SOIL PROPERTIES OF SURFACE MINED LANDS AND THEIR HYDROLOGIC IMPLICATIONS

By

DAVID MARK SILBURN

Bachelor of Engineering

Darling Downs Institute of

Advanced Education

Toowoomba, Queensland

Australia

1980

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1982

SOIL PROPERTIES OF SURFACE MINED
LANDS AND THEIR HYDROLOGIC
IMPLICATIONS

Thesis Approved:

Frank R. Crow
Thesis Adviser

John F. Stone

C. T. Haan

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express gratitude and appreciation to his major adviser Professor Frank R. Crow for guidance and encouragement throughout the study and in preparation of this thesis. Acknowledgments are also due to the faculty and staff of the Agricultural Engineering Department for their support and friendship.

Special thanks are expresed to Dr. John F. Stone of the Agronomy Department for constant interest and advise and to Dr. Arlin Nicks of the USDA Agricultural Research Service for his encouragement and assistance. Appreciation is expressed to Dr. C. T. Haan, Head of the Agricultural Engineering Department, and Dr. Peter D. Bloome, Professor of Agricultural Engineering, for their encouragement to enter into the graduate program.

Geri Hart, student assistant, is acknowledged for her careful work in the laboratory.

Thanks are also due to Mrs. Laura Johnson for her patience and care in typing this thesis.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

The Problem

Surface mining is a major source of necessary minerals and raw materials. At the same time, surface mining disturbs large areas of land, with potential long term adverse consequences. Adequate reclamation is needed to prevent loss of productive land and to maintain the quality of surface and ground water resources.

A total of 13,440 ha of land had been disturbed by surface mining in eastern Oklahoma by 1974 (Friedman, 1974). About one third of this area was mined in the six years prior to 1974. Coal production for the years 1977 to 1979 was about 5 million tons per year, more than twice the production level of 1974 (Oklahoma Department of Mines, 1979). Thus, each year as much as 1200 ha of land in Oklahoma may be disturbed by surface mining.

The introduction of the Surface Mining Control and Reclamation Act of 1977, PL 95-87 (SMCRA, 1977) specifically required that surface mine operators and regulatory authorities investigate and control the hydrologic consequences of mining and reclamation. The mine operator and the state regulatory authority must assess which reclamation practices will be sufficient to (a) insure conditions capable of supporting premining land use or better, and (b) minimize disturbance to the prevailing hydrologic balance at an acceptable cost.

To date there has been very little research into any aspect of surface mine reclamation and hydrology in Oklahoma. The physical properties of spoils and reclaimed soils are not documented and it is difficult to determine a minimum acceptable level of reclamation. The premined or baseline conditions with which a comparison is to be made are also not well known.

Objectives

Increased surface mine production and environmental and regulatory factors call for improved knowledge of the soil conditions on mined areas and the hydrologic consequences of mining and reclamation.

The specific objectives of this research were:

1. to determine the physical properties of minesoils resulting from representative reclamation practices and the physical properties of the baseline or premined soils.

2. to assess by hydrologic modeling, the effects of the changes in soil properties on the hydrologic balance of the mined area.

Scope of Study

A study was made of the soil conditions on three surface mined areas in eastern Oklahoma. Each included a premined and a reclaimed study area. The reclaimed study areas included two areas of topsoiled shale spoil (minimum regulatory requirement) and one area of topsoil over heavy clay spoil over shale spoil. Additionally, samples were taken from a non-topsoiled graded shale spoil area representing older reclamation results.

Undisturbed soil core samples were taken through the profile at three to five sites on each of the seven study areas. Properties measured were bulk density, moisture retention at saturation and at 0.1 and 15 bar suction, texture and percent coarse fragments. Organic matter content, sodium absorption ratio (SAR), pH and salinity levels were measured on composite samples from selected depths. Saturated hydraulic conductivity was measured on undisturbed soil cores from one of the premined areas and two of the reclaimed areas.

Analysis of variance and Duncans multiple range test was used to examine significant differences between premined and reclaimed soil properties. The effect of changes in soil properties on the hydrologic balance was examined using a modeling approach. The physical properties data was used to compile inputs for the CREAMS option two hydrology model. The model was run for each of the premined and reclaimed profiles using 13 years of rainfall and evaporative demand. The depths of simulated runoff from each profile were compared.

CHAPTER II

LITERATURE REVIEW

In the surface mining procedure, the overburden strata immediately above the coal tends to be placed on top of the spoil banks. Because of the way in which the overburden material is removed, dumped and graded, some mixing occurs. Thus the surface spoil* usually consists of a large proportion of material from strata nearest to the coal seam, augmented by varying amounts of materials from upper level strata. During the mining operation, overburden rock is shattered by blasting, and as a result many soil size fines essentially consist of pulverized unweathered rock materials.

Surface Mined Lands in Oklahoma

The Oklahoma coal fields lie in the Western Interior Coal Province, which also includes portions of Iowa,

---

*The term "spoil" refers to the mixture of overburden material resulting from surface mining and onto which soil may or may not be spread to create the minesoil. The term "minesoil" refers to the materials on the surface of a mined area after reclamation in which plants will be expected to grow and soil genesis will occur. It may include spoil, replaced topsoil and subsoil.

Nebraska, Missouri, Kansas and Arkansas. The 30 or more different coal seams recognized in the Western Interior Coal Province were formed largely by sedimentation during the Pennsylvanian period (Rogers, 1951). The overburden strata associated with each coal seam follow the same cycle of rock types although usually one or more rock type is missing. From bottom to top the strata are coal, black shale, gray shales, limestone and calcareous shale (Rogers, 1961). The grey shales are usually the thickest strata, by far. Above the surface mineable coal seams in Oklahoma, the gray shales, or limestone if present, are usually overlain by two to four meters of clay alluvium on which the soil solum is formed.

The soils and overburden materials are usually acid (pH 3.2 to 7.0) although any of the rock types in a particular overburden may be neutral or slightly alkaline. At the ten or more surface mines visited by the author in the northern half of the Oklahoma coal fields, the surface spoil was consistently dominated by gray shale materials. At one site, large limestone rocks were also present on the surface.

In general, spoils in Oklahoma could be considered similar to shaly spoils found in the Appalachian region although spoil in these areas may also contain sandstone and siltstone (Ward et al., 1981; Pedersen et al., 1980; Barnhisel and Massey, 1969).

Physical Properties of Minesoils

Introduction

Spoil materials on surface mined areas usually exhibit high bulk densities, a high proportion of coarse fragments and lower water holding capacities than natural soils. Permeability is often lower than is expected for material containing a large proportion of coarse fragments and is low to very low if the spoil has a well graded distribution of particle sizes. Spoils are also typically low in organic matter and have weakly developed structure. Opeka and Morse (1979) concluded that, barring toxic elements or concentrations of elements, and given the ability to raise the pH above 5.0, any treatments that would increase water infiltration and improve minesoil moisture relationships should be employed and should improve minesoil productivity.

To allow hydrologic modeling of surface mined soils, an understanding of the influence of overburden materials, mining methods and reclamation practices is necessary. A consistent finding in the literature is that the nature of minesoils and the necessary reclamation treatments are site specific. It is possible, however, to predict to some extent the nature of spoils, given a description of the overburden materials and reclamation plan.

Coarse Fragments Content

Coarse fragments are usually defined as particles of effective diameter greater than 2 mm. A high coarse fragments content is a common feature of mine spoils.

Mean coarse fragments contents of spoil are typically in the range of 40 to 70 percent, dry weight basis (Schafer et al., 1980; Smith et al., 1971; Daniels and Amos, 1981; Younos and Shanholtz, 1980). The standard deviation within a mine area is usually around 10 percent (Pedersen et al., 1978; Pettry et al., 1980). Although the majority of fragments are less than 10 cm in diameter, 20 to 50 percent of the spoil may be fragments greater than 2.5 cm (Pettry et al., 1980; Younos and Shanholtz, 1980).

These large proportions of coarse fragments have a significant impact on the physical properties of the spoil. Tests by the author indicate that unweathered grey shale fragments retain minimal water at 0.1 bar soil water suction. Thus the moisture storage capacity may be reduced by an amount equal to the percentage of coarse fragments present. Results from Hensen and Blevins (1979), however, indicated that fragments will provide some available water storage after weathering.

Schafer et al. (1980) found that a differentiation between hard rock and soft (weatherable) rock fragment was needed. Soft rock fragments prevent internal root penetration although they may deliver water to roots in surrounding soil. Weathering of soft rocks leads in time to a gradual change in effective soil texture.

Smith et al. (1971) reported, however, that the expected greater intensity of weathering near the surface had not measurably reduced the percent of coarse fragments of sandstone and several shale types after 70 to 100 years.

Overall, the presence of coarse fragments is expected to reduce the moisture storage capacity of the soil. When tightly packed in soil fines coarse fragments are expected to restrict root development and inhibit infiltration.

Bulk Density and Porosity

Bulk density of mine spoils was reported to be greater than that of nearby undisturbed soils in most studies (Indorante and Jansen, 1981; Pedersen et al., 1980; Younos and Shanholtz, 1980). Although the bulk density of spoils has been reported as low as 1.2 gm/cm^3 (Gee et al., 1978) and as high as 2.2 gm/cm^3 (Haigh, 1978), it was usually in the range of 1.5 to 1.8 gm/cm^3. Bulk density in the surface 0 to 10 cm was usually 10 to 20 percent less than that of the spoil profile in general. Subsoil density of some dense natural soil profiles may approach or exceed that of spoil profiles (Schafer et al., 1980; Younos and Shanholtz, 1980).

Three reasons for higher bulk densities and lower total porosities of mine spoil were suggested by Smith et al. (1971):

1. The spoil contained a higher percentage of rock (shale and sandstone).

2. The rock fragments in spoil tended to be less weathered and less porous than rock fragments in the natural soils.

3. Soil structure in the fines of the minesoil was absent or only weakly developed whereas soil structure in natural soils was more distinct.

The mean specific gravities of shale and sandstone fragments at a mine site in Oklahoma were 2.5 and 2.7 gm/cm^3, respectively (Haigh, 1978). This alone must cause a large increase in spoil bulk density.

Bulk density may also be increased due to compaction caused by mining and grading equipment. Schafer and Nelsen (1978) and Schafer et al. (1979) reported bulk density of spoils to be highly influenced by the kinds of machinery used in deposition. Spoils placed by side-dumping haul trucks had bulk densities as low as 1.4 g/cm^3, similar to the local natural soils. Spoils deposited with scrapers had bulk densities reaching 1.80 gm/cm^3. Spoils deposited by bulldozer and/or dragline had intermediate bulk densities, near 1.5 gm/cm^3. Bulk densities of spoils in southern Illinois indicate that dozer graded spoils, from dragline or wheel mining can be as dense or denser than scraper placed materials (Indoronte and Jansen, 1981). This was probably due to differences in the materials involved and in their moisture contents during placement.

Soil forming processes are known to require many years. Smith et al. (1971) compared the bulk densities of recent surface mining spoils and those of 70 to 130 year old iron ore spoils in West Virginia. They concluded that there had been only slight change in bulk density and total porosity during more than 70 years of soil formation.

Moisture Available in Minesoils

The success of revegetation of surface mined areas is greatly influenced by the available moisture in the reclaimed profiles. Spoils have been reported to be droughty in many studies. For example, Byrnes et al. (1980) and Barnhisel (1977) found that for a wide range of overburden materials, the water storage capacity of spoil was one of the most significantly limiting factors related to plant growth.

Soil moisture retention depends on the soil texture, soil structure and, for spoil particularly, the proportion of the < 2 mm fraction. As spoils usually contain 40 to 80 percent coarse fragments, the amount of the < 2 mm fraction available in which moisture may be stored is a major limitation. Rock fragments that are soft and weatherable (Schafer et al., 1979) or highly weathered (Henson and Blevins, 1979), supply some water to plants.

The available moisture capacity of spoil fines was reported to range from similar to that of natural soil (Pedersen et al., 1980), to one-third to one-half that of natural soils (Younos and Shanholtz, 1980). After correcting for 77 percent coarse fragments content, the available moisture capacity of the spoil ranged from one-third to one-quarter that of the soil when fines had similar capacity to natural soils (Pedersen et al., 1980). Ward et al. (1981) found spoil with 45 percent coarse fragments to have about one-half of the available water of natural soil. These results are similar to the findings of the author.

The total available water holding capacity of a soil profile is dependent on the depth available for plant rooting as well as the available water content of the soil. At some level of bulk density, soil strength begins to inhibit root penetration. Thus, on more dense spoils, total available water may be reduced due to shallow root depth. On a surface mined area studied by Daniels and Amos (1981), over 40 percent of the reclaimed area was underlain by compacted layers (bulk density > 1.8 gm/cm^3) which restricted downward movement of water and severely limited root growth.

It can be concluded that the available water holding capacity of spoil is often lower than is desirable, mostly because of high coarse fragments content. Higher bulk density and lower total porosity accentuate the effect.

Hydraulic Properties of Minesoils

The movement of water into and through the soil profile is a major component of the hydrologic balance. Obtaining representative measurements of these processes is a complex task. This is particularly true for spoils, which are weakly structured and can be easily disturbed. Infiltration measurements in the field are subject to unspecified boundary conditions. Greater horizontal than vertical permeability is possible on stratified minesoils.

Ward et al. (1981) and Rogowski and Jacoby (1979) obtained comprehensive measurements of hydraulic properties using large, instrumented soil bins in which minesoil profiles were reconstructed. Applications of rainfall simulators on minesoils were reported by Gilley et al. (1977), Gee et al. (1978) and Schafer et al. (1979). Small watersheds and plots have been used to obtain measurements of lumped parameters of infiltration, such as the SCS curve number (Fogel et al., 1980).

In general, minesoils exhibit lower water intake rates, total infiltration and saturated hydraulic conductivity than undisturbed natural soils (Smith et al., 1971; Younes and Shanholtz, 1981). Exceptions include spoil containing a large proportion of weatherable sandstone (Schafer et al., 1979) and spoils which are poorly graded and high in coarse fragments (Rogowski and Weinrich, 1981). Spoils formed predominantly from shale and siltstone are likely to have low water transmission properties.

Ward et al. (1981) studied infiltration through reconstructed minesoils, using a rainfall simulator and large instrumented soil bins. The spoil was a mixture of grey and dark shale and sandstone, containing 45 percent coarse fragments. The hydraulic conductivity of the topsoiled spoil profiles appeared to be about an order of magnitude higher than that of the spoil profiles, in the 90 to 100 percent of saturation moisture content range. All of the topsoiled spoil profiles exhibited higher initial infiltration rates and longer times to ponding than the spoil profiles. The low infiltration rates of the spoil profiles were attributed to the material having a well graded texture and high density (1.7 - 1.8 gm/cm^3).

Pedersen et al. (1980) studied infiltration using single ring infiltrometers on natural soils, topsoiled spoil and non-topsoiled spoil in Pennsylvania. The spoil was a mixture of shale, siltstone and sandstone, with an average of 77 percent coarse fragments. Infiltration values on minesoils were lower than on natural soils. Initial infiltration rates were approximately similar for natural soil and topsoiled spoil, while those of non-topsoiled spoil profiles were reduced by one order of magnitude. Final infiltration rates were similar for non-topsoiled and topsoiled spoil, about 0.5 cm/hr. Final rate for the natural soil was 2.5 cm/hr. The final infiltration rate for a one meter deep infiltrometer on the non-topsoiled spoil was 0.1 cm/hr. Lower values are expected on infiltrometers of greater area and overestimation is usual when flow penetrates below the bottom of the ring (Rogowski, 1980). The one meter deep infiltrometer results suggest that the true final infiltration rate of the spoil would be less than 0.5 cm/hr.

When coarse fragments are well packed in fines, leaving few large channels, the fines must carry all water moving downward. Saturated hydraulic conductivity will be reduced if the spoil is more compacted, or if fines are finer textured or the material has a more evenly graded distribution of particle sizes. The most practical procedures for improving minesoil water intake are probably topsoiling, reduction in density and selective placement and mixing of overburden.

Topsoiling as a Reclamation Practice

General

The two major purposes for the placement of topsoil over spoil are to provide an acceptable growth medium for plants and to provide control of infiltration and runoff of water.

Seedbed preparation and stand establishment is generally easier in replaced A-horizon material than in graded spoil (Jensen and Dancer, 1981). Topsoiling usually increases the available water storage and porosity in the soil profile.

Acidic, sodic and saline spoil may severely limit plant growth and should not be exposed to the surface (Power et al., 1981; Holmberg, 1980). Power et al. (1981) found that replacement of topsoil and subsoil over highly sodic spoil gave reasonable yields of several crops and grasses, whereas the spoil alone was only capable of supporting native grasses with reduced yields. Hill (1978) reported that soil, including non-acidic spoil, and water provide the most effective barrier against acid generation, by withholding oxygen from the buried acid spoils.

It should be noted that in some cases, spoil is favorable for plant growth. Studies by Jensen and Dancer (1981) with corn and soybeans in Illinois and by Alderdice et al. (1981) with grasses and legumes in Kentucky show similar yields on non-topsoiled spoils and topsoiled spoils. Spoils were of good quality and topsoils were of mediocre quality.

The Effect of Topsoil Thickness

The depth of topsoil which can be replaced is usually limited to the premine topsoil depth, i.e. the A-horizon. Additional suitable material is often available from the B-horizon, particularly the B-subhorizons with lower clay content. Use of high clay materials is not beneficial as the compaction involved in its placement produces a layer which may be less permeable than the spoil.

The depth of topsoil required may be reduced as the quality of the spoil improves with respect to toxicity, salinity, acidity, moisture storage capacity and density. When reclaiming highly saline or sodic spoil the effective root zone may be limited to the depth of topsoil and subsoil replaced.

Plant Response to Soil Thickness

Huntington et al. (1980) reported a definite trend toward higher yields of corn, wheat and soybeans on plots with deeper soil (replaced topsoil) on acidic grey and black shale spoil in Kentucky. The deepest soil treatment (70 cm) was most productive, especially for years when soil moisture was limited. The response of wheat yield to ripping of the topsoil was equal to or greater than the response to an additional 25 cm to topsoil.

In North Dakota, the yields of all crops studied increased as the total thickness of replaced soil material (topsoil plus subsoil) increased up to the range of 75 to 120 cm (Power et al., 1981). The mine spoil used was of rather poor quality because of excess sodium and low permeability. Yields approached zero as total soil thickness approached zero. Greatest yields of all crops occurred when 20 cm of topsoil was placed over 55 to 110 cm of subsoil. Mixing of topsoil and subsoils reduced yields to 80 to 90 percent of those obtained on non-mixed treatments. Yields tended to decrease when total soil thickness exceeded 150 cm.

It is apparent that the most effective depth of topsoil varies from site to site and depends on the properties of the spoil and soil present. For very poor quality spoils, i.e. spoil with one or more severely limiting property, it would appear best to completely reconstruct the soil. This may require a total soil thickness of about 90 cm including at least 20 cm of topsoil. For spoil of the best quality, major problems will be seed bed preparation, plant establishment and droughtiness. Thus reclamation must be aimed at improving structure, tilth, water intake rate and soil moisture storage capacity.

Runoff and Erosion From Minesoils

There is little runoff data available for surface mined watersheds. The USDA (1979) has begun collecting runoff data from five watersheds in Ohio which are to be mined at some future time. The USGS has monitored 13 mined and unmined watersheds in Tennessee and Indiana since the fall of 1980 (Jennings et al., 1980). The data is to be used for a comparative study of 12 surface mining hydrology models.

Curtis (1972), studying watersheds in Kentucky, found peak streamflow rates were increased by a factor of 3 to 5 after mining. Overton and Crosby (1980), in a watershed modeling study in Tennessee, found simulated peak runoff rate to be doubled after mining.

Fogel et al. (1980) studied runoff from small watersheds in Arizona and derived SCS curve numbers (AMC II) of 80, 90 and 88 for premined soils, bare graded spoils and bare topsoiled spoils, respectively. This indicates increased runoff after mining and a slight reduction in runoff due to topsoiling. Topsoiling should reduce runoff even more, compared to spoil, after plant establishment due to the greater plant growth potential of the topsoiled spoil.

Jensen et al. (1978) found that topsoil application resulted in retention of significantly more water in the surface soil. Non-topsoiled spoils were reported to yield from 3.5 to 6.0 times more runoff than topsoiled spoils, depending on surface conditions.

Runoff Response to Soil Thickness

There have been few studies directly relating the thickness of soil placed over spoil to runoff production. When the spoil has low permeability, it can be inferred that the maximum infiltrated volume is limited to the water storage capacity of the replaced topsoil. Runoff volume is expected to increase as topsoil thickness decreases and permeability of the underlying spoil decreases.

Rainfall simulator studies on sodic, low permeability spoil in North Dakota (Gilley et al., 1977) illustrate the effect of topsoil thickness. Runoff for all non-topsoiled spoil textures was high, averaging 66 to 74 percent of the water applied, depending on surface conditions. On a "wet" run, the 25 cm topsoil treatment yielded 25 percent less runoff than the spoil, apparently due in part to surface sealing of the sodic spoil. Increasing the topsoil thickness from 25 to 61 cm reduced runoff by 24 percent for the same antecedent moisture conditions.

Erosion

Reduction of runoff due to topsoiling should also reduce erosion, all other factors being equal. However, the erodibility of the bare topsoil can exceed that of spoil to such a degree that, even though runoff is reduced, sediment yield is increased by topsoiling (Gilley et al., 1977; Fogel et al., 1980; Mitchell et al., 1982).

Curtis (1971) found erosion and streamflow sediment loads increased sharply after surface mining in Kentucky. Maximum sediment yields occurred during active mining and dropped off within a year or two after completion of mining in some watersheds.

Thus establishment of a protective vegetative cover as soon as possible after topsoiling should be an important priority. The increased potential for vegetation establishment and growth on topsoiled spoil compared with non-topsoiled spoil should offset this higher erosion potential.

