METHODOLOGY FOR HYDROLOGIC EVALUATION OF A POTENTIAL SURFACE MINE: LOBLOLLY BRANCH BASIN, TUSCALOOSA COUNTY, ALABAMA

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Streamflow response of the basin is described by the variable-source-area concept; nearly all water flows through coarse-textured soils and unconsolidated sand and gravel deposits that are underlain by an impermeable clay zone. The resultant peak discharges are small to moderate, and there is very little erosion of slopes or channels. Susceptibility of the soils to compaction by heavy machines and the effects of compaction on soil-water relations are demonstrated.

Estimates of peak discharges made with four methods are divergent, particularly for recurrence intervals of 2, 5, and 10 years; divergence is less for 25-, 50-, and 100-year discharges. A premining estimate of sediment yield made with the Universal Soil Loss Equation and a sediment-delivery ratio is about 2.5 times larger than an estimate made with the sediment rating curve-flow duration method.

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1982

Cover picture--Oblique aerial photograph taken by F. W. Osterwald on May 20, 1978. View is northwest across the Absaloka Mine in the Sarpy Creek basin, Yellowstone County, Montana. Note the reclaimed area in the upper left quadrant.

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply inch-pound units	By	To determine metric units
acres	4.047×10^{-1}	square hectometers
	4.047×10^{-3}	square kilometers
acre-feet	1.233×10^{3}	cubic meters
cubic feet per second	2.832×10^{-2}	cubic meters per second
feet	3.048×10^{-1}	meters
feet per mile	1.894×10^{-1}	meters per kilometer
feet-tons per acre per inch	1.735×10^{-1}	megagram-meters per square hectometer per millimeter
gallons per minute	6.309×10^{-2}	liters per second
inches	2.540×10^{1}	millimeters
	2.540×10^{-2}	meters
miles	1.609	kilometers
millibars	1.020	grams per square centimeter
pounds per cubic foot	1.602×10^{-2}	grams per cubic centimeter
square miles	2.590	square kilometers
tons	9.072×10^{-1}	megagrams
tons per acre	2.242	megagrams per square hectometer
tons per square mile	3.503×10^{-1}	megagrams per square kilometer
degrees Fahrenheit (°F)	[(°F-32) x (5/9) = °C]	degrees Celsius (°C)

GLOSSARY OF SOIL-WATER TERMS

Field saturation - Water content when soil with intact field structure is saturated, and all the voids are full; expressed as a ratio of the weight of water to the weight of dry soil.

Porosity - The ratio of the space in a soil not occupied by solids (volume of voids) to the total volume of bulk soil.
Porosity = 1 - (bulk density ÷ particle density).

Rapidly drainable water - Water in a nearly saturated or saturated soil that can practically drain unimpeded, because of small retention pressures of 0 to 49 millibars.

Retention capacity - Water content of soil when the retention pressure is about 294 millibars. This retention pressure is in the field capacity range where drainage becomes insignificant; expressed as either a weight or volume ratio of water to dry soil.

Slowly drainable water - Water present after a recharge event that is slowly draining, and that is impeded by retention forces ranging from 49 to 294 millibars.

Tightly adsorbed water - Water that does not drain because it is held by retention pressures of 294 millibars and greater.

Water-retention pressure - Pressure caused by the attraction of soil particles for water. The pressure to which a pool of pure water must be subjected to be in equilibrium through a permeable membrane with the soil water.

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LOBLOLLY BRANCH BASIN, TUSCALOOSA COUNTY, ALABAMA

By

L. M. Shown, D. G. Frickel, R. F. Miller, and F. A. Branson

ABSTRACT

Methodology for evaluating premining hydrology and postmining effects of mining and reclamation on the hydrology of an area is presented for a potential mine-permit area of 1,680 acres in the Warrior Coal Field, northwestern Alabama.

Information is included on climate, geology, soil-water relations, vegetation, surface water, ground water, and quality of water. Estimation techniques are used to develop data for reconstructed topography, soil-water relations, vegetation cover, peak flows, flow volumes, soil losses, and sediment yields.

Streamflow response of the basin is described by the variable-source-area concept; nearly all water moving from slopes flows through coarse-textured soils and unconsolidated sand and gravel deposits that are underlain by an impermeable clay zone. The resultant peak discharges per unit area are small to moderate, and there is very little erosion of slopes or channels. Susceptibility of the soils to compaction by heavy machines and the effects of compaction on soil-water relations are demonstrated.

Regression and empirical methods for evaluating streamflow characteristics are compared. Estimates of peak discharges made with four methods are divergent, particularly for recurrence intervals of 2, 5, and 10 years; divergence is less for 25-, 50-, and 100-year discharges.

The Universal Soil Loss Equation (USLE) and sediment-delivery ratios are used to estimate sediment yields for various land and cover conditions from premining until 20 years after reclamation would begin. A premining estimate of sediment yield made with the Universal Soil Loss Equation and a sediment-delivery ratio is about 2.5 times larger than an estimate made with the sediment rating curve-flow duration method.

Research and data needs are discussed regarding: (1) An improved understanding of the hydrology of small, very permeable, upland basins; (2) alternative methods for estimating streamflow and sediment yield of such basins; (3) field evaluation of permeability and erodibility of soils on reclaimed areas; and (4) better understanding of ground-water hydrology and geochemistry of the coal-bearing Pottsville Formation before and after mining.

INTRODUCTION

With increased emphasis on coal as an energy source for the nation, it is anticipated that leasing and production of Federal and privately-owned coal will accelerate rapidly. Permits for new mines will be granted under the Federal Coal Management Program established in 1979. When permit applications are made to the Office of Surface Mining to mine coal deposits by surface-mining methods, mining and reclamation plans must be evaluated for compliance with the permanent regulations of the Surface Mining Control and Reclamation Act of 1977 (Federal Register, March 13, 1979) (hereinafter called "the regulations"). Compliance with State regulations also must be considered when coal ownership is mixed Federal and State or private, and when State regulations are more stringent than Federal regulations.

This report demonstrates the use of available methodology with which the hydrology of the mine site and adjacent areas can be evaluated. The area studied in the Warrior Coal Field of northwestern Alabama (fig. 1) is considered to be representative of southern Appalachian coal fields that are mantled with unconsolidated Cretaceous deposits of sands, gravels, and clays and various mixtures thereof, and which is underlain by a much less permeable formation.

Objectives and Scope of Report

The objective of this report is to demonstrate methodology to provide hydrologic information required for obtaining permits to mine coal and other energy-mineral resources, with respect to the permanent regulations of the Surface Mining Control and Reclamation Act of 1977. Methods that can be used to evaluate the hydrologic system of a potential mine site and adjacent area, for both premining and postmining conditions, are presented. Limitations of alternative methods and the rationale for deciding which method to use in a given situation are discussed for some components of the hydrologic system. Additional objectives are to identify research needed: (1) To describe hydrologic processes prior to, during, and after mining and reclamation; and (2) to improve present methods or to develop new methods for quantifying these processes.

The approach is to quantify and interpret selected hydrologic variables and controlling environmental variables, such as climate, geology, vegetation, and soils, in view of requirements of the regulations dealing with the design of the mining and reclamation plan. Evaluation of potential effects of mining on the hydrology of the area will be emphasized.

This report does not provide a complete analysis of all phases of the hydrology of the study area and there is no intention to evaluate the site as to its suitability for mining. The topics covered in this report address constraints of Federal regulations only. State and local regulations are not considered. Only those aspects of the regulations that are most pertinent to the hydrology of the area are discussed.

Acknowledgments

The authors acknowledge the splendid assistance provided by personnel of the Tuscaloosa Subdistrict of the Water Resources Division when we collected field data and during the preparation of this report. In particular, we thank Celso Puente and John Newton for the benefits of their knowledge of the geology and hydrology of the report area and their frequent counseling whenever we encountered difficulties in understanding the hydrologic system. We also appreciate the help Jack Hill gave us in obtaining the vegetation data.

Definitions

For purposes of this report the *permit area* and *adjacent area* are defined in accordance with the final rules and regulations of the Office of Surface Mining Reclamation and Enforcement (Federal Register, March 13, 1979, p. 15320). The *permit area* is defined as the area within which surface coal mining and reclamation and related activities may be conducted or located during the term of the permit. The *adjacent area* means land located outside the permit area that may be adversely impacted by surface coal mining and reclamation operations (Federal Register, March 13, 1979, p. 15317).

DESCRIPTION OF THE STUDY AREA

Location and Name

The area selected as a study area for demonstration of hydrologic assessment methods lies mostly in a small 2.48 square-mile drainage basin in north-central Tuscaloosa County, Alabama, within the Warrior Coal Field. The basin was selected because it lies above U.S. Geological Survey partial-gaging station number 02462985 and because it is underlain partially by Federally-owned coal as shown in figure 2. The potential permit area includes all of sections 11 and 14, the southeast quarter of section 10, and the east half of section 15 (fig. 2). The adjacent area consists of the remaining area outside of the permit area but within the drainage divide of the basin. Soil, vegetation, and streamflow data collected at sites in the Yellow Creek basin, which borders the study area, was used in evaluating the hydrology of the study area (fig. 1).

The perennial stream draining the basin is unnamed on the U.S. Geological Survey Windham Springs 1:24,000 scale quadrangle; for purposes of this report we have named it "Loblolly Branch" owing to the large area of loblolly pine plantations in the basin. Loblolly Branch basin is a headwater tributary of Yellow Creek located about 15 miles north of Tuscaloosa, Alabama, and about 3 miles west of the Black Warrior River. As shown in figure 1, Loblolly Branch enters Yellow Creek about 1/3 mile downstream from the partial-record gaging station. Yellow Creek, in turn, joins the Black Warrior River about 11 miles downstream after flowing through Lake Nicol and Harris Lake.

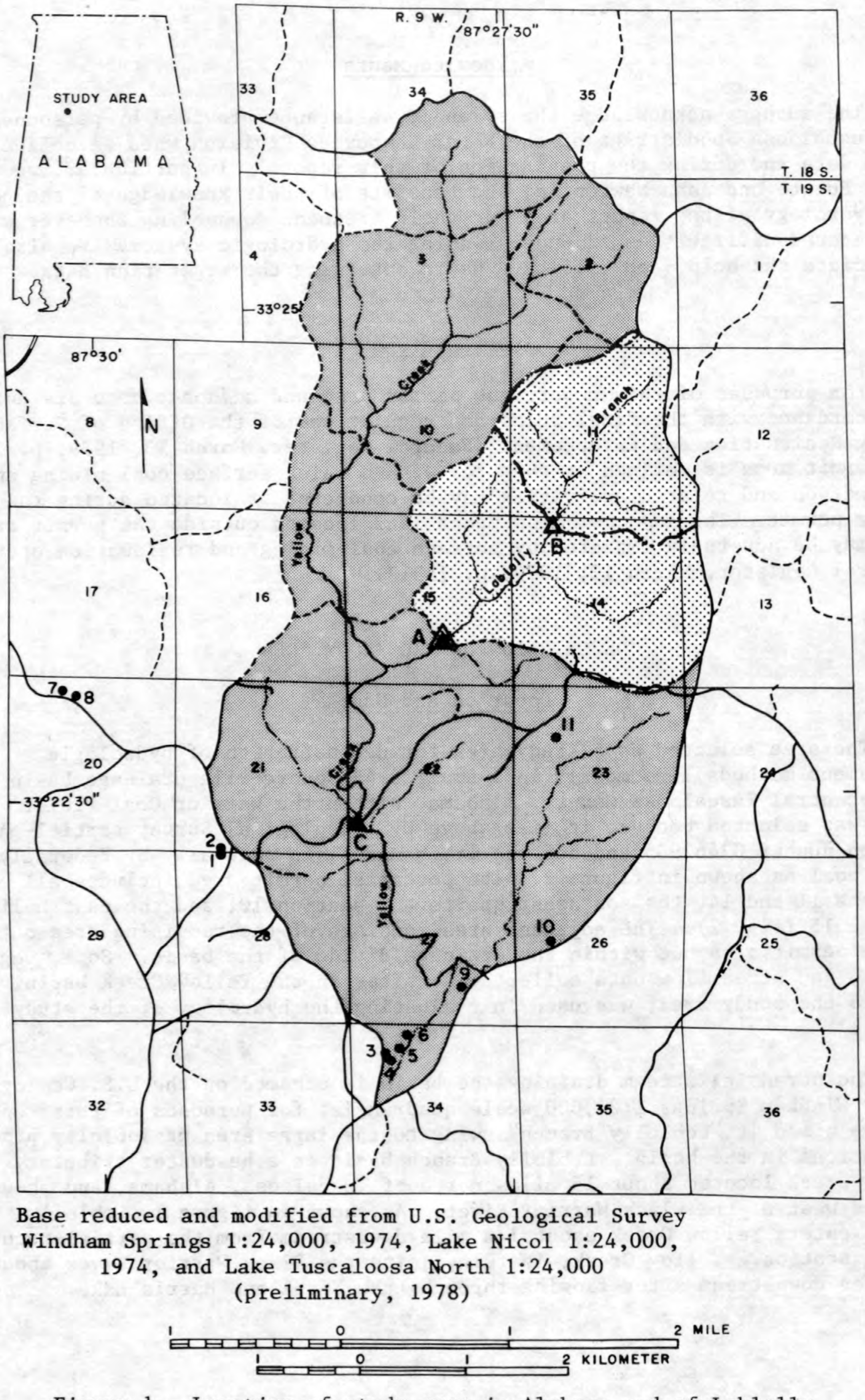
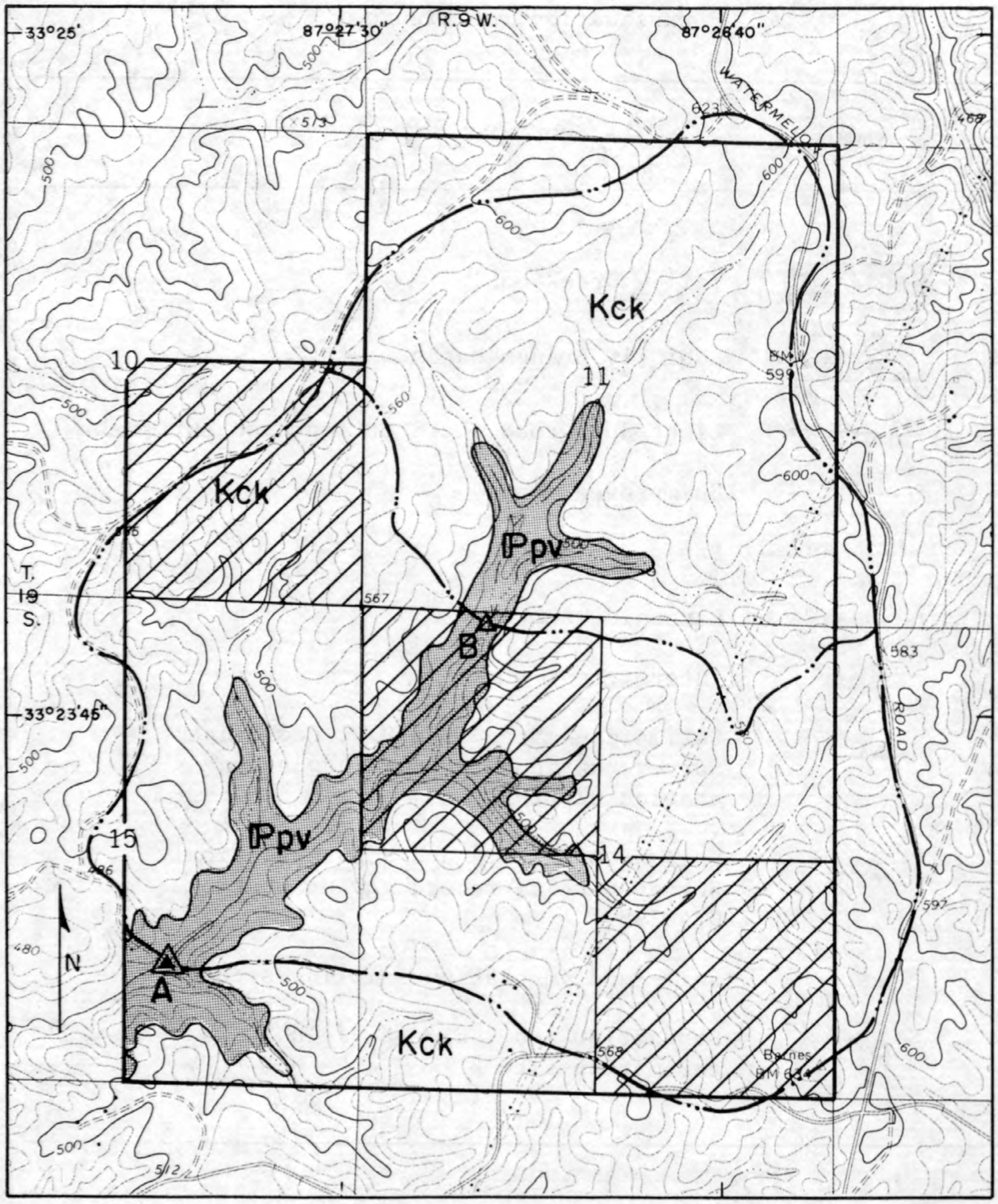


Figure 1.--Location of study area in Alabama and of Loblolly Branch and Yellow Creek basins.

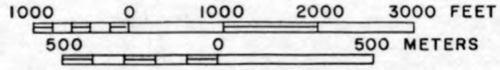
Explanation for figure 1

Symbol	Explanation
	Yellow Creek basin
	Loblolly Branch basin
	Light-duty road, hard or improved surface
	Unimproved road
	Basin divide
	Perennial stream
	Intermittent stream
▲ C	Estimation-site C and U.S. Geological Survey continuous-record gaging station 02462990
A	Estimation-site A and U.S. Geological Survey partial-record gaging station 02462985
• 5	Soil- and vegetation-sampling sites
△ B	Streamflow and sediment-yield estimation-site B



Base from U.S. Geological Survey Windham Springs 1:24,000, 1974

Geology by J. G. Newton (1979), from Puente and others (1980). Coal ownership from U.S. Bureau of Land Management (1975).



CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929

Figure 2.--Loblolly Branch basin and headwater subbasin, and the geology and coal ownership of the permit area.

Explanation for figure 2

Symbol	Explanation	
	CORRELATION OF MAP UNITS	
Unconformity		
Kck	Upper Cretaceous	CRETACEOUS
ℙPpv	Middle and Lower Pennsylvanian	PENNSYLVANIAN
	DESCRIPTION OF MAP UNITS	
Unconformity		
Kck	COKER FORMATION—Basal beds consist of iron-cemented sandstone or conglomerate and unconsolidated fine- to coarse-grained sand, sandy gravel and lenses of gray, sandy clay. Overlain by thin-bedded to massive clay and sandy clay with some beds of fine- to medium-grained sand	
ℙPpv	POTTSVILLE FORMATION—Chiefly light-gray to dark-gray shale; also siltstone, sandstone coal beds and underclay	
	Federal ownership of coal; nonhatched area designated private ownership of coal	
	Permit-area boundary	
	Basin divide	
▲A	U.S. Geological Survey partial-record gaging station 02462985	
△B	Streamflow and sediment-yield estimation site	

Physiography and Relief

Loblolly Branch basin is located in a hilly area near the southern tip of the Cumberland Plateau section, which is at the south end of the Appalachian Plateaus province (Fenneman, 1946). Pine plantations and mixed pine and hardwood forest cover the whole basin. The upland area, where the basin is situated, is one of low to moderate relief and is moderately dissected by a shallowly incised drainage network. As indicated by the topographic base of figure 2, the maximum relief of the basin is about 185 feet. The entire basin consists of gentle to moderately steep hillslopes that form the sides of relatively narrow valleys.

Geology and Coal Resources

Applicable Regulations

The following part of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979) requires that geology and coal resource information be included in a permit application:

Subchapter	Part
G	779.14 Geology description

Surface-mineable coal occurs on the permit area in the Pottsville Formation of Pennsylvanian age. The Pottsville Formation is consolidated and the surface-mineable interval consists chiefly of light-gray to dark-gray shale, siltstone and sandstone (Metzger, 1965). As shown in figure 2, the Pottsville outcrops only in the lower valley floors of Loblolly Branch basin. Strata in the Pottsville strike east and northeast and dip south and southeast about 25 to 30 feet per mile (Puente and others, 1980).

The Coker Formation of Cretaceous age unconformably overlies the Pottsville and covers nearly all of the permit area to a maximum thickness of about 120 feet. The Coker is unconsolidated and the basal sand and gravel beds contrast greatly with the plastic clay at the top of the Pottsville Formation. Puente and others (1980) report that one or more thin beds of iron-cemented sandstone or conglomerate usually are present near the base of the Coker Formation. Strata overlying the basal unit consist largely of thin-bedded to massive clay and sandy clay with occasional beds of fine- to medium-grained sand. The Coker Formation strikes northwestward and dips southwestward about 30 to 35 feet per mile (Puente and others, 1980).

