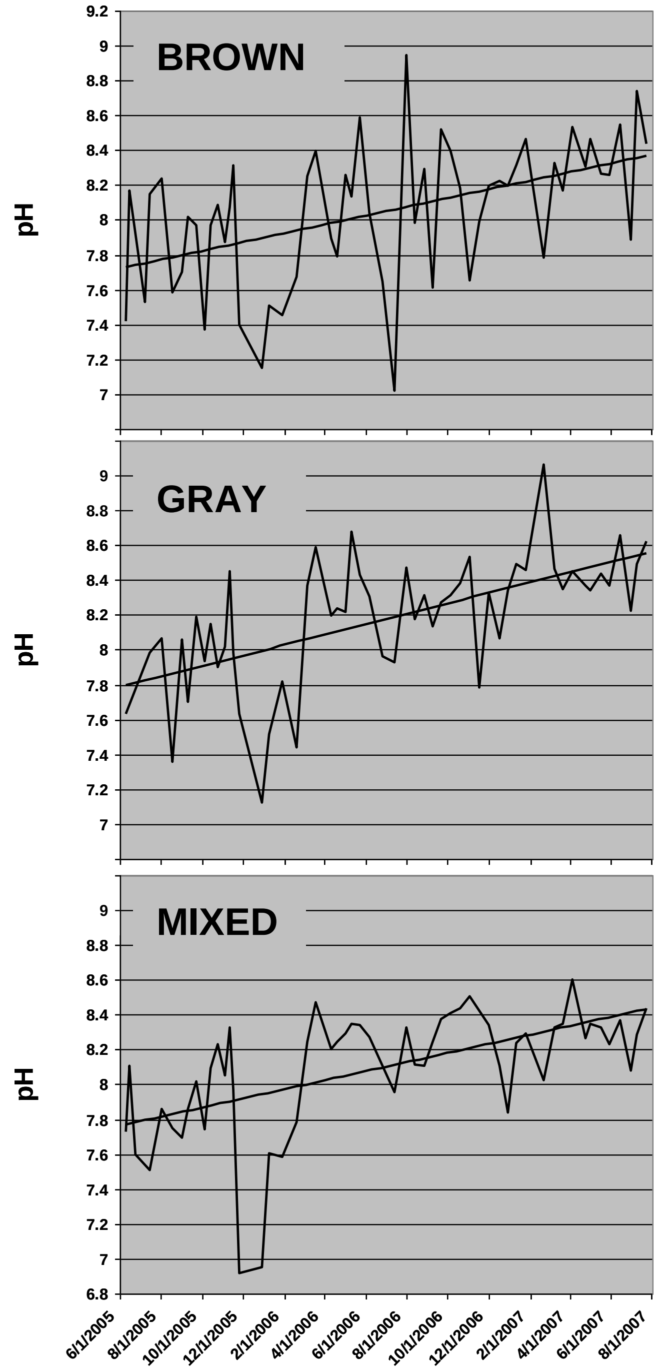

Figure 8. Average pH of water collected from main drain pipes by spoil type over time

Although this experiment looked at twenty elements in the water discharge from the three spoil types, this paper will focus on the two most prevalent elements (Ca and SO_4^{2-}) in the solution makeup. The average sulfate in mg L^{-1} of water collected from main drain pipes at the Bent Mountain surface mine showed a definite downward trend over time for both the GRAY and MIXED soil types (Fig. 9). Sulfate in both spoil types began at levels between 400 and 500 mg L^{-1} and fell to about 100 mg L^{-1} after three years. The two plots of the BROWN spoil type are somewhat of a puzzle. Significant differences were found to exist between the two BROWN plots (1 BR and 3 BR). Plot 3 BR demonstrated an upward trend for sulfate and 1 BR had a downward trend. Averaged together, the two BROWN plots demonstrate a slight upward trend for SO_4^{2-}.