CHAPTER III

SOIL INVESTIGATIONS AND PROCEDURES

The aim of this soil investigation was to provide the soil data necessary to (a) quantify changes in soil properties induced by surface mining and (b) to allow assessment of these changes in terms of their effect on the hydrologic balance.

A study was made of the soil conditions on three surface mined areas in eastern Oklahoma. Each included a premined and a reclaimed study area. The reclaimed study areas included two areas of topsoiled shale spoil (minimum regulatory requirement) and one area of topsoil over heavy clay spoil over shale spoil. Additionally, samples were taken from a non-topsoiled graded shale spoil area representing older reclamation results.

Minesoils Profiles Resulting from Different Levels of Reclamation

The reclamation of mine soil profiles can involve at the one extreme, complete sorting and replacement of all horizons, and at the other extreme, complete mixing of overburden material. Practical reclamation is a trade-off between these extremes, hopefully insuring soil conditions adequate to maintain agricultural productivity and to control runoff and erosion.

This study included measurements of the physical properties of minesoils resulting from each of three levels of reclamation that have been observed on surface mines in eastern Oklahoma. The minesoil profiles resulting from these reclamation practices are:

Non-Topsoiled Spoil

The spoil is usually broken grey shale or shale and clay and is produced by blasting and inverting the overburden with a dragline. Older surface mine areas were rarely graded or planted. Through the 1970's grading was more common and some areas were planted with grasses or cover crops. Volunteer vegetation is slow to cover the surface. Erosion often removes soil formed by weathering of the shale as quickly as it is formed.

Soils formed on very old shale spoil banks are mapped as Kanima Series (USDA-SCS, 1976) and have an altered surface horizon of about 10 cm of shaly silty clay loam. The underlying material is typically very shaly silty clay loam or very shaly silt loam.

Topsoiled Spoil

These profiles consist of mixed broken shale spoil with a minimum cover of 20 cm of topsoil. Establishment of vegetation being mandatory under the SMCRA 1977, grasses are usually planted, or a cover crop of wheat or sorghum is planted the first year followed by grasses. Exaggerated erosion is common in the first year or so, until vegetation becomes established. This is the most common minesoil on mines active since enactment of SMCRA 1977.

Topsoil Over Clay Over Spoil

This profile consists of blasted shale spoil overlain by one or more meters of clay and covered by 20 cm or more of topsoil. Vegetation and erosion are the same as for topsoiled spoil above. This type of minesoil profile results from the size of equipment used in the coal mining operation rather than from a higher level reclamation plan. When the dragline is too small for the overburden depth, scrapers are used to take clay overburden from ahead of the mine pit and spread it on the graded spoil behind the pit. It is not known how common this practice is in eastern Oklahoma coal areas.

Minesoil Profile Sampling

Samples were collected from two study areas reclaimed with topsoil over shale spoil (Porter South and Foyil), as this was the most common reclamation plan since enactment of SMCRA, 1977. The non-topsoiled spoil profile sampled on one study site (Porter South) represents pre-SMCRA, 1977 reclamation. The third reclaimed profile (at Porter North), topsoil over clay over shale spoil, involved more complete sorting of the overburden. Although at first it appears to be a "better" reclamation practice, at least as a medium for plant growth, it is unlikely to be any improvement over the topsoiled spoil profile because of the very low permeability and high salinity of the clay. Thus this reclaimed profile was included as an example of the need for premining soil investigation and selective overburden placement.

Soil Study Areas

Investigations of premined and postmined soils were carried out at mines near Porter in Wagoner County and near Foyil in Rogers County. At Porter two study areas were selected. A summary of premined soils and reclaimed soil profiles at each study site is given in Table I.

These sites were chosen to give a range of runoff potentials (indicated by the hydrologic soil group) and reclamation practices.

The Porter South Mine

The Porter South Mine, operated by Bill's Coal Company, is located in the southern half of Section 17, T16N, R17E, Wagoner County. The town of Porter is located in

TABLE I

SUMMARY OF PREMINED AND RECLAIMED SOILS AT SURFACE MINE STUDY AREAS IN EASTERN OKLAHOMA

Location of Study Site	Dominant Premined Soil Series	Premined[1/] Hydrologic Soil Group	Reclaimed Profile
Porter South	Newtonia silt loam	B	a) Topsoiled spoil b) Non-topsoiled spoil[2/]
Porter North	Taloka silt loam	D	a) Topsoil, over-clay, overspoil
Foyil	Summit silty clay loam	C	a) Topsoiled spoil

[1/] Source: Soil Interpretation Record (Blue Sheets) for each soil series; USDA-SCS, National Cooperative Soil Survey.

[2/] Graded shale spoils were sampled as a separate reclamation treatment.

the northeast quarter of section 17 and is roughly 55 km southeast of Tulsa. The mine permit area, reclaimed study areas and soils are shown in Figure 1.

The topography of the area is rolling prairie with upland slopes of 3 to 5 percent. Premine land use was rangeland for cattle grazing. The majority of the mine area soil was mapped as Newtonia silt loam. The Newtonia series typically has silt loam topsoil with clay content increasing steadily with depth to around 40 percent at 150 cm. Subsoil textures are silty clay loam, silty clay, or clay (USDA-SCS, 1979).

Surface water from the area drains southward into Blue Creek, a tributary of the Arkansas River. Mining has disturbed the main channel of a watershed draining some 580 ha. The 40 ha reclaimed study area is included in two subwatersheds of this watershed.

Dragline stripmining has progressed from east to west across the permit area with a 12.2 cu meter (16 cu yd) dragline working a north-south orientated pit. The overburden profile, consisting of 6 m of clay over 9 m of gray shale, was blasted and inverted by the dragline. A 45 to 60 cm coal seam was removed.

The spoil was graded to approximate the original contour and 20 to 40 cm of topsoil was spread with scrapers. Topsoiling and planting with Bermuda grass were completed on most of the southeast quarter section by the spring of

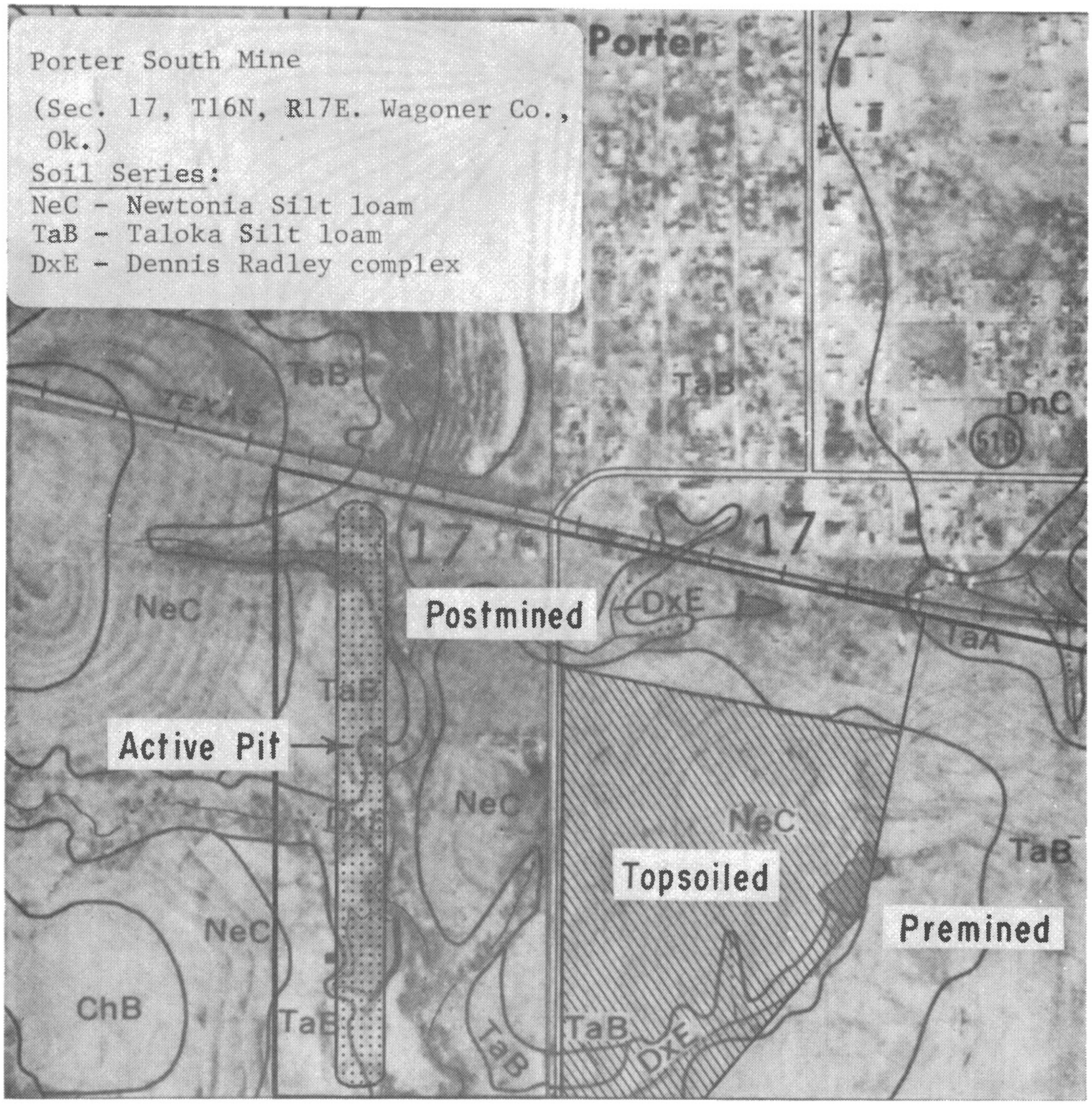

Figure 1. Soil Series, Mined Areas and Topsoiled Study Area at Porter South

1981. The ground surface had a 90 percent cover of grass by the end of 1981. Soil samples were taken on this study area in the fall of 1981.

The Porter North Mine

This mine, also operated by Bill's Coal Company, is located 16 km west and 3.2 km north of Porter in the southern one-half of Section 6, T16N, R17E, Wagoner County.

The soil map, reclaimed study area, and mined area are shown in Figure 2. The topography is rolling prairie with upland slopes of one to three percent. Slopes are less steep than at Porter South and overland flow lengths are longer. Soils are of the Dennis - Taloka - Okemah association with Taloka silt loam predominating. The Taloka series is typically silt loam with clay or silty clay subsoil at 70 cm (USDA-SCS, 1979). The Parsons silt loam in the western portion of the permit area is very similar to the Taloka. The A-horizon thickness of the Parsons series is about one half that of the Taloka.

Surface water drains to Gar Creek, a tributary of the Verdigris River. A channel along the south and southern west sides of Section 6 diverts runoff into an old strip-mine pit to control sediment. The watershed above the sediment pond includes 125 ha, most of which will be mined. A natural watershed of 430 ha includes most of the mine permit area.

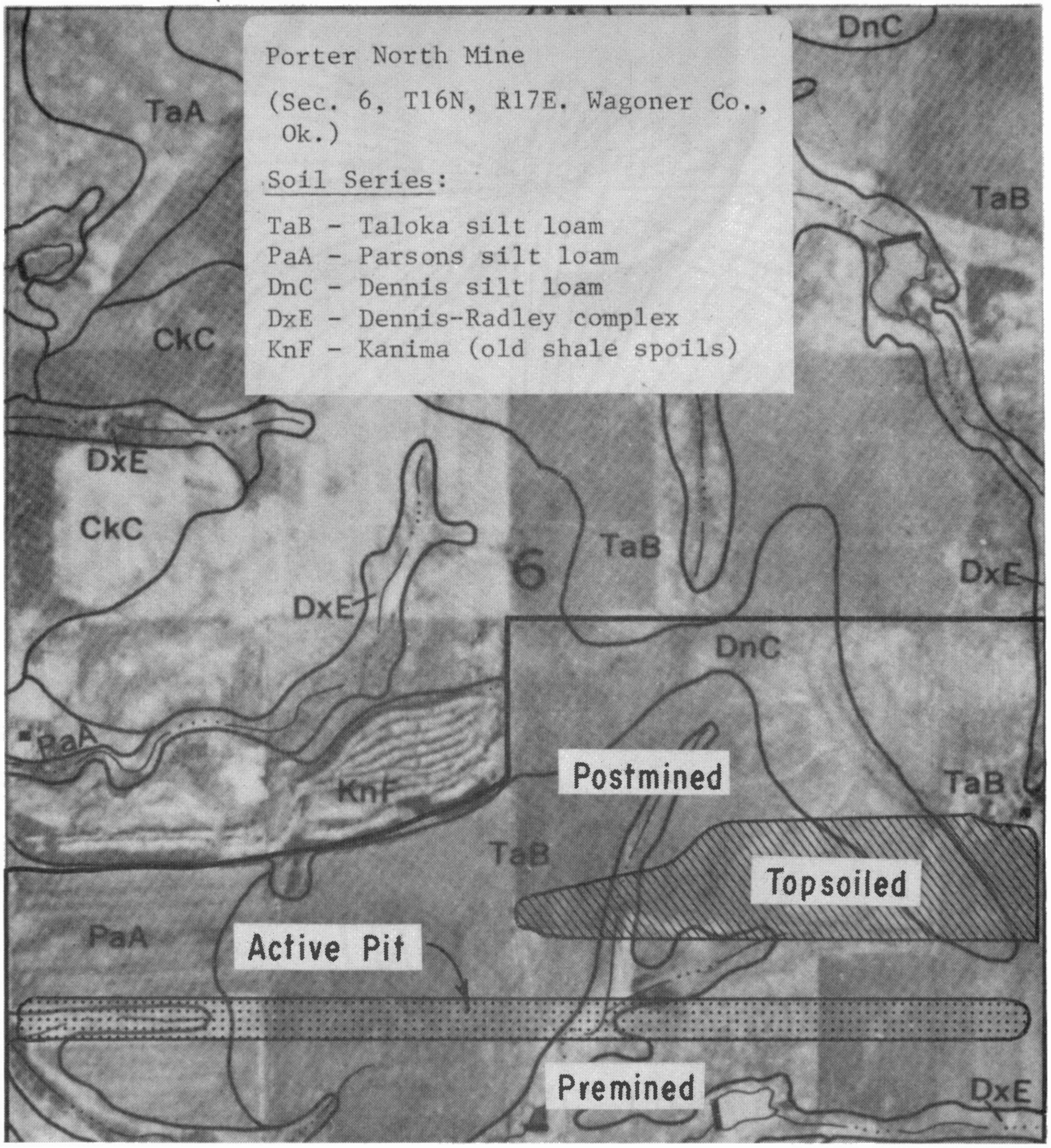

Figure 2. Soil Series, Mined Area and Topsoiled Study Area at Porter North

Overburden consisted of six meters of heavy clay over nine meters of gray shale. A 50 cm coal seam was mined. Mining progressed from north to south starting in 1979. The western portion was started from the old strip mine pit with a second dragline. Topsoil was stockpiled initially and spread directly onto the graded spoil after the pit had advanced. As both draglines were small (3.4 m^3), scrapers were used to remove some of the subsoil and clay overburden. This mining procedure resulted in the reclaimed profile, topsoil over clay over shale, described in the preceding section. The reclaimed study area was topsoiled in February 1981 and planted with grasses in the spring of 1981. Soil samples were collected in the fall of 1981.

The Foyil Mine

The Carbonex Coal Company Foyil Mine is located in the southeast corner of Section 19, T23N, R17E, Rogers County. The site is approximately 60 km north of Porter and 55 km northeast of Tulsa.

The surrounding area is 40 percent forested with somewhat more extreme relief that at Porter. The premined area was cleared rangeland with trees along the stream channel.

As shown in Figure 3, the soil on the uplands was Summit silty clay loam with Verdigris soils along the

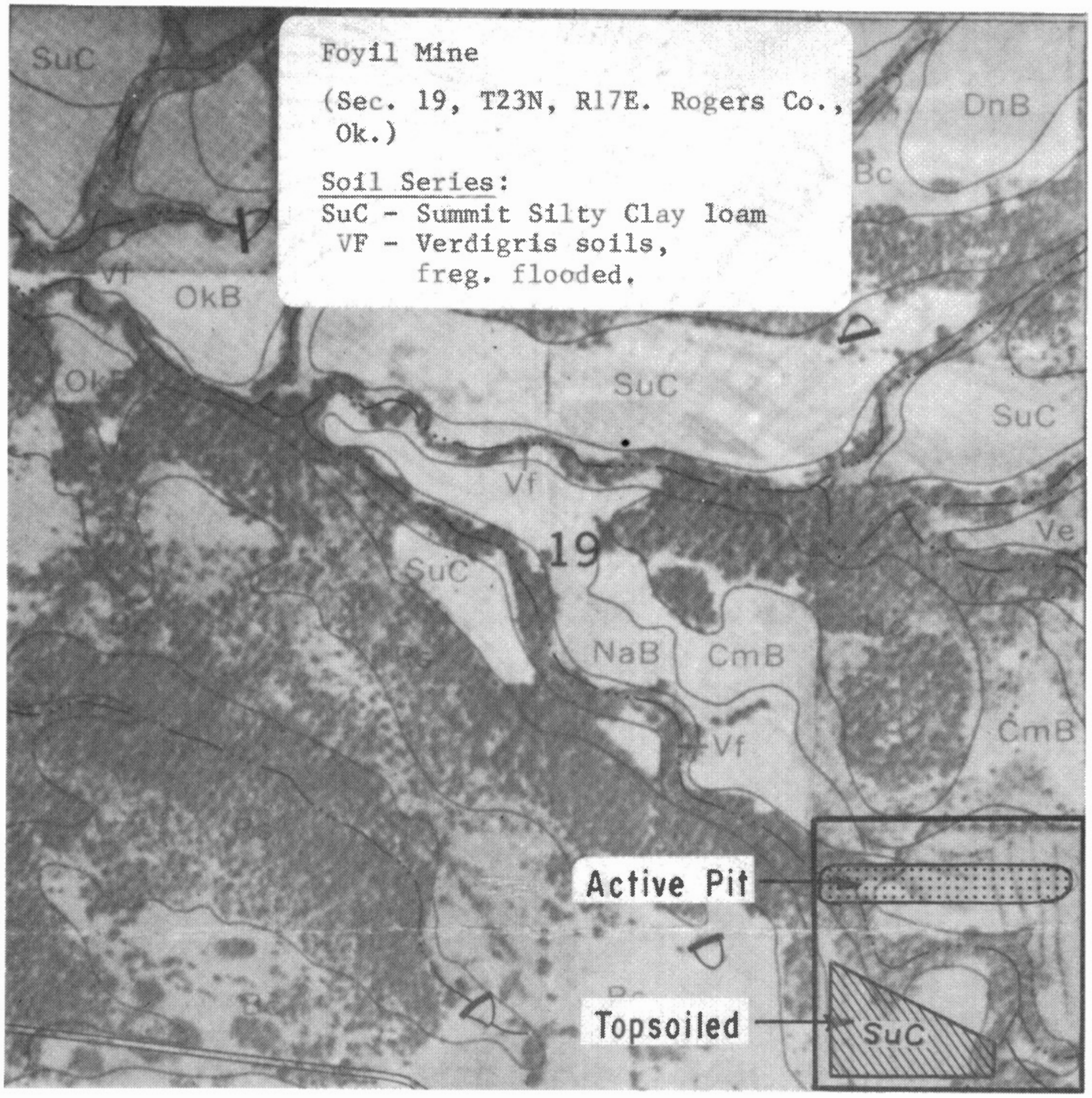

Figure 3. Soil Series, Mined Area and Topsoiled Study Area at Foyil

drainage channels. The Summit soil is typically silty clay loam over a silty clay or clay subsoil (USDA-SCS, 1979).

Runoff flows via Blue Creek into Oologah Reservoir five km to the west. The stream drains a watershed of some 100 ha above the point where it crosses the western permit boundary, including the 16 ha permit area.

Overburden consisted of one to two meters of soil, and one or more meters of fractured limestone over 9 to 18 m of calcareous gray shale. The blasting and dragline mining procedure caused the overburden profile to be inverted and mixed. About 45 cm of coal was extracted with end loaders and large on-road trucks.

The mine pit had moved from south to north across the site, reaching the northern boundary by August 1981. A 4 ha area south of the channel had been graded and topsoiled by the spring of 1981. Soil samples were collected from this small study area in August 1981. Severe rill erosion of the topsoil was evident at this time. No grasses or cover crop had been planted although volunteer grasses and tall weeds provided some ground cover.

Field Sampling of Soil Profiles

The aim of the sampling program was to determine the average value and variation of various soil properties through the profile, on small reclaimed areas and surrounding undisturbed areas representative of the premined condition of the reclaimed area. The premined soils and the reclaimed soils were sampled so a valid comparison could be made. Undisturbed core samples, taken with a hand held sampler, were used to obtain soil for all tests except saturated hydraulic conductivity, for which a hydraulic probe was used. The depth of topsoil on reclaimed areas was recorded at each core and probe sampling site.

Core Samples

Undisturbed core samples were taken at four or more sites on premined and reclaimed soil at Porter South and Porter North. Core samples were taken to a depth of 60 cm with four or more depths per site. The reclaimed profiles at Foyil and at Porter South were similar. Therefore, the Foyil soil-treatments were sampled at only three sites and at two depths (i.e. one in the topsoil and one in the subsoil or spoil). The non-topsoiled spoil profile was included as an additional treatment. Samples collected from exposed graded spoil at Porter South were used to represent the surface layer of the non-topsoiled spoil profile. Below the surface layer, the spoil was considered to be the same in both the non-topsoiled spoil and the reclaimed Porter South profiles. Thus core data from the spoil subsoil of the reclaimed Porter South profile was also used for the non-topsoiled spoil profile.

Probe Samples

A hydraulic soil probe was used to extract 6.7 cm diameter by 110 cm deep soil columns from four sites on both the premined area and the reclaimed area at Porter North. These soil columns were cut up and used for determination of saturated hydraulic conductivity as discussed later in this chapter and in Appendix A.

