Soil water and solute movement in Montana strip mine spoils
by Franklin Brooks Arnold

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
A study was initiated in November, 1974 at the Peabody Big Sky Mine near Colstrip, Montana to determine soil water and solute movement in strip mine spoils. Three spoils treatments, consisting of topsoiled nonvegetated, topsoiled revegetated and nontopsoiled revegetated spoils, and a native range site were studied.

The testing and evaluation of an unsaturated soil water movement model showed the model to be applicable to soil water movement in both the mine spoils and native range.

Calculation of in situ soil water budgets indicated drainage was occurring from the spoils and native range. Both the water movement model and the in situ water budgets indicated that the quantities of soil water movement in the native range was approximately 1.5 times greater than in the spoils.

The lower amount of soil water movement in the spoils was attributed to bulk density, which was 54% higher than native range, and to higher contents of silt and clay than native range. Clay mineralogy analyses indicated that the dominant clay minerals in all treatments were non-expanding lattice clays, which would not greatly limit soil water movement due to expansion upon wetting.

Infiltration rates of the native range were 60-86% higher than those of the spoils. These differences were attributed to the effects of soil structure, vegetation and topsoiling techniques.

Saturated hydraulic conductivity of the native range was 3.5 times greater than that of the spoils treatments. The higher hydraulic conductivity of the native range was attributed to textural differences between the native range and spoils treatments.

No definite trends in solute movement were shown due to the short time span of this study. With the exception of potassium and NCL-N, the solute concentrations of the spoils were not, in general, different from the native range. The spoils contained lower potassium and higher NO3-N concentrations than present in the native range. Exchangeable sodium percentages (ESP) and sodium adsorption ratio (SAR) indicated no sodium problems were present in the spoils and native range.

The higher quantities of soil water movement in the native range compared to the spoils indicate that greater amounts of solute movement into the groundwater may occur from the native range than from the spoils.

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STRIP MINE SPOILS

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ABSTRACT

A study was initiated in November, 1974 at the Peabody Big Sky Mine near Colstrip, Montana to determine soil water and solute movement in strip mine spoils. Three spoils treatments, consisting of topsoiled nonvegetated, topsoiled revegetated and nontopsoiled revegetated spoils, and a native range site were studied.

The testing and evaluation of an unsaturated soil water movement model showed the model to be applicable to soil water movement in both the mine spoils and native range.

Calculation of *in situ* soil water budgets indicated drainage was occurring from the spoils and native range. Both the water movement model and the *in situ* water budgets indicated that the quantities of soil water movement in the native range was approximately 1.5 times greater than in the spoils.

The lower amount of soil water movement in the spoils was attributed to bulk density, which was 54% higher than native range, and to higher contents of silt and clay than native range. Clay mineralogy analyses indicated that the dominant clay minerals in all treatments were non-expanding lattice clays, which would not greatly limit soil water movement due to expansion upon wetting.

Infiltration rates of the native range were 60-86% higher than those of the spoils. These differences were attributed to the effects of soil structure, vegetation and topsoiling techniques.

Saturated hydraulic conductivity of the native range was 3.5 times greater than that of the spoils treatments. The higher hydraulic conductivity of the native range was attributed to textural differences between the native range and spoils treatments.

No definite trends in solute movement were shown due to the short time span of this study. With the exception of potassium and NO_3-N, the solute concentrations of the spoils were not, in general, different from the native range. The spoils contained lower potassium and higher NO_3-N concentrations than present in the native range. Exchangeable sodium percentages (ESP) and sodium adsorption ratio (SAR) indicated no sodium problems were present in the spoils and native range.

The higher quantities of soil water movement in the native range compared to the spoils indicate that greater amounts of solute movement into the groundwater may occur from the native range than from the spoils.

INTRODUCTION

An area of major concern with respect to surface strip mining of coal in the Western United States is the effect of mining on soil water and solute movement. This study was initiated in order to determine soil water and solute movement characteristics in strip mine spoils. Three different spoil treatments and a native range site were compared. The spoil treatments represented a range of geologic material and reclamation techniques. Water and solute movement characteristics obtained from these spoils treatments should be representative of spoils material present in the area surrounding Colstrip, Montana.