Like SO_4^{2-}, average Ca concentrations from the main drain pipes at the Bent Mountain surface mine showed downward trends for all three spoil types (Fig. 10). The trend lines start at the beginning of the experiment between 125 and 150 mg L^{-1} for both the GRAY and MIXED spoil types. Despite a quick upward turn of the curve line at the end of the experiment starting around May of 2007, when an extreme drought affected the water samples, Ca is obviously on a downward trend.

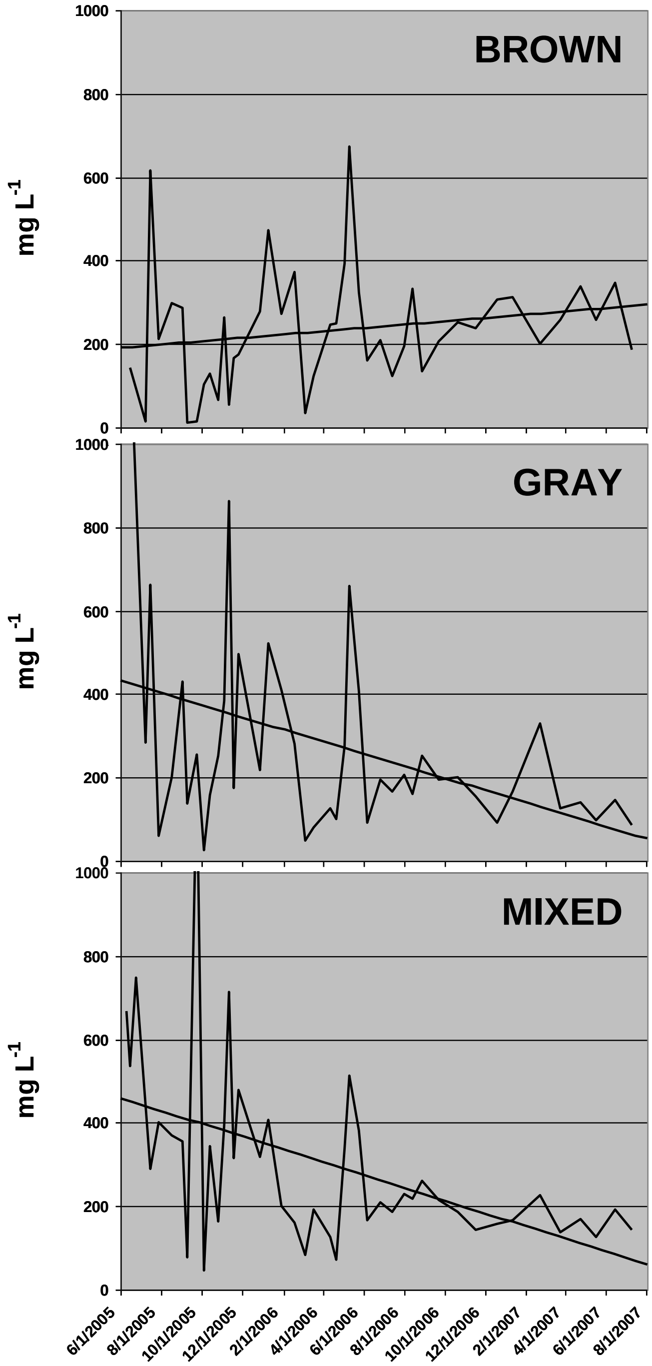

Figure 9. Average SO_4^{2-} in mg L^{-1} of water collected from main drain pipes by spoil type over time