Description of Laboratory Procedures

The undisturbed cores were used to determine bulk density and moisture content at saturation. Both bulk density and moisture at saturation were used to estimate porosity. Core samples were then crushed and subsampled to determine moisture retention at 0.1 bar and 15 bar suction, texture, organic matter content, SAR, pH and salinity. For shale spoils the percentage coarse fragments (>2 mm) was determined by dry sieving. Moisture retention at 0.1 bar was determined for the shale spoil with and without the coarse fragments.

Bulk Density and Moisture Content at Saturation

Soil cores were stored in waxed paper containers during transportation to the laboratory where they were weighed to determine field moisture content. To determine moisture content at saturation selected cores were saturated by upward wetting. Over a period of several days the water level was gradually increased to a level slightly below the top of the core. Saturation was assumed to have occurred when the surface of the soil core was visibly wet and free water was present. No attempt was made to remove entrapped air or impede swelling above the top of the core walls. Entrapped air may reduce the moisture retention while swelling may increase moisture retention.

Cores were then weighed, oven dried at 105°C for 48 hours and reweighed. The volumetric moisture content at saturation was calculated from the volume of water and the volume of the core. Field moisture content was calculated as percent of dry weight. Bulk density was calculated using the dry weight and the volume of the core (344.77 cc). Bulk densities are those occurring at field moisture content rather than at some standardized moisture content or suction. Total porosity (percent volume) was calculated from the bulk density assuming a particle specific gravity of 2.65 gm/cc. and using the equation:

$$\text{Porosity} = 100\ (1 - \text{Bulk Density}/2.65)$$

Soil Preparation

Soil was removed from the cores, crushed by hand with a large roller and sieved through a 2 mm sieve. Retained soil was rerolled and sieved until it was determined that retained soil was essentially non-soil material. Soil passing the 2 mm sieve was not subject to any further mechanical action.

Percent Coarse Fragments

For shaly spoil samples the percentage coarse fragments was determined by dry sieving the entire sample with a 2 mm mesh sieve. Determination for all samples was also made by wet sieving of sub-samples during the particle size distribution procedure.

Soil Moisture Retention

Sub-samples of sieved soil (< 2 mm) were used to determine moisture retention at 0.1 bar and 15 bar suction, using the pressure plate and pressure membrane methods described by Richards (1954). The average of four sub-sample replications was used to characterize each sample. Moisture content was determined as percent, dry weight basis.

To more closely characterize field conditions of shale spoil, 0.1 bar suction moisture content was also determined with the coarse fragments included. The whole sample, 500 to 600 gm, was roughly split into two to provide large replicate sub-samples. The coarse fragments were packed in fine material to insure good capillary conductivity throughout the sample.

Particle Size Distribution and Texture

Particle size distribution was determined for pre-treated and dispersed sub-samples of core soil. The hydrometer method (Bowles, 1978) was used to determine the silt-clay division. Wet sieving (Richards, 1954) was used to determine the percentages of coarse fragments (> 2mm), total sand and sand fractions. The USDA metric particle size classification system was used.

The salinity of some soils was high enough to cause flocculation and give completely erroneous textural classification. Thus a pretreatment involving the dissolving of some mineral matter (particularly carbonates), and removal of soluble salts by centrifuging, was used. Thorough removal of salts and the addition of a small amount of dispersing agent resulted in good dispersion of all soils.

A more complete description of the procedure used is given in Appendix B.

Organic Matter Content, Salinity and pH

Composite samples from selected depths for each pre-mined and reclaimed area were prepared by mixing sub-samples from core samples. Testing was carried out by the Water and Soil Salinity Testing Laboratory, Department of Agronomy, O.S.U., Stillwater, Oklahoma. A Salinity Management Report from this laboratory provides electrical conductivity (EC), total soluble salts (TSS), Sodium, Magnesium and Calcium content, sodium absorption ratio (SAR) and pH of 1:1 soil suspension.

The organic matter test results have a relative precision of about ±0.25 percent organic matter. Thus values of 0.8 percent and 0.5 percent organic matter cannot really be considered different.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity was measured on undisturbed soil cores encased in clear heat shrinkable insulation tubing (Bondurant et al., 1969; Ouattara, 1977) using the constant head method. The mean value, for eight or more tests on each core, was taken as the saturated hydraulic conductivity representative of the core. A detailed description of the field and laboratory methods used to determine saturated hydraulic conductivity is given in Appendix A.

CHAPTER IV

RESULTS OF SOIL INVESTIGATION

Introduction

The results of the soil investigation indicated that the postmined profiles had potential for greater runoff and were less suitable for plant growth than the premined profiles. Runoff potential was considered to be greater because 1) the depth to the least permeable layer in the profiles was reduced by 50 percent after mining, 2) the saturated hydraulic conductivity of the spoils was less than that of the premined subsoils and 3) the volume of large pores was decreased throughout the postmined profiles indicating lower saturated hydraulic conductivity compared with the premined profiles. Bulk density was greater for all postmined profiles than for the premined profiles. The resulting decrease in porosity caused the gravitational water capacity to be reduced.

The clay spoil had higher bulk density than natural soils. Moisture retention properties were similar to natural soils except that gravitational water capacity was reduced. Very low saturated hydraulic conductivity was the most limiting property of the clay spoil. Salinity was high enough to stress moderately tolerant plants.

Shale spoils had greater bulk density and lower porosity, 0.1 bar moisture retention, available water and saturated hydraulic conductivity than the native soils. The presence of 50 to 60 percent coarse fragments was responsible for the significant reductions in 0.1 bar and available moisture. Salinity was a problem for shale spoil at Porter South but not at Foyil. The non-topsoiled spoil profile had many limiting properties including high bulk density, low available water, low saturated hydraulic conductivity and high salinity.

Reclaimed topsoils generally had the same properties as the premined topsoils except that they were more dense. Topsoiling improved the total available water for the shale spoil profiles. Greater topsoil depths would improve the rooting depth for all postmined profiles and further improve total available water.

Depth of Topsoil

Results

The depths of topsoil on the three reclaimed study areas are shown in Table II. A dominant feature on all study areas was the high degree of variability and large range in reclaimed topsoil depth. The mean depth of

TABLE II

DEPTH OF TOPSOIL AT SAMPLING SITES
ON RECLAIMED STUDY AREAS

Location and Soil Profile	Material Underlying the Topsoil	Depth of Topsoil					
		Mean (cm)	STD[1/] (cm)	CV[2/] (%)	N[3/]	Max (cm)	Min (cm)
Porter South, Reclaimed Newtonia	shale spoil	27	9.6	36.0	6	43	15
Porter North Reclaimed Taloka	clay	29	10.5	36.5	12	50	13
Foyil[4/] Reclaimed Summit	shale spoil	20	10.0	50.0	3	30	10

Note: The premined depth of A-horizon was typically: Newtonia SiL and Summit SiCL - 25 to 30 cm, Taloka SiL - 70 cm.

[1/]STD = Standard Deviation

[2/]CV = Coefficient of Variation

[3/]N = No. of Samples

[4/]Topsoil eroded

topsoil and the coefficient of variation (CV) were similar for the Porter South and Porter North study areas. These areas were mined and reclaimed by the same company. The mean depth of topsoil at the Foyil study area was shallower and the CV was higher. This was mostly due to severe erosion of the topsoil before vegetation was established.

Comparison of the postmined profiles with the premined soil profiles shows that most of the A-horizon had been reclaimed at Porter South and Foyil. The Taloka soil at Porter North had a very deep A-horizon, less than half of which was reclaimed. The reclaimed topsoil depths should allow a complete vegetative cover to develop although it is not known if vegetative production will equal premined levels. The properties of the underlying spoil will have a significant effect on the productivity of the reclaimed profiles.

Hydrologic Consequences

A major change hydrologically is that the depth to the layer of least permeability has been reduced by about 20 cm at the Porter South and Foyil sites and by 40 cm or more at the Porter North site. This will result in increased runoff and shorter time to ponding. As the CREAMS model uses a single layer representation of the soil profile to model infiltration with the Green and Ampt infiltration equation, it is difficult to evaluate the influence of the change in depth to the least permeable layer.

Particle Sizes and Texture

Results

The mean particle size distribution and texture for the soil profiles are presented in Table III.

The premined soil profiles have silt loam or loamy topsoils with higher clay contents in the subsoil. Texture of subsoils for all the native soils was silty clay or clay*. The least permeable horizon was expected to be the B2-horizon. Depth of topsoil (A-horizon) was 25 to 30 cm at Porter South and Foyil and 70 cm at Porter North. The depth to the B2-horizon was about 50 cm at Porter South and Foyil. It was 70 cm or greater at Porter North. The initial infiltration rate of the Summit soil, with more clayey topsoil, is potentially lower than that of the other native soils. The Taloka soil, being deeper, will have greater cummulative infiltration capacity than the other soils.

At Porter North the texture of the postmined topsoil was silt loam. Particle size distribution was very similar to that of the premined Taloka soil. The reclaimed clay layer beneath the topsoil, referred to as clay spoil, was one or more meters deep. The texture varied between silty clay and clay, with the clay content ranging

---

*National Cooperative Soil Survey, Soil Interpretations Record (Blue sheets) for each series, USDA-SCS.

TABLE III

MEAN PARTICLE SIZE DISTRIBUTION AND TEXTURE OF PREMINED AND POSTMINED SOILS

	Mean Particle Size Distribution #							
	Premined				Postmined			
Depth (cm)	Sand	Silt (% < 2mm)	Clay	Texture	Sand	Silt (% < 2mm)	Clay	Texture
Taloka Silt Loam - Porter North - Topsoiled Clay Spoil								
5-12	22.5	67.6	9.9	SiL	22.4	65.2	12.3	SiL
9-26	21.5	69.8	8.8	SiL	21.9	65.5	12.6	SiL
30-37	24.0	62.6	13.4	SiL	11.3	38.4	50.3	SiC/C*
36-43	16.4	66.9	16.6	SiL	16.3	43.7	40.0	SiC*
50-57	17.2	61.9	20.8	SiL	11.4	43.9	44.7	SiC*
60-67	18.8	65.0	16.2	SiL	--	--	--	---
Newtonia Silt Loam - Porter South - Topsoiled Shale Spoil								
5-12	36.7	54.3	9.0	SiL	25.8	62.2	12.0	SiL
19-26	29.2	51.0	19.8	SiL	24.5	59.0	16.5	SiL
23-30	--	--	--	---	25.5	56.5	18.0	SiL
36-43	26.6	43.7	29.7	L/SiC$	24.1	58.1	17.8	Sh.SiL**
50-57	22.0	43.8	34.2	L/SiC$	21.2	61.5	17.3	Sh.SiL**
Porter South - Non-topsoiled Shale Spoil								
5-12					20.9	71.9	7.2	Sh.SiL**
36-43					24.1	58.1	17.8	Sh.SiL**
50-57					21.2	61.5	17.3	Sh.SiL**
Summit Silty Clay Loam - Foyil - Topsoiled Shale Spoil								
5-12	29.1	44.1	26.8	L/CL	20.9	56.7	22.4	SiL
23-30	19.5	51.6	29.0	L/SiCL$	26.1	55.8	18.1	Sh.SiL**

#Means of particle size distributions for 3 to 9 soil samples.

*Clay Spoil

**Shale Spoil. Sh.SiL = Shaly Silt Loam.

$Textural class for the mean distribution differed from the classes of individual samples. The textures listed are those of the sample, not the means.

from 32.4 to 50.3 percent. The clay spoil was structurally massive, very firm when wet, with a high shrink-swell potential and extremely low permeability. This material was removed from the 2 to 3 m deep clay layer which underlies the premined soil solum.

At Porter South the texture of both the reclaimed and premined topsoil was silt loam. Particle size distribution data in the table show that the reclaimed topsoil was relatively homogeneous, lacking the slight horizonation of the premined soil profile between the 5-12 and 19-26 cm depths.

At Foyil the texture of the reclaimed topsoil was silt loam. The premined topsoil was loam or clay loam and the samples from 23-30 cm depth were loam or silty clay loam. The influence of this change in topsoil texture on the runoff potential of the mined area was considered slight compared with the effects of the shallow depth of reclaimed topsoil and the properties of the shale spoil.

For the shale spoils at Porter South and Foyil the texture of the fines was silt loam. Soils of this texture are generally considered suitable for plant growth and to have desirable hydraulic properties. The very high bulk density and the coarse fragments present in these spoils probably overshadow the influence of the texture of the fines.

The spoil profiles had similar textures and appeared to be fairly homogeneous, with no horizonation. The surface spoil samples (5-12 cm), which had been exposed to weathering for 3 to 6 months, exhibited lower clay and higher silt contents than the deeper shale spoil samples. The short time of exposure and small sample size preclude attributing this lower clay content to erosion.

Barnhisel and Massey (1969) found that a more or less vigorous mechanical dispersion technique can change the particle size distribution results for shale spoils. Shale encountered in Oklahoma ranged from reasonably soft to hard. Some fragments could be broken by mechanical action during sampling or testing. Fragments were not prone to slaking in water although they appeared to be softer and more easily fractured once wet. Mechanical dispersion was avoided during the textural analysis. The resulting particle size distributions were fairly consistent between samples and exhibited less variability than samples from native soils.

Bulk Density

Results

Table IV shows the mean bulk density for the soil profiles at various depths. The postmined soils were consistently more dense than the premined soils at the same depth. The shale spoil materials below 12 cm depth were by far the most dense (1.85-1.96 gm/cm^3) and were significantly different from all other materials. Mean

TABLE IV

MEAN BULK DENSITY (gm/cm^3) OF PRE-MINED AND POST-MINED SOIL PROFILES

Depth (cm)	Porter North		Porter South		Foyil		Non-topsoiled Spoil
	Pre-mined	Post-mined	Pre-mined	Post-mined	Pre-mined	Post-mined	
5-12	1.35_{F} 1/	1.55_{BCD}	1.44_{DEF}	1.56_{BCD}	1.41_{DEF}	1.57_{BCD}	1.66_{B}**
19-30	1.44_{DEF}	1.64_{B}	1.40_{FE}	1.63_{BC}	1.46_{CDEF}	1.85_{A}**	
30-37	1.42_{DEF}	1.63_{BC}*					
36-43	1.49_{CDEF}	1.61_{BC}*	1.48_{CDEF}	1.96_{A}**			1.96_{A}**
50-57	1.53_{BCDE}	1.61_{BC}*	1.52_{BCDEF}	1.91_{A}**			1.91_{A}**
60-67	1.50_{BCDEF}						

1/ Values with the same letter are not significantly different @ 5% level.

* Clay spoil

** Shale spoil

bulk density of the premined soils ranged from 1.35 to 1.53 gm/cm^3, increasing (non-significantly at 5 percent level) with depth. The mean bulk density of postmined topsoil and heavy clay spoil ranged from 1.55 to 1.63 gm/cm^3, with maximum bulk density occurring at the 19-30 cm depth. Differences in bulk densities between study areas and between depths were not significant for these postmined non-shale materials. Postmined topsoil and clay spoil had slightly higher densities than the premined subsoils though the differences were not significant.

The materials ranked in descending order of bulk density were: Buried shale spoil >> surface shale spoil > heavy clay spoil = reclaimed topsoil just above the spoil (19 - 30 cm depth) > premined subsoils = reclaimed topsoils > premined topsoils.

The bulk density of the shale spoil (1.85-1.96 gm/cm^3) was slightly higher than reported in other areas (eg. 1.75-1.85 gm/cm^3 in Kentucky; Ward et al., 1981) and lower than densities of 1.9 - 2.2 gm/cm^3 reported for spoil in Oklahoma by Haigh (1978). The major factors contributing to the high bulk densities were 1) the spoil contained a high proportion of rock fragments, 2) the rock fragments were dense, (Haigh (1978) reported a specific gravity of 2.5 gm/cm^3 for shale in Oklahoma), 3) soil structure was absent in the spoil fines and 4) compaction by dozers and scrapers used in grading and topsoiling. No particular reason was apparent for the slightly though not significantly lower densities of shale spoil at the Foyil study area.

The density of the clay spoil at Porter North was probably increased because scrapers were used to spread it when moisture content was high. The topsoils at the three study areas were also spread with scrapers. Being of similar textures they were compacted to about the same density.

The influence of higher postmined density on plant growth cannot easily be expressed quantitatively. Root penetration into soil is dependent on soil strength which varies with both soil moisture content and bulk density. Roots may penetrate into a dense soil at high moisture content but not into a moderately dense soil at low moisture content due to the greater soil strength. As bulk density increases, the overall potential for growth stress and yield depression increases. Bowen (1981) suggests as a rule-of-thumb (with many exceptions) that bulk densities of 1.55 and 1.65 gm/cm^3 will severely impede root growth and thus reduce yields on clay loams and silt loams, respectively.

According to this rule-of-thumb, the postmined silt loam topsoils should not severely impede root growth, although they are more likely to impede growth than premined topsoils. The density of the clay spoil was greater than the rule-of-thumb value for clay loam. These materials were also structurally massive which would further limit root penetration. The high density of the shale spoils has a high potential for limiting root growth to within the overlying topsoil. As the less dense shale spoil layer only extends 5 to 10 cm into the surface of the non-topsoiled spoil profile, sparse vegetation is likely if no special treatment is used on non-topsoiled areas.

Bulk densities of postmined soils appear high enough to reduce plant yields. In order of decreasing desirability, with respect to bulk density, the soil profiles were ranked as follows: Premined soils > topsoil over clay > topsoiled spoil > non-topsoiled spoil.

Hydrologic Consequences

Bulk density, in itself, is not considered a good indicator of soil permeability. Mason et al. (1957) found that the correlations between hydraulic conductivity and bulk density were negative and generally of a low absolute value. Hirschi and Moore (1980) found that bulk density explained little of the variation in the parameters describing the soil moisture retention characteristics of Midwest soils. Both of these studies involved natural soils with bulk densities usually not exceeding 1.6 gm/cm^3. The effect of bulk density above 1.6 gm/cm^3 on hydraulic properties may be greater. Low infiltration rates into spoil profiles were attributed, in part, to high densities by Ward et al. (1981). Increased density must at some level begin to significantly reduce the number and size of continuous pore channels through the soil and thus inhibit water movement.

Coarse Fragments

Results

The mean percentages of coarse fragments (> 2 mm) in spoil at Porter South and Foyil are shown in Table V. The shale spoils were the only soil material containing significant amounts of coarse fragments. The mean coarse fragments content of the surface spoil (5-12 cm depth) at Porter South was 47 percent while that below 12 cm ranged from 57 to 61 percent. There was, however, little certainty that a trend towards lower coarse fragments content nearer the surface actually occurred in the field. Each mean represented only three samples and the standard deviations were relatively large. The standard deviations, which ranged from 3.3 to 13.5 percent, were similar to values reported by Pedersen et al. (1978) and Pettry et al. (1980). At Foyil the spoil contained 46 percent coarse fragments.

Hydrologic Consequences

Coarse fragments are expected to significantly reduce the available moisture holding capacity of the spoil. The coarse fragments are also expected to reduce infiltration

TABLE V

PERCENTAGE COARSE FRAGMENTS AND 0.1 BAR MOISTURE RETENTION OF SPOIL WITH AND WITHOUT COARSE FRAGMENTS

Sample Depth	Mean % Coarse Fragments & (STD)[1]	Mean 0.1 Bar Moisture Retention	
		Coarse plus Fines	Fines only (< 2mm)
(cm)	(% < 2mm)	(% dry weight)	
	Porter South - Shale Spoil		
5-12	47.0 (13.5)	15.2[2]	25.3
36-43	61.0 (9.3)	15.4	26.2
50-57	57.0 (3.3)	16.1	26.9
	Foyil - Shale Spoil		
23-30	45.8 (11.9)	18.2[2]	30.6
	All other soils were low in % coarse fragments.		

[1]STD = standard deviation, shown in parenthesis adjacent to the mean value.

[2]Estimated assuming the same reduction in moisture retention due to coarse fragments as was measured for 36-43 and 50-57 cm samples at Porter South, i.e., Moisture c. (Coarse + fines) = 0.6 x moisture c. (fines).

to some degree because they are flat, platey and lie horizontally, and are very tightly packed. Spaces between fragments are filled by smaller fragments and fines, giving the spoil profile the appearance of being massive. The platey shale fragments create a torturous path for water flow and reduce the cross sectional area for downward flow.

Results from moisture retention tests at 0.1 bar suction for spoil samples from 36-43 and 50-57 cm depths at Porter South are shown in Table V. For spoil containing coarse fragments the mean 0.1 bar values were 15.4 and 16.1 percent compared with 26.2 and 26.9 percent for the fines. This represented a 40 percent reduction in moisture retention due to coarse fragments. It was calculated that the coarse fragments retained an average of 8.5 percent moisture at 0.1 bar. Pedersen et al. (1980) and Hanson and Blevins (1979) reported that shale fragments retained 6.8 percent moisture or greater at 15 bar. It is apparent that the shale fragments, though slightly porous, supply very little available water storage capacity.