Surface-mineable coal beds in the Loblolly Branch basin are in the Brookwood coal group of the Pottsville Formation. The Brookwood group consists of five coal beds, two of which are thin or absent in most places (Culbertson, 1964). These beds are high-volatile A-bituminous coals with low to moderate ash contents and low sulfur contents (Culbertson, 1964). Drilling logs furnished by the U.S. Geological Survey and the U.S. Bureau of Land Management for four test wells around the perimeter of the basin and one well within the basin indicate the presence of two to four coal beds. A geologic cross section that traverses the basin (Puente and others, 1980) shows the occurrence of two continuous coal beds. The upper bed, however, is truncated near the south divide of the basin at the Coker-Pottsville contact.

Individual coal beds penetrated in the test wells ranged from 2 to 24 inches in thickness for coals that were within 132 feet of the land surface. Total thickness of all beds in each well ranged from 14 to 44 inches.

Soils

Applicable Regulations

The following part of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979) requires that soil information be included in a permit application:

Subchapter	Part
G	779.21 Soil-resource information

A soil survey of Tuscaloosa County conducted by the U.S. Soil Conservation Service (unpublished preliminary mapping, 1976) shows that the hilly phase of the Smithdale Association soils, cover nearly all of Loblolly Branch basin. A small area in the lower end of the basin is mapped as Smithdale-Pikeville Association. Extrapolation of soils data from soil-water monitoring sites located in various topographic positions in Yellow Creek basin (fig. 1) indicates that the U.S. Soil Conservation Service survey was not sufficiently detailed in Loblolly basin to identify adequately, for mine-reclamation planning purposes, all of the major soil series there.

About 80 percent of the permit area is covered with deep, coarse-textured soils developed on gentle to moderately steep hillslopes in sands, sandy gravels, loams, and various mixtures thereof, all derived from the unconsolidated Coker Formation. This understanding of the soils is based on the water-retention-capacity data from soil-water monitoring sites on hillslopes and in upper hollows, and especially from site 11 (fig. 1), which is near Loblolly basin and probably represents most of the hilly terrain in the basin. These coarse-textured soils, some of which are very gravelly, have loamy-sand A horizons 50 to 55 inches thick, underlain by loamy sand to sandy loam B horizons about 50 inches or more thick.

Other types of soils occur on the slightly- to moderately-sloping broad drainage divides. These soils apparently occur as about 10 small patches that cover about 9 percent of the permit area. These soils are very old and well-developed and have a definite zone of clay accumulation in the B horizon. This is indicated by water-retention capacity and bulk-density data for site 2 (fig. 1). These data are presented later in this report in the water-relations-in-soils section. The A horizons of these soils, consisting mainly of quartz particles, have a sandy-loam texture and are 20 to 25 inches thick except on severely compacted sites where they are only 10 and 14 inches thick. B horizons are loam- to sandy-clay-loam textured and are 25 to 30 inches thick. In the general vicinity of the permit area, small patches of soils of this type have been cleared and are used for crops and pastures, but forest cover remains on them in the permit area.

Other soils that occur on the permit area are those that are derived partly or wholly from the Pottsville Formation. The exposure of Pottsville Formation covers about 10 percent of the permit area in the lower hillslopes and narrow valley bottoms along the lower reaches of Loblolly Branch (fig. 2). Based on sampling at site 9 (fig. 1), soils developed on the Pottsville Formation are relatively shallow and are finer-textured than soils developed from the Coker Formation. The A horizons are loamy and are about 16 inches thick. The B horizons have a loam- to clay-loam texture and grade into weathered shale at a depth of about 36 inches. It is likely that much of the soil over the Pottsville Formation is modified to some degree by sands and gravels transported from the Coker Formation, which lies upslope of the area where the Pottsville is exposed. These soils would be coarser-textured and probably would be somewhat deeper than the soil at site 9.

Another type of soil, minor in terms of area covered, probably exists along the channels and drainageways. These alluvial soils were not sampled, but they probably are coarse-textured and poorly developed. These soils are wet most of the time because they are flooded frequently and the ground-water table is near the surface. The depth of ground water controls the depth of soil development. Series descriptions prepared by the U.S. Soil Conservation Service for several of the series that probably occur on Loblolly Branch basin indicate that all of the soils are strongly acid to very strongly acid.

Vegetation

Applicable Regulations

The following parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979) require that vegetation and land-use information be included in a permit application:

Subchapter	Part
G	779.19 Vegetation information
	779.22 Land-use information

Loblolly Branch basin is in the upper portion of the vegetation type mapped by Küchler (1964) as the oak-hickory-pine (*Quercus-Carya-Pinus*) forest. As indicated by the order of genera in the oak-hickory-pine type name, an undisturbed or climax stand should have an abundance of oaks, followed by hickories, and some pines. Present stands within the basin have been logged repeatedly and some have been replaced by pine plantations; therefore, the native vegetation on the study area has been modified to various degrees.

Vegetation Mapping

Good-quality aerial photographs at a scale of 1:24,000 are desirable for vegetation mapping. The order of preference of photographs is color, false color infrared, then black-and-white. False color infrared is useful if degree of wetness of different habitats is of special interest. Photographs taken early in the growing season give the best definition of vegetation-type differences.

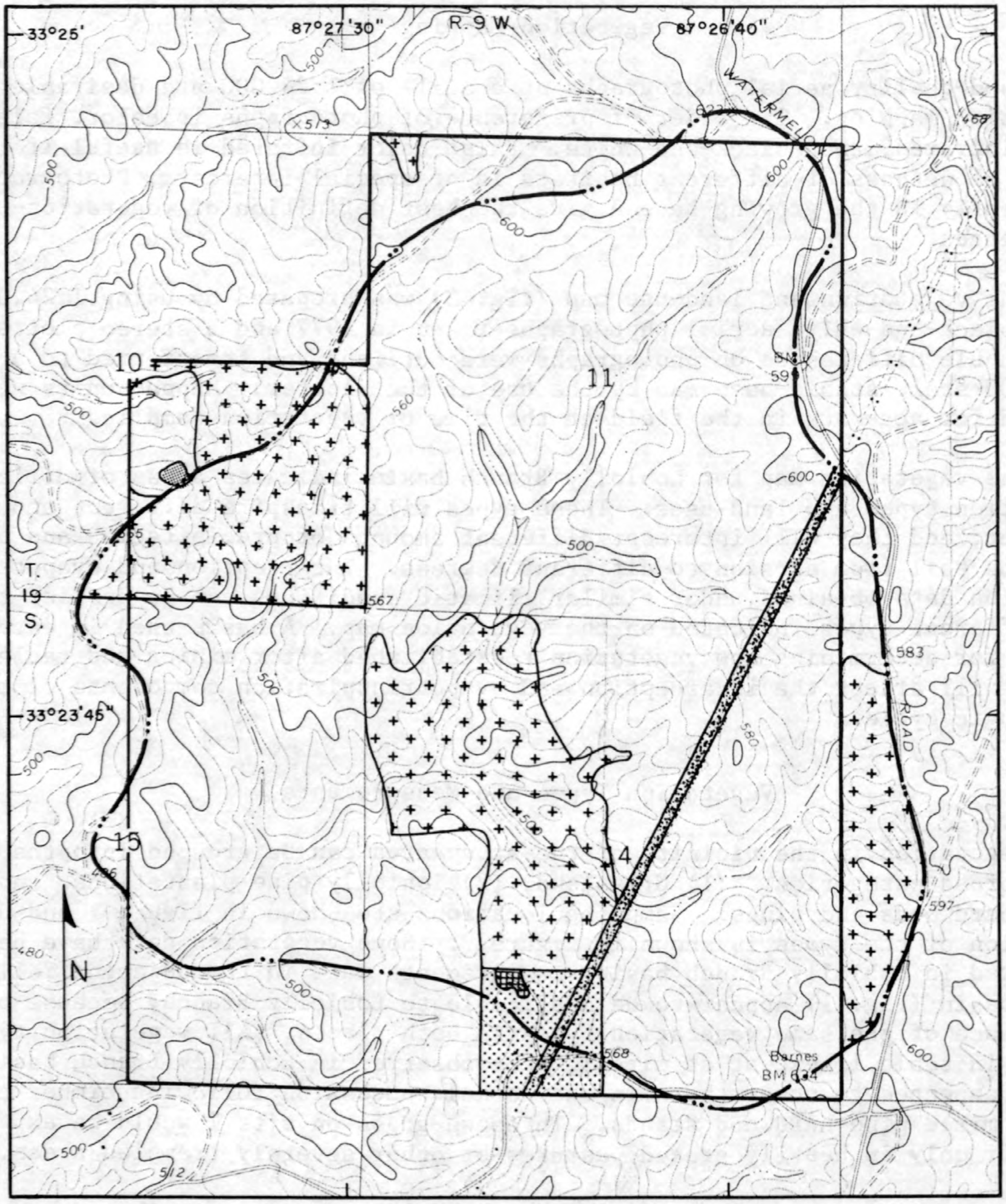
The vegetation and land-use map (fig. 3) was prepared by using 1:24,000-scale black-and-white aerial photographs taken in 1977 and a stereo plotter. Discernable differences on photographs were outlined and transferred to a 1:24,000-scale stable-base map by the use of the plotter. Mapped units were checked for accuracy in the field at the time of vegetation sampling.

The vegetation map for Loblolly Branch basin indicates areas of different vegetation types and land uses. These types will transpire different amounts of water, and they will intercept different amounts of precipitation and protect the soil from erosion to different degrees. Interception and evapotranspiration data obtained under similar climatic conditions can be applied to the different types indicated on the vegetation map. A basis then is established for determining how vegetation reestablished after mining and reclamation will affect the interception and evapotranspiration components of the hydrologic cycle.

Vegetation Types and Measurements

Vegetation in the vicinity of the study area can be grouped into the three broad categories: (1) Grassland, (2) loblolly pine plantations, and (3) mixed hardwoods and pines. Sampling locations are shown in figure 1 and distribution of the types is shown in figure 3. Some vegetation data have been collected in Loblolly Branch basin; measurements made in the adjacent Yellow Creek basin (fig. 1) appear to be applicable to Loblolly Branch, because of occurrence of the same vegetation types in both places. All vegetation types listed in table 1, except at site 1, were observed in Loblolly Branch basin or can be expected to occur there in the normal succession following timber cutting in the mixed pine-hardwood stands. Threeawn grass on site 1 would be expected to occur only in heavily grazed pastures or other severely trampled areas.

There are no natural grasslands in the Yellow Creek basin, but areas such as pastures (site 1, fig. 1) and a powerline right-of-way (site 3) are cleared of most woody vegetation and now are occupied by grasses. The fast-growing loblolly pine is a favored wood for pulp production and has been planted at sites 2, 7, 8, and 11, and in the Loblolly Branch basin (fig. 3). Mixed hardwoods and pines, in various stages of succession toward climax following logging, occur at sites 5, 6, 9, and 10. In general, the older pine plantations and the higher stages of plant succession in mixed hardwoods and pines have the most aerial cover and greatest foliage depths. Herbaceous plants decrease as cover by woody plants increases. Hardwoods may be considered invaders in pine plantations, because they become established naturally. Hardwoods probably would become dominant over man-planted pines with sufficient time.



Base from U.S. Geological Survey
Windham Springs 1:24,000, 1974

1000 0 1000 2000 3000 FEET
500 0 500 METERS
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929

Figure 3.--Vegetation and land-use map of Loblolly Branch basin based on aerial photography taken in March, 1977.

Explanation for figure 3

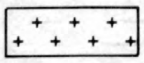
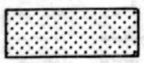
Symbol	Explanation
	Areas cleared of woody species and either seeded or allowed to become invaded by herbaceous species, primarily grasses. Along the powerline right-of-way the dominant grass is broomsedge
	Commercial loblolly pine plantations in various stages of maturity. Aerial cover and foliage depths increase with ages of the planted stands. Hardwood species, such as blackjack and red oak, form the understory
	Cutover stands in various stages of succession towards climax, which consists of mixed hardwood and pine species. Prominent species are mockernut, hickory, blackjack oak, red oak, Virginia pine, shortleaf pine, and longleaf pine
	Clear-cut areas have predominantly herbaceous cover, but these areas will naturally revert to or be planted to trees
	Houses and yards
	Cropland
	Permit area boundary
	Drainage divide

Table 1.--*Aerial cover and foliage depths of vegetation at soil-moisture sampling sites in the Yellow Creek basin, Tuscaloosa County, Alabama - October 1979*

[Line-intercept transects 100 feet in length were used for woody plants and first-contact point-quadrat measurements were made along 50-foot transects for herbaceous species. Aerial cover is in percent and foliage depth in feet]

		Grasslands				Loblolly pine plantations			
Vegetation type		Broomsedge		Threeawn-Post oak		Loblolly pine-Blackjack oak		Loblolly pine-Blackjack oak	
Location (soil moisture well number)		3		1		11		7	
Genus and species	Common name	Cover	Depth	Cover	Depth	Cover	Depth	Cover	Depth
Woody plants									
Callicarpa americana	French mulberry	----	----	----	----	----	----	----	----
Carya glabra	Pignut hickory	----	----	----	----	----	----	----	----
Carya tomentosa	Mockernut hickory	----	----	----	----	----	----	----	----
Carya sp.	Hickory	----	----	----	----	----	----	----	----
Cornus florida	Flowering dogwood	----	----	----	----	----	----	----	----
Hydrangea quercifolia	Oakleaf hydrangea	----	----	----	----	----	----	----	----
Lonicera japonicus	Japanese honeysuckle	----	----	----	----	----	----	----	----
Lonicera sp.	Honeysuckle	----	----	----	----	----	----	----	----
Nyssa sylvatica	Black gum	----	----	----	----	----	----	----	----
Oxydendrum arboreum	Sourwood	----	----	----	----	----	----	10	1.5
Pinus echinata	Shortleaf pine	----	----	----	----	----	----	----	----
Pinus palustris	Longleaf pine	----	----	----	----	----	----	----	----
Pinus taeda	Loblolly pine	----	----	----	----	81	8.6	100	10.4
Pinus virginiana	Virginia pine	5.3	----	----	----	----	----	----	----
Quercus alba	White oak	----	----	----	----	4	T[1/]	----	----
Quercus falcata	Southern red oak	----	----	----	----	----	----	----	----
Quercus marilandica	Blackjack oak	----	----	----	----	8	0.5	3	0.2
Quercus montana	Chestnut oak	----	----	----	----	----	----	----	----
Quercus rubra	Northern red oak	----	----	----	----	8	1.3	----	----
Quercus stellata	Post oak	----	----	17	2.6	----	----	----	----
Sassafras albidum	Sassafras	----	----	----	----	----	----	----	----
Rhus sp.	Sumac	----	----	----	----	----	----	1	0.1
Rubus sp.	Blackberry	----	----	----	----	----	----	----	----
Vaccinium arboreum	Sparkleberry	----	----	----	----	----	----	----	----
Vitus sp.	Grape	----	----	----	----	----	----	----	----
Herbaceous plants (grasses and forbs)		74.0	2.6	71.0	0.9	16	1.0	41.3	1.0
Total foliage depth			2.6		3.5		11.4		13.2

1/ Less than 0.1 feet.

Table 1.--Continued

Loblolly pine plantations				Mixed hardwoods and pines									
Loblolly pine-Virginia pine		Loblolly pine-Red oak		Virginia pine-Blackjack oak		Virginia pine-Red oak		Southern red oak-Virginia pine		Virginia pine-Blackjack oak		Mockernut hickory-Post oak	
2		8		4		5		10		6		9	
Cover	Depth	Cover	Depth	Cover	Depth	Cover	Depth	Cover	Depth	Cover	Depth	Cover	Depth
----	----	----	----	----	----	5	T[1]	----	----	----	----	----	----
----	----	----	----	4	T[1]	----	----	----	----	19	1.1	----	----
7	0.5	----	----	----	----	9	0.7	----	----	----	----	31	6.8
----	----	----	----	----	----	----	----	----	----	----	----	2	0.1
----	----	34	5.1	----	----	19	1.7	24	1.3	----	----	44	3.5
34	0.8	----	----	----	----	8	0.3	1	T[1]	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	4	0.1
----	----	----	----	26	2.5	----	----	30	4.2	----	----	3	0.4
----	----	----	----	----	----	----	----	----	----	----	----	27	3.7
----	----	14	2.1	----	----	----	----	----	----	----	----	----	----
50	6.0	73	8.7	----	----	----	----	----	----	5	1.2	----	----
20	2.3	----	----	49	6.2	42	4.6	91	10.2	61	8.8	28	4.2
22	7.7	----	----	----	----	----	----	----	----	----	----	16	1.9
----	----	----	----	----	----	----	----	55	6.9	----	----	----	----
5	0.2	6	0.3	35	6.0	----	----	----	----	32	6.6	----	----
----	----	----	----	----	----	----	----	----	----	----	----	1	T[1]
----	----	12	1.8	----	----	37	5.1	----	----	9	1.8	11	1.0
----	----	----	----	----	----	8	2.4	----	----	26	6.5	29	4.1
----	----	----	----	2	T[1]	----	----	6	0.4	----	----	----	----
3	0.1	----	----	----	----	----	----	----	----	----	----	----	----
2	T[1]	----	----	----	----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----	----	----	----	9	0.2
----	----	----	----	----	----	5	0.8	----	----	----	----	----	----
		----	----	----	----	----	----	----	----	----	----	----	----
33.7	T[1]	----	----	----	----	----	----	13.3	0.2	----	----	9.7	0.2
	17.6		18.0		14.7		15.6		23.2		26.0		26.2

Aerial cover in all the tree types sampled in October 1979 exceeded 100 percent (table 1). Species cover in the multiple layers above each sample line measured as much as 205 percent aerial cover for the mockernut-hickory and post-oak type. Foliage depths for each species along a 100-foot transect line were computed by the equation:

$$\text{Foliage depth} = \sum_{n=1}^{a} \frac{H_n \times L_n}{L_t} \qquad (1)$$

where

a = designation of an individual species;

n = an individual occurrence of a species;

H_n = height, in feet, of each species over the sample line;

L_n = the length of foliage, in feet, over a vertical projection of the line; and

L_t = the total length of the transect.

The calculations give a length-weighted average of foliage depth for the transect (in feet), which is an estimate of the depth for the type. This measurement method is similar to that used by McDonald and Hughes (1968).

Ages and heights of trees have an effect on interception and transpiration; therefore, they affect the streamflow of a basin. Estimated ages of representative individuals of the dominant tree species on each sampling site (fig. 1) were determined by counting annual growth rings on radial cores obtained with an increment borer at breast height. Growth-ring counts were adjusted to account for the required time for young trees to reach breast height. The resultant estimated ages are listed in table 2, with other descriptive data. Average age of pine species was 27 years; average age of oak and hickory was 39 years.

Data for understory vegetation (plants less than 6 feet in height) are shown in table 3. Metal pins projected vertically at 2-inch intervals along 50-foot lines were used to measure vegetation and soil-surface conditions in October 1979. The first contacts by projected pins were recorded, and the data represent percent cover or hits per 100 pins (Levy and Madden, 1933). Bare soil and rock were present only in the grassland types; all tree types had a complete understory cover of mulch or vegetation. The presence of bare soil would indicate higher surface runoff from these grasslands than from tree types. Branson and Owen (1970) found runoff closely related to amounts of bare soil for semiarid watersheds in western Colorado. Mulch, which can intercept precipitation and reduce erosion, was far less abundant in grasslands than in forests; most of the understory species were shrubs and grasses. Shrubs, grasses, and forbs tended to decrease with increasing maturity of tree stands, especially in the pine plantations. In some tree stands, there were no understory species and only a thick cover of surface mulch.