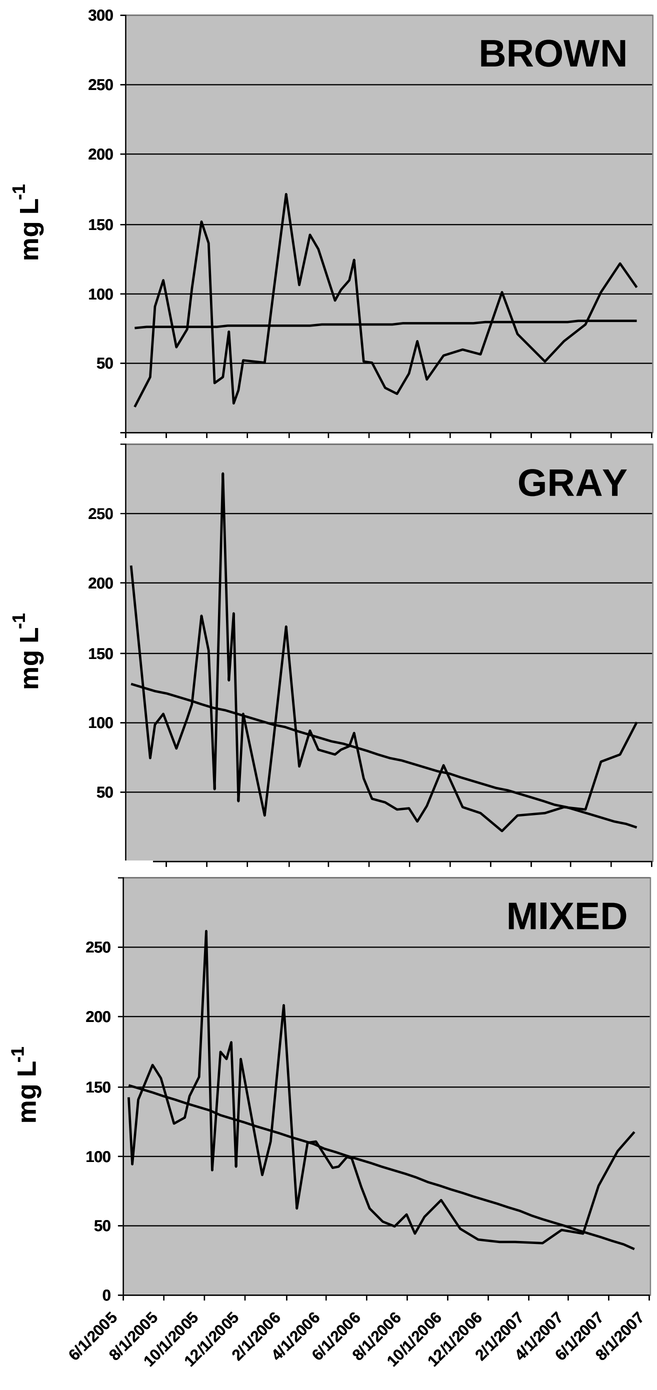

Figure 10. Average Ca in mg L^{-1} of water collected from main drain pipes by spoil type over time

Figure 11 shows the average EC in μS cm^{-1} of water collected from the main drainpipes by spoil type over time. The EC in the GRAY and MIXED spoil types fell and, in the BROWN spoil type, the average EC remained level. Researchers have reported on an apparent EC threshold of approximately 500 μS cm^{-1} for the benthic invertebrate community in headwater streams of Kentucky and other coal producing Appalachian states impacted by mine drainage (Pond, 2004; Pond and Passmore, 2007). In these studies a marked decline in presence of species from the Order Ephemeroptera were observed in streams draining surface mined areas and all had EC levels above 500 μS cm^{-1}. As such, the downward trend in the GRAY and MIXED spoil types from 1500 μS cm^{-1} and above to approximately 500 μS cm^{-1} over the duration of the study period is encouraging.