Soil Moisture Retention

Measured Gravimetric Moisture Retention

Table VI shows the average gravimetric moisture retention at 0.1 and 15 bar suction and the mean available

TABLE VI

MEAN GRAVIMETRIC MOISTURE RETENTION AT 0.1 AND 15 BAR SUCTION AND MEAN AVAILABLE WATER

Depth	Premined: Mean Moisture Content			Postmined: Mean Moisture Content		
	0.1 Bar[1/]	15 Bar[1/]	Avail. Water[2/]	0.1 Bar[1/]	15 Bar[1/]	Avail. Water[2/]
(cm)	(% dry weight)			(% dry weight)		
Taloka Soil - Porter North - Topsoiled Clay Spoil						
5-12	37.8	6.4	31.4	31.5[4/]	6.1	25.4
19-26	34.3	4.8	29.4	33.9	10.2	23.7[3/]
30-37	33.0	5.6	27.4	43.5[3/]	18.0[3/]	25.5
36-43	33.4	7.2	26.1	35.8	14.6	21.2*
50-57	35.6	10.2	25.4	39.7	17.7	22.0*
60-67	33.4	8.8	24.6			
Newtonia Soil - Porter South - Topsoiled Shale Spoil						
5-12	31.3	6.0	25.4	34.6	6.6	28.6
19-26	32.1	8.7	23.3	32.5	8.1	24.4
23-30				37.3	9.5	27.8
36-43	37.4	12.5	24.8	15.4[4/]	8.4	7.0[4/]**
50-57	34.3	15.0	19.4	16.1[4/]	8.9	7.2[3/]**
Porter South - Non-topsoiled Shale Spoil						
5-12				15.2[4/]	6.4	8.8[4/]**
36-43				15.4[4/]	8.4	7.0[4/]**
50-57				16.1[4/]	8.9	7.2[3/]**
Summit Soil - Foyil - Topsoiled Shale Spoil						
5-12	36.2	13.8	22.4	37.4	14.7	22.7
23-36	35.4	15.8	19.6	18.2[4/]	9.6[3/]	8.6[4/]**

[1/]Determined with sieved soil. For 0.1 bar soil included coarse fragments.

[2/]Available water = 0.1 Bar moisture content - 15 bar moisture content.

[3/]Denotes postmined moisture retention significantly different from premined at 5 percent level.

[4/]Denotes postmined moisture retention significantly different from premined at 0.5 percent level.

* Clay spoil and ** Shale Spoil

water content of the profiles. Statistically significant differences between moisture content at the same suction are indicated for means at the same depth. For the non-topsoiled spoil the statistical comparison was made with moisture retention of the premined profile at Porter South.

The moisture retention characteristics of the shale spoils were very different from those of the other soil materials. The 0.1 bar moisture retention was significantly less than that of the other soils. This was attributed to the presence of the coarse fragments. The 15 bar moisture retention of the shale spoils was similar to the other soils. The mean available water of shale spoils was about one third that of the other soils. Moisture retention characteristics of the postmined topsoils at Porter South and Foyil were similar to their premined counterparts.

At Porter North the 0.1 bar moisture retention and the available water capacity were reduced in the postmined profile compared to the premined profile. The difference in 0.1 bar moisture retention was highly significant in the 5 to 12 cm depth, probably due the loss of organic matter when the topsoil was reclaimed. At the 30 to 37 cm depth in the postmined profile both the 0.1 bar and 15 bar moisture retention were high due to the high clay content (50 percent) of the samples. Although the differences between the moisture characteristics of the premined and postmined profiles at Porter North were statistical significant in some cases the actual magnitude of the changes were not great (7 to 19 percent of the premined available water capacity was lost).

Porosity

The porosity of selected soil samples was determined from bulk density and also from moisture retention at saturation. Porosity values calculated by the two methods are plotted against each other in Figure 4. The majority of the data points lie within ± 5 percent volume of the equal value line. For these values neither of the methods appeared superior to the other.

Two groups of data points lie outside of ±5 percent of the equal value line. These data points represent samples from the clay spoil at Porter North and from the shale spoils. Both groups had greater porosity by the saturation method than by the bulk density method. The clay spoils were observed to swell during wetting. Porosity determined by the saturation method was considered more representative of these swelling clay materials. For the shale spoils the greater porosity by the saturation method was attributed to disturbance of the spoil during sampling and upon wetting. Porosity calculated from bulk density was considered more reliable for the shale spoil. Porosity from bulk density was used for all samples except those from Porter North.

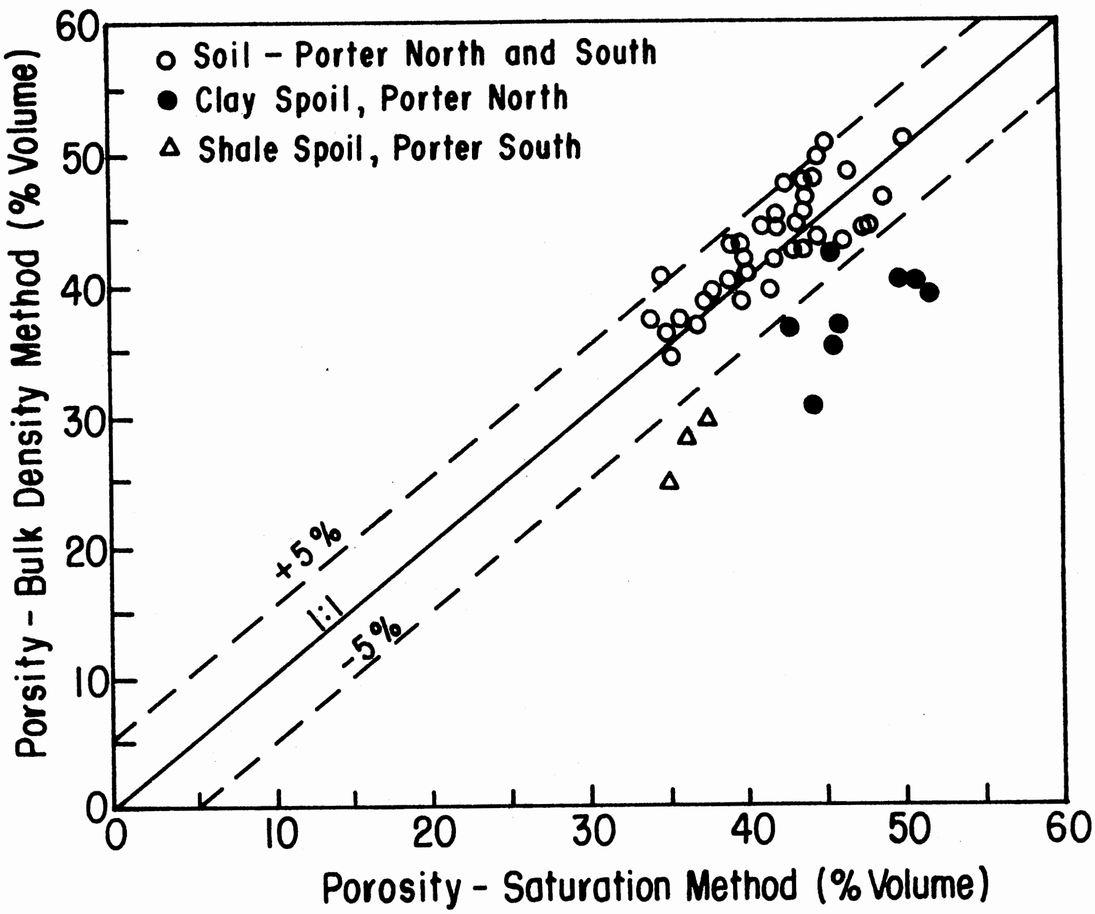

Figure 4. Comparison of Soil Porosity Determined From Bulk Density and by Measuring the Moisture Content of Undisturbed Cores at Saturation

Volumetric Moisture Retention

Average volumetric moisture retention at 0.33 and 15 bar suction and the average porosity for the soil profiles are presented in Figures 5 through 8. The 0.33 bar values were calculated from measured 0.1 and 15 bar values, as described in Appendix C. These corrected values were considered to more closely approximate field capacity than the 0.1 bar moisture retention.

At Porter North the moisture characteristics of the postmined topsoil were similar to those of the premined topsoil. The clay spoil exhibited very high 15 bar moisture retention resulting in reduced available water in the postmined subsoil compared with the premined subsoil. The porosity of the topsoil was reduced and the porosity of the subsoil was greater after mining. Greater 0.33 bar moisture retention resulted in a large decrease in the gravitational water capacity of the postmined subsoil. Compared with the shale spoils, the clay spoil had more desirable moisture retention characteristics.

At Porter South and Foyil the shale spoils had much less available water capacity than the natural soils. This was expected from the coarse fragments and gravimetric moisture retention results. Available water and 15 bar moisture were relatively unchanged for the topsoils. Porosity of the postmined soils was always less than that of the premined soils, particularly for the shale spoils.

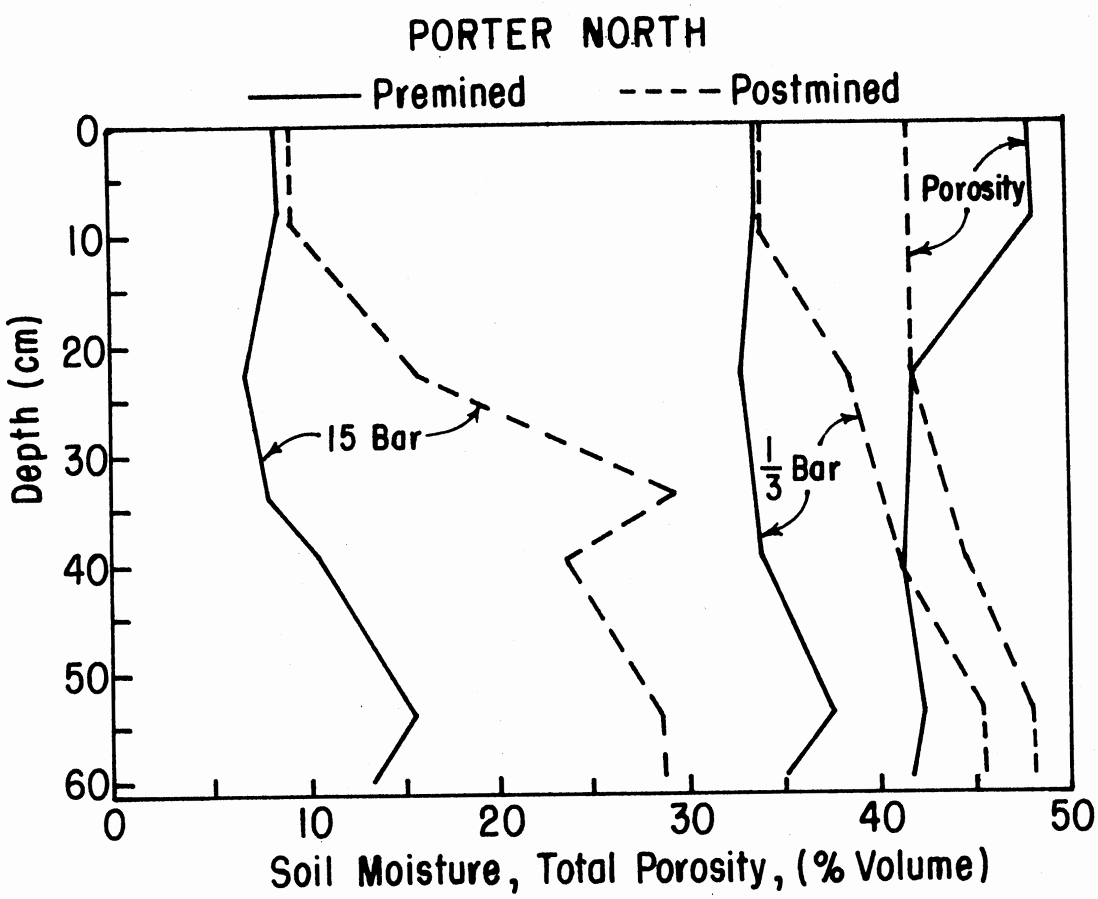

Figure 5. Average Volumetric 0.33 and 15 Bar Soil Moisture Retention and Porosity for the Premined and Postmined Profiles at Porter North.

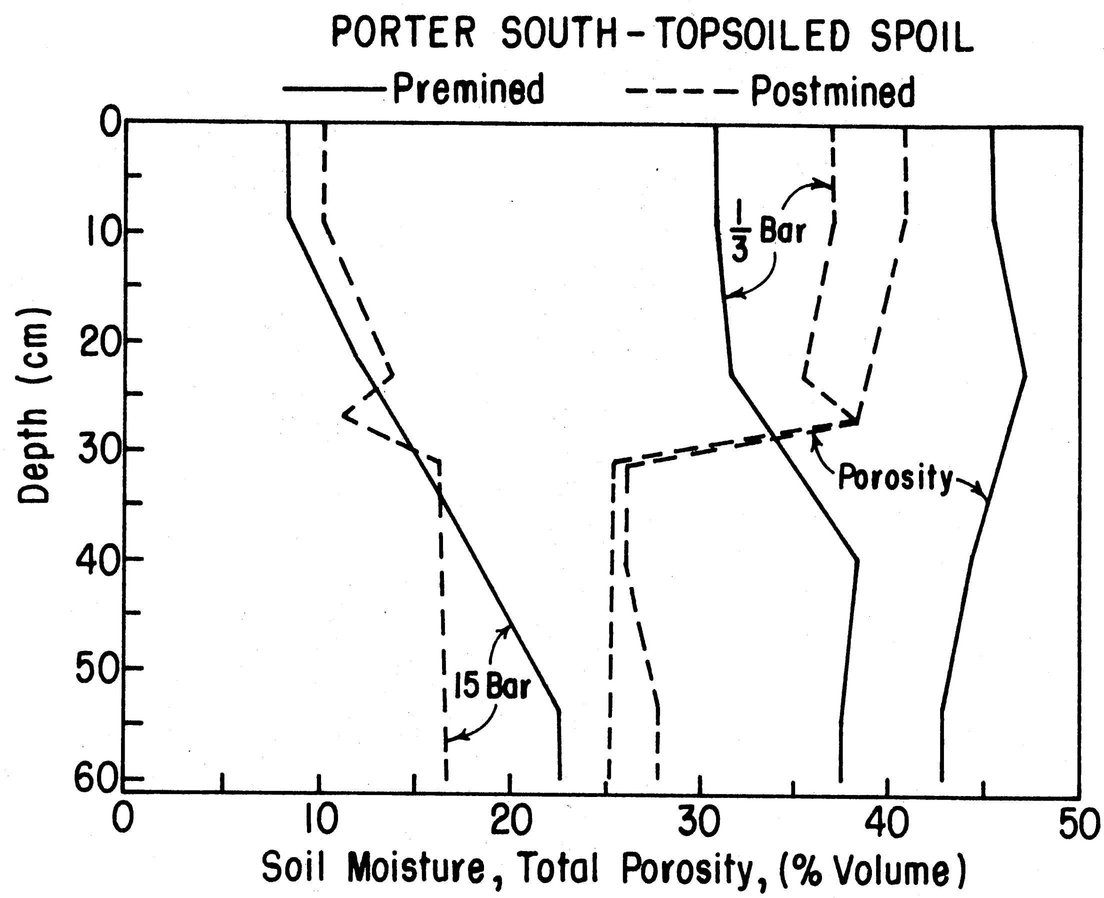

Figure 6. Average Volumetric 0.33 and 15 Bar Soil Moisture Retention and Porosity for the Premined and Topsoiled Spoil Profiles at Porter South

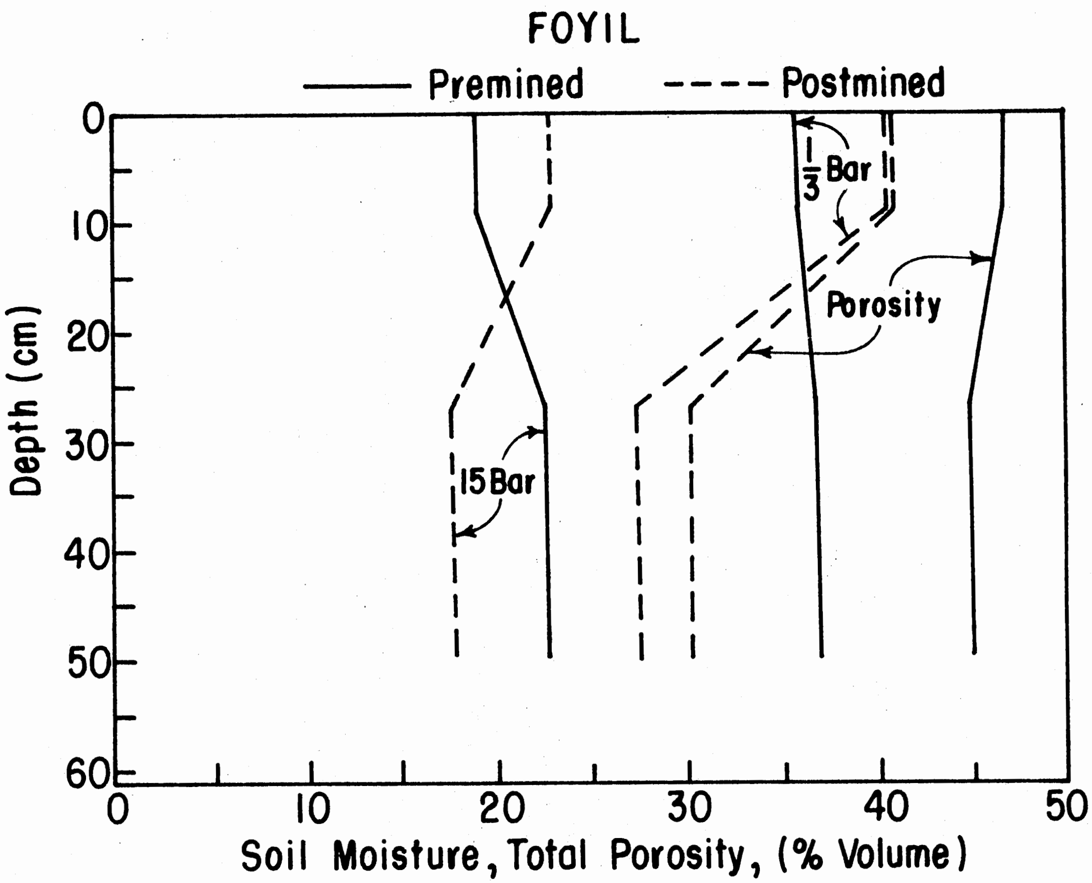

Figure 7. Average Volumetric 0.33 and 15 Bar Soil Moisture Retention and Porosity for the Premined and Postmined Profiles at Foyil

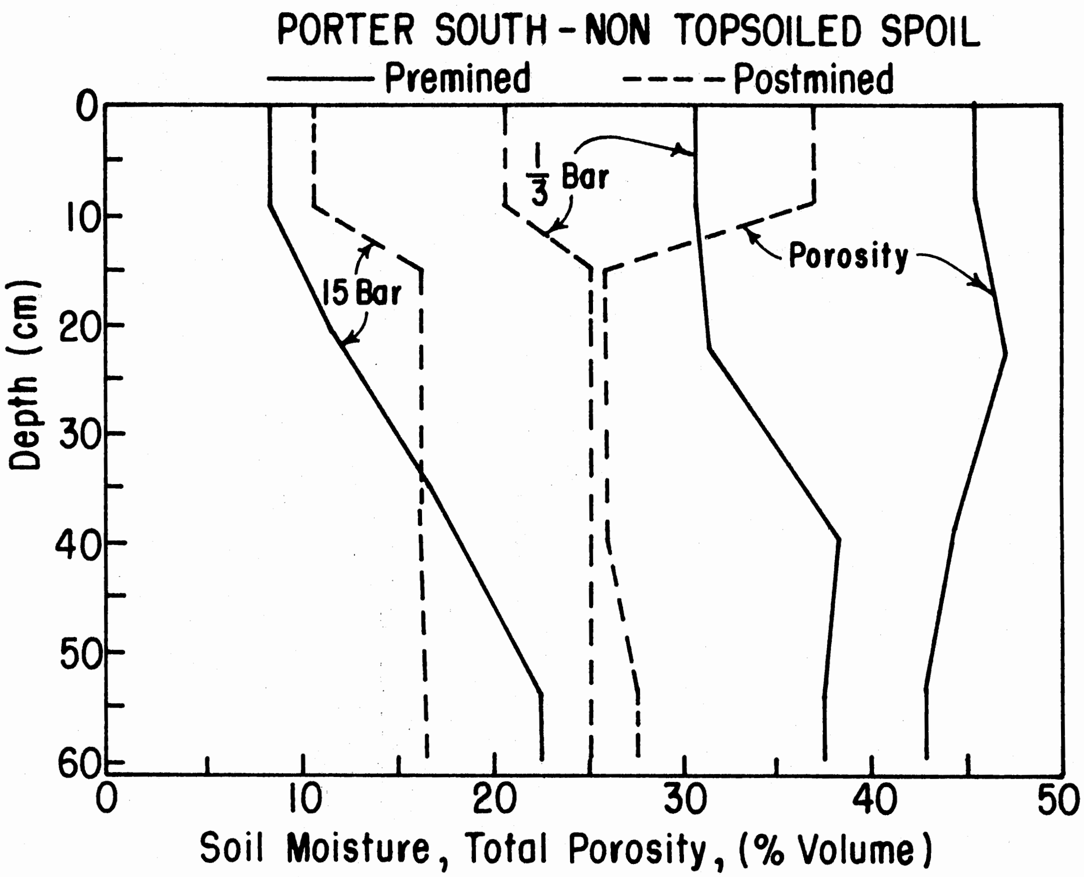

Figure 8. Average Volumetric 0.33 and 15 Bar Soil Moisture Retention and Porosity for the Premined and Non-Topsoiled Spoil Profiles at Porter South.

The gravitational water storage of the postmined topsoils and shale spoils was greatly reduced compared with the premined soils.

The non-topsoiled spoil profile had similar 15 bar moisture and greatly reduced 0.33 bar moisture and porosity compared with the premined soil at Porter South. The available moisture was about one half that of the premined soil. Gravitational water capacity was very low, except in the surface 12 cm. The greater gravitational water storage of the surface spoil compared with the spoil below 12 cm, was representative of the field situation where the coarse fragments were not packed so tightly, creating many large pores.

Total Water Storage Capacities

The weighted average moisture capacities and total available water for the profiles are presented in Table VII. The wilting point and topsoil porosity values in this table were used to represent the profiles in modeling.

The most significant change was the reduction in total porosity of the profiles after mining. For the shale spoil profiles (Porter South and Foyil), field capacity was also reduced slightly. The non-topsoiled spoil profile had particularly low porosity and field capacity. At Porter North, the porosity was decreased and the field capacity increased resulting in very low gravitational water capacity in the postmined profile.