Table 2.--*Estimated ages, diameters, and heights of dominant tree species at soil-moisture sampling sites in the Yellow Creek basin, 1980*

[Data modified from T. J. Hill, U.S. Geological Survey, written commun., 1980]

Sample site location	Tree species	Estimated age (years)	Diameter at breast height (feet)	Tree height (feet)
1	Post oak (*Quercus stellata*)	62	3.84	49
1	Longleaf pine (*Pinus palustris*)	29	3.34	47
2	Loblolly pine (*Pinus taeda*)	12	1.15	23
2	Virginia pine (*Pinus virginia*)	19	2.64	29
3	Blackjack oak (*Quercus marilandica*)	15	0.19	6
4	Blackjack oak (*Quercus marilandica*)	39	1.80	28
4	Virginia pine (*Pinus virginia*)	30	1.30	49
5	Virginia pine (*Pinus virginia*)	31	2.20	44
5	Northern red oak (*Quercus rubra*)	62	3.00	50
6	Virginia pine (*Pinus virginia*)	30	1.50	57
6	Post oak (*Quercus stellata*)	56	3.20	50
7	Loblolly pine (*Pinus taeda*)	18	1.32	27
7	Blackjack oak (*Quercus marilandica*)	21	0.82	14
8	Loblolly pine (*Pinus taeda*)	22	2.22	27
8	Southern red oak (*Quercus falcata*)	14	0.61	14
9	Post oak (*Quercus stellata*)	59	3.20	51
9	Mockernut hickory (*Carya tomentosa*)	61	2.74	45
10	Southern red oak (*Quercus falcata*)	40	2.03	46
10	Virginia pine (*Pinus virginia*)	35	2.66	60
11	Blackjack oak (*Quercus marilandica*)	16	0.95	20
11	Loblolly pine (*Pinus taeda*)	17	1.70	33

Table 3.--*Cover by understory species, in percent, for vegetation types at soil-moisture sampling sites in the Yellow Creek basin, Tuscaloosa County, Alabama*

		Grasslands		Loblolly pine plantations	
	Vegetation type............	Broomsedge	Threeawn-Post oak	Loblolly pine-Blackjack oak	Loblolly pine-Blackjack oak
	Soil moisture well number....	3	1	11	7
Genus and species	Common name				
Trees					
Acer rubrum	Red maple	----	----	----	----
Carya tomentosa	Mockernut hickory	----	----	----	----
Pinus virginiana	Virginia pine	5.3	----	----	----
Quercus marilandica	Blackjack oak	----	----	----	1.7
Shrubs					
Casmanthium sessilifolium	Casmanthium	----	----	----	0.3
Hydrangea sp.	Hydrangea	----	----	----	----
Lonicera japonicus	Japanese honeysuckle	----	----	----	----
Lonicera sp.	Honeysuckle	----	----	2.0	----
Oxydendrum sp.	Sourwood	----	----	----	1.0
Pteridium aqualinum	Bracken fern	----	----	7.7	31.0
Rhus copallina	Shining sumac	----	----	----	0.7
Rhus sp.	Sumac	----	----	0.3	----
Rubus sp.	Blackberry	----	----	0.3	----
Smilax sp.	Greenbrier	----	----	1.7	0.3
Vaccinium sp.	Blueberry	----	----	----	2.3
Unidentified shrubs		0.7	----	----	----
Grasses					
Andropogon gerardi	Big bluestem	0.3	----	----	----
Andropogon saccharoides	Silver beardgrass	1.7	----	----	----
Andropogon virginicus	Broomsedge	51.7	4.0	2.7	2.7
Aristida longispica	Threeawn	----	54.3	----	----
Digitaria sp.	Crabgrass	----	----	----	----
Eragrostis sp.	Lovegrass	----	----	----	----
Panicum scribnerianum	Scribner's panicgrass	----	1.3	----	----
Paspalum notatum	Bahia grass	----	9.7	----	----
Sorghastrum mutans	Indiangrass	4.0	----	----	----
Unidentified grasses		----	----	----	----
Forbs					
Physalis sp.	Groundcherry	0.3	----	----	----
Plantago purshii	Wooly Indianwheat	----	0.3	----	----
Solidago sp.	Goldenrod	----	----	----	0.7
Unidentified forbs		----	0.7	1.3	0.7
Lichen		2.7	----	----	----
Bare soil		3.7	2.7	----	----
Rock		8.3	1.3	----	----
Mulch		21.3	25.0	84.0	58.7

Table 3.--Continued

Loblolly pine plantations		Mixed hardwoods and pines				
Loblolly pine-Virginia pine	Loblolly pine-Red oak	Blackjack oak-Virginia pine	Virginia pine-Red oak	Southern red oak-Virginia pine	Virginia pine-Blackjack oak	Mockernut hickory-Post oak
2	8	4	5	10	6	9
----	----	----	----	1.0	----	----
----	----	----	----	----	----	1.7
----	----	----	----	----	----	----
0.7	----	----	----	----	0.7	----
----	----	----	----	----	----	1.0
----	----	----	----	----	----	----
24.0	----	----	----	----	24.0	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	1.7	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
1.0	----	----	----	----	1.0	0.3
----	----	----	----	----	----	1.0
----	----	----	1.3	9.7	----	5.7
0.7	----	----	----	----	0.7	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
6.7	----	----	----	----	6.7	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
0.7	----	----	----	1.0	0.7	----
----	----	----	----	----	----	----
----	----	----	----	----	----	----
66.3	100.0	100.0	98.7	86.7	66.3	90.3

Effects of Vegetation on Evapotranspiration

Swift and others (1975) reported that combined interception and transpiration (evapotranspiration) was 36 inches (46 percent of precipitation) for a mature oak-hickory forest at Coweeta, North Carolina, for a near-normal year when precipitation was 78.3 inches. A computer model, calibrated with oak-hickory data, was used to simulate evapotranspiration rates for a white-pine forest and for a clear-cut area one year after the cut. The simulated evapotranspiration rate was 46 inches (59 percent of precipitation) for white pine, and 23 inches (29 percent of precipitation) for the clear cut. Swift and others' (1975) estimates of interception were 12 percent of annual precipitation for oak-hickory and 17 percent for pine.

Evapotranspiration for the Yellow Creek basin (fig. 1), which has about the same proportion of land-use and vegetation types as Loblolly Branch basin, has been estimated to be about 56 percent of annual precipitation (30.8 inches), determined by difference between annual precipitation and streamflow (Celso Puente, U.S. Geological Survey, oral commun., 1980). Pine plantations cover about 76 percent of Loblolly Branch basin; mixed hardwoods and pines cover about 21 percent; and other land uses cover about 3 percent (fig. 3). Transfer of the Coweeta evapotranspiration-precipitation percentages of Swift and others (1975) to Loblolly Branch basin results in pine plantations accounting for about 80 percent of basin evapotranspiration; mixed hardwoods and pines accounting for about 19.5 percent; and other land uses accounting for about 0.5 percent. Any changes in vegetation types on Loblolly Branch basin resulting from mining and reclamation will have an effect on streamflow volume, which will be directly proportional to changes in evapotranspiration rates.

Climate

Climatological information that may be requested by regulatory authorities to be included in a permit application is listed in subchapter G, part 779.18 of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979). This includes: (1) Average seasonal precipitation; (2) average direction and velocity of prevailing winds; and (3) seasonal temperature ranges. In addition, calculation of runoff volumes and peak discharges requires precipitation amounts for storms of selected recurrence intervals and durations.

The study area has a subtropical climate characterized by hot, humid weather and little day-to-day temperature change. July is normally the hottest month of the year and January is the coldest. The average length of growing season is 225 days, from late March to early November. Temperatures below 0 degrees Fahrenheit are rare.

Mean annual precipitation at the nearest weather station, Bankhead Lock and Dam, is 53.21 inches, based on the period 1941 to 1970 (U.S. Department of Commerce, 1978). Bankhead Lock and Dam is on the Black Warrior River about 11 miles northeast of Loblolly Branch basin. Most of the precipitation occurs as rainfall, and slightly more than 50 percent of the annual precipitation occurs during the 5-month period from December through April. Summer precipitation normally occurs as afternoon thunderstorms, which are brief and more intense but smaller in areal extent than winter and early spring frontal-storm systems.

Climatic information listed in table 4 indicates the magnitude of monthly temperature, precipitation, and windspeed that may be expected in the Loblolly Branch basin. The absolute values of these variables in the basin may be slightly different from those listed. Precipitation amounts for a variety of storm durations and recurrence intervals are listed in table 5.

PREMINING HYDROLOGY OF THE STUDY AREA

Land use is another factor that controls the hydrology of a basin, in addition to the climatic and land characteristics described in the previous section. A change in land use, such as surface mining, will change the hydrology of a basin. The first step in quantifying or otherwise assessing the changes is to evaluate the hydrology under existing land and land-use characteristics. The existing hydrologic system is evaluated in discussions of soil moisture, surface water, ground water, water quality, erosion, and sediment yield; methodology for making the evaluation also is discussed.

The Premining Hydrologic System

Characteristics of the soils in Loblolly Branch basin suggest a system that seldom produces surface runoff. There is, in fact, little evidence of overland flow in the basin, yet the streams do flood in response to precipitation events. In an attempt to better explain this type of system, which is prevalent in forested watersheds of the humid southeastern United States, Hewlett (1961b) proposed the variable-source-area concept of upland streamflow.

According to the variable-source-area concept, much of the flood hydrograph results from subsurface flow, rather than sheet and rill flow. This subsurface flow often is delayed sufficiently to form a second peak on the hydrograph--the first peak resulting from precipitation falling directly on the channel and the saturated and (or) impermeable slopes bordering the channel. These bordering slopes make up the initial contributing area. As the storm continues, the bordering area of saturated soils expands both in width and length, thus increasing the area contributing to streamflow. After the precipitation ends, the contributing area shrinks to its original size as the saturated soils drain. This fluctuating size of contributing area gives rise to the term "variable-source area."

The system prevails where there is a certain combination of a litter layer overlying very permeable surface soils and frequent, low-intensity, high-volume precipitation events, such that the so-called excess rainfall necessary for overland flow rarely occurs. Rather, the rainwater moves down through the soil to a less permeable layer, either in the soil or at shallow depths in the

Table 4.--*Summary of temperature, precipitation, and wind information applicable to the Loblolly Branch study area*

Month	Mean temperature[1/]			Mean[2/] precipitation (inches)	Wind[3/]	
	Monthly (degrees Fahrenheit)	Daily maximum (degrees Fahrenheit)	Daily minimum (degrees Fahrenheit)		Mean velocity (miles per hour)	Prevailing direction
January	46	58	35	5.32	8.5	South
February	49	61	38	5.55	9.2	North
March	55	67	43	6.36	9.6	South
April	64	77	51	5.01	8.8	South
May	72	84	59	3.59	7.0	South
June	79	91	67	3.95	6.2	South-southwest
July	82	93	70	4.45	5.8	South-southwest
August	81	93	69	4.05	5.5	Northeast
September	75	87	63	3.31	6.7	East-northeast
October	64	78	50	2.40	6.3	East-northeast
November	53	66	39	4.11	7.7	North
December	46	58	35	5.11	8.1	North-northwest
Annual	64	76	52	53.21	7.5	South

[1/] At Tuscaloosa Airport.--From U.S. Department of Commerce, 1978.

[2/] At Bankhead Lock and Dam.--From U.S. Department of Commerce, 1978.

[3/] At Birmingham Airport.--From Ruffner, 1978.

Table 5.--*Estimated precipitation amounts for selected storm recurrence intervals and durations for the Loblolly Branch study area*[1/]

Storm duration	Storm recurrence interval (years)					
	2	5	10	25	50	100
	Precipitation amounts (inches)					
30 minutes	1.5	1.8	2.0	2.3	2.6	2.8
1 hour	1.8	2.3	2.6	2.9	3.2	3.5
3 hours	2.5	3.1	3.5	4.0	4.4	4.9
6 hours	3.0	3.8	4.3	5.0	5.5	6.0
12 hours	3.6	4.5	5.2	6.0	6.7	7.3
24 hours	4.2	5.3	6.1	7.0	7.7	8.5

[1/] From U.S. Department of Commerce, 1961.

underlying geologic formation, then moves laterally to discharge into a channel. Some of the flow may result from displacement of water stored from a previous storm (Hewlett and Hibbert, 1967). The result is that the main flood peaks are delayed for hours or even days; the peak discharges are less than they would be with overland flow conditions, and little, if any, sheet and rill erosion can occur.

Base flows of the streams in the Yellow Creek and Loblolly Branch basins are sustained by ground-water discharge from the aquifer at the base of the Coker Formation. This means that some water percolates through the soils and the Coker Formation, and, thus, recharges the aquifer.

Water Relations in Soils

Applicable Regulations

The Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979) do not specifically require information on water relations in soils in permit applications. However, water relations in soils are addressed in this report, because of their importance in many of the hydrologic processes operating in the study area. The following parts of the regulations address topics that involve water relations in soils:

Subchapter	Part
G	780.18 Reclamation plan: general requirements
K	816.21 Topsoil: general requirements
	816.22 Topsoil: removal
	816.23 Topsoil: storage
	816.24 Topsoil: redistribution
	816.41 Hydrologic balance: general requirements

Hydrologic responses of soils are evident in terms of how much water (1) flows off the surface, (2) drains rapidly through the soil to produce storm flows, and (3) drains slowly through the soil to sustain ground-water levels and base flows of streams. Interactions among soils, climate, and these processes determine the kinds and amounts of vegetation, and the quantity of water that vegetation will extract from the soil.

Porosity and soil-particle surface are the two most important variables that control water relations in soils. Soil porosity is computed by subtracting the volume of solids from a unit volume of bulk soil, using the equation:

$$\text{porosity} = 1 - (\text{bulk density} \div \text{particle density}).$$

A value of 165.4 pounds per cubic foot is normally used for particle density.

Soil-particle surface influences the status of soil water in two important ways: (1) As particle size decreases, the amount of adsorptive surface increases, increasing water-retention capacity; and (2) as soil-particle surface increases, a given quantity of water is distributed over more area and is held with greater retention forces.

Infiltration rates affect soil-water relations in many places, particularly in cases of intense rainfall on medium- and fine textured-soils. Infiltration rates are not intensively addressed in this report because they probably are not limiting factors, owing to the very porous nature of the coarse-textured surface soils. Permeability ranges for each horizon of soil series are published by the Soil Conservation Service as part of their soil survey interpretations; those data would probably be adequate for mine-permit studies where infiltration rates are needed.

Infiltration data obtained with natural rainfall or a rainfall simulator (Bertrand, 1965) on plots 12 square feet and (preferably) much larger in area, would be more accurate than U.S. Soil Conservation Service data, and may be required for soils with small infiltration rates. Another method for obtaining infiltration rates discussed by Bertrand (1965) is the use of double-ring infiltrometers. These values are usually less accurate than those obtained on plots with natural or simulated rainfall.

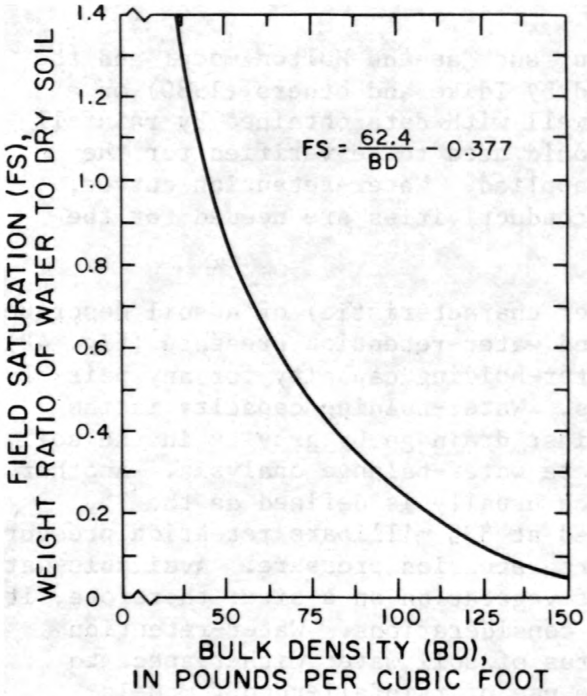
Equations for computing infiltration, such as the Holton model and the Green and Ampt model, have been evaluated by Idike and others (1980) on a loam soil, results that compared fairly well with data obtained by rainfall simulation. These and other equations would need to be verified for the particular soils to which they would be applied. Water-retention curves, water-holding capacities, and hydraulic conductivities are needed for the application of most equations.

The water-retention curve (soil-water characteristic) of a soil describes the relationship between water content and water-retention pressure (fig. 4B). The water-retention curve defines the water-holding capacity for any pair of upper and lower retention-pressure limits. Water-holding capacity is the volume of water that can be retained against drainage by gravity in the soil; it is a necessary component of any complete water-balance analysis. Another example is available-water capacity, which usually is defined as the difference in the volume of water retained at 333 millibars retention pressure and the water retained at 15,000 millibars retention pressure. Available-water capacity affects the kinds and amounts of vegetation on a site; therefore, it is important for reclamation and erosion considerations. Water-retention curves also are used to evaluate the status of soil water with respect to computations of infiltration rates by the use of rainfall-runoff models (Leavesley and others, 1981) or infiltration models (Idike and others, 1980).

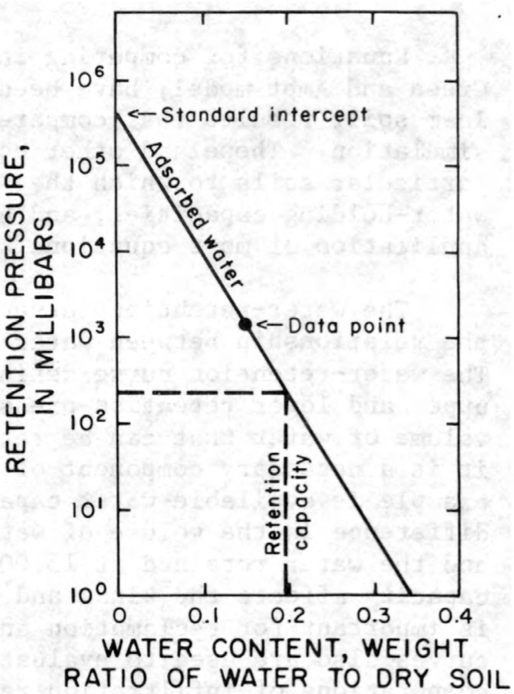
Pressure plate and (or) pressure membrane apparatus in the laboratory are normally used to obtain data to determine soil-water retention curves; these techniques have been described by Richards (1965). As with all techniques for evaluating the water-retention curve, the most accurate values are obtained by using "undistributed" core samples, in which the field structure is preserved. The disturbance factor has the greatest effect at small retention-pressure values of less than 200 millibars. Field structure is extremely difficult to preserve, even by coring, in the loamy sand surface soils of the study area.

Another pressure-control apparatus called the Tempe cell (Reginato and Van Bavel, 1962) is used to obtain more accurate data for small water-retention pressures. This apparatus was devised to protect the fragile structure of sandy soils; a cored sample, retained in a brass cylindrical insert, is placed in the pressure cell, which only holds one sample. Weighings are done on the complete assembly preserving the structure and maintaining firm contact between the sample and the porous plate. Moisture content and retention pressure values are determined stepwise from 0 to about 2,000 millibars, which is the pressure limit for the cell (R. J. Reginato, U.S. Department of Agriculture, Agricultural Research Service, oral commun., 1982). Other means of obtaining accurate data at small retention pressures are the use of tension plates or tables (Hillel, 1971) or by obtaining samples at measured distances above a static water table in the field.

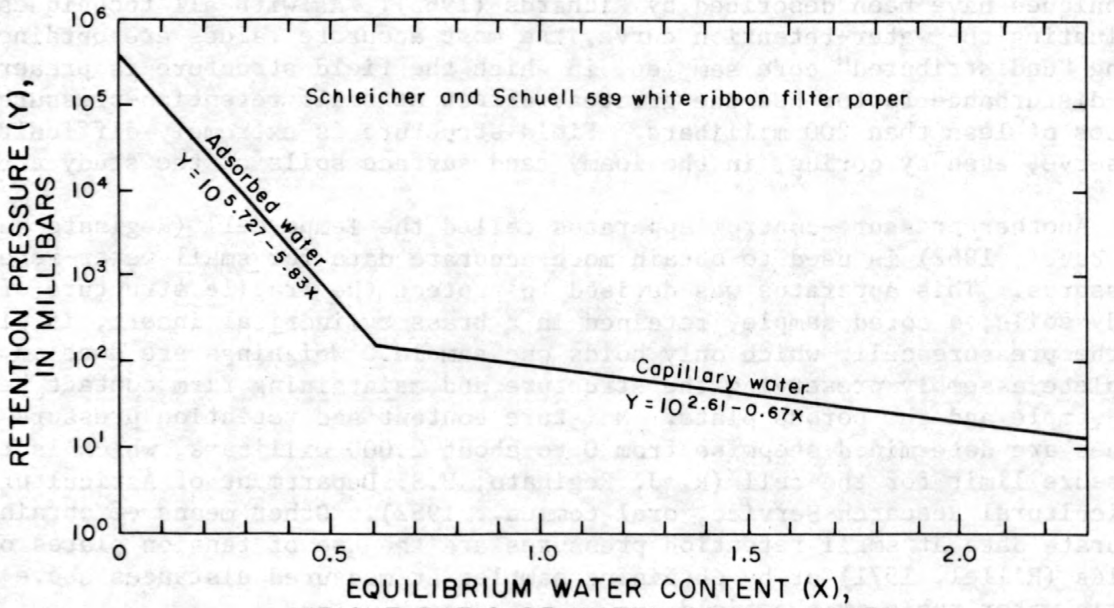
Most of the moisture-retention data reported in the literature, such as the large mass of data reported by Rawls and others (1981), was obtained by pressure-plate and pressure-membrane methods. These data, which are identified by soil series, or data available from the Soil Conservation Service or a university could be used to estimate moisture-retention curves for the same soil series occurring on a proposed mine permit area.