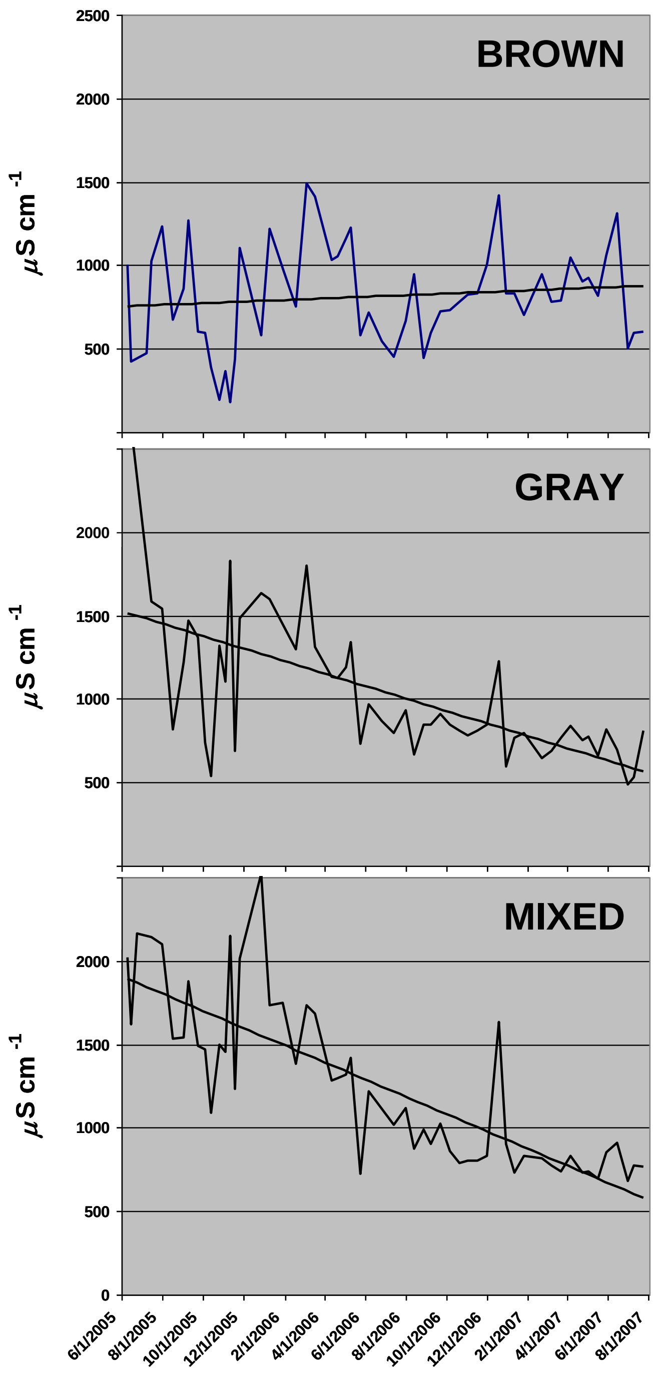

Figure 11. Average electrical conductivity in µS cm $^{-1}$ of water collected from main drain pipes by spoil type over time

A comparison of the hydrograph characteristics discharge volume, discharge duration, lag time and response time revealed no significant differences among the spoil types (Table 5). Peak discharge was significantly higher in BROWN than MIXED, while GRAY was not significantly different than the other spoil types.

Table 5. Means and standard deviations of hydrograph characteristics[1] and volume of stones[2] by spoil type. Spoil types with the same letter are not significantly different at p = 0.05 level.

PARAMETER	TREATMENT		
	BROWN	**GRAY**	**MIXED**
Discharge Volume (m^3)	9.2 ± 8.4 (a)	6.9 ± 6.6 (a)	13.2 ± 15.8 (a)
Peak Discharge ($m^3/s \times 10^{-4}$)	8.4 ± 6.6(a)	5.5 ± 3.7 (ab)	4.5 ± 3.8 (b)
Discharge Duration (days)	4.7 ± 3.3 (a)	6.0 ± 4.0 (a)	7.7 ± 5.2 (a)
Lag Time (days$\times 10^{-2}$)	7.5 ± 8.7 (a)	9.9 ± 17.8 (a)	15.6 ± 19.0 (a)
Response Time (days$\times 10^{-2}$)	6.2 ± 12.4 (a)	2.5 ± 2.9 (a)	5.8 ± 8.0 (a)
Volume of Stones (%)	4.8 ± 3.7 (c)	22.6 ± 0.9 (b)	42.6 ± 6.6 (a)

[1]data from main drain pipe discharges for largest rainfall events over the duration of the experiment
[2]following modified procedure by Eriksson and Holmgren (1996), representing the upper 40 cm of the soil profile.