A study of native range was necessary in order to obtain information regarding soil water and solute movement characteristics in land undisturbed by mining activities. Results obtained from the native range site served as a basis of comparison for information obtained from the spoil areas. The native range site was chosen to be as representative as possible of mineable rangeland in the Colstrip area.

The objectives of this study were to:

1) test and evaluate an unsaturated soil water movement model and apply the model to the mine spoils and native range;
2) determine the in situ water budget in spoils and native range in order to determine quantities and rates of soil water movement on a hydrologic year basis;
3) measure various physical characteristics in spoils and adjacent native range soils in order to explain differences in water movement which existed and to determine the effects of mining on these physical characteristics; and
4) determine solute concentrations and translocation occuring in spoils and native range soils.

This study was conducted at the Peabody Big Sky Mine near Colstrip, Montana.

LITERATURE REVIEW

Coalfields in 8 western states - Montana, Wyoming, North Dakota, South Dakota, Utah, Colorado, New Mexico and Arizona - underlie in excess of 100 million acres and contain more than two trillion tons of coal. The coal deposits in Montana alone contain 13% of the total reserve in the United States (National Academy of Sciences, 1974). The area underlain by coal bearing rocks in Montana is 51,300 square miles which is 35% of the total area of the state. The projected area of land in Montana that will be disturbed by surface coal mining by the year 2000 is in excess of 42,000 acres (Copeland and Packer, 1972). It is important that sound reclamation techniques be established for these areas and that a thorough knowledge of the effects of mining on both the disturbed areas and surrounding areas is obtained.

Thus far, the major portion of reclamation research has been concerned with revegetation of strip mined areas. Emphasis has not been on the effects of mining on soil properties such as soil water and solute movement. Information on these factors is important since any changes in soil water and solute movement could result in changes in the overall hydrologic system and groundwater quality of the area.

Verma and Thames (1975) have done some preliminary work on soil moisture in strip mine spoils in Arizona. Using a neutron probe, it was shown that partial recharge of the soil water occurred during the snowmelt period. However, soil moisture remained near the permanent wilting point to a depth of 200 cm during most of the period from September through May. No statements were made as to the occurrence or amount of drainage from the spoils.

Sindelar, et al (1973) conducted a study which involved the effects of three different spoils surface manipulation treatments on soil moisture and revegetation at the Rosebud mine near Colstrip, Montana. Using soil moisture blocks, it was shown that the soil water potential at the surface remained near 15 atmospheres from May through November for all treatments. At 30 and 60 cm depths, soil water potential remained above 15 atmospheres for most of the period while the soil water potential remained significantly above 15 atmospheres for the entire period at a depth of 120 cm. The difference between these results and those of Verma and Thames was probably due to Montana's higher annual precipitation and lower mean annual temperature. Also, the surface manipulation treatments used tend to retain surface runoff allowing the water to enter the soil.

In stripping operations, the overburden is usually deposited in long, roughly parallel ridges or banks. These banks are then graded or leveled by moving the tops of the ridges into the valleys resulting in near level or rolling topography.

Curtis (1973) measured moisture and density relations of graded strip mine spoils in Kentucky. The study area was divided into four blocks running parallel to former ridges which had been leveled. Two of the blocks were scarified by traversing the plots with a road grader equipped with ripper teeth. His results showed approximately 20% higher bulk densities at the 30 to 270 cm depths in the leveled ridges as compared to the spoils material which had been moved into the valleys. The moisture contents (g/g) were significantly higher in the valleys than in the leveled ridges. It was assumed that the ridges became compacted in two ways. First, the weight of the stacked spoils resulted in compaction and second, the heavy equipment used in the grading operations resulted in compaction of the spoils. It was also found that scarification had little effect in reducing the surface density. Over the winter, however, all four plots showed a significant decrease in surface density which was attributed to frost action during the winter. Thus, in areas where frost action is encountered, such as Montana, significant reductions in surface densities could occur.

Limstrom (1960) did a study on strip mine spoils in Ohio. The infiltration rates on ungraded spoils banks and on adjacent graded banks were determined. The ungraded banks had infiltration rates of 10 cm/hr as compared to 1.5 cm/hr on the graded banks. Evidently the resurfacing of mine spoils can result in compaction and affect water movement in these spoils.

Resistance to compaction is determined by particle size distribution and composition of the particles in a soil. Compaction is most easily achieved with soils consisting of different particle sizes where smaller particles can be forced into voids between larger particles (Warkentin, 1971). This results in a decrease in pore volume and therefore a higher bulk density.