A.--Relation for predicting field saturation from bulk density.



B.--Water-retention model for a soil sample.



C.--Water-retention model for filter-paper discs used to measure water-retention pressure in soils.

Figure 4.--Relations used to evaluate field saturation and water-retention properties of soils (modified from Miller and McQueen, 1978). (Use of tradenames does not imply endorsement by the U.S. Geological Survey.)

The filter-paper method for determining water-retention curves (McQueen and Miller, 1968) was used in this study, because the curves were available for sites in the Yellow Creek basin (fig. 1), and these sites are representative of the soils in the Loblolly Branch basin. With the filter-paper method, water-retention pressure is determined from field samples with existing water contents; the samples are not saturated in the laboratory and not subjected to unnatural pressure as they are with pressure apparatus. Like the pressure methods, the filter paper measures matric pressure and not osmotic pressure. Total pressure can be measured, if the filter paper is kept separated from the soil sample, while both are sealed in the same container.

Measurement Techniques

Water-retention properties of soils can be approximated if adequate measurements are obtained of variations in field saturation and water-retention capacity of soils with depth. Contiguous 4-inch increments of soil are sampled with a 2-inch-diameter, orchard-type auger or coring equipment from the surface to a depth sufficient to define the hydrologically active zone. All the soil in each increment obtained with an auger is placed in a soil-moisture can with a filter-paper disc, and the can is sealed with plastic tape (McQueen and Miller, 1968). If cored samples are obtained, a filter paper is placed at each end of the core and the core sleeve is sealed. The two filter-paper moisture contents are averaged to account for the moisture gradient that is likely to occur from one end of the core to the other.

The adsorbed water-retention model of a sample or layer of soil can be obtained from a single measurement of soil-water content and the associated water-retention pressure (fig. 4B). The retention-pressure scale is presented in exponential form with a base of 10. The model is very similar in concept to one developed by Hewlett (1961a) for a permeable sandy-loam soil, using pressure-plate and tension-table methods. He showed the relation of water content to water-retention pressure as a straight-line function on a semilogarithmic graph over the pressure range of 39 to 10,784 millibars. This model is based on the assumption that capillary forces are a minor factor compared to adsorbtive forces in a draining or drying soil, even for high-moisture contents; therefore, a separate capillary segment is not shown for the model in figure 4B.

To construct the model in figure 4B, a line is extended from the $10^{5.727}$ millibar point on the pressure axis (ovendry at 230°F) through a data point representing a measured water content of a soil layer and the associated measured retention pressure. This modeling technique is an updated version of the one reported previously by McQueen and Miller (1974) and Miller and McQueen (1978).

Retention pressure associated with the water content of a soil sample is determined from the water content of a standard filter paper enclosed with the soil at the time of sampling; this paper has been treated with a chemical to prevent deterioration (McQueen and Miller, 1968). The filter paper is allowed to come to water equilibrium while stored for a week in an incubator where the temperature is maintained at 68 ± 0.1°F. Calibration relations for the filter paper are illustrated in figure 4C. These exponential relations are based on the combined calibration data of Miller and McQueen (1968) and Al-Khafaf (1972). This method is valid for a wide range of soil-water pressures and utilizes field samples with existing water contents.

Soil Porosity and Water-Status Models

Models for approximating amount of soil porosity and the partitioning of soil water according to retention pressure can be derived using the concepts and measurements discussed above. Such models have been prepared for four different sets of soil profiles, where neutron-moisture wells were established in the Yellow Creek basin (fig. 1); they are representative of soils occurring on Loblolly Branch basin. The models for the dominant soil on Loblolly basin are shown in figure 5. Models are presented graphically in two forms, with water contents on a weight basis in one form (fig. 5A) and water contents on a volume or porosity basis in the other (fig. 5C).

The weight-basis graphs and bulk-density graph represent the base data obtained from field sampling and laboratory analyses. The porosity graphs in figure 5C represent the soil's capacity for retaining adsorbed water and for containing drainable water; the fate of the water that enters the soil can be inferred from the graph. The variables graphed include water contents at the 294- and 49-millibar levels of retention pressure and at field saturation (fig. 5A). This approach of volume partitioning of the soil-water system is similar to one used by Holtan, England, and Whelan (1965).

The water content when the retention pressure is 294 millibars was chosen as the indicator of retention capacity (see glossary and fig. 4B), because that is about the pressure at which drainage due to gravity becomes insignificant. The retention capacity of a soil is proportional to the particle surface area and is independent of void space except in cases of severely compacted soils. The water content when the retention pressure is 49 millibars was chosen in the partitioning procedure, because that is about the level at which adsorptive forces become so small that drainage of water is practically unimpeded. Also, soil-water measurements at sites in the Yellow Creek basin (fig. 1) showed water-retention pressures to be about 49 millibars for draining soils sampled about one day after a rainstorm.

Field saturation (see glossary and figs. 4A and 5A) is the water content on a weight basis, when all voids are filled with water in a soil with field structure intact. It is determined from bulk density (fig. 5B) using the curve or the equation in figure 4A. These relations were derived by using values of 62.4 pounds per cubic foot for the density of water and 165.4 pounds per cubic foot for particle density. Field-saturation values can be converted to porosity values by multiplying by bulk density.

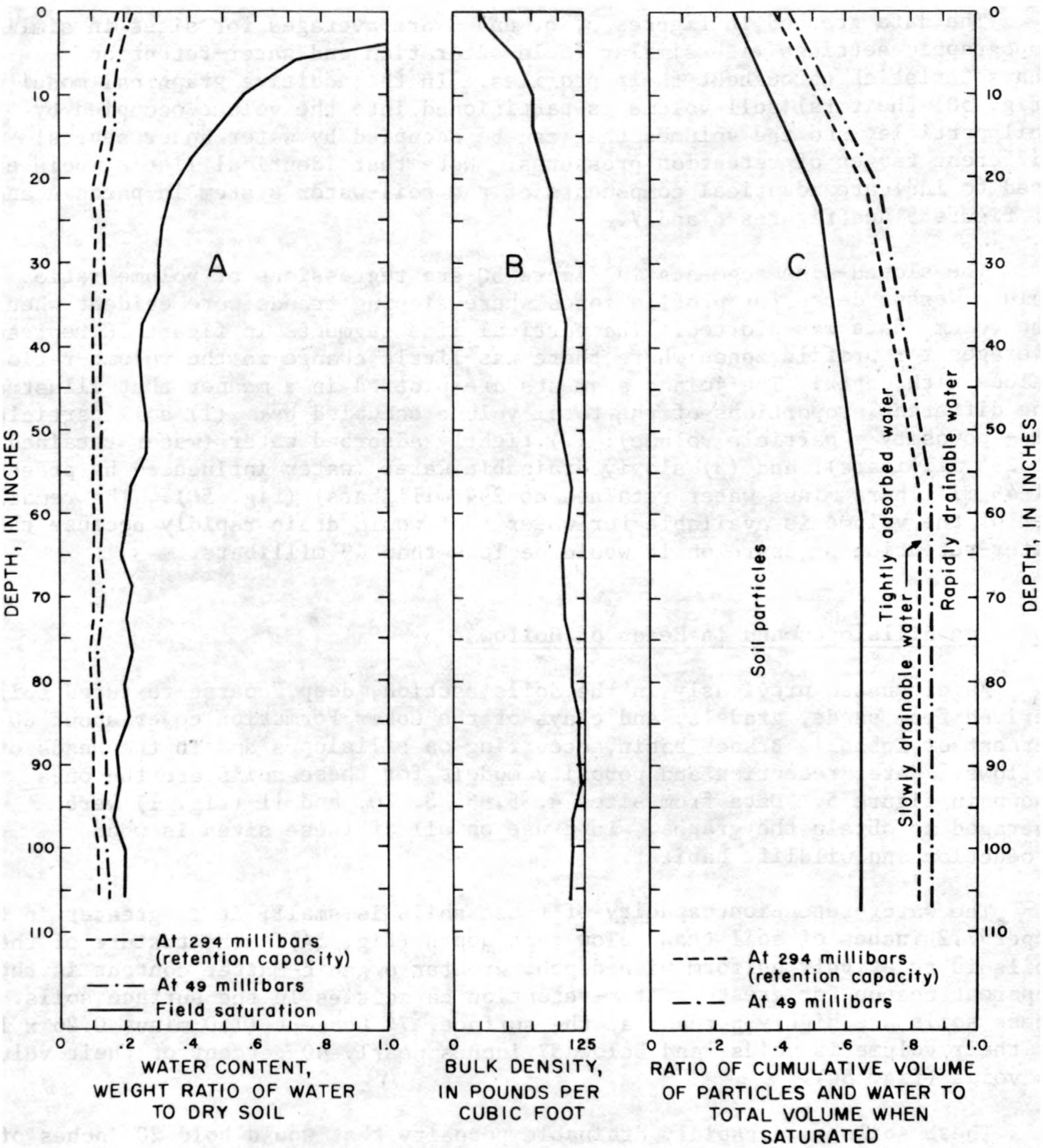


Figure 5.--Water-retention, bulk-density, and porosity models for highly porous soils on hillslopes.

The data graphed in figures 5, 6, and 7 are averages for sites in similar topographic settings with similar field saturation and water-retention characteristics throughout their profiles. In the additive graphical model (fig. 5C) the total soil volume is partitioned into the volume occupied by soil particles and the volumes that can be occupied by water under several different ranges of retention pressures. Note that identical line symbols are used to indicate identical components of the soil-water system in parts A and C of figure 5 and figures 6 and 7.

The sloped-line segments in figure 5C are regressions of volume-ratio values versus depth for profile zones where sloping trends were evident when the volume data was plotted. The vertical line segments in figure 5C represent averages for profile zones where there was little change in the volume-ratio values with depth. The joined segments are plotted in a manner that illustrates the different proportions of the total volume occupied by: (1) soil particles (1 - porosity = particle volume); (2) tightly adsorbed water (water retained at 294 millibars); and (3) slowly drainable water (water influenced by pressure of 49 millibars minus water retained at 294 millibars) (fig. 5C). The remainder of the volume is available for water that would drain rapidly because the water-retention pressure on it would be less than 49 millibars.

Soils on Hillslopes and in Heads of Hollows

As discussed previously in the Soils section, deep, coarse-textured soils derived from sands, gravels, and clays of the Coker Formation cover about 80 percent of Loblolly Branch basin, occurring on hillslopes and in the heads of hollows. Water retention and porosity models for these soils are the ones shown in figure 5. Data from sites 4, 5, 6, 8, 10, and 11 (fig. 1) were averaged to obtain the graphs. Land use on all of these sites is wood production and wildlife habitat.

The water-retention capacity of these soils is small; it is greater in the upper 7.2 inches of soil than below that depth (fig. 5A). The texture of the soils is relatively uniform with depth; greater organic-matter content is the apparent reason for greater water-retention capacities in the surface soils. These soils are highly porous; at the surface, 74 percent (1.0 minus 0.26 x 100) of their volume is voids, and below 57 inches nearly 40 percent of their volume is voids (fig. 5C).

These soils have rapidly drainable porosity that would hold 20 inches of water between the surface and 105-inch depth. Because of this large porosity and the associated large permeability, surface runoff rarely occurs. This is corroborated by observation of the accumulation of leaves and organic matter in low areas that could function as drainageways. The infrequent occurence of overland flow in forested basins in humid areas has been documented by Nutter and Hewlett (1971), and by numerous other investigators. When water enters the soil, after any deficits in tightly absorbed water and slowly drainable water have been satisfied, the remaining water probably drains through the soil into the underlying Coker Formation.

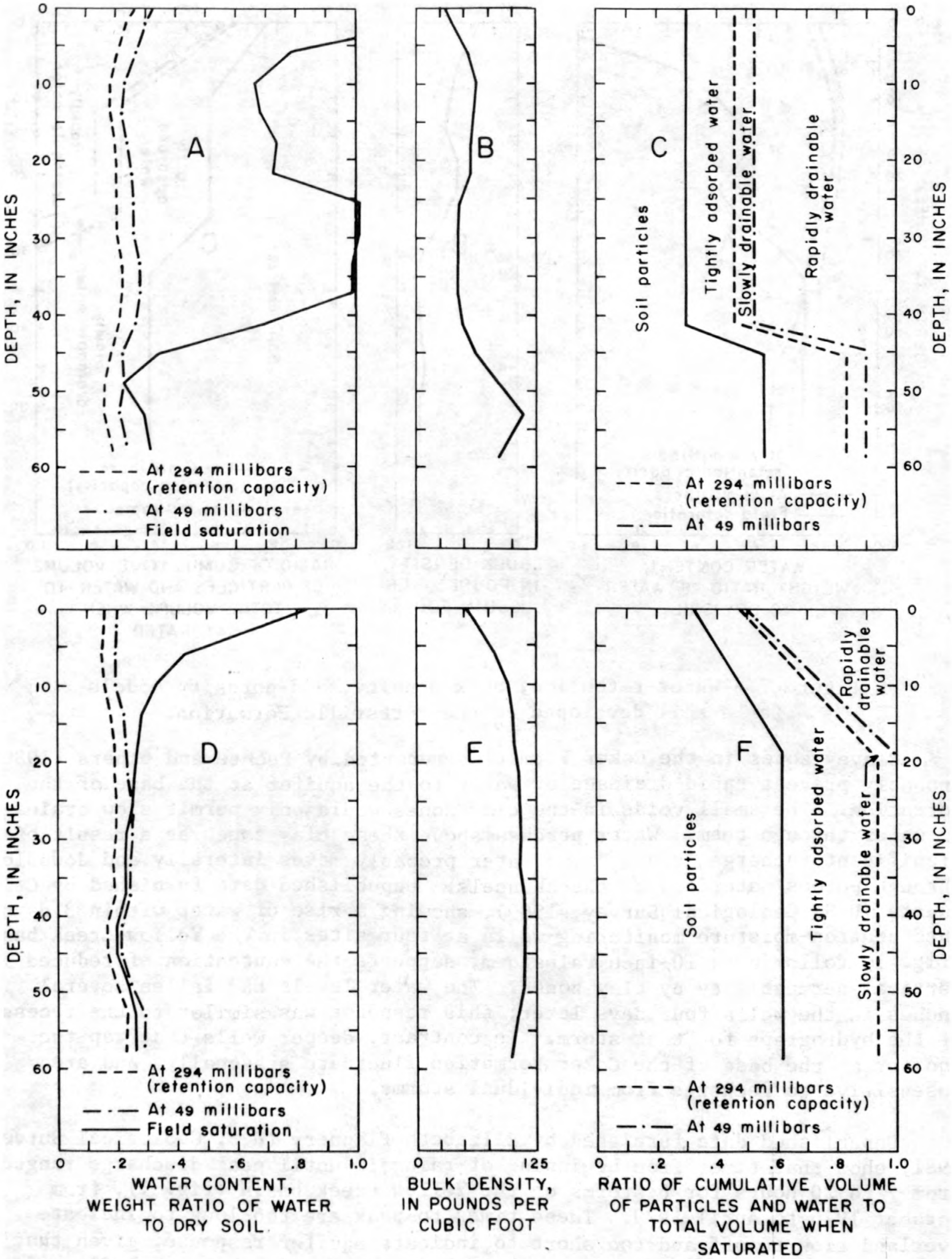


Figure 6.--Water-retention, bulk density, and porosity models for well-developed soils on broad divides. The three soils represented in D, E, and F are severely compacted compared to the soils represented in A, B, and C.

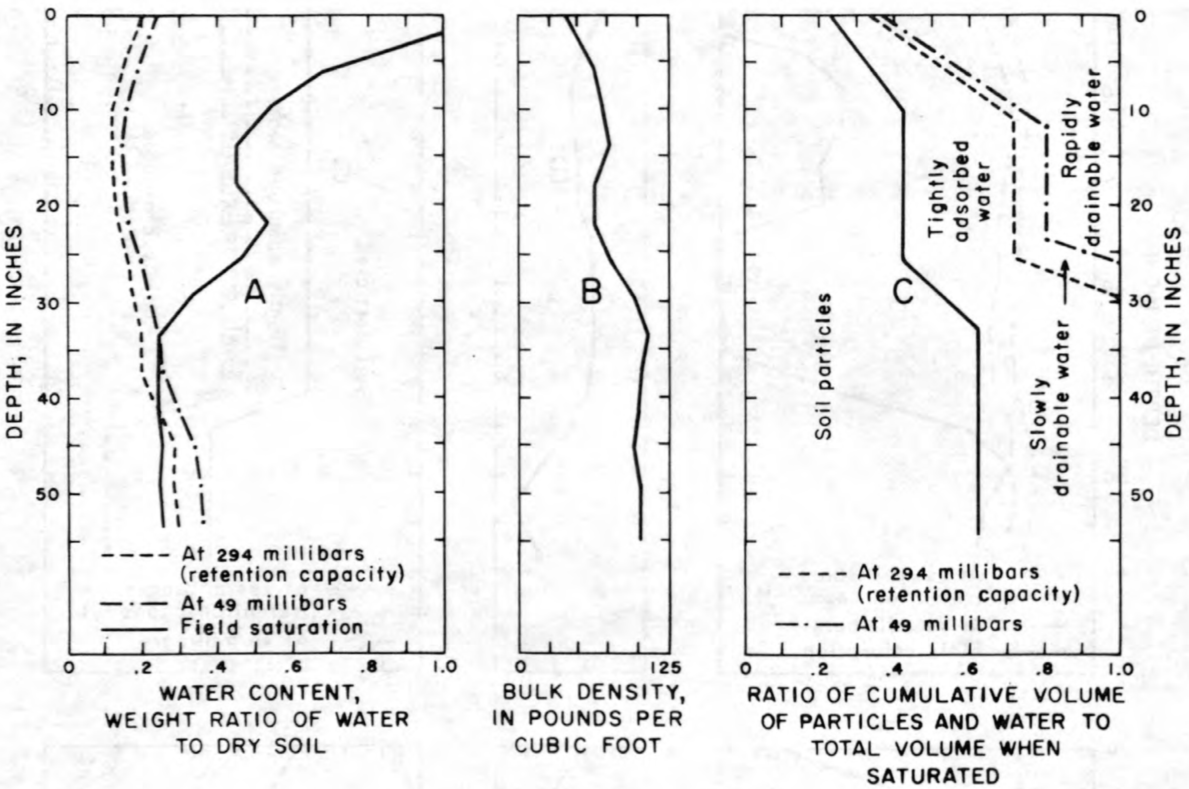


Figure 7.--Water-retention, bulk-density, and porosity models for a soil developed on the Pottsville Formation.

Clayey zones in the Coker Formation reported by Puente and others (1980) probably prevent rapid drainage of water to the aquifer at the base of the formation. The small voids in the clay zones would only permit slow drainage of water through them. Water perches above these clay zones as a result of significant recharge events; some water probably moves laterally and downslope through porous materials to the channels. Unpublished data furnished by Celso Puente (U.S. Geological Survey, 1980), showing a rise of water within 3 days into neutron-moisture monitoring wells at four sites in the Yellow Creek basin (fig. 1) following a 10-inch rainstorm, supports the contention of reduced vertical permeability by clay zones. The water levels had fallen several inches in the wells four days later; this response was similar to the recession of the hydrograph for that storm. In contrast, deeper wells that tap the aquifer at the base of the Coker Formation fluctuate seasonally, and are insensitive to recharge from individual storms.

Unpublished data furnished by Elizabeth Flannery (U.S. Geological Survey, 1981) show that times from beginning of rainfall until peak discharge ranged from 7 to 20 hours for 6 storms on the Yellow Creek basin (fig. 1), from October 1976 to April 1979. These times to peak are too long to indicate overland flow runoff and too short to indicate aquifer response, given that there are flow-retarding clayey layers above the aquifer. Lateral flow of water through the soils or sandy and gravelly layers in the Coker Formation is indicated by these times to peak.

Slowly drainable water has been detected between rains in the soils at sampling sites in the vicinity of Loblolly Branch. Evapotranspiration and drainage slowly remove this water from soils, so the frequency of rains determines how much of the time it is present.