These results indicate that spoil type was not a controlling factor with regards to the hydrologic response of loose-graded spoil. The similarity of key hydrograph parameters among the three treatments indicates that spoil type selection does not appear to be a critical component in controlling the hydrology of the experiment during the study period. Rather, the mechanism of spoil placement, whether via loose-graded techniques or compaction, appears to be the dominate factor with regards to hydrology. However, these results are preliminary in that the effect of mature trees on the hydrologic cycle is not yet readily apparent. An examination of the discharge volume did not reveal any significant temporal changes, which would be expected if the trees were beginning to exert a notable influence on the hydrologic budget. At the time of the study, the planted trees were relatively small in comparison to the size and depth of the test cells. As the trees mature, it is expected that they will influence the water budget and this percentage will decrease due to canopy closure, litter formation, and evapotranspiration. However, the degree of this influence is not yet known. Chang (2003) estimated that between 10 and 20% of annual precipitation is intercepted by the forest canopy, and Helvey and Patric (1965) estimated that 1 to 5% of annual precipitation is absorbed by the forest litter. Thus, any difference in future tree growth and survival between the treatments will likely exert an influence on the hydrology.

Notably, all three spoil types demonstrated low discharge volumes, long durations of discharge, and low peak discharge rates. On average, discharge occurred for approximately five to eight days following a rain event. Sloan and Moore (1984) noted that a key to sustaining baseflow conditions for streams located in forested catchments was the slow release of infiltrated waters from the soil matrix. Forested watersheds typically have little surface runoff. Rather, subsurface processes, such as interflow, dominate. Waters, which were infiltrated into the forest soils, are slowly released, thereby sustaining stream flows (Chang, 2003; Chen, 1988). Peak discharge rates, which were quite small, were typically between 4×10^{-4} and 7×10^{-4} m^3/s. The small peak discharges measured from the six plots are quite promising with respect to concerns regarding potential flooding from mine activities. Prior research efforts that demonstrated increases in peak flows from mining activities, such as those conducted by Bryan and Hewlett (1981) and Bonta et al. (1997), investigated watersheds that did not utilize the FRA. Such minimal peak discharges, as those measured from the six plots, are not expected to lead to increases in peak flows as compared to un-mined conditions. As with the volume of discharge, it is expected that peak flows will be reduced as the forest matures. Robinson et al. (1991) associated reductions in peak flows with forest growth, noting that the greatest rate of reduction occurred during the first ten years of afforestation.

Unlike the hydrograph characteristics, significant differences were noted with regards to the percent volume of stones between the three spoil types (Table 5). All three treatments were significantly different with the order of stoniness being MIXED, GRAY, and then BROWN. Interestingly, stoniness did not have an effect on the hydrograph characteristics with regards to spoil type. It was hypothesized that a greater level of stoniness would equate to an increased presence of megapores and macropores to the point of influencing hydrologic response, as the presence of such conduits would notably increase rainfall infiltration (note that no surface runoff has been observed) and hence interflow. However, the lack of treatment differences with respect to the measured hydrograph characteristics indicates that the level of stoniness is not as influential a factor as originally hypothesized, likely due the already large presence of megapores and macropores generated from the method of spoil placement. The low discharge volumes, low peak discharges, and long discharge durations indicated that a sizeable portion of the infiltrated rainfall was absorbed into the spoil medium to be slowly released over a period of days. Results pertaining to the spoil texture indicated a greater percentage of sand in the MIXED and GRAY treatments and a larger percentage of fines (i.e. silt and clay) in the BROWN treatment (Table 2). As with stone volume, the spoil texture differences among the treatments did not influence hydrograph characteristics.