TABLE VII

TOTAL AVAILABLE WATER AND DEPTH WEIGHTED AVERAGE MOISTURE CAPACITIES OF THE PROFILES

Treatment	Root Depth (cm)	Weighted Average M.C. Wilting Point (cm/cm)	Field Capacity (cm/cm)	Porosity (cm/cm)	Total Avail. Water (cm)
		Porter South - Newtonia Soil			
Premined	60	0.15	0.35	0.45 (0.46)[1/]	11.6
Topsoil/	47	0.13	0.32	0.34 (0.41)	8.9
Spoil	60	--	--	--	10.03
Non-	30	0.15	0.25	0.30 (0.34)	2.81
Topsoiled Spoil	60	--	--	--	5.42
		Porter North - Taloka Soil			
Premined	60	0.10	0.34	0.46 (0.47)	14.57
Topsoil/ Clay	60	0.19	0.39	0.40 (0.41)	12.14
		Foyil - Summit Soil			
Premined	60	0.22	0.37	0.46 (0.49)	8.99
Topsoil/	40	0.20	0.35	0.36 (0.42)	5.64
Spoil	60	--	--	--	7.60

[1/] Porosity for topsoil; surface 10 cm for non-topsoiled spoil.

Total available water (TAW) of the postmined profiles was less than that of the premined profiles in all cases. When the same root depth (60 cm) was used, the TAW of the reclaimed profiles which were topsoiled was not very much less than that of their premined companion. When the root depths of the postmined profiles at Porter South and Foyil were reduced to account for high densities and coarse fragments, the TAW was reduced significantly. The non-topsoiled spoil profile at Porter South had highly unfavorable TAW, even if roots penetrated deeply. Topsoiling was very beneficial from the point of view of water availability as it increased both the potential rooting depth and the storage capacity per unit of root depth.

Hydrologic Consequences

The postmined profiles all showed a large decrease in gravitational water capacity compared with the premined profiles. Mason et al. (1957) suggest that the percentage of pores drained at low moisture suction, i.e. the gravitational water, gives a good approximation of the percentage of larger pores. It was apparent that the postmined profiles had a greatly reduced large pore volume compared with the premined profiles. Mason et al. (1957), studying data from 10,000 cores, found that the percent of large pores was positively and consistently correlated with the saturated hydraulic conductivity. It was concluded that the saturated hydraulic conductivity of the postmined profiles would be reduced compared with the premined profiles, due to the decrease in large pore volume.

Saturated Hydraulic Conductivity

Results

Table VIII shows the mean saturated hydraulic conductivity (K_{SAT})* for undisturbed cores from the premined soil (Taloka) and the postmined clay spoil at Porter North. Results are also given for undisturbed cores of shale spoil from Porter South.

The K_{SAT} values for the clay spoil were consistently lower than the premined values, by two order of magnitude or more. K_{SAT} values showed no trend with depth for the clay spoil. The very high value at site 2, 80 to 85 cm depth, was considered erroneous. The average K_{SAT} for the clay spoil, with the erroneous value and the zero value excluded was 0.0094 cm/hr, compared with an average K_{SAT} of 0.69 cm/hr for the premined soil (90-95 cm depth).

K_{SAT} varied considerably within and between sites on the premined study area. The very low values at site

---

*The K_{SAT} values were means of 10 or more replications on each core. Variation of K_{SAT} within replications for each core is discussed at the end of Appendix A.

TABLE VIII

MEAN SATURATED HYDRAULIC CONDUCTIVITY OF UNDISTURBED CORES FROM THE PORTER NORTH STUDY AREA AND FOR SHALE SPOIL FROM PORTER SOUTH

Sampling Depth (cm)	Premined				Reclaimed			
	Site	K_{SAT} 1/ (cm/hr)	CV (%)	N	Site	K_{SAT} 1/ (cm/hr)	CV (%)	N
				Taloka SiL - Porter North - Clay Spoil				
30-40	C	16.1	0.8	8				
	D	4.79	4.6	18				
40-50	C	1.53	3.8	10	1	0.0141	19.9	13
	D	5.35	2.5	7	2	0.00271	7.3	12
					3	0.00028	23.4	6
55-60					1	0.00458	15.3	8
60-70	B	2.60	3.0	13	1	0.00221	7.8	11
	C	6.09	5.3	13	2	0.0	no flow	
	D	0.00044*	14.8	11	3	0.00157	11.7	6
					5	0.00137	7.5	9
80-85	B	0.270	12.0	11	1	0.0577	20.3	11
	C	1.841	6.3	10	2	5.50*	2.3	4
90-95	B	0.927	6.2	10	3	0.0060	15.6	13
	C	0.130	23.2	11	5	0.0038	14.5	9
	D	1.014	18.2	11				
95-100	D	0.0039*	16.4	11				
				Porter South - Shale Spoil				
30-50						0.311	15.0	9
						0.011	40.0	5

1/ K_{SAT} = mean saturated hydraulic conductivity for N number of tests on each undisturbed soil core.

* Values considered erroneous.

D, 60-70 cm and 95-100 cm depths, were considered erroneous and not representative of the Taloka soil. On the average there was a consistent trend of decreasing K_{SAT} with depth for the premined soil. The measured values of K_{SAT} were similar to saturated hydraulic conductivity for Taloka silt loam from Holtan (1968). Holtan's values ranged from 1.0 to 5.0 cm/hr in the upper 50 cm and from 0.05 to 0.50 cm/hr for the 50-100 cm depths.

Although only two values of K_{SAT} were available at Porter South it was apparent that the shale spoil was generally less permeable than the premined soil. Data from Ward et al. (1981), Younos and Shanholtz (1980) and Pedersen et al. (1980) for shaly spoils cover a similar range and indicate the K_{SAT} of shale spoil is likely to be 0.1 cm/hr or less.

In summary, the soil materials ranked in order of decreasing saturated hydraulic conductivity were: topsoil > premined subsoil > shale spoil > clay spoil.

Hydrologic Consequences

When the permeability of the subsoil is very low, as was the case for the postmined profile at Porter North, the cummulative infiltration capacity of the profile during a rainfall event is limited to the storage capacity of the topsoil. As the topsoil depth was about 30 cm Porter North, runoff would occur after 9 cm of rainfall when the topsoil was at wilting point. Runoff would occur after 1.5 cm of rainfall when the topsoil was at field capacity. If the rainfall intensity was greater than the intake rate of the topsoil, runoff would occur sooner. When the permeability of the spoil is greater, as for the shale spoil compared with the clay spoils, or the topsoil depth is greater, time is ponding is longer and total runoff is reduced.

Based on the K_{SAT} of the subsoil or spoil only (i.e ignoring the effects of topsoil depth and water storage capacity) the profiles ranked from greatest to least runoff potential were: Topsoil over clay spoil at Porter North > postmined profiles at Porter South and Foyil > premined profiles.

Salinity

Results

Salinity levels in terms of Total Soluble Salts (TSS in ppm) and Electrical Conductivity of saturation extract (EC in micro mhos/cm) are presented in Table IX. Ranked in order of decreasing salinity the soil materials were: clay spoil > shale spoil at Porter South > Surface Shale spoil > reclaimed topsoil at Porter North > shale spoil at Foyil = reclaimed topsoil at Foyil and Porter South = Premined soils.

TABLE IX

TOTAL SOLUBLE SALTS AND ELECTRICAL CONDUCTIVITY OF COMPOSITE SAMPLES FOR PRE-MINED AND POST-MINED SOILS

Depth (cm)		Porter North		Porter South		Foyil		Non-topsoiled Spoil
		Pre-mined	Post-mined	Pre-mined	Post-mined	Pre-mined	Post-mined	
9	TSS[1]	1290	2220	1250	1330	1240	810	2840 **
	EC	1950	3360	1890	2010	1880	1230	4305 I
23	TSS	1010	3670			1120	1870 **	
	EC	1530	5565 I[2]			1595	2835	
40	TSS	900	8320 *	880	7030 **	1435		7030 **
	EC	1355	12600 III	1335	10550 II	2175		10550 II
54	TSS	920	8120 *	830	7030 **			7030 **
	EC	1395	12300 III	1260	10550 II			10550 II

* Clay Spoil and ** Grey Shale Spoils.

[1] TSS = Total Soluble Salts, ppm; EC = Electrical Conductivity, micro mhos/cm.

[2] Recommendations given by Water and Soil Salinity Testing Lab., Agron. Dept., O.S.U.

I   Salinity sufficiently high to reduce yield of moderately tolerant crops.

II   As for I above - TSS is about twice normal levels.

III   Salinity sufficiently high to reduce yield of even salt tolerant crops - TSS is about three times normal levels.

The clay spoil at Porter North and the shale spoil at Porter South had salinity levels considered high enough to stress plants and reduce yields.

The premined soils exhibit low salinity levels through out the profile. The salinity of the reclaimed topsoil and the premined topsoils from which they were derived were generally similar. At Porter North, however, salinity was noticeably higher in the reclaimed topsoil than the premined topsoil, particularly in the sample from just above the clay spoil. This suggests that some clay spoil was mixed with the topsoil during reclamation. Some upward movement of salts from the clay spoil may have occurred although the study area was reclaimed less than a year prior to sampling.

On topsoiled saline spoil areas root growth below the topsoil will be inhibited. According to Davidson (1981) the root mass is expected to remain in the topsoil for several years, whether the spoil is saline or not. Thus plant stress due to salinity was not expected to be immediately apparent. Salinity is expected to significantly affect plant cover conditions on non-topsoiled saline spoils. The soil profiles ranked in order of increasing limitation due to salinity were: Premined soils = topsoiled spoil at Foyil < topsoiled shale spoil at Porter South < topsoiled clay spoil < non-topsoiled shale spoil.

Acidity (pH)

Results

The pH of composite samples from various depths for each profile are presented in Table X. The pH values of the premined soils ranged from 4.6 to 6.4 while pH values of postmined soils ranged from 4.9 to 7.3. These results suggest that mining had no detrimental affects on the apparent acidity of the mined areas. Potential acidity was not measured.

The variability in pH of the spoils, from 4.9 to 7.3, was not unexpected as the pH of overburden strata in Oklahoma is known to vary from extremely acid to alkaline (Rogers, 1951). The use of composite samples from each depth precludes determination of variation spatially on each study area. Similarly extreme acidity or "hot spots" may have been missed or averaged out by the mixing of samples.

Organic Matter Content

Results

Organic matter contents of composite samples from the premined and postmined soils are presented in Table XI. Organic matter contents of premined soils were low (2.0 percent or less) as is typical of Oklahoma soils. Organic matter levels of postmined topsoils were usually one half

TABLE X

pH FOR PRE-MINED AND POST-MINED SOIL PROFILES

Depth (cm)	Porter North		Porter South		Foyil		Non-topsoiled Spoil
	Pre-mined	Post-mined	Pre-mined	Post-mined	Pre-mined	Post-mined	
9	5.3	5.2	5.5	5.6	5.1	5.7	7.3 **
23	4.8	5.3			5.4	6.4 **	
40	5.0	7.1 *	6.4	5.2 **	4.6		5.2 **
54	5.1	4.9 *	6.3	5.2 **			5.2 **

* Clay Spoil

** Grey Shale Spoils

Key to Acidity	pH
Extremely Acid	<4.5
Very Strongly Acid	4.5-5.0
Strongly Acid	5.1-5.5
Medium Acid	5.6-6.0
Slightly Acid	6.1-6.5
Neutral	6.6-7.3
Mildly Alkaline	7.4-7.8

Ref: USDA Handbook No. 18, "Soil Survey Manual," 1951.

Note: pH for 1:1 soil to water suspension for composite samples.

TABLE XI

ORGANIC MATTER CONTENT AND SODIUM ABSORPTION RATIO OF COMPOSITE SAMPLES FOR PRE-MINED AND POST-MINED SOIL PROFILES

Depth (cm)	Porter North		Porter South		Foyil		Non-topsoiled Spoil
	Pre-mined	Post-mined	Pre-mined	Post-mined	Pre-mined	Post-mined	
			Organic Matter Content (%)				
9	1.9	0.6	1.5	0.8, 1.1	2.0	0.8	0.7 **
23	1.1	0.8			1.5	0.7 **	
40	0.9	0.5 *		1.0 **	1.0		1.0 **
54	0.9	0.1 *		0.7 **			0.7 **
			Sodium Absorption Ratio (SAR)				
9	1.0	2.0	1.0	2.0	0.0	1.0	3.0 **
23	1.0	3.0			1.0	3.0 **	
40	2.0	3.0 *	11.0	2.0 **	1.0		2.0 **
54	4.0	3.0 *	12.0	3.0 **			3.0 **

* Clay spoil

** Grey shale spoil

(or less) those of premined topsoils. Spoils registered organic matter levels similar to reclaimed topsoils and premined subsoils. This may be due to the presence of carbon containing substances other than organic matter, especially coal fragments.

Low organic matter levels tend to reduce soil aggregation and influence many of the properties of soils. Improvement in organic matter content would be beneficial to soil structure and hydraulic properties of the soils.

Sodium Absorption Ratio

Results

The sodium absorption ratio (SAR) of the premined and postmined soils are presented in Table XI. The SAR of both the premined and postmined soils was low. The problems specific to sodic soils which are sometimes troublesome on minesoils were not prevalent on the mine areas studied.

CHAPTER V

HYDROLOGIC MODELING OF RUNOFF FROM PREMINED AND POSTMINED SOIL PROFILES

Introduction

The aim of this part of the study was to investigate the effect of changes in soil properties, caused by surface mining, on the hydrology of runoff source areas.

A modeling approach was used. This approach allows the relative difference in hydrologic response of various premined and reclaimed soil profiles to be estimated under the same environmental conditions (i.e. the same rainfall, evaporative demand, etc.).

The model (CREAMS hydrology option two) was run for each of the seven soil-treatment profiles described in the previous chapters. To maintain objectivity in parameter value estimation, selection criteria were defined for each soil parameter used by the model. Input values for each parameter were then selected by applying the same criteria for all of the profiles.

The CREAMS Hydrology Model

Model Suitability

The CREAMS model (Knisel, 1980) was used because

a) It is physically based, allowing soil parameter inputs to be estimated from measured soil properties.

b) It provides a continuous simulation of the soil moisture balance and runoff response for as many years as data is available, ie. for a range of wet and dry periods.

The CREAMS model has limited capability to account for spatial variability of soil properties and topographic features. It is essentially a model for a single hydrologic response unit or a "field scale" area. This level of simplicity was quite suitable for study of individual premined and reclaimed soil profiles.

Brief Description of CREAMS

The CREAMS hydrology model computes storm runoff depth, using a continuous simulation of soil moisture between storms to compute the antecedent soil moisture condition.

Two alternative infiltration-rainfall excess options are available with CREAMS. Option one is the daily runoff model, based on the SCS Curve Number model. Option two uses an infiltration simulation based on the Green and Ampt infiltration relation and breakpoint rainfall input data to calculate rainfall excess. Both options generate the peak runoff rate for each runoff producing event. Option two was used in this study.

For a more complete description of the CREAMS model the reader is referred to the CREAMS users manual (Knisel, 1980).

Generalized Watershed and Environmental Factors

The model was run for each of the soil profiles for the same simple generalized watershed and environmental conditions.

Meteorological Data

Breakpoint rainfall, average monthly temperature (TEMP(J)*), and average monthly net radiation (RAD(I)) data, for 13 years (1941 to 1953), from the GUTHRIE W-5 watershed, were used for all simulations. This watershed is located in Logan county in central Oklahoma about 145 km west of the Porter mine study areas.

Plant Cover Condition

The annual leaf area index (LAI or X(I)) versus time pattern was selected to simulate poor grass cover

---

*The abbreviations are those used in the CREAMS User's Manual (Knisel, 1980).

conditions. The values for pasture in excellent condition, given in the CREAMS Manual (Knisel, 1980) were halved as suggested. A winter cover factor (GA) of 0.5, suitable for grass, was used.

Watershed Descriptors

The CREAMS option two describes the watershed using the area (DACRE), field slope (SLOPE), length of flow path (XLP) and Manning roughness coefficient for field surface (RMN). These four watershed parameters were measured on a watershed at the Porter South mine. As only the depth of runoff was considered in this study any typical inputs could have been used. DACRE was 28 ha (70 ac), SLOPE was 0.02 m/m, XLP was 550 m (1800 ft) and RMN was 0.035, for overland flow through grass.

Soil Profile Parameters

The soil profile parameter values were selected for each of the seven soil-treatment profiles described in chapters three and four, using the selection criteria given below. Of the soil input parameters, simulated runoff volume is significantly sensitive to the effective saturated hydraulic conductivity (RC) and moderately sensitive to the soil evaporation parameter (CONA), the effective capillary suction (GA) and the porosity (POROS). The simulated mean soil moisture is significantly sensitive to POROS and the portion of available water storage filled at field capacity (FUL). It is also moderately sensitive to CONA. The other soil parameters only slightly affect simulated runoff volume and average soil moisture.

Formulation of Input Selection Criteria

Selection criteria for soil parameter values were compiled to allow objective assessment of inputs. Thus the value of each parameter was selected according to the same predetermined criteria for all of the profiles.

The selection criteria were based on:

a. knowledge of how the model describes the soil profile and soil water movement into and within the profile (See Knisel, 1980), and

b. by comparing CREAMS soil parameter values, optimized for gaged watersheds, with known physical properties of the watershed soils (Pathak, 1982).

For each parameter, a choice was usually made between using 1) a weighted average value for the profile, 2) a value for the topsoil or 3) a value for the subsoil.

Selection Criteria and Determination of Inputs

RC - Effective saturated hydraulic conductivity. The RC value for each soil profile was taken as the saturated hydraulic conductivity of the least permeable layer in the soil profile.

Estimates were made from measured data when available, otherwise, conductivity was estimated from soil texture using average values published by Rawls et al. (1981). A detailed description of the data used for estimation of RC values is given later in this chapter.

GA - Effective capillary suction. The capillary suction was estimated from the RC value. Musgrave's hydraulic conductivity ranges (Hawkins, 1980) were used to choose a high, medium or low value within each hydrologic soil group (e.g. C+, C, C-). The GA value was then selected for the soil group, using the relationship between soil groups and GA values given in Table II-9 in the CREAMS manual (Knisel, 1980). Values were decreased by 2.5 cm if the topsoil was deep or friable, or increased by 2.5 cm for very shallow or very dense topsoil.

FUL - Portion of plant available water storage filled at field capacity. The weighted average FUL value for the root zone was used.

A FUL value was calculated for each soil sample using the following equation from Foster et al. (1980).

$$FUL = \left(\frac{\text{Field Capacity} - BR15}{\text{Porosity} - BR15}\right)$$

Field capacity was estimated from moisture retention of sieved soil at 0.1 bar suction by applying the corrections described in Appendix C.

The mean value of FUL was calculated for each sampling depth for each soil-treatment. The profiles were divided into layers down to the maximum root depth and the mean values were assigned to the pertinent layers. Depth weighted average values of FUL were then calculated for the total root zone of each soil-treatment profile.

POROS - Soil porosity. POROS was taken as the average value of porosity for the soil surface layer (topsoil).

Porosity was calculated from bulk density for all profiles, except the Taloka premined and reclaimed profiles, for which the moisture content at saturation was used, to account for swelling of the clay subsoil.

BST - Portion of plant available water storage filled when simulation begins. Plant available water storage is the soil water storage between the wilting point and the total porosity (Knisel, 1980). The simulation began on the first of January, when soil profiles in Eastern Oklahoma are usually fairly wet. Therefore, BST values were estimated from field moisture content measurements taken on the mine study areas in the fall of 1981.

CONA - Soil evaporation parameter. Values of CONA were selected for topsoil texture from "Mean Physical Properties of Soils", Franzmier (USDA-SCS, 1982).

BR15 - Immobile soil water content (cm/cm). The value used for BR15 was the depth weighted average moisture content at wilting point for the root zone.

Volumetric moisture content at wilting point was calculated as the product of the gravimetric moisture content at 15 bar suction and the total porosity. The average was calculated for each layer in the root zone. The depth weighted average for the root zone was then calculated.

DP - Depth of root soil zone (inches). DP is the total root depth minus the depth of the surface soil layer, DS. Total root depth was taken as 60 cm (24 inches) except when bulk density was extreme, as was the case for the spoil or topsoiled spoil profiles. The root zone was assumed to extend 30 cm into the non-topsoiled spoil. The total root depth for topsoiled spoil was assumed to be equal to the average measured topsoil depth plus 20 cm.

DS - Depth of surface soil layer. A DS value of five cm (two inches) was used for all profiles in accordance with the recommended range given in the CREAMS Manual (Knisel, 1980). Little information was available on which to base a more detailed selection.

Selection of RC Values

For most parameters a straight forward estimate was possible using the measured data presented in the previous chapter. Estimation of RC, the parameter to which the model is most sensitive, was more complex because conductivity was not measured for all of the profiles.

Saturated hydraulic conductivity was measured on undisturbed cores from the Taloka premined and reclaimed profiles at the Porter North study area. Results for the reclaimed profile (heavy clay spoil) are very consistent while those from the premined profile vary widely. These results are given in Chapter IV.

For the shale spoil, only two conductivity measurements were successfully obtained (0.011 cm/hr and 0.31 cm/hr) due to the practical difficulties involved in collecting undisturbed samples. As the model is very sensitive to the RC value, and three of the seven profiles include shale spoil, more information was desirable to ensure a reliable estimate. A search of prevalent literature was made for conductivity data on mine spoils of similar physical and chemical properties. A summary of the characteristics and conductivities of shaly spoil from this study and others is given in Table XII.