Swift and others (1975) have simulated soil-water retention pressures of 40 to 300 millibars, which are similar to those involved with slowly drainable water, by applying a hydrologic model to one of the Coweeta watersheds in North Carolina. They showed these retention pressures to be present in the upper 1 foot of soil 21 percent of the time from June 1 to September 15, 1972, and 44 percent of the same period in 1971, for both oak-hickory and white-pine stands. For clear-cut conditions, slowly drainable water was present 79 percent of the same period for both years.

The tightly adsorbed water illustrated in figure 5C is considered to be not drainable as it is held at retention forces in excess of 294 millibars. Part of that water, however, is available for use by vegetation, and the amount of use is a function of the frequency and amount of precipitation during a season or year.

Well-Developed Soils on Broad Divides

Scattered patches of very old, well-developed soils occur on broad divides throughout the area; these patches comprise about 9 percent of the permit area. These soils apparently occur on relict surfaces of a previous landscape developed on the Coker Formation. The A horizons of these soils consist mainly of quartz grains coated with organic matter and are moderately permeable; the B horizons consist mainly of accumulated clay minerals and iron oxides and are much less permeable.

All soils on the permit area are susceptible to compaction resulting from land use because of their porous nature. Effects of compaction, however, are much more severe for soils with moderate- to fine-textured B horizons such as the well-developed soils on broad divides. In figure 6, a comparison is made between soil-water relations of a relatively undisturbed reforested soil (parts A, B, and C) and average relations for three soils that have been severely compacted (parts D, E, and F). The undisturbed soil is site 2 and the compacted sites are 1, 3, and 7 in figure 1. Site 1 is in a pasture where large numbers of cars are parked sometimes; site 3 is on a cleared powerline right-of-way; and site 7 is a reforested site where severe compaction was indicated.

All four soils are similar with respect to their water-retention capacities, but have different bulk densities. The average bulk density is greater at all depths in the three compacted soils (fig. 6E) than in the noncompacted soil that is under forest cover (fig. 6B). The greater levels of bulk density induced by compression have resulted in reductions in void space. Field-saturation values at depths below 24 inches have been reduced to the level where slowly drainable water would fill all of the available voids with none remaining for rapidly drainable water (fig. 6F). However, compression forces were not great enough to overcome the pressure with which the slowly drainable water is retained.

Models derived from these two sets of data indicate large differences in rapidly drainable porosity resulting from different land uses and different degrees of compaction in pine plantations. There are 21 inches of porosity available for rapidly drainable water in the noncompacted soil (fig. 6C) and 5 inches available in the compacted soil (fig. 6F). Also, permeability rates would progressively decrease from the surface downward in the compacted soils because of the progressive decrease in rapidly drainable void space (fig. 6F). It is probable that surface runoff sometimes occurs from these sites during prolonged intense storms when rainfall rates exceed infiltration rates; however, there was very little evidence of erosion at these sites.

Most of the water that runs off the divides on which these sites are located likely would be absorbed by the highly permeable soils on the hillslopes below the divides. Therefore, routes by which water moves from the broad divides to channels are nearly identical to the routes of water moving from hillslopes.

Soils Developed on the Pottsville Formation

The Pottsville Formation is exposed on about 10 percent of the permit area on lower hillslopes adjacent to the Loblolly Branch channel as indicated by the geologic map (fig. 2). The soil modeled in figure 7 was sampled at site 9 on figure 1 and probably is typical of soils developed in material derived from the Pottsville Formation. However, at any given place where the bedrock is mapped as Pottsville Formation, the soil could be derived mainly from coarser materials from the Coker Formation upslope of the site. Nonetheless, the soil illustrated is significantly shallower in depth (fig. 7A), and below 40-inch depth, it has a greater water-retention capacity than the soils derived from the Coker Formation (figs. 5 and 6).

The bulk density of the lower part of this soil is great enough that below 40-inch depth all voids are filled with water at a moisture content that is less than the retention capacity (fig. 7A). Because of increased bulk density and increased water-retention capacity below about 30-inch depth, there is no void space for drainable water below that depth (fig. 7C). The rooting depth of vegetation is the maximum depth to which water can move. Water moves to the rooting depth because some of the tightly adsorbed water probably is used by vegetation, and that water could be replaced by rainfall. However, for practical purposes, vertical movement of water is blocked below 30 inches.

Both slowly drainable and rapidly drainable water would be forced to move laterally to the streams in soils such as this one. Although porosity for rapidly drainable water extends deeper in this soil than the compacted soils discussed previously, this soil has only 7 inches of such porosity (fig. 7C). During prolonged intense storms, the capacity of this soil to contain and transmit rapidly drainable water may be exceeded. This would be true especially in Loblolly Branch basin where such soils on the Pottsville Formation would be fed water draining laterally through the Coker-derived soils upslope from them. Therefore, the potential for overland flow in Loblolly basin is greatest on areas that have soils similar to that illustrated in figure 7.

Conclusions

Surface soils on the permit area are very permeable because they are sandy and the forest litter protects the surface from raindrop splash and retards overland flow. On much of the area, subsoils extending to depths of 100 inches or more also are permeable. Water in excess of the storage capacity of these soils (fig. 5) penetrates to a clay zone either at the base of the soil profile or at a shallow depth in the Coker Formation. Water perches above these zones; much of the water then moves laterally downslope, and is discharged into channels in less than 24 hours. Some water slowly penetrates these clay zones and supplies the aquifer at the base of the Coker Formation.

Soils developed on the Pottsville Formation and severely compacted soils on divides underlain by the Coker Formation have subsoils with very restricted permeability; therefore, water may move laterally in the permeable surface soils as a result of significant rainfall (Fig. 6D, E, F and Fig. 7). Also, because these soils have only 5 to 7 inches of porosity, there is a greater probability of the infiltration rate being exceeded by the rainfall rate, or the soils becoming saturated during an extreme event.

The fragile structure of the surface soils on the permit area makes them quite vulnerable to compaction. The average porosity of these soils that were severely compacted was about 25 percent of the porosity of a similar soil that was not compacted (fig. 6).

Significant differences in the water-holding capacities and porosities of the soils were obtained by augering samples and using the filter-paper method to define the water-retention relation of each sample. Water-holding capacities computed from these relations for soils sampled in the Yellow Creek basin resulted in reasonable simulation of hydrographs with a rainfall-runoff model (G. H. Leavesley, U.S. Geological Survey, oral commun., 1982).

Surface Water

Applicable Regulations

Streamflow discharge information that may be required in a permit application, or to meet design standards stipulated by the regulations, is listed in the following parts of the Surface Coal Mining and Reclamation

Regulations (Federal Register, March 13, 1979):

Subchapter	Parts	
G	779.16	Surface-water information
K	816.42	Water quality
	816.43	Overland flow conveyances
	816.44	Stream channel diversions
	816.45	Sediment control
	816.46	Sedimentation ponds
	816.72	Valley fills
	816.73	Head-of-hollow fills
	816.74	Rock fills
	816.153	Road drainage
	816.163	Road drainage
	816.173	Road drainage

Specific items required include the peak discharges produced by the 2- and 10-year recurrence interval storms of the duration that produces maximum peak discharges in the permit area; the peak discharges produced by the 10-, 20-, 25-, and 100-year, 24-hour precipitation events; the peak discharge produced by a 2-year, 6-hour precipitation event; and the runoff volume produced by a 10-, 25-, and 100-year, 24-hour precipitation event. Also required are, "* * * minimum, maximum and average discharge conditions which identify critical low-flow and peak discharge rates of streams sufficient to identify seasonal variation; * * *." The intent of this latter requirement is not clear, in that peak discharges are, by definition, the maximum instantaneous flow rates to occur in a specified time period, usually one year; therefore, peak discharges do not have seasonal variation. However, the probability that the annual peak discharge will occur during a given part of the year can be evaluated, as can the variation of mean flows throughout the year.

Streamflow Estimation Methods

Runoff volume and peak-discharge measurements usually are not available at potential mine sites; estimation techniques must be used for planning and design of required erosion- and water-control structures. Several techniques are available for estimating streamflow characteristics; the attributes of each technique should be considered relative to areal hydrologic characteristics when a method is selected for a particular site. However, the method actually used often is determined by the type and amount of available data, the time-frame for acquiring additional data, and by existing laws and regulations.

Deterministic physical-process models are based on physical laws and require measurements of initial and boundary conditions with other input data. If basin conditions are described adequately by independent variables, these models can provide highly accurate estimates of runoff volumes and peak discharges. However, because of the complexity of the processes being modeled, many simplifications and approximations usually must be made to keep the model physically and economically manageable. The result is a number of coefficients or parameters that are difficult, if not impossible, to evaluate directly. Therefore, these models must be verified with data from the watersheds where the models are to be applied. Often, necessary rainfall and discharge data are not available during the early stages of a project, when the model is needed for planning. These models also require considerable data to describe the watershed and use large blocks of computer time. Persons applying these models must be skilled in computer programming, mathematics, modeling techniques, and hydrology. Physical-process models are most useful for extending length of streamflow records and predicting effects of changes, such as mining and reclamation, imposed on the watershed.

In a cooperative effort, the U.S. Geological Survey and the U.S. Bureau of Land Management are proceeding with the development and implementation of a small-watershed systems model, as described by Van Haveren and Leavesley (1979) and by Leavesley and others (1981). A modular program package has been developed and is maintained in a single computer-system library. Each module (set of subroutines) of this library defines a component of the hydrologic cycle or contains subroutines for parameter optimization, data handling, and model-output analysis. Given a specific problem, the hydrologist can select a main program routine and the specific modules that define his problem.

Parametric models, commonly known as regression equations, use statistical techniques to relate physical characteristics of a watershed to its hydrology. Geometric, geomorphic, land-use, and climatic characteristics are used most often because they are readily available. Development of model coefficients for a region where the regression model is to be applied involves use of data from numerous sites over a relatively homogeneous area and allows prediction of flow characteristics at ungaged sites. Models can be developed for both streamflow peaks and volumes, but volume data often are unavailable, especially for smaller watersheds. Accuracy of these models depends on how well the selected watershed characteristics describe streamflow characteristics; it usually is expressed as the standard error of estimate. Model accuracy depends on accuracy of input data sampling error and model error (or form of the regression equation). When selecting a regression model for use at an ungaged site, an important consideration is that the data base used to develop the model should include data from watersheds similar in size to the ungaged watershed. While regression models are not as versatile as physical-process models, they are easier to use and often provide an adequate quantification of premining hydrology. However, because they generally are developed with data from relatively undisturbed basins, they cannot be used to estimate streamflow characteristics for postmining conditions. Also, because the values obtained with this method are based on some average of the data used to develop the equations, estimates for a specific basin may be considerably different from actual discharges it produces, especially for small basins. This difference in discharges occurs when a parameter that significantly influences the discharges from the small area is not included as an independent variable in the regression model.

One type of regression model that may be applicable for estimating premining discharges in surface-mining areas relates resultant factors rather than causative factors to streamflow characteristics (Osterkamp and Hedman, 1979). This technique--the so-called channel-geometry method--is based on the assumption that a channel adjusts in size and shape to the size of flows it carries. The theory is that consistent channel features are formed by flows, and that these features may be used as reference levels for making repeatable measurements of channel dimensions. Although it has not been verified, it is believed that channel dimensions, after an appropriate transition period, will reflect adjustments in the flow regime caused by land use and upstream regulation. However, the channel-forming processes are not fully understood, and continued research is needed.

Once equations relating channel-geometry and streamflow characteristics have been developed for an area, channel geometry can be used as a simple means of estimating streamflow characterisitics at many ungaged sites. Best results are obtained on perennial streams. Users of this method should receive field training first, to insure identification of the same reference levels that were used to develop the equations.

The U.S. Geological Survey has numerous publications that describe regression models for estimating magnitude and frequency of floods for various areas using both watershed characteristics and channel-geometry measurements. Channel-geometry equations have been developed for several areas of the western United States (Hedman and Kastner, 1977; Hedman and others, 1972; Scott and Kunkler, 1976; Lowham, 1976); there are none for the area of the Loblolly Branch study site, although the method is valid and potentially useful for this area. The regression models that may have application at the Loblolly Branch site are cited in the next section of this report.

The U.S. Soil Conservation Service (1972) has developed an empirical model that relates rainfall to direct runoff through a series of numbered curves. A curve is selected by consideration of soil type, land use, and antecedent soil-moisture conditions. The method was developed in the 1950's from a large amount of plot and small-basin runoff data. It was developed to give consistent runoff volumes and peak-discharge rates for the design of conservation structures on farms and ranches. It does not consider baseflow discharges that should be added to estimates computed with this method. Frequencies of the computed discharges are based on frequencies of the design-precipitation events and may not correspond to frequencies of actual flood events. Available streamflow data always should be used to check results obtained by this method.

Estimates of Premining Peak Discharges

Premining discharges provide a standard by which to judge whether or not changes in the prevailing hydrologic balance caused by surface-mining activities have been minimized, as required by the regulations. Estimates of premining discharges for Loblolly Branch were made with available regression models and with the U.S. Soil Conservation Service method. The regression models are based on historical streamflow records and basin characteristics but do not satisfy the regulation requirement that discharge estimates be based on precipitation events of specified recurrence intervals, which the U.S. Soil Conservation Service method does. Because of time and data constraints, estimates were not attempted with a physical-process model for either premining or postmining discharges.

Regression Models.--The magnitude and frequency of floods in Alabama have been described by Peirce (1954), Gamble (1965), Hains (1973), and Olin and Bingham (1977). Models of Hains (1973) are based on data collected through September 1971 and can be used on basins as small as 1 mi^2 (square mile). These models use a geographic factor to account for the effect of geology on discharge. Although the observed streamflow records used by Olin and Bingham (1977) were longer than those of previous reports, reliability of the resulting flood-frequency data were further improved by combining them with synthetic flood-frequency data generated with the U.S. Geological Survey rainfall-runoff model (Dawdy and others, 1972). Olin and Bingham (1977) suggest that their equations provide the best estimates of floods on streams with drainage areas of 1 to 15 mi^2. They further suggest that results of their models be combined with those of Hains (1973) for use on streams with drainage areas of 15 to 25 mi^2, and that Hains' 1973 model be used for drainage areas larger than 25 mi^2. They also suggest a method for combining the results of the two models.

Hains (1973) reported the following general model for Alabama streams with less than 500 mi^2 of drainage area:

$$Q_n = C_R \; C_G \; A^{0.7} \; S^{0.2} \; S_T^{\;a} \; Z^b \qquad (1)$$

where

Q_n is the estimated peak discharge of recurrence interval n, in cubic feet per second;

C_R is a regression constant that varies with n;

C_G is a geographic coefficient;

A is the drainage area, in square miles;

S is the main channel gradient, in feet per mile;

S_T is basin storage, in percent plus 1.0;

Z is [sin (X + 30) + 1.1];

X is the angle of the main channel, in degrees; and

a, b are exponents that vary with n.

The values of C_R, C_G, a, and b can be determined from a map and a table provided by Hains (1973).

Drainage area (A), channel gradient (S), basin storage (S_T), and angle of the main channel (X) should be measured on the largest scale topographic maps available. The drainage boundary should be delineated on the map and the area measured with a planimeter. Stereo aerial photographs are useful for delineating boundaries in relatively flat areas. Main channel gradient is the slope of the channel between points that are 10 percent and 85 percent of the distance from the estimation site to the drainage divide. Above each stream junction, the main channel is the one that drains the largest area. The length measured should be the meander length of the channel and not the length of the stream valley. The stream should be extended on the map to the basin divide. Certain electronic planimeters have the capacity to measure accurately the length of line traced, or channel length can be determined by stepping with a draftsman's dividers set to a small increment, preferably 0.05 mi (mile) or less. Altitudes at the 10 percent and 85 percent points are determined by interpolation between contour lines. Basin storage is the percentage of the total basin area shown on topographic maps to be covered by lakes, ponds, and swamps; a value of 1.0 percent is added to avoid having zero values. The angle of the main channel is measured as the azimuth (degrees clockwise from North) of the line, in the direction of flow, between the 10 and 85 percent points used above for computation of the channel gradient.

The value of C_G may be determined by solving equation 1 for C_G when Q_n is known, rather than using a regional value from Hains' (1973) map. Thus, the value of C_G for the Loblolly Branch sites can be computed with the discharge record from U.S. Geological Survey station 02462990 (Yellow Creek near Northport, Alabama), located about 1.5 mi downstream from Loblolly Branch site A (fig. 1). This location usually will be referred to as site C in the remainder of this report. The record for the Yellow Creek station indicates a Q_2 discharge of about 630 ft^3/s (cubic feet per second) (based on a Log Pearson-Type III distribution and 5 years of record). By substituting 630 for Q_n in equation 1, the value of C_G is found to be 0.70. The regionalized value of C_G for this site is 0.74, determined from the map provided by Hains (1973). Using this means for determining the value of C_G makes it imperative that the gaged and ungaged basins be hydrologically similar.

Using a value of 0.70 for C_G, the Hains' (1973) model for the Loblolly Branch basin becomes:

	Average standard error of estimate (percent)	
$Q_2 = 74.2\ A^{0.7}\ S^{0.2}\ S_T^{-0.174}$	35	(2)
$Q_5 = 125.2\ A^{0.7}\ S^{0.2}\ S_T^{0.126}$	24	(3)
$Q_{10} = 164.8\ A^{0.7}\ S^{0.2}\ S_T^{-0.098}\ Z^{-0.009}$	21	(4)
$Q_{25} = 219.2\ A^{0.7}\ S^{0.2}\ S_T^{-0.067}\ Z^{-0.020}$	17	(5)
$Q_{50} = 263.6\ A^{0.7}\ S^{0.2}\ S_T^{-0.044}\ Z^{-0.026}$	17	(6)
$Q_{100} = 310.0\ A^{0.7}\ S^{0.2}\ S_T^{-0.020}\ Z^{-0.035}$	18	(7)

Olin and Bingham (1977) reported the following basin-characteristic models for Alabama streams:

	Average standard error of estimate (percent)	
$Q_2 = 92.8\ A^{0.646}\ S^{0.237}$	43.9	(8)
$Q_5 = 166.2\ A^{0.683}\ S^{0.193}$	30.6	(9)
$Q_{10} = 229.8\ A^{0.700}\ S^{0.166}$	30.3	(10)
$Q_{25} = 332.0\ A^{0.716}\ S^{0.132}$	31.5	(11)
$Q_{50} = 421.7\ A^{0.727}\ S^{0.110}$	32.6	(12)
$Q_{100} = 532.1\ A^{0.731}\ S^{0.087}$	33.9	(13)

where

Q_n = the estimated peak discharge, in cubic feet per second, for the recurrence interval n;

A = the drainage area above the site, in square miles; and

S = the main channel gradient, in feet per mile.

Drainage area (A) and channel gradient (S) should be measured as described above for the Hains' (1973) models. For the remainder of this report, the two sets of models will be referred to as the Hains' and the Olin-Bingham methods or equations.

The accuracy of the Hains' and Olin-Bingham equations is expressed as the average standard error of estimate, in percent. This is the average error to be expected as the difference between computed and actual discharges in about two-thirds of the cases. Regression coefficients of the Olin-Bingham equations are statistically significant at the 5 percent level; significance levels of the regression coefficients of the Hains' equations were not given. These equations will reasonably predict the peak discharges for a specific ungaged basin, if the values of the basin characteristics (independent variables) for that basin are similar to the average value of the characteristics for all the basins used in developing the equations. However, if the ungaged basin has characteristic values that are extreme, such as soils that are either highly permeable or highly impermeable, the equations may give poor estimates for that basin.

Discharges were estimated at sites A and B in Loblolly Branch and at site C in Yellow Creek basin (figs. 1 and 2) with both the Hains' and the Olin-Bingham methods. Drainage areas, channel slopes, basin storage, and main channel azimuths were measured on 1:24,000-scale topographic maps; resulting values are listed in table 6. Discharges obtained by these methods are shown in the form of flood-frequency curves in figure 8.

Table 6.--*Premining parameter values for Hains' (1973) and Olin and Bingham's (1977) methods of estimating peak discharges at Loblolly Branch and Yellow Creek sites*

Site	Storage (percent)	Drainage area (square miles)	Main channel slope (feet per mile)	Azimuth (degrees)
A	1.0	2.48	62	217
B	1.0	0.93	93	217
C	1.0	8.23	28	190

U.S. Soil Conservation Service Method.--The U.S. Soil Conservation Service method can be used to estimate runoff volume produced by specified precipitation events. It also includes procedures for developing hydrographs and routing them through reservoirs and channels. The basic U.S. Soil Conservation Service method is described in the National Engineering Handbook, Section 4 (U.S. Soil Conservation Service, 1972). Shortcut procedures, in the form of tables and graphs, have been developed to simplify use on small watersheds and for special situations (U.S. Soil Conservation Service, 1973, 1975).