The clay fraction of soils is generally considered as being the particle size class which is the major limiting factor to water movement. However, the silt fraction can also have a great effect on soil water movement. Diebold (1954) related silt content to bulk density and permeability. He studied 215 medium textured soils in the southwestern United States. It was found that soils with greater than 40% silt had higher bulk densities than the soils with less than this amount of silt. For all soils, the permeability decreased with increasing bulk density. For soils with the same bulk density, the permeabilities for soils with less than 40% silt were several times higher than those for the soils with higher silt contents. Also, for soils with low bulk densities (non-compacted), the infiltration rates were 1.5 times greater for soils with less than 40% silt. At bulk densities approaching 1.5 g/cm^3, the infiltration rates were twice as high for the lower silt content soils. Diebold speculated that the silt acts as a clogging material resulting in lower permeability and infiltration rates.

Upon compaction, at least three changes in porosity will occur:

(1) the total porosity is reduced; (2) the total number and relative volume of small pores increase; and (3) the total number and relative volume of larger pores decreases (Hill and Sumner, 1967). Due to these changes in porosity, water transmission in compacted soils is greatly affected. The volume of water flowing through a tube or pore per unit of time is proportional to the fourth power of the radius. Halving the size of the tube decreases volume of flow by a factor of 16. Therefore, decreasing the large voids through compaction has a large effect in decreasing water transmission in saturated soils. It has been found that the logarithm of the saturated hydraulic conductivity decreases linearly as void ratio increases (Warkentin, 1971).

The relationship between porosity and unsaturated hydraulic conductivity is less straightforward. The large voids are filled with air and do not contribute to water flow, so there is less decrease in conductivity with decreasing porosity.

Jackson (1963) studied the effects of soil texture and compaction on unsaturated hydraulic conductivity. He found that the hydraulic conductivity decreased with increasing compaction for a soil with high clay content but the hydraulic conductivity changed little with compaction for a coarse grained soil.

Waldron, et al. (1970) examined the effect of compaction on the unsaturated hydraulic conductivity of a Yolo loam. The hydraulic conductivities were determined under isotropic confining pressures of

0.1 to 3.2 Kg/cm^2. For a decrease in porosity of 0.52 to 0.40 the hydraulic conductivity decreased from $2x10^{-4}$ cm/sec to $1.5x10^{-6}$ cm/sec. This decrease in porosity is equivalent to an increase in bulk density of 1.33 to 1.60 g/cm^3.

Gumbs and Warkentin (1972) worked with a swelling clay soil packed into columns. It was found that small increases in bulk density over the range of 1.10 to 1.25 g/cm^3 markedly decreased the rate of unsaturated water flow in the sample.

The preceding discussion of the effects of compaction on water movement was limited to soils since no information could be located on water movement in mine spoils. However, the effects of compaction which were discussed would affect mine spoils in the same manner.

More extensive research is needed in the area of soil water and solute movement in mine spoils. This information is needed not only to determine reclamation procedures and future use of the mine spoils but also to determine the effects of strip mining on surrounding areas. Any changes in soil water and solute movement characteristics could conceivably affect the water supplies of nearby homesites and the quality of existing range and cropland near the mining areas.

METHODS AND MATERIALS

Site Description and Design

The study area was located on the Peabody Big Sky Mine in southeastern Montana. The four treatments were topsoiled nonvegetated spoils, topsoiled revegetated spoils, nontopsoiled revegetated spoils and native range. The treatment plots all had approximately the same slope and aspect. Each treatment contained three replications measuring 10x10 meters for a total size of 10x30 meters for each treatment. The field site and design is shown in Figure 1.

The topsoiled nonvegetated site was mined in February, 1974. The site was reshaped and topsoiled during the spring of 1974. The site is shown in Figure 2.

The topsoiled revegetated site was mined in October, 1970 and reshaped and topsoiled in the winter of 1972. This site was seeded the following spring at 25 lbs/acre to a mixture of crested wheatgrass, intermediate wheatgrass, western wheatgrass, smooth brome, alfalfa, yellow sweetclover, white sweetclover and green needlegrass. The topsoiled revegetated spoils site is shown in Figure 3.