From Table XII it is evident that the shale spoil from Porter, Oklahoma is similar to the Kentucky spoil tested by Ward et al. (1981). The Porter spoil had

TABLE XII

SATURATED HYDRAULIC CONDUCTIVITY, PHYSICAL AND CHEMICAL PROPERTIES OF SPOIL MATERIALS AT PORTER SOUTH AND FROM SELECTED PUBLISHED SOURCES

Overburden Material (Location)	Bulk Density (gm/cm^3)	Texture, (% > 2mm)	SAR, Salinity	K_{SAT} (cm/hr)	Methods
1/ Gray Shale Porter South	1.96 (1.87-2.00)	SiL (59%)	SAR=2 TSS=7030 4/ EC=10550	0.011 0.31	Undisturbed cores.
2/ Dark and Gray Shale, sandstone (Kentucky)	1.71 1.73 1.82	SaL/L (45%)	SAR=1.4 TSS=7400 EC=5530	0.14 0.22 0.04	Large reconstructed profiles
				Final Infiltration Rates	
3/ Sandstone, shale, clay. (Pennsylvania)	1.70	SaL (75%)	---	0.1 0.3-1.1	1 meter deep infiltrometer Single ring infiltrometers

Source of data:

1/ Measurements by the author for shaly spoil from Porter South Study Area.

2/ Ward et al. (1981).

3/ Pedersen et al. (1980) and Pedersen et al. (1978).

4/ TSS = Total Soluble Salts (ppm) and EC = Electrical Conductivity (mhos/cm).

similar salinity and SAR, higher bulk density, higher percentage of coarse fragments and was less sandy than the Kentucky spoil. The latter factors tend to decrease saturated hydraulic conductivity. The conductivity value of 0.04 cm/hr, found by Ward for the most dense profile tested was considered more likely to apply to the Porter, Oklahoma spoil. Pedersen et al. (1978) and Younos and Shanholtz (1980) present values in the same range.

Thus an RC value of 0.04 cm/hr (0.0157 in/hr) was selected for the shale spoil profiles. This is between the two measured rates for the Porter South spoil.

Saturated hydraulic conductivity was not measured for the Newtonia and Summit premined profiles. Although they were measured for the Taloka premined profile and additional data was available from Holtan (1968) a representative minimum value for the profile was not clearly apparent.

Rawls et al. (1981) report average saturated conductivity values of soils according to textural classification. Conductivities, published by Rawls, were assigned to representative textural profiles of the premined soils.

The saturated hydraulic conductivity values, measured or estimated from texture, for the three premined profiles and the four reclaimed profiles are summarized in Table XIII.

Using the selection criteria for RC values, which states that the saturated hydraulic conductivity of the

TABLE XIII

SATURATED HYDRAULIC CONDUCTIVITY DATA USED TO SELECT RC VALUES FOR THE PROFILES

Premined			Postmined		
Depth (cm)	Texture	K_{SAT} 1/ (cm/hr)	Depth (cm)	Texture	K_{SAT} 1/ (cm/hr)
		Porter South - Non-topsoiled Spoil			
			0-110+	Shaly SiL	0.04 2/
		Porter South - Newtonia Soil			
0-44	SiL	1.32	0-27	SiL	1.32
44-67	SiCL/CL	0.15/0.23	27-110+	Shaly SiL	0.04 2/
67-94	SiC/SiCL	0.09/0.15			
94-120	SiC	0.09			
		Foyil - Summit Soil			
0-40	SiCL/Loam	0.15/0.68	0-20	SiL	1.32
40-58	SiC/Clay	0.09/0.06	20-110+	Shaly SiL	0.04 2/
58-110+	Clay	0.06			
		Porter North - Taloka Soil			
0-70	SiL	1.32	35-50	SiC/Clay	0.0057 3/
70-95	SiC	0.09	50-70	SiC/Clay	0.0074
95-125	SiCL/SiC	0.15/0.09	70-85	SiC/Clay	0.058
	Clay	0.06	85-100	SiC/Clay	0.0059
			Average for all cores = 0.0094		

1/ K_{SAT} is saturated Hydraulic Conductivity, estimate for given texture from Rawls et al. (1981) except where denoted 2/ or 3/.

2/ Sat. Hyd. Conductivity for shale spoil from Ward et al. (1981).

3/ Mean values of Sat. Hyd. Conductivity measured by the author.

least permeable layer in the profile will be used, RC values were selected from the conductivities summarized in the Table XIII.

For the premined Newtonia, Summit and Taloka profiles RC values of 0.09, 0.06 and 0.09 cm/hr respectively were selected. An RC value of 0.0094 cm/hr, the average of measured conductivities for the clay subsoil, was used for the reclaimed Taloka profile (topsoil over clay over spoil) at Porter North.

In accordance with the selection criteria, an RC value of 0.04 cm/hr was used for the three profiles involving a shale spoil subsoil, i.e. the non-topsoiled spoil profile and the topsoiled spoil profiles at Porter South and Foyil. It was assumed that differences in soil parameters related to the surface layer (GA and POROS) of the profile, would cause the model to correctly predict the effects of initial infiltration differences in profiles with similar subsoils.

Soil Parameter Input Values

The soil parameter values used to model each of the seven profiles are given in Table XIV.

TABLE XIV

SOIL PARAMETER INPUT VALUES FOR PREMINED AND RECLAIMED PROFILES USED IN THE CREAMS HYDROLOGY SIMULATION

	Profile						
	Porter South			Porter North		Foyil	
CREAMS Soil Parameter	Premined Newtonia	Non-Topsoiled Shale Spoil	Topsoiled Spoil	Premined Taloka	Topsoil Over Clay	Premined Summit	Topsoiled Shale Spoil
RC (cm/hr)[1/]	0.09	0.04	0.04	0.09	0.0094	0.06	0.04
(in/hr)	0.0354	0.0157	0.0157	0.0354	0.0037	0.0236	0.0157
GA (in)	18.0	22.0	20.0	18.0	20.0	19.0	20.0
FUL (in/in)	0.69	0.91	0.90	0.69	0.91	0.64	0.87
POROS (in/in)	0.46	0.30	0.41	0.49	0.42	0.47	0.41
BST (in/in)	0.75	0.5	0.5	0.75	0.75	0.75	0.5
CONA	4.5	4.0[2/]	4.5[3/]	4.5	4.5	4.0	4.0[4/]
BR15 (in/in)	0.15	0.15	0.13	0.10	0.19	0.22	0.20
DS (in)	2.0	2.0	2.0	2.0	2.0	2.0	2.0
DP (in)	22.0	9.8	16.5	22.0	22.0	22.0	14.0

[1/]The CREAMS model requires input values in English units.

[2/]CONA for silt loam fines was reduced to 4.0 to account for coarse fragments in surface.

[3/]CONA for silt loam (= 4.5).

[4/]CONA for silty clay loam (= 4.0) (Franzmier in USDA-SCS, 1982).

CHAPTER VI

RESULTS OF HYDROLOGIC MODELING

This chapter presents the results of simulating the depth of runoff for each of the profiles using the CREAMS hydrology model option two. The soil parameter input values for the CREAMS model simulation are listed in Table XIV at the end of Chapter V.

Summary

The depth of runoff was consistently greater after mining. Compared to their premined condition the mean annual runoff for the postmined profiles ranged from 27 to 153 percent greater. Topsoiling was predicted to reduce runoff after mining at Porter South. Runoff from the topsoiled spoil profile was 49 percent greater than premined compared with 59 percent for the non-topsoiled spoil profile.

The differences in runoff mostly reflect differences in RC values, which were based on the saturated hydraulic conductivity of the least permeable layer in each profile. Other effects which were expected to increase runoff after mining were not fully represented in the simulation. These effects are discussed below. The predicted increase in runoff after mining was considered conservative. Simulated runoff for the non-topsoiled spoil profile was underestimated. An improved approach is needed to quantify the effect of topsoil depth and topsoil properties on the infiltration parameters.

Results

Mean Annual Depth of Runoff

Mean annual simulated runoff depths for each profile are shown in Figure 9. Runoff was consistently greater for the postmined profiles than for the premined profiles.

At Porter North the topsoiled clay spoil profile resulted in a 153 percent increase in mean annual runoff compared with the premined profile. Mean annual runoff for the postmined profile was 358 mm (49 percent of the mean annual rainfall) compared with 141 mm (19 percent of mean annual rainfall) for the premined profile. This large increase in runoff was expected considering the very low permeability of the clay spoil compared with the premined subsoil.

At Porter South and Foyil the mean annual depths of runoff for the topsoiled spoil profiles were 49 and 27 percent greater than for the premined conditions, respectively. The runoff depths were similar for the postmined profiles at Porter South and Foyil. Both of these profiles involved topsoiled shale spoil. The properties of

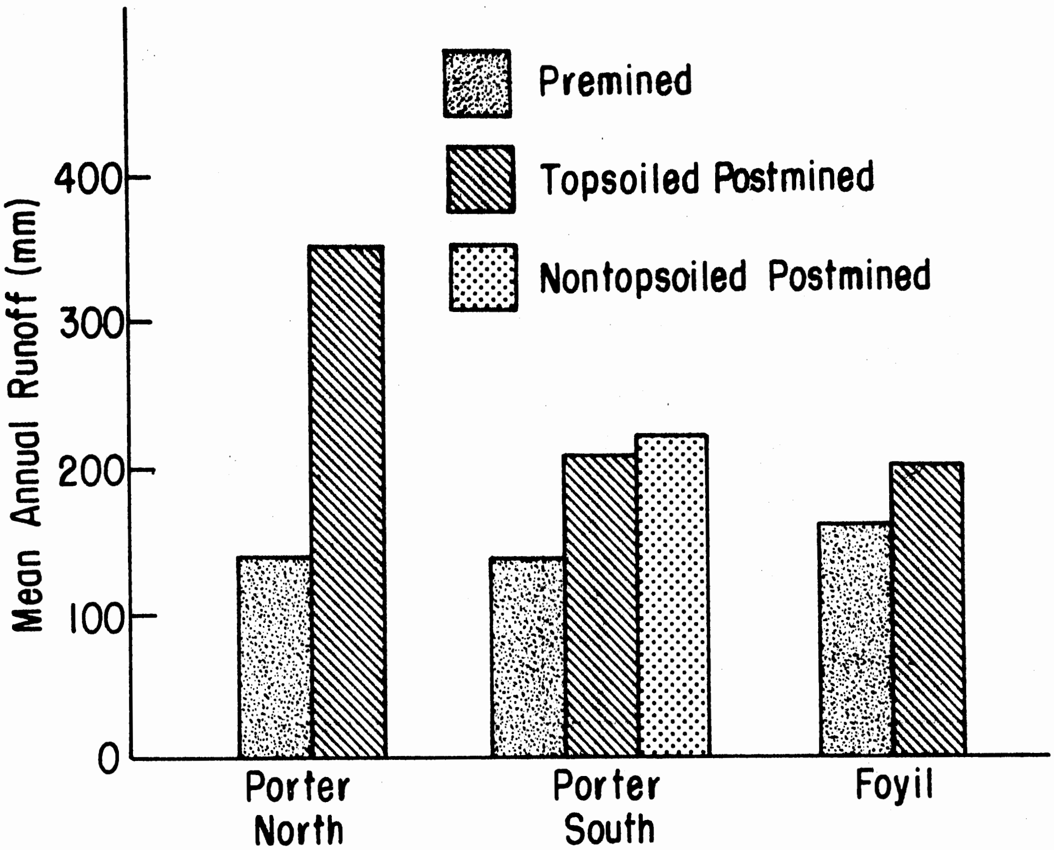

Figure 9. Mean Annual Simulated Runoff for the Premined and Postmined Soil Profiles

the topsoils were similar at these study areas.

For the non-topsoiled spoil profile at Porter South the mean annual runoff was 59 percent greater than for the premined profile compared with 49 percent greater for the topsoiled shale spoil. The same RC value was used for profiles with shale spoil subsoil, whether topsoiled or not. Therefore, reduction of runoff when topsoil was present was mainly due to the greater porosity (POROS) of the topsoiled spoil profile.

Annual Depths of Runoff

Figures 10 through 12 and Table XV show the total simulated runoff for each year. The postmined profiles show a fairly consistent increase in the depth of runoff for each simulation year, rather than a consistent percentage increase. Average annual runoff was increased by 217, 70, and 43 mm after mining at Porter North, Porter South, and Foyil, respectively. For the non-topsoiled spoil profile the average increase was 84 mm. The increase in annual depth of runoff after mining was slightly greater than average in wet years and slightly less than average in dryer years.

Discussion

General

Runoff increased after mining, as was expected from

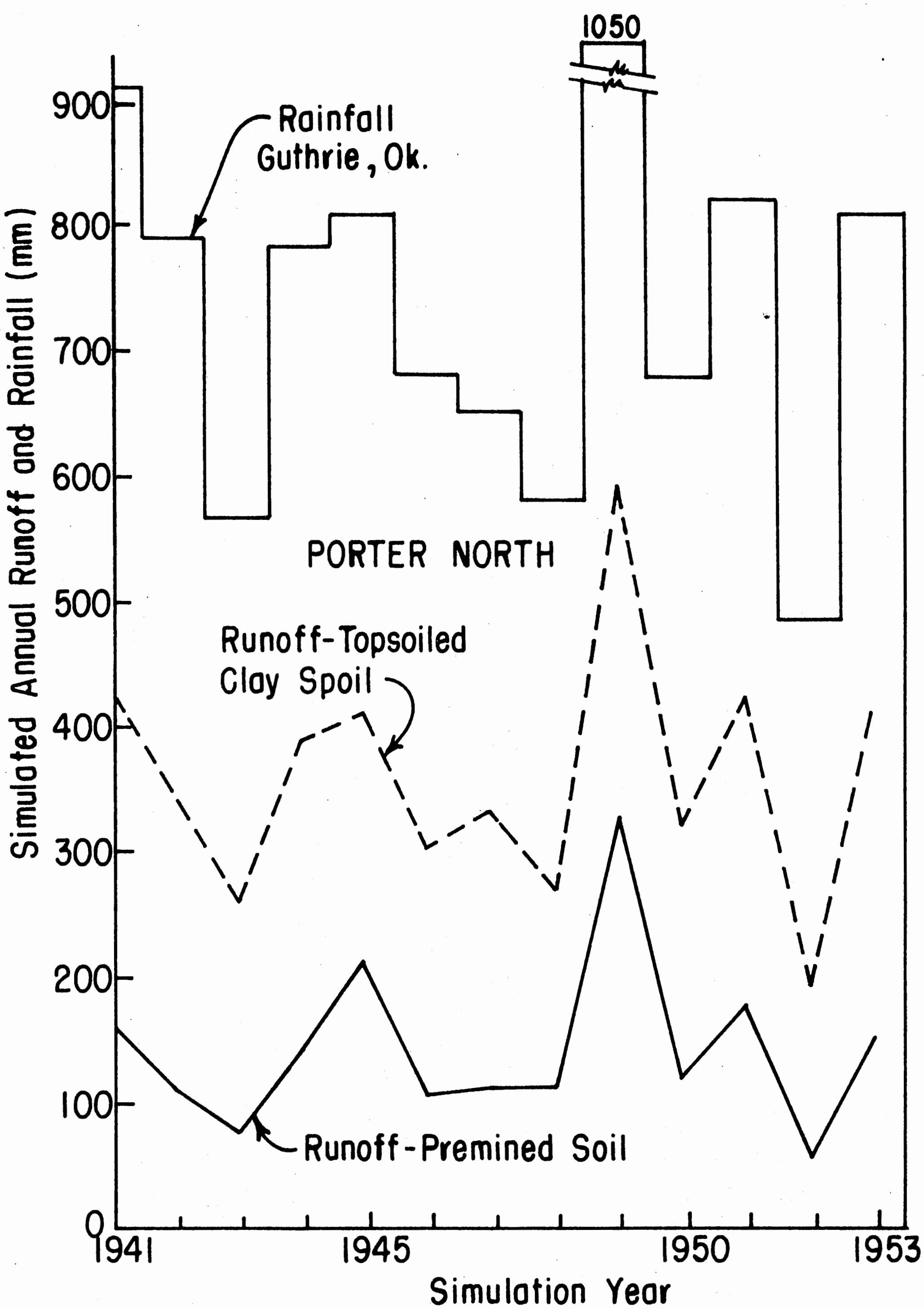

Figure 10. Annual Rainfall and Annual Simulated Runoff for the Premined and Post-mined Profiles at Porter North

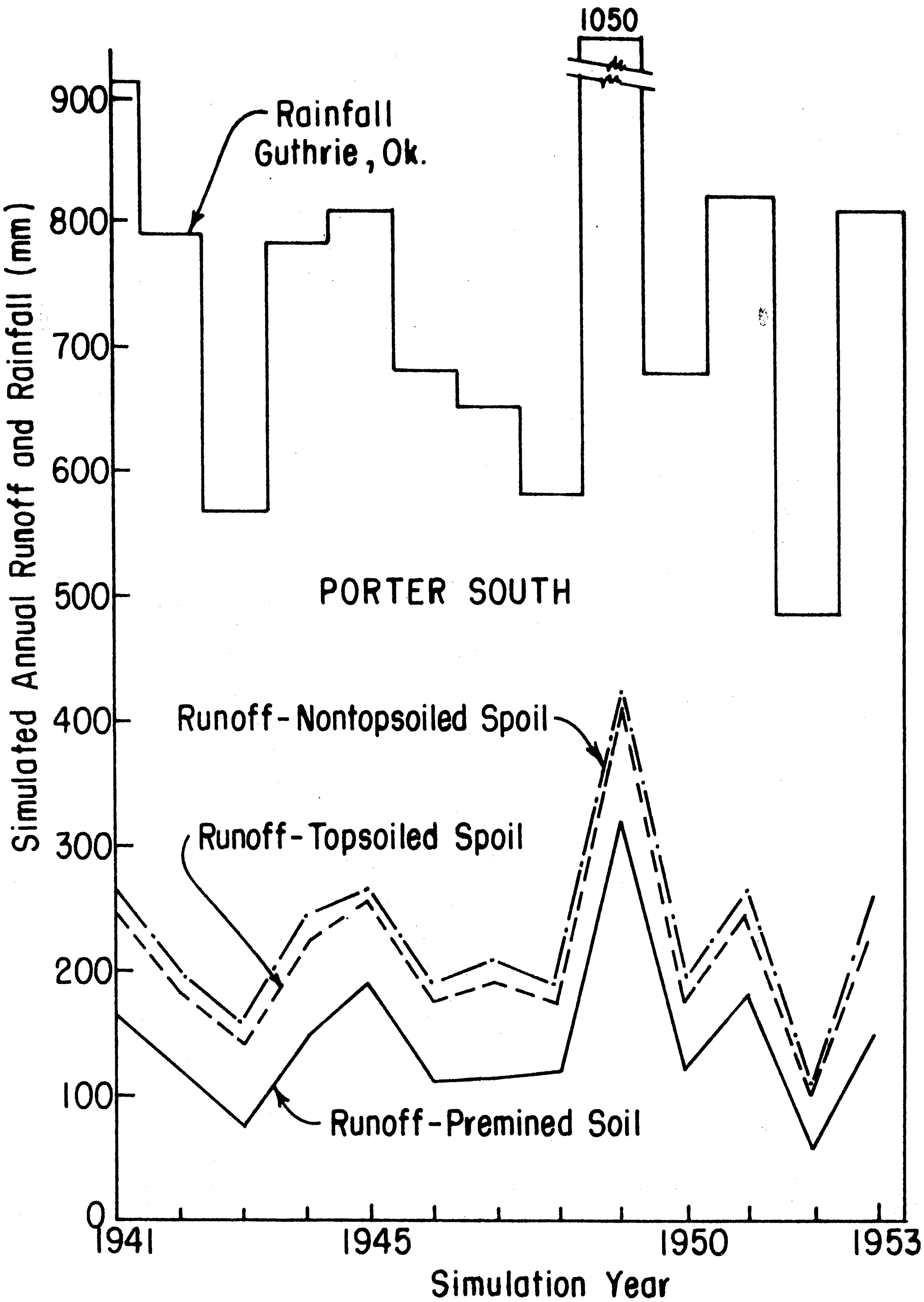

Figure 11. Annual Rainfall and Annual Simulated Runoff for the Premined, Topsoiled Spoil and Non-Topsoiled Spoil Profiles at Porter South.