The basic relationship used with this method to determine runoff volume is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (14)$$

where

Q is runoff volume, in watershed inches;

P is the storm rainfall, in inches; and

$$S = \frac{1,000}{CN} - 10 \qquad (15)$$

where

S is the potential maximum retention, in inches: and

CN is a curve number value based on soil, land use and condition, and antecedent soil-moisture conditions.

Different combinations of these parameters have been assigned CN values on experimental data.

The first requirement for determining appropriate CN value for an area is a map of the basin showing ground-cover type and condition; condition refers to the range of vegetation density. Procedures for delineating vegetation types and for estimating type density are described in the Vegetation section

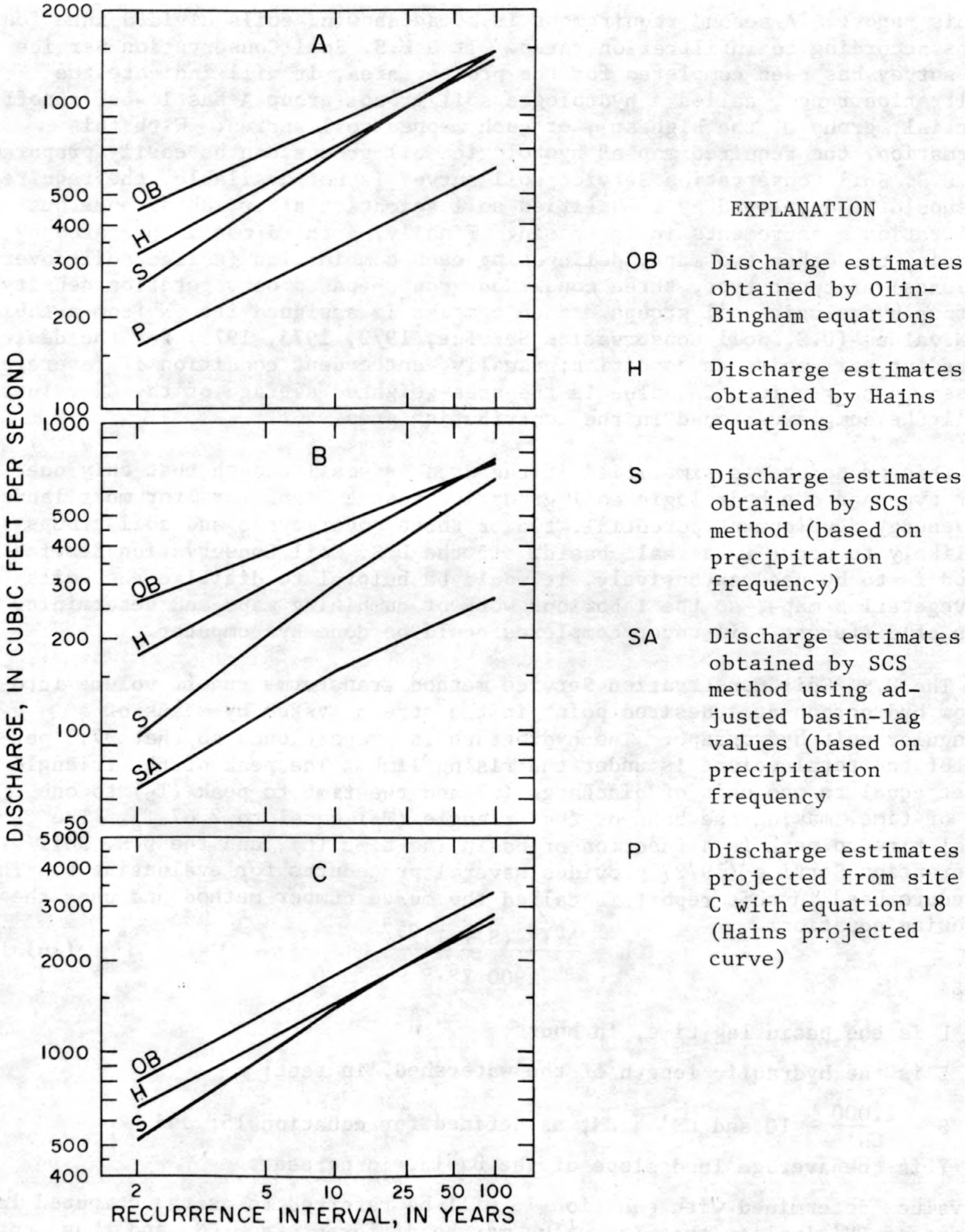


Figure 8.--Flood-frequency curves estimated by various methods for (A) Loblolly Branch, site A; (B) Loblolly Branch, site B; and (C) Yellow Creek, site C.

of this report. A second requirement is a map showing soils divided into four groups according to infiltration rates. If a U.S. Soil Conservation Service soil survey has been completed for the project area, it will indicate the infiltration range, called a hydrologic soil group (group A has lowest runoff potential; group D, the highest), of each mapped soil series. With this information, the required map of hydrologic soil groups can be easily prepared. If a U.S. Soil Conservation Service soil survey is not available, the required map should be developed by a qualified soil scientist after making numerous infiltration measurements in the basin. Finally, a third map is prepared by combining the other two maps, delineating each combination (called soil-cover complexes) of cover type, three condition groups (based on vegetation density), and four hydrologic soil groups. Each complex is assigned its CN from a table of CN values (U.S. Soil Conservation Service, 1972, 1973, 1975) for the desired antecedent soil-moisture condition; usually, antecedent condition II (average) is used. The required CN value is the area-weighted average of the CN values of all the complexes found in the contributing area.

This procedure is simplified if the area is small enough that only one cover type and one hydrologic soil group is present. However, for most lands with energy development potential, two or three cover types and soil groups are likely to occur in a small basin. If the U.S. Soil Conservation Service method is to be used extensively, it would be helpful to digitize the soils and vegetation maps, so the laborious work of combining maps and determining areas of different soil-cover complexes could be done by computer.

The U.S. Soil Conservation Service method transforms runoff volume into a flow hydrograph at a desired point in the stream system by means of a triangular unit hydrograph. The hydrograph is proportioned so that 37.5 percent of the total volume is under the rising limb. The peak of the triangle is set equal to one unit of discharge (Q) and the time to peak (T_p) to one unit of time, making the base of the triangle (T_b) equal to 2.67 T_p. The actual time to peak is a function of basin lag time (L), and the U.S. Soil Conservation Service (1972) provides several procedures for evaluating L. The procedure used in this report is called the curve number method and uses the following equation:

$$L = \frac{\ell^{0.8} (S + 1)^{0.7}}{1900 \, Y^{0.5}} \qquad (16)$$

where

L is the basin lag time, in hours;

ℓ is the hydraulic length of the watershed, in feet;

$S = \frac{1,000}{CN'} - 10$ and $CN' \approx CN$, as defined for equation 15; and

Y is the average land slope of the basin, in percent.

Lag values determined with equation 16 will be referred to as the computed lag. The use of CN' implies that its value may be different from CN, and thus, that it should be selected to fit the specific conditions encountered in a basin. This equation was developed to span a broad set of conditions, including heavily forested watersheds with a high percentage of the runoff coming from subsurface flow, a prevalent condition where the variable-source-area concept applies.

Incremental runoff volumes are determined by assuming that P and Q in equation 14 represent accumulated rainfall volumes. Then:

$$R_j = Q_j - Q_{j-1} \qquad (17)$$

where

R is the incremental runoff volume;

Q is accumulated runoff volume; and

j is the number of time increments of length DT, after accumulation began.

The value selected for DT should not exceed 0.25 T_p. Peak-discharge rate for each increment of runoff (R_j) is determined with an empirical equation, and the incremental hydrographs are plotted with successive hydrographs, each beginning one time interval (DT) later than the previous hydrograph. Ordinates of a composite flood hydrograph are obtained by summing the ordinates of all incremental hydrographs at the end of each time interval, DT. This procedure can be simplified if only the flood peak is desired (U.S. Soil Conservation Service, 1972, 1973).

A computer program has been developed to simplify the use of the U.S. Soil Conservation Service method on complex projects (U.S. Soil Conservation Service, 1965). Its use should be considered when watersheds are larger than 2,000 acres; where many subareas exist with different runoff characteristics; where reservoirs are present; or when historical storm events need analysis (U.S. Soil Conservation Service, 1975). A copy of the source program can be obtained through the U.S. Department of Commerce, National Technical Information Service (NTIS).

The basic U.S. Soil Conservation Service procedure was applied at sites A and B in Loblolly Branch and at site C in Yellow Creek basin for premining conditions (fig. 1). Parameter values required were: (1) Drainage area, in acres; (2) CN; (3) 24-hour precipitation amounts, in inches; (4) average basin slope, in percent; and (5) hydraulic length, in feet. Drainage areas and average basin slopes were measured on 1:24,000-scale maps. Average basin slopes were determined by the summation of contour-lengths method. Soils in Loblolly Branch basin are in hydrologic soil group B (U.S. Soil Conservation Service, unpublished preliminary soils mapping, 1976). Primary land uses in the basin are commercial forest and game habitat. Cover consists of pine plantations and cutover areas of mixed pines and hardwoods in various stages of maturity (see Vegetation and Vegetation Types and Measurements sections). In assigning CN values to this hydrologic system, strong consideration should be given to the extent of soil compaction caused by previous wood-harvesting operations and its effect on the soil's ability to hold and transmit water (see Water Relations in Soils section). Since some recovery from compaction may occur, the length of time since the last harvest is also of some importance. On these bases, the oldest tree stands were assigned the lowest CN value, and the clear-cut areas were given the highest CN rating.

Parameter values used are listed in table 7. The listed CN values are in reasonable agreement with the CN values obtained from the analyses of six storm hydrographs observed at site C (average CN = 62). Values of 24-hour

Table 7.--*Premining parameter values for U.S. Soil Conservation Service method*

Site	Drainage area (acres)	Hydraulic length (feet)	Average basin slope (percent)	Curve number values, CN
A	1,587	12,360	11	58
B	595	6,560	10	55
C	5,267	29,440	10	58

precipitation amounts for various recurrence intervals are listed in table 5. A type II storm-distribution pattern is applicable in this region (U.S. Soil Conservation Service, 1972). Resulting design peak discharges are shown as flood-frequency curves (S curves) in figure 8. Discharges produced by 6-hour precipitation events can be estimated with the same procedures, by substituting a 6-hour storm distribution and the 6-hour precipitation amounts from table 6 to obtain the mass-rainfall curve. The 6-hour storm-distribution curve is provided by the U.S. Soil Conservation Service (1972, p. 21.81).

Since the U.S. Soil Conservation Service method involves only storm runoff, the addition of baseflow discharges to these values should be considered. This usually can be done by direct measurement of baseflow or by transferring the mean daily discharge for a period(s) not affected by storms from a nearby, hydrologically similar basin. On the basis of the record at U.S. Geological Survey gaging station 02462990 (on Yellow Creek about 1.5 mi below site A), baseflow discharges for the Loblolly Branch sites were considered small in comparison to the peak discharges and were not added to the values shown in figure 8.

Evaluation of Results.--The U.S. Soil Conservation Service method gives estimates of the discharge and volume produced by the n-year precipitation event. Recurrence intervals of the discharges obtained with the Olin-Bingham and Hains' methods are based on the recurrence of the actual flood event rather than on the precipitation event that caused the flood. Because of this difference, discharges estimated with the U.S. Soil Conservation Service method are not comparable with those obtained with the other two methods in a strict hydrologic sense; however, results of the different methods are compared here because all the methods potentially have the same use.

The discharge record for the gaging station at site C (fig. 1) provides a basis for evaluating the estimation methods applied here. The 5 years of record available at this site should give a reasonable value for the peak discharge with a 2-year recurrence interval; this value is 630 ft^3/s. In addition, concurrent discharge measurements have been made at Loblolly Branch site A (fig. 2) (partial record station 02462985, tributary to Yellow Creek near Northport, Alabama) and at site C. With these data, the following relationship between the discharges at sites A and C was developed (Celso Puente, U.S. Geological Survey, written commun., 1981):

$$Q_A = .43\, Q_C^{.92} \tag{18}$$

where

Q_A is the discharge at site A, in cubic feet per second; and

Q_C is the discharge at site C, in cubic feet per second.

The standard error of estimate for equation 18 is 30 percent.

Flood-frequency curves were drawn for sites A, B, and C from the discharges estimated with the Olin-Bingham, Hains', and U.S. Soil Conservation Service methods (fig. 8). For site C, the three curves are generally parallel and are in reasonable agreement, especially the Hains' and U.S. Soil Conservation Service curves. The discharges estimated by the Olin-Bingham equations are about 24 percent greater than those of the Hains' equations. This difference is believed to be due mainly to the consideration of the effects of geology in the Hains' equation by inclusion of the geographic coefficient C_G; it indicates the importance of geology to the hydrology of this area.

The discharges estimated with the U.S. Soil Conservation Service method for site C are nearly coincident with those from the Hains' equation for recurrence intervals of 10 years and greater, but diverge downward at smaller recurrence intervals. Attempts to calibrate the U.S. Soil Conservation Service procedure with storm hydrographs measured at site C showed that the basin lag parameter varies with storm size as well as with basin characteristics. This is consistent with the variable-source-area concept of upland streamflow and suggests that the U.S. Soil Conservation Service and Hains' curves could be brought into closer agreement by adjusting the value of basin lag used in the computations of discharges for the small recurrence-interval storms. Manipulation of the basin lag time seems a possible means of calibrating the U.S. Soil Conservation Service procedure to the hydrology of Loblolly Branch basin for estimating postmining discharges.

The curves of all three estimating procedures are nearly parallel at recurrence intervals of 10 years or more, but since the Hains' equation was fitted to the measured 2-year recurrence-interval discharge (by adjusting the value of C_G), it is considered to give the best discharge estimates at site C. Because equation 18 was developed from actual discharge measurements, it is assumed to give the best estimates of discharges at site A, using the appropriate value from the Hains' curve for site C as the independent variable (Q_C). The flood-frequency curve obtained in this manner for site A is shown in figure 8A (curve P) and will be referred to as the Hains' projected curve or discharges. The supposed superiority of this procedure for estimating discharges at site A cannot be verified without several years of peak-discharge measurements at that site; it is given preference because it is based on actual discharge measurements at the two sites. This relationship (eq. 18) is unique to sites A and C and should not be assumed to apply to other ungaged sites.

The flood-frequency curves estimated for site A (fig. 8A) with the Olin-Bingham, Hains', and U.S. Soil Conservation Service methods are in fairly close agreement at the 100-year recurrence interval, but diverge considerably as the recurrence interval decreases. Notably, all three methods give considerably larger estimates (115 percent greater) than the Hains' projected curve, which is assumed to be the best estimate for site A.

The fact that the Olin-Bingham and Hains' methods give reasonable estimates at site C (but apparently much less reasonable values at sites A and B) points to a common shortcoming of regression models. The particular combination of parameters in the model may provide the best relationship between the parameters and hydrology of the input basins as a group, but this combination does not necessarily provide an equally good representation of the site-specific hydrology of one basin. These parameters generally used are not complete representations of the hydrologic processes, but are only indices of some of the factors that affect storm-runoff magnitudes. The same shortcoming may be true of the U.S. Soil Conservation Service method, especially with respect to the equation used to determine basin lag time (eq. 16), and in the selection of CN values. Research is needed to identify parameters that more closely represent the hydrologic processes, to reduce standard errors of estimate, and provide models that are valid for a broad range of basin conditions. Since soils and vegetation are affected critically by mining and reclamation activities, and both are of great importance to the infiltration and evapotranspiration aspects of the streamflow process, this research effort should attempt to identify usable soil and vegetation parameters.

The foregoing assessment of U.S. Soil Conservation Service, Olin-Bingham, and Hains' methods leaves some question as to the consistency of these methods for estimating flood discharges at ungaged sites in the study area, such as site B. The best approach for estimating discharges at ungaged sites in this area would appear to be by the use of concurrent discharge measurements from site C and the ungaged site. An equation similar to equation 18 then would be developed and the frequency curve for site C projected to the ungaged site, as it was for site A. If obtaining discharge measurements is not feasible, then one of the other three methods would have to be used.

The frequency curves obtained with U.S. Soil Conservation Service, Olin-Bingham, and Hains' methods for site B are shown in figure 8B. Assuming that these curves represent overestimates of the actual frequency curve, as appears to be the case at site A, the U.S. Soil Conservation Service method would give the best results of the three.

These estimates might be adjusted downward by assuming that the overestimates at site B are of the same proportions as those at site A. The necessary steps in one scheme for accomplishing such an adjustment are shown in table 8. By trial and error, the values of basin lag (fitted lag) needed to reproduce the Hains' projected discharges at site A with the U.S. Soil

Table 8.--*Procedure for estimating peak discharges at Loblolly Branch site B using lag ratios from site A with the U.S. Soil Conservation Service method*

[ft^3/s = cubic feet per second; SCS = U.S. Soil Conservation Service]

	Site A				Site B	
Recurrence interval (years)	Hains[1/] projected discharge (ft^3/s)	SCS[2/] discharge (computed lag = 1.3) (ft^3/s)	Fitted lag	Lag ratio: $\left(\frac{\text{fitted lag}}{\text{computed lag}}\right)$	Estimated lag (column 5 x 0.9)[3/]	Estimated[4/] discharge (ft^3/s)
1	2	3	4	5	6	7
2	160	250	2.5	1.9	1.7	65
10	330	690	3.5	2.7	2.4	155
25	430	960	3.8	2.9	2.6	195
100	600	1,460	4.2	3.2	2.9	275

1/ Curve P in figure 8A.

2/ Curve S in figure 8A.

3/ Computed lag = 0.9.

4/ Curve SA in figure 8B.

Conservation Service method were determined. The ratios of these fitted lag values to the lag values computed with equation 16 (computed lag) for site A are assumed valid for site B. Appropriate lag values for site B are the products of the lag ratios and the site B computed lag. Adjusted discharge estimates for site B are listed in table 8 and are shown in figure 8B as curve SA. This procedure also can be used to estimate postmining discharges by assuming that the same lag ratios apply to postmining conditions.

The foregoing assumptions and procedures used to estimate discharges at site B apply specifically to sites A and B and are contingent on the discharge relationship developed between sites A and C (eq. 18). They do not necessarily apply to other drainages within Yellow Creek basin. Differences between discharge estimates obtained with equation 18 and those obtained with the Olin-Bingham, the Hains', and the U.S. Soil Conservation Service methods would suggest that unadjusted estimates of the latter three methods will be larger than actual discharges, and that the U.S. Soil Conservation Service method might give closest estimates of actual discharges.

Estimates of Premining Runoff Volumes

No regression models have been developed for estimating flood volumes at the Loblolly Branch site. In a study similar to that described by Olin and Bingham (1977), Craig and Rankl (1978) developed a relation between peak discharge and runoff volume for individual storm events in Wyoming. They also provide equations similar to the peak-discharge equations described in the previous section, which are used to estimate flood volumes from basin characteristics. Either type of relation would be useful and could be developed from the same basic data used by Olin and Bingham (1977), with the aid of the rainfall-runoff model described by Dawdy, Lichty, and Bergmann (1972). Although such equations would help provide a more complete premining description of the local hydrology based on streamflow records, it is beyond the scope of the present report to develop them. Runoff volume also can be estimated empirically with the U.S. Soil Conservation Service method; volumes obtained by this method for Loblolly Branch are listed in table 9.

Estimates of Premining Low Flows

As instantaneous minimum flows are of little use, low flows usually are reported as a combination of their duration and frequency of occurrence. The events commonly reported and used are the 7-day, 2-year ($7Q_2$) and the 7-day, 10-year ($7Q_{10}$) low flows. The $7Q_{10}$ is the lowest average rate of flow for 7 consecutive days to or below which streamflow can be expected to decline in 10 percent of the years, on average. Flows will be less than the 2-year event in one-half the years, on average, and the 2-year event may be considered as the normal low-flow discharge.

Table 9.--*Premining streamflow volumes calculated by the U.S. Soil Conservation Service method*

Site	Runoff volume, in acre-feet, for indicated storm recurrence intervals			
	2-year	10-year	25-year	100-year
A	100	240	320	460
B	30	78	105	155
C	330	800	1,055	1,525

Three reports describe $7Q_2$ and $7Q_{10}$ low-flow characteristics and duration at gaged sites on Alabama streams: Peirce (1959, 1967) and Hayes (1978). In addition, Bingham (1979) has provided regression equations for estimating $7Q_2$ and $7Q_{10}$ low flows at ungaged sites.