Summary

Observations indicate that by the third year after planting, the GRAY spoil had an overall higher average survival (88%) than the BROWN spoil (86%), and the MIXED spoil (81%). In 2007, no significant differences were observed in the survival between the BROWN spoil and GRAY spoil for all species combined, but both BROWN and GRAY were significantly different than MIXED.

The BROWN spoil however, showed significantly more growth in height, diameter and tree volume index than the GRAY and MIXED spoil. The average height in cm for BROWN was 65.8, MIXED was 44.7, and GRAY was 35.2. The average volume in cm^3 for BROWN was 235, MIXED was 36, and GRAY was 84. The tree species that performed the best in terms of tree volume index on all three spoil types was yellow poplar. By 2007 on the BROWN spoil type, yellow poplar grew over twice as much in volume than its closest planted tree competitor, green ash. Yellow poplar achieved the highest volume (mean = 466.3 cm^3), followed by green ash (mean = 228.8 cm^3), and then by red oak (mean = 177.2 cm^3). The species that had the least volume on the BROWN spoil type after three years was white oak (mean = 96.6 cm^3).

Perhaps the more important observation that could be used at this time to predict the likelihood that a healthy and productive forest would eventually return on the three spoil types is the amount of ground cover established through natural regeneration. By the third growing season (2007), the average percent ground cover of the volunteer vegetation on the three spoil types was found to be 66.4% on the BROWN spoil, 5.8% on the MIXED spoil, and 2.0% on the GRAY spoil. The BROWN spoil was found to contain 61 different species, whereas 35 different species were observed on the MIXED spoil and 12 different species were found on the GRAY spoil. In 2007, fifty-eight percent of the volunteers were native species. Natural succession is occurring in regards to both the population of new species on the three spoil types, but also in regards to the change of species on the plots. For example, the majority of the volunteer vegetation on the BROWN spoil in 2006 was composed of three species: *Tussilago farfara*

(Coltsfoot), *Chenopodium album* (Lambsquarter), and *Phytolacca americana* (Pokeweed). By 2007, the two most common volunteer species were coltsfoot and pokeweed, but lambsquarter was replaced with *Lespedeza cuneata* (Sericea lespedeza) (a non-native species) on the BROWN spoil.

Spoil type did not affect the discharge volume, discharge duration, lag time or response time during the study period. Overall, measured discharge volumes were low (approximately 11 percent of rainfall), peak discharges were quite small (between 4×10^{-4} and 7×10^{-4} m^3/s), and the duration of discharge was long (on average five to eight days). Preliminary assessment of the hydrological response of the loose-dumped spoil indicated that characteristics of a forested watershed are evident, even at this early stage. The expectation is that interception and storage will increase as the forest matures, thereby further reducing discharge volumes and peak discharges.