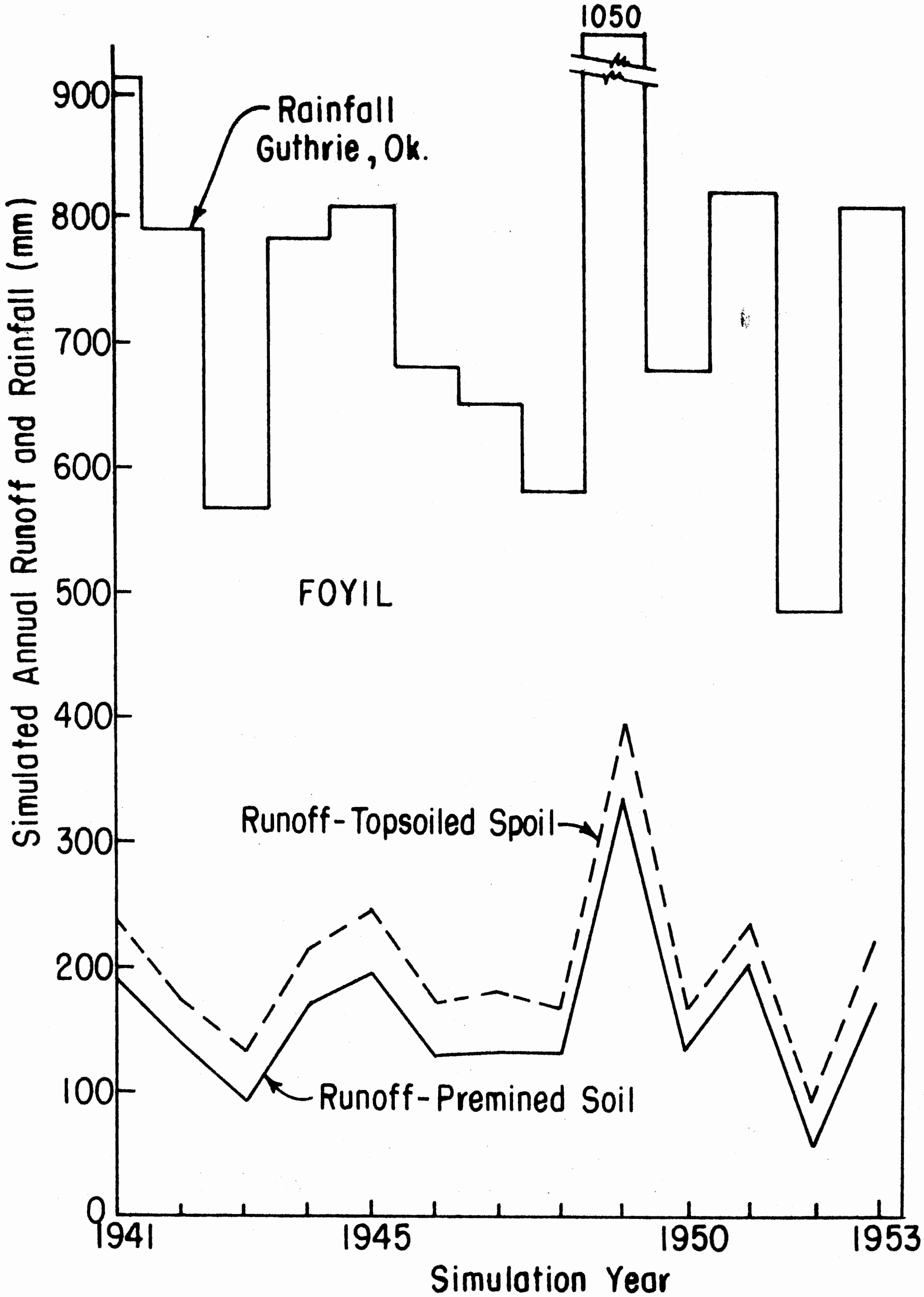

Figure 12. Annual Rainfall and Annual Simulated Runoff for the Premined and Postmined Profiles at Foyil

TABLE XV

ANNUAL RAINFALL AND ANNUAL SIMULATED RUNOFF FOR THE PREMINED AND POSTMINED SOIL PROFILES

		Simulated Annual Runoff (mm)						
		Porter North		Porter South			Foyil	
Year	Rain-fall	Pre-Mined	TS[1/] Clay Spoil	Pre-Mined	TS Shale Spoil	Non-TS Shale Spoil	Pre-Mined	TS Shale Spoil
1941	912	166	432	163	247	263	186	237
42	790	109	353	119	180	201	138	173
43	566	75	259	74	141	154	92	133
44	785	143	388	145	223	245	171	218
45	810	188	412	188	259	265	199	246
46	679	107	300	110	176	189	130	172
47	650	116	332	114	188	207	132	183
48	582	116	270	120	173	184	132	168
49	1052	325	587	318	415	422	337	397
50	678	118	319	120	173	193	135	169
51	820	177	418	179	246	263	206	237
52	483	31	188	53	101	104	55	91
53	810	147	410	145	235	258	170	226
Mean	737	141	358	142	211	226	160	203

[1/]TS = Topsoiled.

interpretation of the results of the soil investigation. Increased runoff from the postmined profiles was expected because 1) the saturated hydraulic conductivity of the least permeable layer was less than that of the premined profiles, 2) the depth to the least permeable layer was reduced by 50 percent or more, and 3) the gravitational water storage capacity, and therefore the volume of large pores, was decreased. This was expected to reduce the saturated hydraulic conductivity of topsoils and subsoils after mining.

Of these three major changes in soil properties only the first was effectively represented in the modeling. The hydrologic consequences of changes in soil properties can only be predicted if the different properties of the profiles can be incorporated into the model. The CREAMS model has certain limitations which prevent incorporating every feature of the soil profile. Only three parameters directly affect the infiltration computation in CREAMS. These are RC, GA and antecedent moisture expressed as a portion of POROS. The simulated runoff is very sensitive to the RC value and moderately sensitive to GA and POROS. A reliable objective approach for estimating the RC and GA values from measure physical properties of a layered soil profile is not available. As the CREAMS infiltration submodel represents the soil profile as a single layer, it is difficult to model the influence of the depth to the least permeable layer. It is also difficult to objectively incorporate the effect of an overall reduction in saturated hydraulic conductivity throughout the profiles.

The results of the runoff simulation were considered indicative of changes in the saturated hydraulic conductivity of the least permeable layer in each profile. The other effects which were expected to increase runoff after mining were not fully represented in the simulation. The predicted increase in runoff after mining was therefore considered conservative.

Effect of Topsoiling on Runoff

Because of the limitations associated with the CREAMS model, the simulation was not sensitive to the depth of topsoil or the properties of the topsoil. The increase in simulated runoff for the spoil profile without topsoil was due to a reduction in POROS and a slight increase in GA. Simulated runoff from the non-topsoiled spoil profile was considered to be underestimated. A two layer infiltration model would provide a more accurate estimate of the difference between runoff from topsoiled spoil and from non-topsoiled spoil. Alternatively, infiltrometer data could be used to provide fitted RC and GA values for spoil profiles with and without topsoil.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

Soil Properties

This study involved measurement of the physical properties of premined and reclaimed soil profiles on three surface mined areas in eastern Oklahoma. The reclaimed profiles at Porter South and Foyil involved topsoil over shale spoil. The reclaimed profile at Porter North involved topsoil over clay spoil. Additionally samples were taken from a graded shale spoil area at Porter South which had not been topsoiled. All premined soils involved silt-loam or loam topsoils and less permeable silty clay subsoil.

Undisturbed soil core samples were taken through the profiles at three to five sites on each of the seven study areas. The cores were used to determine bulk density and moisture content at saturation. Porosity was estimated from both these measurements.

Core samples were then crushed and subsampled to determine moisture retention at 0.1 bar and 15 bar suction, texture, organic matter content, SAR, pH, and salinity. The percentage of coarse fragments (> 2mm) was determined for the shale spoils. Moisture retention at 0.1 bar was determined for the shale spoil with and without coarse fragments. The moisture retention at 0.33 bar was estimated from 0.1 and 15 bar values to more accurately represent field capacity. Saturated hydraulic conductivity was measured on undisturbed cores from the premined soil and clay spoil at Porter North and from the shale spoil at Porter South.

The average depths of reclaimed topsoil were 29, 27 and 20 cm at Porter North, Porter South and Foyil, respectively. The depths equaled the depth of premined A-horizon at Porter South and Foyil and about one half the premined A-horizon at Porter North. The depth to the least permeable horizon, the B2 in the premined and the spoil in the postmined profiles, was reduced by about 50 percent after mining.

Postmined topsoils were all silt loam texture. They generally had properties similar to those of premined topsoils except that they were more dense. As a result porosity and gravitational water capacity were reduced.

The clay spoil had silty clay or clay texture and was structurally massive and very firm when wet. Bulk density was greater than for the premined subsoils. For the clay spoil, porosity determined from moisture retention at saturation was considered more valid than porosity calculated from bulk density. Porosity, 0.1, 0.33 and 15 bar moisture were greater and gravitational water and available water capacities were less than for the premined subsoils. Saturated hydraulic conductivity was one to two orders of magnitude less than that of the premined subsoils. Salinity was high enough to severely stress plants and reduce yields.

The shale spoil contained 45 to 65 percent coarse fragments. The texture of fines was silt loam. The coarse fragments were flat, platey, lay horizontally and were very tightly packed. Spaces between fragments were filled by smaller fragments and fines. Although shale fragments are slightly porous most of the water in the pores is held at 15 bar suction or greater. Porosity, gravitational water and available water capacities, and 0.1 and 0.33 bar moisture retention were significantly reduced compared with the premined soils. This was mostly attributed to the presence of the coarse fragments. Bulk density was significantly greater than for all other soil materials in the study and approached 2.0 gm/cm^3. Saturated hydraulic conductivity of the shale spoil was about one order of magnitude less than that of the premined subsoils. Shale spoil at Porter South was saline enough to stress plants and reduce yields. The shale spoil at Foyil was not saline.

In summary, the postmined profiles were consistently more dense and had lower permeability than premined profiles. The most limiting properties of the clay spoil profile were very low permeability and high salinity. For the shale spoil profiles the most limiting properties were high bulk density, low available water and low permeability. Topsoil, being superior to spoils in all respects, afforded improvement in all properties although more than 30 cm of topsoil may be required. High salinity is apparently a potential problem with spoil materials in Oklahoma.

Runoff

The CREAMS hydrology model (option two using Green and Ampt infiltration) was used to model the moisture balance and depth of runoff for the seven profiles. Soil parameter input values were derived from the measured properties using objective selection criteria. Thirteen years of breakpoint rainfall and evaporative demand data from the Guthrie W-5 experimental watershed were used for all simulations. Cover conditions for grassland in fair to poor condition were used.

The mean annual depth of runoff ranged from 27 to 153 percent greater after mining. The topsoiled clay spoil at Porter North yielded the greatest mean annual runoff; 358 mm or 49 percent of the mean annual rainfall compared with 141 mm or 19 percent of mean annual rainfall for the premined profile. Mean annual runoff from the topsoiled spoil profile at Porter South was 49 percent greater than premined compared with 59 percent for the non-topsoiled spoil profile.

Runoff was expected to increase after mining because:

1) the saturated hydraulic conductivity of the least permeable layer was reduced by an order of magnitude or more,

2) the depth to the least permeable layer was reduced by 50 percent,

3) the gravitational water storage capacity, and therefore the volume of large pores, was decreased. This was considered indicative of reduced hydraulic conductivity throughout the postmined profiles compared with the premined profiles.

Of these conditions, only the first was objectively incorporated into the hydrologic modeling. The differences in runoff mostly reflect differences in the effective saturated hydraulic conductivity parameter (RC), which was based on the saturated hydraulic conductivity of the least permeable layer in the profile. The predicted increases in runoff after mining were considered conservative. Runoff for the non-topsoiled spoil profile was considered to be underestimated. An improved approach is needed to quantify the effect of topsoil depth and topsoil properties on the infiltration parameters in the CREAMS model.

Conclusions

1) Shale spoils are inferior to premined soils with respect to all physical properties measured. Bulk density is higher and porosity, gravitational water capacity, available water capacity and saturated hydraulic conductivity are less than for the premined soils. Coarse fragments are the major cause of the poor hydraulic properties of the shale spoil.

2) Clay spoils are inferior to premined soils because of their very low saturated hydraulic conductivity. The clay spoils also have high bulk density, massive structure, fine texture and high 15 bar moisture retention.

3) Shale spoils have better water transmission properties but poorer water storage properties than clay spoils.

4) Topsoiling of shale spoil improves the water storage properties and potential rooting depth of the postmined profile.

5) Compaction during the reclamation process increases the bulk density and decreases porosity and gravitational water capacity. For the topsoil other physical properties are unaffected by reclamation.

6) High salinity is a potential problem with both clay and shale spoils in Oklahoma.

7) The hydrology simulations indicate that runoff is increased after mining. Placement of clay spoil near the

surface is particularly detrimental to the hydrology of the mined area.

8) The hydrology simulations indicate that topsoiling reduces runoff from the shale spoil.

Recommendations for Further Research

Further research should include measurement of the infiltration properties of shale spoil with various depths of topsoil and under various cover conditions. The infiltration properties should be expressed in a form directly applicable to the level of hydrologic modeling used by surface mine hydrologists for design purposes' e.g. the SCS Curve Number. As shale spoil is very common on surface mined lands in eastern Oklahoma this information would be widely applicable. Small watersheds and plots could be used although more rapid data collection would be achieved using a large rainfall simulator. The results of this research would provide better definition of the extent of the increase in runoff after mining. Definition of minimum reclamation requirements would be improved.

REFERENCES CITED

Alderdice, L., R. L. Howard and H. Groves. 1981. "Possible Treatments as Alternatives to Topsoil Replacement on Surface Mine Sites." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Barnhisel, R. I. 1977. "Reclamation of Surface Mined Coal Spoils." USDA/EPA Interagency Energy - Environmental Research and Development Program Report, CSRS-1, EPA-600/7-77-093.

Barnhisel, R. I. and H. F. Massey. 1969. "Chemical, Mineralogical and Physical Properties of Eastern Kentucky Acid Forming Coal Spoil Materials." Soil Science. 108:367-372.

Baver, L. D., W. H. Gardner and W. R. Gardner. 1972. Soil Physics, 4th ed. John Wiley and Sons, New York, pp. 381-384.

Bondurant, J. A., R. V. Worstell and C. E. Brockway. 1969. "Plastic Casings for Soil Cores." Soil Science. 107:70-71.

Bowen, H. D. 1981. "Alleviating Mechanical Impedence," Chapter 2. In: Modifying the Root Environment to Reduce Crop Stress. Arkin, G. F. and H. M. Taylor (eds.), ASAE Monograph No. 4, ASAE, St. Joseph, Michigan.

Bowles, J. E. 1978. Engineering Properties of Soils and Their Measurement. 2nd ed., McGraw-Hill, New York.

Curtis, W. R. 1972. "Strip Mining Increases Flood Potential of Mountain Watersheds." Proceedings of National Symposium on Watersheds In Transition, Fort Collins, Colorado, pp. 357-360.

Danials, W. L. and D. F. Amos. 1981. "Mapping, Characterization and Genesis of Minesoils on a Reclamation Research Area in Wise County, Virginia." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Davidson, W. H. 1981. "Rooting Characteristics of Grasses on Topsoiled Surface Mines." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 7-11.

Davidson, J. M., L. R. Stone, D. R. Nielsen and M. E. Larve. 1969. "Field Measurement and Use of Soil-Water Properties." Water Resources Research, 5(6):1312-1321.

Elrick, D. E. and C. B. Tanner. 1955. "Influence of Sample Pretreatment on Soil Moisture Retention." Soil Science Soc. Am. Proc. 19:279-282.

Evangelou, V. D., R. E. Phillips and J. S. Shepard. 1981. "Salt Generation in Pyritic Coal Spoils and Its Effect on Saturated Hydraulic Conductivity." Submitted for publication in Soil Sci. Soc. Am. J.

Fogel, M. M., L. H. Hekman, Jr., and L. Duckstein. 1980. "Predicting Sediment Yield from Strip Mined Land." Proceedings of Symposium on Watershed Management, ASCE, Boise, Idaho, July 21-23, pp. 176-187.

Friedman, S. A. 1974. "The Investigation of the Coal Reserves in the Ozarks Section of Oklahoma and Their Potential Uses, Final Report to the Ozark Regional Commission." Oklahoma Geological Survey, July 10.

Gee, G. W., A. Bauer and R. S. Decker. 1978. "Physical Analysis of Overburden Materials and Mine Land Soils." pp. 665-686. In: Proc. Symposium on Reclamation of Drastically Disturbed Lands, F. W., Schaller, and P. Sutton (eds.), Am. Soc. Agron - Crop Sci. Soc. Am.-Soil Sci. Soc. Am., Wooster, Ohio, Aug. 9-12, 1976.

Ghebremedhin, Tesfa and M. S. Salkin. 1978. "An Analysis of Oklahoma's Coal Industry." Ok. Ag. Exp. Stn. Res. Rep. P-780. Nov.

Gilley, J. E., G. W. Gee, A. Bauer, W. O. Willis and R. A. Young. 1977. "Runoff and Erosion Characteristics of Surface Mined Sites in Western North Dakota." Trans. of ASAE, 20(4):697-700.

Gray, F. and G. Fults. 1982. Personal Communications. Soil Classification Laboratory, Department of Agronomy, Oklahoma State University, Stillwater, OK.

Haigh, M. J. 1978. "Microerosion Processes and Slope Erosion on Surface-Mined Dumps at Henryetta, Oklahoma." Oklahoma Geology Notes, U38, No. 3.

Hanson, C. T. and R. L. Blevins. 1979. "Soil Water in Coarse Fragments." Soil Sci. Soc. Am. J. 113:819-820.

Hill, R. D. 1978. "Methods of Controlling Polutants," Chapter 39. In: Reclamation of Drastically Disturbed Lands. Am. Soc. Agron., Crop Sci. Soc. Am. and Soil Cons. Soc. Am., Madison, WI. pp. 696-697.

Hirschi, M. C. and I. D. Moore. 1980. "Estimating Soil Hydraulic Properties from Soil Texture." ASAE Paper No. 80-2523, ASAE, St. Joseph, Michigan.

Holmberg, G. V. 1980. "Vegetation Establishment on Abandoned Coal Mined Lands." Trans. of ASAE, 23(1):117-120.

Holtan, H. N., C. B. England, G. P. Lawless, and G. A. Schumaker. 1968. "Moisture-Tension Data for Selected Soils on Experimental Watersheds." USDA-ARS, ARS 41-144.

Huntington, T. G., R. I. Barnhisel and J. L. Powell. 1980. "The Role of Soil Thickness, Subsoiling and Lime Incorperation Methods on the Reclamation of Acid Surface Mine Soils." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Indorante, S. J. and I. J. Jansen. 1981. "Soil Variability on Surface Mined and Undisturbed Land in Southern Illinois." Soil Sci. Soc. Am. J. 45:564-568.

Jansen, I. J. and W. S. Dancer. 1981. "Row Crop Yield Response to Soil Horizon Replacement After Surface Mining." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 7-11.

Jennings, M. E., W. P. Carey and D. W. Blevins. 1980. "Field Studies for Verification of Surface Mining Hydrology Models." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Jensen, I. B., R. L. Hodder and D. J. Dollhopf. 1978. "Effects of Surface Manipulation on the Hydrologic Balance of Surface-Mined Land." In: Ecology and Coal Resource Development International Congress of Energy and the Ecosystem, M. K. Wali (ed.), University of North Dakota, June 12-16, pp. 754-761.

Johnson, K. S. 1971. "Reclamation of Mined Coal Lands in Eastern Oklahoma." Oklahoma Geological Notes. 31:111-123.

Knisel, W. G. (ed.). 1980. "CREAMS: A Field - Scale Model For Chemical, Runoff, and Erosion from Agricultural Management Systems." USDA Conservation Res. Rep. No. 26, 640 pp.

Mason, D.D., J. F. Lutz and R. G. Petersen. 1957. "Hydraulic Conductivity as Related to Certain Soil Properties in a Number of Great Soil Groups - Sampling Errors Involved." Soil Sci Soc. of Am. Proc. pp. 554-560.

Mehvys, G. R., L. H. Stolzy, J. Letey and L. V. Weeks. 1975. "Effects of Stones on the Hydraulic Conductivity of Relatively Dry Desert Soils." Soil Sci. Soc. Am. Proc. 39:37-42.

McIntyre, R. B., V. I. Vatanakul and G. R. Stewart. 1979. "Measuring Hydraulic Conductivity in Clay Soils: Methods, Techniques and Errors." Soil Sci. 128:171-185.

Mitchell, K. J., D. D. Gustavson, W. C. Moldonhover and J. N. Scarborough. 1982. "Erodibility of Reclaimed Surface Mined Topsoil." ASAE Paper No. 82-2025, ASAE, St. Joseph, Michigan.

Oklahoma Department of Mines. 1979. "Annual Report," Chief Inspectors Office, Oklahoma City, Oklahoma.

Opeka T. and R. Morse. 1979. "Use of Green-manure Amendments and Tillage to Improve Minesoil Productivity." EPA-600/7-79/257, December 1979.

Ouattara, M. 1977. "Variation of Saturated Hydraulic Conductivity with Depth for Selected Profiles of Tillman-Hollister Soil." (Unpublished Master's of Science Thesis, Oklahoma State University, Stillwater, Oklahoma.)

Overton, D. E. and E. C. Crosby. 1980. "Simulation of Effects of Contour Coal Strip Mining on Stormwater Runoff and Pollutant Yields." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Pathak, C. 1982. Personal Communication. Agricultural Engineering Department, Oklahoma State University, Stillwater, Oklahoma.

Pedersen, T. A., A. S. Rogowski and R. Pennock, Jr. 1978. "Comparison of Morphological and Chemical Characteristics of Some soils and Minesoils." Rec. Rev. Vol. 1, pp. 143-156.

Pedersen, T. A., A. S. Rogowski and R. Pennock, Jr. 1980. "Physical Characteristics of Some Minesoils." Soil Sci. Soc. Am. J. 44:321-328.

Pettry, D. E., W. F. Miller and J. W. Darden. 1980. "Reclamation of the Knob Surface Mine, Alabama, Using Selected Overburden Material." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Philip, J. R. 1957. "Theory of Infiltration: Sorptivity and Algebraic Infiltration Equations." Soil Sci. 84:257-264.

Power, J. F., F. M. Sandoval, R. E. Ries and S. D. Merrill. 1981. "Effects of Topsoil and Subsoil Thickness on Soil Water Content and Crop Production on a Disturbed Soil." Soil Sci. Soc. Am. J. 45:124-129.

Rai, D., P. J. Wierenga and W. L. Gould. 1974. "Chemical and Physical Properties of Core Samples from a Coal Bearing Formation in San Juan Co., New Mexico." New Mexico Ag. Exp. Stn. Res. Rep. 287, Sept.

Rawls, W. J., D. L. Brakensiek and K. E. Saxton. 1981. "Soil Water Characteristics." ASAE Paper No. 81-2510, ASAE, St. Joseph, Michigan.

Richards, L. A. (ed.). 1954. "Diagnosis and Improvement of Saline and Alkali Soils." USDA-ARS. U.S. Salinity Laboratory Staff, Ag. Handbook No. 60.

Rogers, N. F. 1951. "Strip-mined Lands of the Western Interior Coal Provence." Missouri Ag. Exp. Stn. Res. Bull. 475. May, 1951.

Rogowski, A. S. and Weinrich. 1981. "Modeling Water Flux on Strip-Mined Land." Trans. of ASAE. 24(4):935-940.

Rogowski, A. S. and E. L. Jacoby, Jr. 1979. "Monitoring Water Movement Through Stipmine Spoil Profiles." Trans. of ASAE. 22(1):104-109, 114.