The equations are:

$$7Q_2 = 0.24 \times 10^{-4} (G - 30)^{1.07} (A)^{0.94} (P - 30)^{1.51} \quad (19)$$

$$7Q_{10} = 0.15 \times 10^{-5} (G - 30)^{1.35} (A)^{1.05} (P - 30)^{1.64} \quad (20)$$

where

$7Q_2$ = 7-day, 2-year low flow, in cubic feet per second;

$7Q_{10}$ = 7-day, 10-year low flow, in cubic feet per second;

G = streamflow-recession index, in day per log cycle of discharge depletion;

A = drainage area, in square miles; and

P = mean annual precipitation, in inches.

The average standard error of estimate for equation 19 is 38 percent, and the average standard error of estimate for equation 20 is 39 percent.

The streamflow-recession index (G) is an expression of the hydraulic characteristics of aquifers that discharge to the stream. It is defined by the straight-line portion of a semilog plot of the streamflow recession after a rainstorm. Bingham (1979) describes the procedure in detail and provides a map showing the applicable values of G for any area in Alabama. A map of the mean annual precipitation also is provided. The drainage area (A) should be measured on an appropriate topographic map (as described in the section of this report on estimation of premining peak discharges).

Loblolly Branch basin and Yellow Creek basin lie within an area where the mapped value of G is 32. Bingham (1979) states the $7Q_2$ discharges in such areas are less than 0.3 ft^3/s and the $7Q_{10}$ discharges are less than 0.1 ft^3/s. However, the lowest instantaneous discharge measured during the 2-year period of record at partial-record station 02462985 (site A, fig. 1) was about 1.3 ft^3/s (Celso Puente, U.S. Geological Survey, written commun., 1981) and the measured $7Q_2$ discharge at gaging station 02462990 (site C, fig. 1) for a 5-year period was 3.8 ft^3/s (Elizabeth Flanary, U.S. Geological Survey, oral commun., 1981). While a specific period of record may not include the true $7Q_2$ or $7Q_{10}$ discharges, the magnitudes of the measured flows do suggest that the $7Q_2$ and $7Q_{10}$ discharges at site A probably are larger than those indicated by Bingham's (1979) map.

This apparent disparity may be due, in part, to the difficulty of making precise delineations of G value areas on a 1:1,000,000-scale map. Perhaps this is why Loblolly Branch basin is shown within an area with a mapped G value of 32, although its geology would suggest a value in the 35 to 140 range. It would seem that, in this case, a weighted average of this range, based on the areal extent of geologic formations, would provide a more accurate G value for computing low-flow estimates at Loblolly Branch basin with equations 19 and 20, that the map does.

If the $7Q_2$ discharge can be defined for a site, then the best way to evaluate G for the contributing area above the site is by solving equation 19. Thus, for the 8.23 mi^2 area above site C (which includes Loblolly Branch basin) a G value of 151 is obtained by substituting the measured $7Q_2$ value of 3.8 ft^3/s (based on 5 years of record) in equation 19. This value of G should be valid for all ungaged sites within Yellow Creek basin and for nearby ungaged sites with contributing areas that are underlain by the Pottsville and Coker Formations in approximately the same proportion as they occur in Yellow Creek basin.

Another method of estimating the low-flow characteristics at an ungaged site is described by Riggs (1970, 1973). Discharge measurements of low flows at the ungaged site are plotted against concurrent flows at a nearby gaging station where the low-flow frequency curve is defined. Low-flow characteristics at the gaging station then can be transferred through that relation to estimate characteristics at the ungaged site. This procedure is analogous to the one used earlier in this report to transfer peak discharges from site C to site A with equation 18. It is considered the best means of estimating $7Q_2$ and $7Q_{10}$ low-flow discharges at site A and at all other ungaged sites within Yellow Creek basin. However, a separate discharge transfer relationship (such as equation 18) must be developed for each site where discharge estimates are needed. A modification of the method can be used to estimate mean monthly and mean seasonal flows (Riggs, 1969).

The low-flow discharge estimated for the Loblolly Branch sites under premining conditions and the methods used are listed in table 10. Values for site B probably are less than would be obtained by developing a discharge-transfer equation similar to equation 18. The discharge-transfer method is not

Table 10.--*Premining low-flow discharges for Loblolly Branch sites*

[$7Q_2$ = 7-day, 2-year low-flow discharge; $7Q_{10}$ = 7-day, 10-year low-flow discharge; ft^3/s = cubic feet per second]

Site	Estimation method	Estimated discharges (ft^3/s)	
		$7Q_2$	$7Q_{10}$
A	Equation 18	1.4	0.7
B	Equations 19 and 20	0.5	0.1
C	$7Q_2$--measured	3.8	
	$7Q_{10}$--equation 20		1.8

valid for making postmining low-flow estimates. Bingham's (1979) equations might have some potential for this purpose if a procedure for estimating the value of G for postmining conditions could be developed.

Quality of Surface Water

Applicable Regulations

Water-quality information that may be required in a permit application is listed in the following parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979):

Subchapter	Part
K	816.42 Hydrologic balance: water quality standards and effluent limitations
	816.48 Hydrologic balance: acid-forming and toxic-forming spoil

Surface water sampled at the gage on Loblolly Branch (site A, fig. 2) is soft, acidic, and low in dissolved solids (Puente and others, 1980). Analyses listed in table 11 indicate that the chemical and physical characteristics of the water are similar to rainfall at Tuscaloosa, Alabama, in 1973 and 1975. Notable differences were that the rainfall was more acidic, had a greater nitrate concentration and a lower bicarbonate concentration.

Low total nitrogen and total phosphorus concentrations of Loblolly Branch water are indicative of a stream that is relatively free of organic pollution,

Table 11.--*Comparison of selected physical and chemical constituents of rainfall in Tuscaloosa, Alabama, in 1973 and 1975 with constituents of streamflow in Loblolly Branch in 1977 and 1978*

[Adapted from Puente and others (1980); ft^3/s = cubic feet per second; μmhos/cm = micromhos per centimeter; mg/L = milligrams per liter]

Constituent	Tuscaloosa rainfall, mean of five analyses	Loblolly Branch streamflow[1/]		
		Mean	Range	Number of analyses
Discharge, ft^3/s	-----	4.6	1.1-12.4	18
Specific conductance, μmhos/cm at 25 degrees Celsius	13	11	8-18	15
pH (median value)	4.4	6	5.2-6.8	13
Calcium, mg/L	0.6	0.6	0.1-1.3	5
Magnesium, mg/L	.1	.2	.1-.4	5
Sodium, mg/L	.64	1.5	.9-2.4	4
Potassium, mg/L	.2	.2	.1-.4	5
Bicarbonate, mg/L	.8	5.	3.-8.	11
Sulfate, mg/L	1.2	1.6	.7-2.9	9
Chloride, mg/L	1.3	1.2	1.2-1.3	2
Nitrate, mg/L	.42	.01	0-.01	2

[1/] U.S. Geological Survey partial record station 02462985.

with these nutrient species being derived from rainfall and from the decomposition of organic matter in the soils. Puente and others (1980) show that concentrations of dissolved trace elements are below the maximum limits recommended by the U.S. Environmental Protection Agency (1976) for drinking water. Suspended-sediment discharge from Loblolly Branch site A (fig. 2) is low; for an 18-month period in 1977 and 1978 Puente and others (1980) report that suspended-sediment discharge ranged from 0.01 to 33 tons per day.

Ground Water

Applicable Regulations

Ground-water information that may be required in a permit application is listed in the following parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979):

Subchapter	Part
G	779.15 Ground water information
K	816.50 Hydrologic balance: ground water protection
	816.51 Hydrologic balance: protection of ground water recharge capacity
	816.103 Backfilling and grading: covering coal and acid- and toxic-forming materials

Information about ground water in the study area is limited, especially for the Pottsville Formation. The report of Puente and others (1980), however, provides some information obtained at springs and wells in the Yellow Creek basin that is applicable to Loblolly Branch basin.

Ground-Water Occurrence and Movement

The Pottsville and Coker Formations have extremely diverse water-bearing characteristics. The Pottsville is relatively impermeable, but water occurs in openings along fractures and bedding planes in the overburden rocks and coal beds in the upper more-weathered part of the formation (Puente and others, 1980). Springs and seeps most commonly discharge from fractures and coal beds and most of these cease flowing during dry periods.

Recharge to the Pottsville in the Loblolly Branch basin apparently occurs chiefly in the main stream and principal tributaries in the lower valley, as those are the only places where the Pottsville crops out in the basin (fig. 2). The prominent clay at the top of the Pottsville appears to be an effective aquiclude, which hampers direct recharge from the saturated basal strata in the overlying Coker Formation (Puente and others, 1980).

Sand and gravel beds at the base of the Coker Formation are the principal source of domestic water supply in and near Loblolly Branch basin. A number of wells tap these beds, and one of the most prominent spring lines in Alabama occurs in the outcrop where the beds overlie the Pottsville Formation (Puente and others, 1980). Maximum yields available to wells from the Coker in the basin appear to be about 100 gallons per minute where the saturated beds are the thickest. Springs used for domestic water supplies generally discharge 1 to 5 gallons per minute according to Puente and others (1980).

The entire expanse of the Coker Formation in Loblolly Branch basin is recharge area. The Coker is permeable, but percolation may be hampered in places by the occurrence of clay beds above the coarse-grained basal strata. This may cause some discharge of ground water at elevations above the base of the formation; probably most of this discharge occurs as increased evapotranspiration from the forests in areas where soil water perches sometimes. The general direction of ground-water flow in the Coker Formation is southwesterly along dip and parallel to the valley of Loblolly Branch. Within the basin, some near-surface ground water moves toward the channels and is their source of flow.

Quality of Ground Water

Very little information exists about the quality of ground water in the Pottsville Formation underlying the Loblolly Branch basin. Puente and others (1980) state, however, that water in the Pottsville in the general vicinity is usually hard but of good chemical quality. Field determinations of specific conductance and pH were made at four wells completed in the Pottsville within about 4 miles of the study area. Conductances ranged from 163 to 400 micromhos per centimeter at 25°C and pH ranged from 6.9 to 7.5 (Puente and others, 1980).

Chemical analyses of water from two wells completed in the Coker Formation near the lower divide of Loblolly Branch basin and from a spring about 0.31 mile downstream from the mouth of the basin are included in the report by Puente and others (1980). With specific conductances ranging from 16 to 25 micromhos per centimeter at 25°C and hardness of $CaCO_3$ ranging from 2 to 9 milligrams per liter, the water is very soft and of excellent quality. Data presented by Puente and others (1980) show that the quality of ground water from the Coker Formation is nearly as good as that of rainwater at Tuscaloosa.

Erosion and Sediment Yield

Applicable Regulations

Information about erosion rates and sediment yields that may be required in a permit application is listed in the following parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979):

Subchapter	Part
K	816.42 Hydrologic balance: water quality standards and effluent limitations

816.45 Hydrologic balance: sediment control measures
816.46 Hydrologic balance: sedimentation ponds

A rather obvious reason for evaluating soil loss or erosion on a permit area is to obtain premining values for comparison with soil-loss rates during mining, and after mining and reclamation. After soil-loss values are obtained, they can be used with sediment-delivery ratios to obtain estimates of sediment yields from basins. Estimates of sediment yield are essential for the efficient design of detention ponds and for the scheduling of pond maintenance.

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) has been developed over the past 30 years, primarily for use on cropland fields (Wischmeier and Smith, 1978). In recent years, there have been some adaptations of the method to rangelands and to construction and surface-mine sites. The equation appears to be the best available method for evaluating soil loss by rill and inter-rill erosion from slopes in mined and reclaimed areas. Additional research, which is discussed in the Recommendations for Research section, is necessary to answer some unknowns about applicability of the method on mined lands.

The USLE is given as:

$$A = R\ K\ LS\ C\ P$$

where

A is computed soil loss, in tons per acre;

R is a rainfall factor expressed as a product of rainfall energy, in foot-tons per acre per inch, of rain times maximum 30-minute intensity, in inches per hour, for a given storm, or regimen of storms, for a period of days or for a year;

K is soil erodibility, in tons per acre per unit of R;

LS is a dimensionless slope factor accounting for slope lengths and gradients and is the value of the ratio of a given length and gradient to that of a standard erosion plot 72.6 feet long and a uniform 9 percent gradient;

C is a dimensionless cover factor accounting for protection and stabilization effects of any type of vegetation and any type of mulch and is the ratio of soil loss from an area with the specified cover to that of an identical area in continuously tilled, fallow condition; and

P is a dimensionless erosion-control practice factor for practices such as contour tillage, furrowing or terracing, and diversion dikes or ditches, and is the ratio of soil loss when a practice is used to the loss from straight row cropping upslope and downslope.

In this report we have adapted the proposal of Chen (1974) to combine the C and P factors for construction sites and call it the control-practice factor (CP). Chen further proposed that:

$$CP = C_s \times C_r \times C_o$$

where

C_s is the control factor due to surface stabilization or protection treatments, such as seeding or vegetation, mulches, tillage, or chemicals;

C_r is the control factor due to runoff-reduction practices, such as berms, interceptor dikes, benches, or terraces; and

C_o is due to other types of practices not included in C_s or C_r.

All of the practices considered in this report are C_s or C_r type; therefore, the value of C_o is unity.

Mapping of soil-loss units and factor evaluations requires considerable time and resources so ordinary use of the USLE is limited to small areas such as permit areas. Application of the USLE to larger areas, such as a complete coal field, would be facilitated by digitization of various soil, vegetation, and topographic maps and tables of values of the various factors of the equation, so that the combining of maps and assignment of factor values could be done by computer.

Preliminary procedures for applying the method on both mined and unmined land in the western United States are given in an interim report prepared by the U.S. Department of Agriculture Soil Conservation Service (1977) for the U.S. Environmental Protection Agency, Region VIII.

A rather thorough presentation of the application of the USLE to mined lands appears as the Erosion and Sediment Yield chapter in the textbook entitled Hydrology and Sedimentology of Surface-Mined Lands by Haan and Barfield (1978). This is an excellent reference to use for the Appalachian coal fields, such as the one considered in this report, and for midcontinent coal fields. All of their example computations are for Appalachian cases with the attendant topography, climate, and vegetation factors, which are much different from those in western coal regions.

Rigorous analysis of the topography, especially of slope gradients and slope lengths, is necessary to delineate soil-loss units as shown in figure 9. Soil-loss units are areas of quasi-uniform slopes and soils that are delineated on the basis of relief, drainage patterns, and land use on topographic maps with the aid of aerial photographs. Details and examples regarding development of soil-loss-unit maps, sometimes called erosion-factor maps, are given in the U.S. Soil Conservation Service report (1977). In this study, the soil-loss units were delineated on 1:24,000-scale topographic maps according to ranges of slope gradients that usually varied from 0 to 2 percent within each range for gradients less than 10 percent. For gradients of 10 percent and greater, the variation within ranges was usually 4 or 5 percent, with some as much as 8 percent. Where there were two distinct sets of slope lengths in the original unit, a unit was split into two units.

U.S. Geological Survey topographic maps at 1:24,000 scale with a 20-foot contour interval are inadequate for accurate slope analysis for most areas. Delineation of first- and second-order channels and the slopes that drain to these channels usually is impossible for gentle to moderately steep areas using these maps. On the maps, it appears that such slopes are oriented toward larger-ordered channels; therefore, measurements on the maps result in slope lengths that are longer than actual and slope gradients that are less than actual. Maps at 1:12,000 scale (1 inch = 1,000 feet) with contour intervals of 10 feet in the steeper areas and 5 feet in the flatter areas might be adequate; further research is needed. If only 1:24,000-scale maps are available, it is recommended that pairs of stereo photographs and field measurements of lengths and gradients of representative slopes be used to delineate soil-loss units and evaluate the LS factor of each unit.

Sediment-Yield Estimation Methods

Soil-loss values made with the USLE can be used with sediment-delivery ratios to make estimates of sediment yields from drainage basins. Sediment-delivery ratio is the proportion of the soil lost from slopes or other landforms that actually is discharged from a basin at the outlet, and not deposited someplace within the basin. Because the USLE only accounts for sheet and rill erosion, any significant gully or channel erosion can be evaluated by measurements of changes in channel geometry; that amount of erosion must be added to the USLE values. The resultant value for total soil loss is divided by measured sediment yield to determine the sediment-delivery ratio of a basin.

The most reliable predicted values of sediment-delivery ratios are obtained from local or regional studies, in which the procedure described in the previous paragraph is applied to sets of basins. Roehl (1962) studied such a set of small watersheds in the southeastern Piedmont Province of North Carolina, South Carolina, and Georgia. Relations of sediment-delivery ratio to basin relief-length ratio, to stream length, and to drainage area developed by Roehl in that study appear to be valid for predicting sediment-delivery ratios in the southern Appalachian coal fields.

Surveys of sediment deposits in ponds that intercept flows from small watersheds is a widely accepted technique for obtaining estimates of annual sediment yields and sediment-delivery ratios. Procedures for surveying ponds or reservoirs are given in the Sedimentation Engineering Manual (Vanoni, 1975) and by Heinemann and Dvorak (1965). Methods for converting from volume units to weight units of sediment and for correcting for sediment-trap efficiencies of ponds are given in the Sedimentation Engineering Manual (Vanoni, 1975).

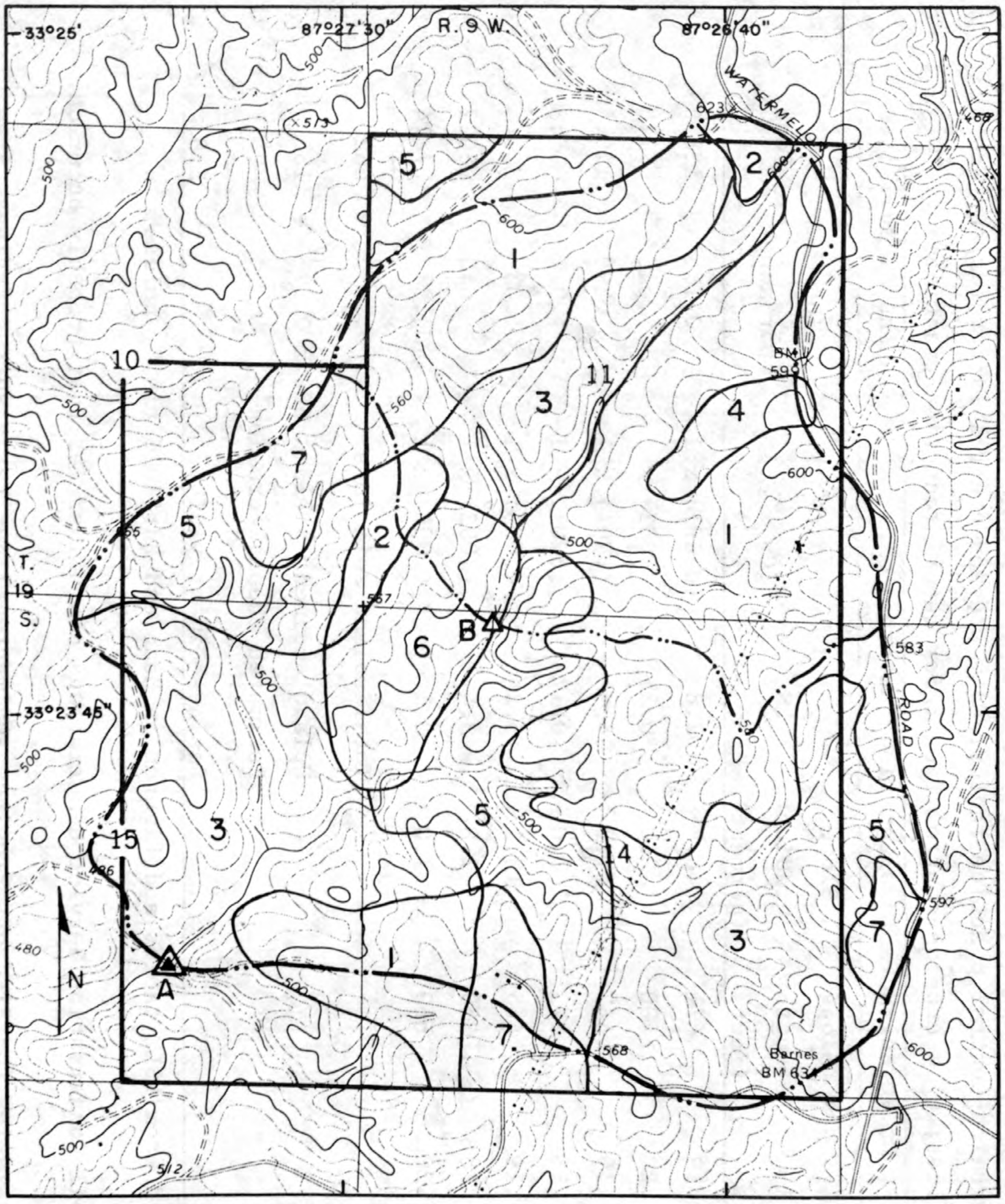
As pointed out by Haan and Barfield (1978), the U.S. Soil Conservation Service maintains a countrywide program in which thousands of small reservoirs are surveyed periodically to determine sediment contents. A local or State Soil Conservation Service office, therefore, may have available sediment-yield records for one or more ponds in watersheds that are similar in size, soils, vegetation, land use, and topography to watersheds on a given permit area. This sediment-yield data would be useful in hydrologic evaluation of a permit area.