Mining activity began on the nontopsoiled revegetated site in September, 1970. This site was recontoured several times, the last of which was in the winter of 1974. The site was seeded the following spring to the same mixture and rate as for the topsoiled revegetated spoils area. The resulting stand of vegetation for this site was poor. The nontopsoiled revegetated site is shown in Figure 4.

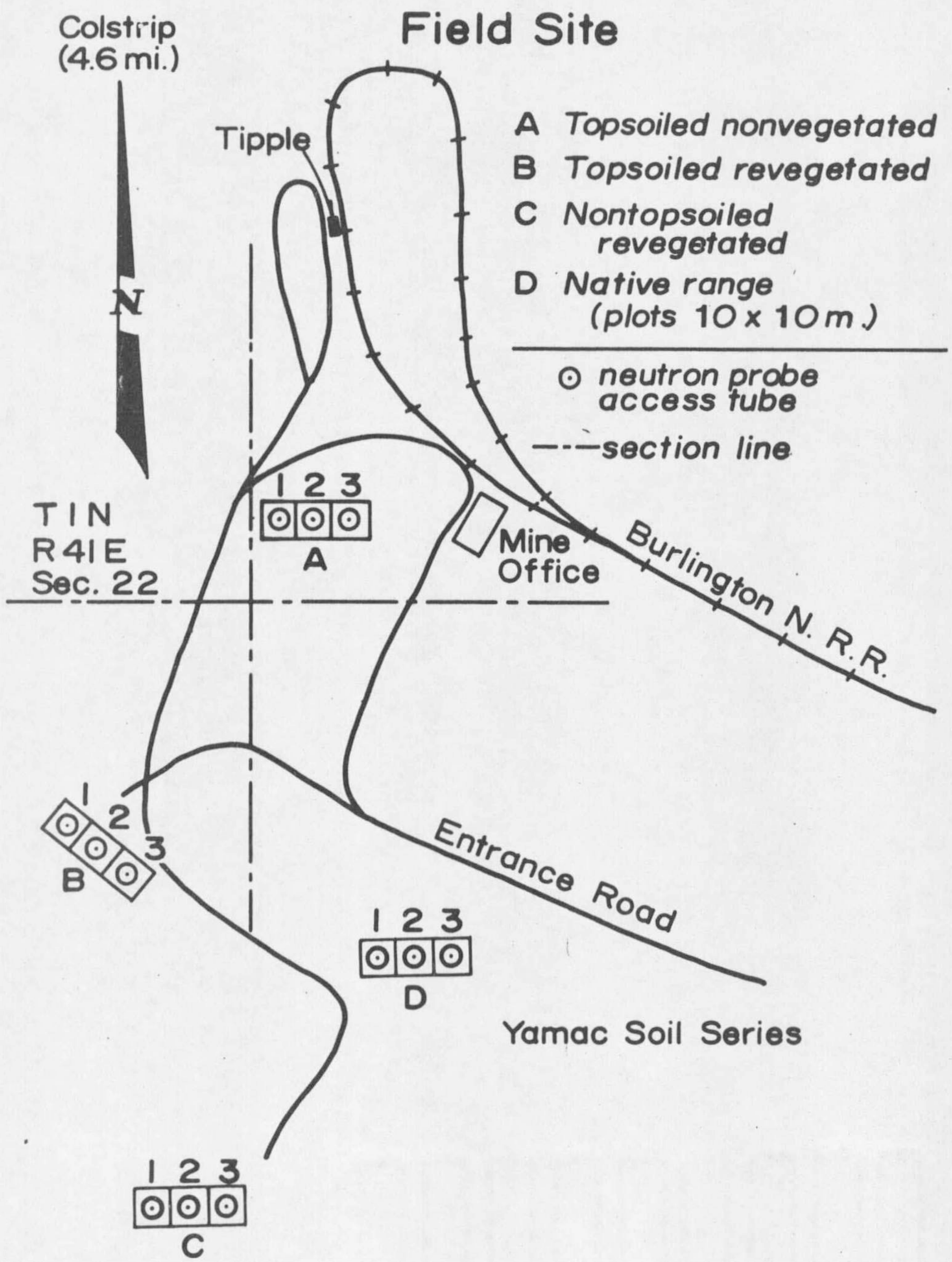

Figure 1. Experimental plot design of the study area at the Peabody Big Sky Mine.