Regulatory Implications

On March 2, 2007, the US Federal Register published a rule issued by OSMRE that is designed to remove an impediment to planting trees by revising the revegetation success standards for forestry post-mining land uses in Tennessee (Federal Register, 2007). The previous ground cover success standard in Tennessee for areas where trees were to be planted required 80% of a reclaimed mine site to be covered with ground cover vegetation before it is considered successfully revegetated. Similar heavy ground cover requirements currently exist in other coal states. Researchers have determined that revegetation levels of this magnitude are far too high to allow for successful tree survival and growth. They have also demonstrated that planting tree seedlings in loose or lightly graded material, including rough and rocky spoil with little or no groundcover, will produce survival and growth rates that are comparable to tree growth on un-mined lands. Because of the reduced grading and compaction, infiltration is also increased, while storm runoff and sedimentation are decreased. These factors will lead to reduced erosion. The Tennessee Federal Program has issued regulation 30 CFR 942.816 (f) (3), (4) and 942.817 (e) (3), (4), that effectively eliminates the former 80% ground cover standard for mine sites on areas where the FRA is implemented. The rule change in Tennessee requires a standard that is specifically geared to the unique characteristics of each mine site and to the proposed postmining land use. The new regulation calls for minimizing ground cover competition with woody plants by limiting ground cover to that necessary to control erosion and off-site sedimentation, and support the post mining land use on the mine site. Other state regulatory authorities in the Appalachian Region are considering new regulations that would change their groundcover standards for success to be similar to those of the Tennessee Federal Program. The findings of this study provide added support for OSMRE's change in the Tennessee revegetation regulations and added justification for reducing heavy ground cover requirements in other coal states. The observations made at Bent Mountain regarding the amount of volunteer vegetation imply that spoil type can be a unique characteristic of a mine site in the consideration of how much initial herbaceous ground cover to seed with planted tree seedlings. Less initial seeding may be required if it can be anticipated that a specific type of spoil material will be inherently receptive to volunteer vegetation. In addition to a minimum stocking density of 471 trees ha^{-1} (300 ac^{-1}), the general requirements for a final or Phase III bond release on a reclaimed surface mine in the state of Kentucky with an approved post mining land use of forest land is the expiration of the five year bond liability period and successfully achieving at least 80% ground cover (KDSMRE, 2003). The BROWN spoil type at Bent Mountain has achieved 66% ground cover from natural regeneration alone in three years without the seeding of any grasses or legumes or the application of a fertilizer or soil amendment. Further, with 86% survival in the third year of the experiment, the stocking rate is nearly twice that required by the Kentucky regulations.

Another regulatory implication of this study is that mine sites reclaimed with loose-graded spoil has hydrologic characteristics that may contribute to lesser downstream problems than mine sites with conventional grading characterized by compaction. Results from this study show that loose-graded spoil is characterized by low discharge volumes, small peak discharges, and long durations of discharge. Preliminary assessment of the hydrological response of the loose-dumped spoil indicated that characteristics of a forested watershed are evident, even at this early stage and the expectation is that interception and storage will increase as the forest on an FRA site matures, thereby further reducing discharge volumes and peak discharges. Considering the hydrologic characteristics related to discharge volumes and peak discharges alone, this study indicates that mine spoils need not be separated for reclamation as long as the spoil is placed in accordance with the loose-dumped techniques outlined in the FRA. From a water chemistry standpoint, the surface mine on Bent Mountain provides at least one example of where loose-dumped spoil has achieved the characteristics of a forested watershed within the short span of three years with the expectation of reducing discharge volumes and peak discharges as the forest on the experimental site matures.

The BROWN spoil type appears to have a higher productivity potential than GRAY and MIXED based on the chemical and physical characteristics of the three spoil types. This observation is reflected in the response of the planted trees which are growing better in regards to height, diameter and tree volume index on the BROWN spoil, followed by the MIXED spoil. The reality of the situation is that each mine site is geologically unique and many different possibilities exits for creating a very suitable tree rooting material. On most surface mine sites in Appalachia, there are usually several spoil materials or combinations of materials that are acceptable topsoil substitutes, some perhaps better than others, but many might be found to be good enough to support a healthy and productive forest. If all spoil types on a mine site have equal availability, and the attributes necessary for good tree growth are confirmed to exist in the BROWN, it should be selected over GRAY or MIXED. Conversely, a brown weathered sandstone with a manganese toxicity, such as exists in some isolated cases in West Virginia for example, may have to be rejected in favor of a GRAY or MIXED spoil type even if it has less availability. SMCRA has put forth stringent regulations which require the identification of acid- and toxic-forming materials which may adversely affect water quality, or be detrimental to vegetation or to public health and safety if not buried and/or treated. Such materials must be carefully buried or blended with nontoxic materials and/or treated to control the impact on surface and ground water, and to minimize adverse effects on plant growth and the approved post mining land use. In regards to growing trees on surface mines, the “premium” spoil type may just not be feasible, or even possible in all cases. It is for that reason that the first step of the FRA says to, “Create a suitable rooting medium…comprised of topsoil, weathered sandstone **and/or the best available material** (emphasis added)”

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