Sandoval, F. M., J. J. Bond, J. F. Power and W. O. Willis. 1973. "Lignite Mine Spoils in the Northern Great Plains - Characteristics and Potential for Reclamation." Mimeo for presentation at Symposium on Mined-land Reclamation, Pittsburgh, Pennsylvania, March 7-8.

Schafer, W. M., G. A. Nielsen and W. D. Nettleton. 1980. "Minesoil Genesis and Morphology in a Spoil Chronosequence in Montana." Soil Sci Soc. Am J. 44:802-807.

Schafer, W. M., G. A. Nielsen, D. J. Dollhopf and K. L. Temple. 1979. "Soil Genesis, Hydrological Properties, Root Characteristics, and Microbial Activity of 1- to 50-Year Old Stripmine Spoils." EPA 600/7-79-100, Cincinnati, Ohio.

Schafer, W. M. and G. A. Nielsen. 1978. "Soil Development and Plant Succession on 1- to 50-Year Old Stripmine Spoils in Southeastern Montana." In: Ecology and Coal Resource Development International Congress of Energy and the Ecosystem, M. K. Wali (ed.), University of North Dakota, June 12-16, pp. 754-761.

Schroer, F. W. 1976. "Chemical and Physical Characterization of Coal Overburden." North Dakota Agricultural Exp. Stn., Farm Res. 34(1):5-11.

Smith, R. M., E. H. Tryon and T. H. Tyner. 1971. "Soil Development on Mine Spoil." West Virginia Agri. Exp. Stn. Bull 604T.

Tyner, E. H., E. H. Tyron and S. L. Galpin. 1954. "Soil Development Trends on Century-Old Iron Ore Spoil Banks." Agron. Abstracts. 46:52.

Unger, P. W. 1975. "Water Retention of Core and Sieved Soil Samples." Soil Sci Soc. Am. Proc. 39:1197-1200.

USDA. 1979. "Research on the Hydrology and Water Quality of watersheds Subject to Surface Mining, Phase 1." USDA-SEA-AR, Cushocton, Ohio, In Bureau of Mines Open File Report 31-80, April, 1979.

USDA-SCS. 1982. "A SCS User's Guide for CREAMS Field Scale Model for Chemical Runoff and Erosion from Agricultural Management Systems." USDA-SCS, Agricultural Research Service, Southern National Technical Center, Fort Worth, Texas, January.

USDA-SCS. 1979. Soil Interpretation Records (Blue Sheets) for Oklahoma, Nat. Cooperative Soil Survey.

USDA-SCS. 1976. "Soil Survey of Wagoner Co., Oklahoma."

USDA-SCS. 1966. "Soil Survey of Rogers Co., Oklahoma."

Young, K. K. and J. D. Dixon. 1966. "Overestimation of Water Content at Field Capacity From Sieved Sample Data." Soil Sci. 101:104-107.

Younos, T. M. and V. O. Shanholtz. 1980. "Soil Texture and Hydraulic Properties of Post-Mining Soil as Related to the Premining Soil Horizons." Proceedings of Symposium on Surface Mining Hydrology, Sedimentology and Reclamation, Lexington, Kentucky, December 1-5.

Ward, A. D. and R. E. Phillips. 1981. "Infiltration Through Reconstructed Surface Mine Spoils and Soils." ASAE Paper No. 81-2508, ASAE, St. Joseph, Michigan.

Zur, B. 1976. "The Pulsed Irrigation Principle for Controlled Soil Wetting." Soil Science. 122:282-291.

APPENDIXES

APPENDIX A

MEASUREMENT OF SATURATED HYDRAULIC CONDUCTIVITY USING HEAT SHRINK CASING

Saturated hydraulic conductivity was measured on undisturbed soil cores encased in clear heat shrinkable insulation tubing (Bondurant et al., 1967; Ouattara, 1977), using the constant head method.

The heat shrink casing gives support to the samples for handling and testing. It also provides an excellent seal, preventing abnormal flow path development, a problem found with solid metal liners. The heat shrink does not enter the soil pores, thereby creating an indeterminate cross-sectional area, as can occur with paraffin or fluid plastic coatings.

As saturated hydraulic conductivity determination methods vary widely and the method used here is not in widespread use, a more detailed description of field and laboratory procedures is presented.

Field Sampling

"Undisturbed" soil columns were collected with a hydraulic soil probe, mounted on a pick-up truck. Soil columns of 6.7 cm diameter and 110 cm depth were removed. The column could be removed from the probe unbroken if soil moisture was near field capacity. Depth from the soil surface was marked on the soil with an oil pen. The columns were cut into manageable lengths (10 to 20 cm) and stored in labeled plastic bags. The lengths of soil could be transported unbroken if they were packed in boxes with styrofoam packing pellets. Heat shrinking in the field was found to be difficult with both propane gas and the electric heat gun.

Sampling by this method was not possible for shaly spoil materials. This material was very dense (bulk density up to 2.0 gm/cc), never at more than 12 percent moisture content (dry weight basis), with the shale plates often lying horizontally. No significant penetration of the cutting edge was achieved.

To obtain undisturbed test material for the spoil, 7.6 cm by 7.6 cm cores were taken with a hand sampler. In some cases over one hundred blows of the hammer were required compared with about eight for a moist topsoil and fifteen to twenty for a moist, dense, clay. These "undisturbed" cores yielded unbroken sections from two to five cm long, with rough fracture planes approximately perpendicular to the vertical core axis.

Laboratory Procedures

A set of plexiglass end plates, the same diameter as the soil core, each with two access tubes and a slightly hollowed out inside face, were fabricated.

A stand was built to hold the cores and measuring cylinders, and to provide a constant outflow head. A second, higher, shelf was provided for wetting up of cores from the same constant head water source. The constant head was provided using a 20 liter Mariotte bottle, with a smaller reservoir to smooth out the effect of bubbles entering the mariotte bottle.

Selected soil column sections were trimmed to give flat square ends and a length which would allow a measurable volume of flow in a reasonable time. Larger measurement volumes reduce the error due to intermittent dripping of outflow. At very high flow rates the head would not remain constant and time measurement errors may have become significant. Any scratchs along the side of the soil were smoothed so that the heat shrink sealed against the soil.

Ten cm diameter, clear heat shrink insulation (Polyolefin) was used to case the cores. The heat-shrink is designed to shrink about 50 percent in diameter and 10 percent in length. The soil core was placed between two plexiglass end plates in a precut length of the heat shrink. Heat was applied evenly overall with an electric heat gun. Wide rubber bands were put over the heat shrink on the end plates and hose clamps tightened over them to ensure no leakage.

Each cased soil core had its own connection tubes so that it could be wet up on a low head stand, sealed and then connected into the conductivity test stand. This allowed the conductivity test stand to be operated continuously at the constant head with up to eight cores while others were wetting up.

The inflow head was measured with a vertical glass tube against a metric rule. The elevation of each of the eight permanent outflow droppers was measured relative to the graduations on the rule. Outflow volume from each core was measured with 10 ml and 20 ml graduate cylinders. Time of flow was measured with a stop watch for times up to 30 minutes and a minute timer for times up to 3000 minutes.

To reduce internal erosion of soil cores and interaction between the perolating water and exchangeable sodium in the soil, a 1500 ppm $CaCl_2$ solution was used, as discussed by Ouattara (1977). Cores were wet up from the bottom, with head increasing in steps from zero cm until the water covered the top of the core. No attempt was made to remove entraped air as this was considered more relevant to field conditions.

All cores were tested at least eight times, i.e. the flow was stopped, the volume and flow time recorded and the measuring cylinder changed. The head was approximately 20 cm of water for all tests. Room temperature was recorded with a hydrothermograph during the test period and remained within ± 2°C of 20°C for all tests. A thermoplastic film (PARAFILM) was used to ensure no evaporation from the measuring cylinders during tests.

The saturated hydraulic conductivity was calculated using Darcy's law in the form.

$$K_{SAT} = - \frac{VL}{At\ (h_2 - h_1)}$$

where:

K_{SAT} = saturated hydraulic conductivity (cm/hr)

V = volume of water flowing through the sample (cm^3)

t = time of flow (hrs)

L = length of the soil column (cm)

A = cross sectional area of the column (cm^2)

h_1 = hydraulic head of the outlet (elevation of the outlet dropper on rule) (cm)

h_2 = hydraulic head at the inlet (elevation of water in glass riser tube) (cm)

The K_{SAT} was calculated for each flow interval and the average calculated for each core. The coefficient of variation (CV) for average conductivity values of all individual cores tested ranged from 0.75 percent to 23.4 percent with a mean CV of 9.6 percent. Cores did not exhibit consistent decrease or increase in conductivity with increased total time of flow as indicated by other authors (Ouattara, 1977; McIntyre et al., 1979). The majority of cores did not appear to show any trend with increased total time of flow.

APPENDIX B

MEASUREMENT OF PARTICLE SIZE
DISTRIBUTION AND TEXTURE

Particle size distribution was determined for pre-treated and dispersed sub-samples of core soil, using the hydrometer method (Bowles, 1978) to determine the silt-clay division. Wet sieving (Richards, 1954) was used to determine the percentages of coarse fragments (> 2mm), total sand and sand fractions. Sieves were chosen to give USDA metric particle size classes. Particles of effective diameter less than 0.002 mm (2 micron) were considered clay and particles larger than 0.05 mm were considered sand.

Sample Pretreatment and Dispersion

Results of particle size distribution can be affected by the amounts of organic matter and mineral matter (which cement particles together), and soluable salts (which flocculate particles) present in the soil (Gray and Fults, 1981). Organic matter content of the soils tested was low. Thus no special treatment was used to remove organic materials.

In some soils, soluble salt levels were high enough to flocculate the clay, causing all particles to settle within an hour or so. This causes completely erroneous textured classification. To minimize these effects, the soil sub-samples were treated as follows.

Sodium Acetate, buffered to pH5 with Acetic acid, was used to dissolve some of the mineral matter, particularly carbonates. Mineral matter liberated by this process and already soluble salts were removed by washing with deionized water and centrifuging. Repetition of the washing, centrifuging and pouring off of saline supernatant results in a soil suspension very nearly dispersed. A small amount of dispersing agent (10 ml of 4 percent sodium Hexa Meta Phosphate buffered to pH 10 with sodium carbonate) was used to complete dispersion. This procedure eliminated the need for mechanical action to disperse soil particles.

This method is essentially the same as that used by the Soil Classification Laboratory, Dept. of Agronomy, Oklahoma State University (Gray and Fults, 1981), except for the exclusion of the organic matter treatment.

Calculations

A computer program was used to calculate the sand, silt, clay content and the sand fractions using the hydrometer readings and times over 24 hours, blank reading, water temperature, total weight and weight retained by each sieve. The program also finds the texture according to the USDA texture triangle. The sand, silt and clay contents were calculated as percent of the total soil less than two mm. The coarse fragments percent (> 2 mm) was calculated as percent of total weight including the greater than two mm material.

APPENDIX C

ESTIMATION OF FIELD CAPACITY AND WILTING POINT FROM MOISTURE RETENTION OF SIEVED SOIL

Soil moisture characteristics are often estimated from laboratory moisture desorption measurements on soil samples that have been crushed and sieved (Richards et al., 1954; Young et al., 1966). The measured desorption water contents are gravimetric expressions and must be multiplied by bulk density to obtain volumetric values.

In this study, moisture retention was determined on sieved soils, at 0.1 and 15 bar suctions. While the 0.1 bar moisture contents can be, and were, used to make a relative comparison of the moisture holding characteristics of different soils, they cannot necessarily be used directly as an estimate of field capacity.

The reasons for this are: (a) the soil moisture suction at "field capacity" depends on the wetting conditions to which the data is to be applied, and (b) the moisture retention of sieved soil is usually an overestimation of moisture retention of undisturbed soil at suctions less than 1.0 bar.

Soil Moisture Suction at Field Capacity

The water content to which a soil will wet is determined largely by the depth of water on the surface during wetting, time duration of wetting and whether the wetting was continuous or intermittent (Philip, 1957; Zur, 1976). Intermittent application has a similar effect to wetting the soil with a very thin layer of water (or even with water under suction) (Zur, 1976). The net effect is to leave the soil in a dryer condition. Soils wet for several days with water ponded 10 cm deep commonly show resultant soil moisture suctions of about 0.1 bar (Davidson et al., 1969). Soils wet with a very thin water layer from furrows or by intermittent rain showers commonly show resultant soil moisture suctions of about 0.33 bar (Baver et al., 1972).

Thus for soil wetted under natural rainfall, moisture content of undisturbed soil at 0.33 bar suction is considered a reasonable estimate of field capacity.

Estimation of 0.33 Bar Moisture Content

Moisture release curves from Elrick et al. (1955) and Davidson et al. (1969) indicate that moisture content is approximately linearly related to the log of the soil moisture suction between 0.1 bar and 15 bar suctions.

Thus moisture content at 0.33 bar can be estimated by interpolation. Using similar triangles, the relationship can be derived as:

$$\frac{0.33 \text{ Bar M.C.} - 15 \text{ Bar M.C.}}{0.1 \text{ Bar M.C.} - 15 \text{ Bar M.C.}} = \frac{\log(15) - \log(0.33)}{\log(15) - \log(0.1)}$$

Where M.C. means moisture content. Rearranging and calculating the log term gives

0.33 Bar Moisture content =

(0.1 Bar M.C. x 0.76) + (15 Bar M.C. x 0.24)

Overestimation of Water Content From Sieved Sample Data

When gravimetric 0.1 bar moisture content of sieved soil was multiplied by bulk density to obtain volumetric moisture content, a large proportion of the resultant values were greater than the total porosity value of the soil. Although this irregularity is more likely at lower suctions (0.1 bar c.f. 0.3 bar) and is accentuated when bulk density is higher (porosity decreases and volumetric moisture content is increased), it is evidently possible with any sieved soil data.

Young et al. (1966) compared the 0.33 bar volumetric moisture content of sieved samples with the porosity of the natural soil fabric for 430 horizons from 66 soil series. Almost half of the 0.3 bar volumetric moisture content values were greater than the porosity and were thus "impossible." Samples with clay contents of 35 percent and above yielded impossible 0.3 bar volumetric moisture content values more often than possible ones. Even soils with 10 to 15 percent clay yielded some impossible values.

Young concluded that if 0.3 bar moisture retention was to be used to estimate field capacity, use of sieved samples could result in serious errors, regardless of texture and that more reliable estimates are obtained by using undisturbed samples. Studying moisture release of cores and sieved soils at suctions from 0.01 to 15 bar, Elrick et al. (1954) found that core samples should be used at all moisture suctions below 1.0 bar.

Relationships Between Moisture Retention of Cores and of Sieved Soil

Unger (1975) used core and sieved sample data from 26 soils, ranging in texture from sand to clay, to derive a simple regression equation predicting core water content at 0.33 bar suction from sieved soil water content at 0.33 bar suction. The data points and regression line are shown in Figure 13. Data from Elrick et al. (1955) and from five cores of Newtonia silt loam (Porter South study area) at 0.1 bar suction are also shown. Unger's equation appears to fit all the data reasonably well.

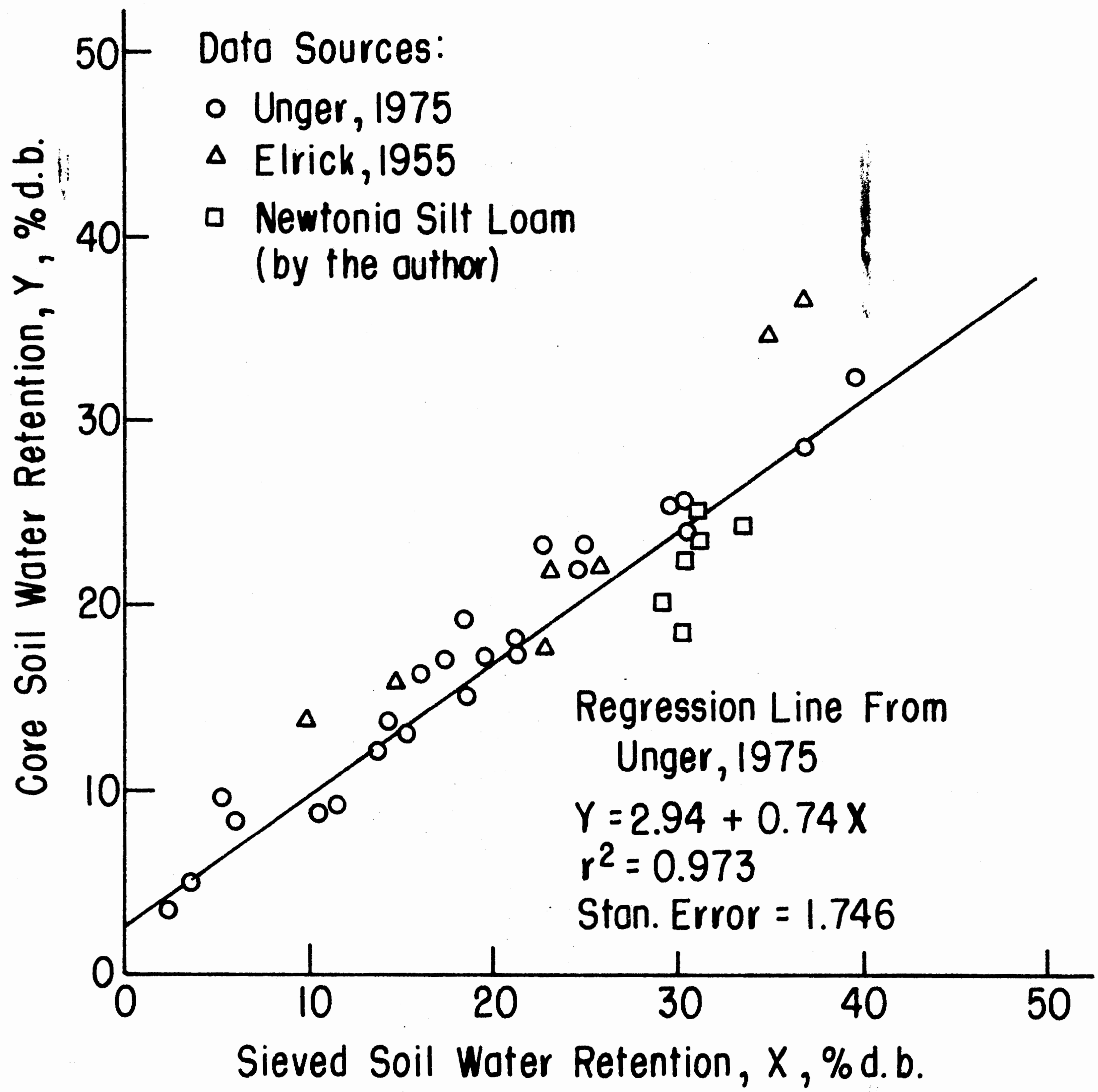

Figure 13. Soil Water Retention of Sieved Soils Plotted Against Soil Water Retention of Cores, at 0.33 Bar Suction

Further simple regression analysis of the Unger data, including 15 bar sieved soil moisture content, clay and silt contents in the model, provided little improvement in the correlation coefficient (r^2). This indicates that changes in the core and sieve 0.33 bar moisture already account for changes in the texture of the soil (i.e. finer textured soils have both higher core and higher sieved water content).

The Unger regression equation was used to correct sieved soil moisture data to account for the change in structure caused by disturbing the soil fabric. Moisture retention at 0.1 bar and 15 bar was used to estimate the 0.33 bar moisture retention for sieved soil (as described above). Core moisture retention was then calculated from the 0.33 bar sieved soil moisture content using the regression equation. When multiplied by bulk density to give volumetric water content and compared with porosity, this estimate of field capacity yielded a low frequency of impossible values.

Estimation of Wilting Point

The moisture retention at 15 bar suction is often used as an estimate of wilting point or the immobile soil water content referred to in the CREAMS manual (Knisel, 1980). Elrick et al. (1955) and Unger (1975) noted that the absolute magnitude of differences between core and sieved soil moisture at 15 bar suction are not large.

Little advantage is gained for the considerable inconvenience in using core samples over sieved samples at these high suctions.

Consistent results can be obtained if sieved samples are tested on a pressure membrane apparatus which applies a compactive force to the samples (Richards et al., 1954). Thus the 15 bar moisture content of sieved samples multiplied by bulk density was used as the volumetric moisture content at wilting point.

Summary

Field capacity was assumed to be closely approximated by moisture content of undisturbed soil cores at 0.33 bar suction. Measured 0.1 bar and 15 bar sieved soil moisture content was used to calculate the 0.33 bar sieved soil moisture assuming a semi-log relationship between soil moisture suction and moisture content. The 0.33 bar sieved soil moisture was corrected to approximate moisture retention of undisturbed core soil using the regression equation of Unger (1975). This corrected value was multiplied by bulk density to obtain volumetric field capacity.

Wilting point was assumed to be closely approximated by the volumetric moisture content of sieved soil at 15 bar suction.

VITA

David Mark Silburn

Candidate for the Degree of

Master of Science

Thesis: SOIL PROPERTIES OF SURFACE MINED LANDS AND THEIR HYDROLOGIC IMPLICATIONS

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Goomeri, Queensland, Australia, February 6, 1958, the son of Mr. and Mrs. William E. Silburn.

Education: Matriculated from Murgon State High School, Murgon, QLD, Australia, in December, 1974; received Bachelor of Engineering degree from the Darling Downs Institute of Advanced Education, Toowoomba, QLD, in May, 1980; enrolled in Master's program in August, 1980 at Oklahoma State University; completed requirements for the Master of Science degree at Oklahoma State University in December, 1982.

Professional Experience: Student Member of the American Society of Agricultural Engineers; Graduate Research Assistant, Oklahoma State University. Agricultural Engineering Department, 1980-1982; Member of the Honor Society for Agricultural Engineering, Alpha Epsilon (in United States); Member of the Agricultural Engineering Society of Australia.