Normally, there will be several ponds on or near a permit area that can be surveyed to determine the volume of sediment they contain even if they have never been surveyed before. This approach requires that information about the age, frequency and amounts of spillage, and maintenance of the pond be available from the landowner, the contractor who constructed the pond, or in some cases, Federal agencies such as the U.S. Department of the Interior Bureau of Land Management, the U.S. Department of Agriculture Soil Conservation Service, or U.S. Department of Agriculture Agricultural Stabilization and Conservation Service.

Specific surveying techniques for existing ponds that have not been surveyed before include probing (spudding) the sediment from a boat with a dull-pointed rod or bar to determine the elevation of the original bottom, and sounding the water to determine the elevation of the top of the sediment. An accurate survey can be made for perennial or ephemeral ponds, except those where ground water enters through the bottom of the pond. The sediment thickness also can be measured by coring the sediment or it can be augered if the pond is dry and the sediment is not more than one or two feet thick. Additional details regarding equipment and procedures are given in Gottschalk (1952) and in the U.S. Soil Conservation Service National Engineering Handbook, Section 3 (1968).

Soil-Loss and Sediment-Yield Estimates

Soil-loss units are delineated in figure 9, according to slope gradients and lengths and silvicultural practices. The annual rate of soil loss for each unit computed with the USLE is shown in table 12, along with values for each of the USLE factors. Variations in soil loss among the units mainly are attributable to differences in slope characteristics and in the amounts of canopy cover resulting from timber harvesting and restocking practices, as indicated in 1:24,000-scale aerial photographs taken in March 1977. An estimate of 90 percent tree-canopy cover for a mature stand of loblolly pine (T. J. Hill, U.S. Geological Survey, written commun., 1980) was used as a reference value in evalutation of amounts of canopy cover. These soil-loss rates are small and they agree with field observations by the authors and colleagues that indicated very little sheet wash or rill erosion, because of the dense mat of forest litter on the watershed. Even though these soil-loss estimates are small, they appear to overestimate actual loss; the estimates of slope length used in the computations probably are longer than actual lengths and would be a cause of overestimates of soil loss.



Base from U.S. Geological Survey
Windham Springs 1:24,000, 1974

1000 0 1000 2000 3000 FEET
500 0 500 METERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL
DATUM OF 1929

EXPLANATION

———	Permit-area boundary	(4)	Soil-loss unit
—··—	Drainage divide	A,B	Sediment-yield estimation sites

Figure 9.--Soil-loss units on the permit area and on Loblolly Branch basin before mining.

Table 12.--*Annual premining soil-loss and sediment-yield estimates for Loblolly Branch basin*[1/]

[R = rainfall-erosivity factor; K = soil erodibility factor; LS = slope gradient and length factor; CP = combined cover and erosion-control practice factor; C_s = erosion-control factor for surface stabilization practices; C_r = erosion-control factor for runoff-reduction practices]

Unit	Area (acres)	Universal Soil Loss Equation factors						Annual soil loss	
		R	K[2/]	Slope length (feet)	Slope gradient (percent)	LS	CP (C_s x C_r)	Tons per acre	Tons
1	584.1	350	0.19	671	8.4	2.8	(0.001) x 1	0.186	108.6
2	41.3	350	.20	400	2.0	0.31	(.002) x 1	.043	1.8
3	500.0	350	.19	467	11.7	4.5	(.001) x 1	.299	149.5
4	25.4	350	.18	275	1.0	0.17	(.001) x 1	.011	0.3
5	254.0	350	.19	465	13.1	5.2	(.003) x 1	1.037	263.4
6	93.5	350	.18	1,350	7.8	3.4	(.003) x 1	.643	60.2
7	88.9	350	.20	660	7.0	2.1	(.006) x 1	.882	78.4
						Total upland soil loss			662
						Upland sediment yield: 662 x 0.28[3/] =			185
						Estimated channel erosion[4/]			94
						Basin sediment yield			279

[1/] Factor values obtained from USLE tables and figures in Haan and Barfield (1978) unless otherwise indicated.

[2/] K values from U.S. Soil Conservation Service descriptions of soil series that probably occur on the basin.

[3/] From Roehl's (1962) relation for Piedmont Province sediment-deliver ratio versus drainage area.

[4/] Based on assumed bank erosion of second-, third-, and fourth-order channels shown on Windham Springs 1:24,000-scale quadrangle. All material was assumed to be transported out of basin.

Channel-erosion rates on the watershed are small also, but a significant part of the sediment yielded from Loblolly Branch basin apparently results from slight scouring of channel banks and beds during the larger floods in the normal streamflow regimen. Curtis (1979), in a summary paper on hydrologic aspects of surface mining in the eastern United States, stated that: "Where mineral soil is fully protected by a cover of litter and humus, the surface of upland forests contribute little or no sediment to streams. However, there is some erosion and sedimentation in the adjacent to stream channels."

The only satisfactory method for obtaining reliable data on channel erosion is by periodic surveys of monumented cross sections. The schedule of this report and travel constraints did not permit the establishment of cross sections. The channel-erosion rates shown in table 11 and other tables on postmining soil loss, therefore, were based on reconnaissance observations of channels in mined and unmined areas in the vicinity, and on estimation of the amount of material that would be eroded from channel banks and beds during one year. All of the material that was eroded was assumed to be transported from the basin and not deposited within the channels or on flood plains or terraces.

A sediment-delivery ratio factor must be applied to the total upland soil-loss amount to obtain an estimate of sediment yield from the watershed because the USLE does not account for deposition that may occur at places where slopes become less steep or deposition in channels or on flood plains. The relation of sediment-delivery ratio to drainage area developed by Roehl (1962) in the Piedmont Province was used for Loblolly Branch. As shown in table 12, the sediment yield of Loblolly Branch resulting from upland and channel erosion was estimated to be 279 tons per year.

Celso Puente (U.S. Geological Survey, written commun., 1980), using the flow duration-sediment rating curve method (Miller, 1951), has estimated the sediment yield from Loblolly Branch to be 112 tons per year, based on monthly suspended-sediment samples taken over a two-year period. Puente used the correlation of instantaneous discharges between the partial-record gage on Loblolly Branch and the continuous-record gage on Yellow Creek to obtain a flow-duration curve for Loblolly Branch basin. Daily sediment loads from the sediment-rating curve for Loblolly Branch were weighted according to the flow-duration curve to obtain an estimate of annual suspended-sediment discharge.

The estimate of sediment yield made by Puente includes suspended sediment resulting from both upland and channel erosion. However, it does not include bedload sediment, which could be a significant part of the total sediment discharge, particularly during the larger floods of the normal regimen, because of the predominance of sandy soils in the basin.

The estimate of sediment yield developed in this report with the USLE may be an overestimate of actual sediment yield, because the soil-loss rates appear to exceed actual rates. Puente's estimate may be smaller than an actual one would be for the reason given in the previous paragraph. A several-year record of sediment discharge from Loblolly Branch, including bedload measurements, would be needed to determine a measured (actual) value with which to assess the accuracy of the two estimates.

POTENTIAL EFFECTS OF MINING AND RECLAMATION

Potential effects of mining and reclamation on the hydrologic system of Loblolly Branch basin include changes in: (1) Landforms and topography; (2) soil types, depths, infiltration rates, moisture-retention capacities, and erodibilities; (3) types and amounts of vegetation; (4) quantity and quality of streamflow; (5) soil-loss rates and sediment yields; (6) aquifer characteristics and performance; and (7) quantity and quality of ground water.

Some of the effects will be significant and potentially serious, and others will be insignificant. The degree of significance is addressed in each of the topic sections that follow based on available data and (or) knowledge of the pertinent hydrologic processes.

Because there was no specific mine plan, the following assumptions were made to provide a basis for defining and evaluating effects: (1) The whole permit area would be mined; (2) the topography would be returned to the same general configuration; and (3) the area would be returned to a loblolly pine plantation.

Changes in Topography

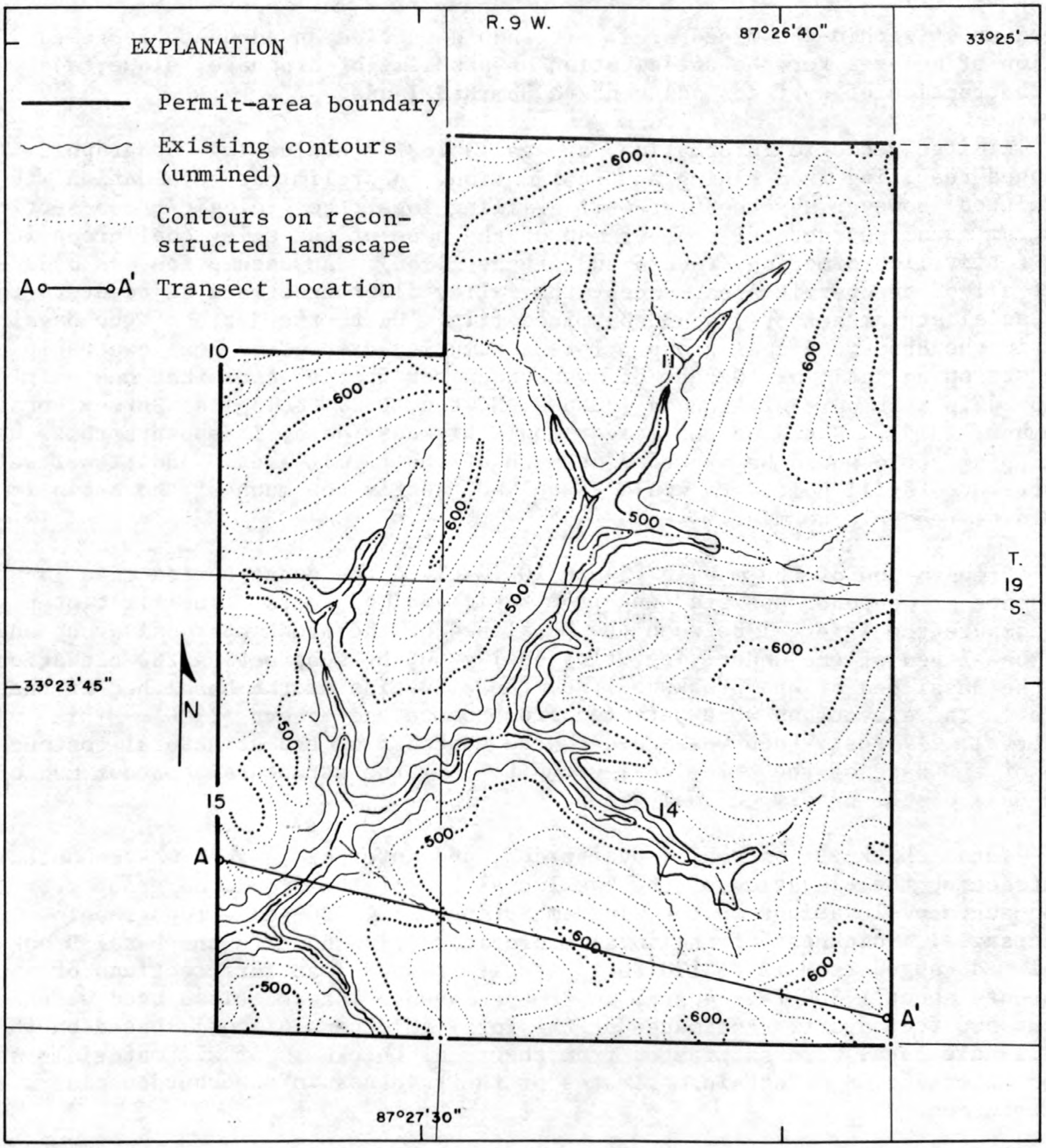
Applicable Regulations

Information about changes in topography that may be required in a permit application is listed in the following parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 13, 1979):

Subchapter	Part
K	816.54 Hydrologic balance: stream buffer zones
	816.73 Disposal of excess spoil: head of hollow fills
	816.102 Backfilling and grading: general grading requirements
	816.105 Backfilling and grading: thick overburden
	816.133 Postmining land use

A postmining terrain map (fig. 10) provides an estimate of the surface topography following mining and reclamation. This map is based on the concept of lifing out the overburden as one unit, removing the coal, and replacing the overburden in the original position. The thickness of the replaced overburden is assumed to have increased by 20 percent because of the increase in void space resulting from the fracturing and pulverizing of consolidated strata in the Pottsville Formation and bulking of the unconsolidated Coker Formation.

The map provides a simple approximation of the reconstructed surface of a mined area without assuming a mining plan or calculation of overburden volumes



Grid from U.S. Geological Survey Windham Springs 1:24,000, 1974

Mapped by D. L. Dunagan

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 10.--Reconstructed topography of permit area after mining and reclamation. The overburden was assumed to be replaced on a cut-by-cut basis and was graded smooth. Comparison of land-surface elevations before and after mining and grading were made along transect A — A'.

moved about within the mined area. It should provide an adequate representation of an area for the anticipation of problems of drainage, slope, and reconstruction of surfaces adjacent to unmined lands.

Limited geologic information was available for evaluating topographic changes resulting from mining and reclamation. A preliminary evaluation was permitted, however, by the test-well drilling logs, the geologic cross-section diagram, and a structural contour map of the base of the Utley coal group in the Pottsville Formation (Puente and others, 1980). An assumption was made that all of the permit area, except the valley floor under and adjacent to the perennial stream network, would be mined (fig. 10) to the depth of the basal bed in the Brookwood coal group. This assumption disregards coal ownership and the stripping ratio of 40 feet of overburden per foot of coal that customarily is used in that part of Alabama (John G. Newton, U.S. Geological Survey, oral commun., 1979). Based on the meager coal-thickness data, it appears that the stripping ratio would be exceeded on much of the permit area. Additional well-distributed drill-hole data would establish exactly how much of the basin it would be feasible to mine.

Preparation of the map in figure 10 involved the construction of a sequence of contour maps starting from basic geologic data. The first step was to compute the interval between the basal bed of the Brookwood coal group and the basal bed of the underlying Utley coal group by subtracting the elevation of the basal bed of the Brookwood from the elevation of the basal bed of the Utley. The elevations were obtained from Puente and others (1980). This interval, 217 feet, then was added to the contours on the structural contour map of the base of the Utley coal group to form the structural contour map of the base of the Brookwood coal group.

Total thickness of coals, overburden, and interburden then was computed by subtracting the elevation of the basal coal bed of the Brookwood group from the land-surface elevations on the Windham Springs 1:24,000-scale topographic quadrangle. Thickness of the total geologic section down to the basal Brookwood coal bed ranged from 13 to 170 feet, usually computed at intersections of contours about 1,500 feet apart; in steeper areas, intersections used were about 500 feet apart. Estimates of the total thickness of coal, based on the drill-hole data, were subtracted from the total thickness of all materials at each intersection to obtain estimates of the thickness of overburden plus interburden.

These values were increased by 20 percent for expansion resulting from the fracturing and pulverizing of bedrock and the loosening of unconsolidated soils and underlying strata in the Coker Formation during mining and reclamation. Finally, the thickness of expanded overburden was added to elevations on the base of the Brookwood coal group and the resultant elevations using a 20-foot contour interval.

The contours were drawn relatively smooth in accordance with grading during reclamation which normally eliminates small hollows, low ridges, and short steep slopes that are characteristic of the premining landscape. Around the edges of the permit area and adjacent to the perennial streams, the contours were shaped so that they would merge smoothly with the contours of adjacent unmined land.

Land-surface elevations along a transect before and after mining and reclamation are shown in figure 11. The transect was located to show marked changes in the surface elevation on the permit area. Along most of the transect, surface elevations would increase because the coals are thin and the overburden is relatively thick over much of the permit area. Even where the overburden is thinnest (12 feet) the removal of the 1-foot coal bed would not compensate for a 20-percent expansion of the overburden. At the drill hole where the coal is thickest (3.7 feet), there is 126 feet of overburden which would expand about 25 feet because of mining and reclamation. The surface would be raised 1.4 feet in the thin overburden case and about 21 feet in the thick overburden case.

Near the right end of the transect in figure 11, the reconstructed land surface is about 65 feet higher than the original surface, from filling of the upper end of a tributary valley. In comparing the contours of figure 10 with the premining contours of figure 9, it can be seen that partial or complete filling of upper tributary valleys or hollows would occur from overburden expansion and the reshaping process. The land surface, however, would be lower along one segment of the transect (fig. 11). This is because of the orientation of the tributary valley would shift; before mining, the transect would be positioned on the valley side parallel to the valley floor; after mining, the valley floor would cross the transect.

With the filling of upper valleys, the gradients of the valley floors would be increased, particularly in the northern half of the permit area. Gradients of four upper valley floors in sections 10 and 11 were measured before mining and after reshaping of the land surface. Locations and lengths of the specific valley-floor reaches are indicated in figure 10. Gradients before mining ranged from 2.8 to 3.6 percent, as measured on the map in figure 9. After mining and reshaping, the gradients ranged from 2.9 to 6.8 percent, as measured on the map in figure 10. Serious channel erosion is not expected to occur as a result of these increases in upper valley-floor gradients, with the possible exception of reach 3 (fig. 10) whose gradient would be 6.8 percent. It may be necessary to control erosion there with additional measures such as grassed waterways.

Soils and Water Relations in Soils

The assumption was made that about 10 feet of loamy sand, sandy loam, or gravelly sand of the existing soil and upper Coker Formation would be stock-piled before mining and placed back on the surface after mining and grading of the spoils. Further, it was assumed that finer-textured materials, such as the subsoil of the old soils on the divides, would be covered with at least 3 feet of sandy or gravelly soil.

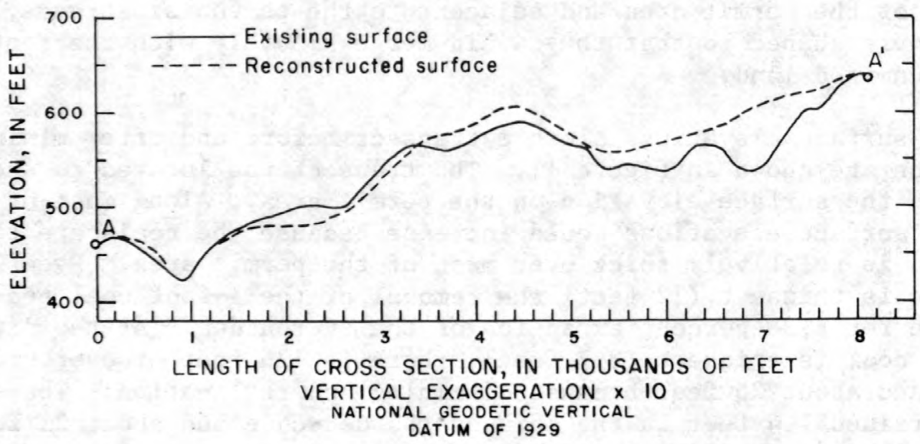


Figure 11.--Cross section showing land-surface elevations before and after mining and reclamation along a transect across the permit area.

Replaced soils would be somewhat less resistant to compaction than premining soils because of inadvertent mixing of finer-textured B-horizon materials and subsoils with the sandy surface soils during mining. The objective would be to attempt to eventually reestablish the soil hydrologic systems illustrated in figures 5 and 6A, B, and C with adequate surface-soil porosity for rapid infiltration and lateral drainage, and some porosity at depth for deep drainage to maintain baseflows.

The area where soils are derived from the Pottsville Formation will not be mined as indicated in figure 10; the hydrology of these soils would not be changed to any significant degree. The soil sampling and soil-water modeling techniques described in the premining section of this report could be used to determine whether desired hydrologic characteristics have been achieved in reconstructed soils on mined areas.

Alteration of the variable source-area flow system discussed in the Premining Hydrologic System section could affect seriously the hydrologic regime of Loblolly Branch causing increased peak discharges and hillslope erosion. For example, during mining and reclamation activities, alteration would occur if the surface soils are replaced by loamy or clayey materials or if these surface soils are compacted by indiscriminate trailing of heavy machinery. In either case, the reduced porosity would cause larger and more frequent occurrences of overland flow and hillslope erosion, both of which are minimal under present conditions. A major consideration for areas that are hydrologically similar to the Loblolly Branch site is whether to reconstuct soils to resemble the present system as much as possible or to resort to extensive use of detention structures and other conservation measures to handle the increased peak discharges and sedimemt loads. Two long-term consequences of extensive use of the latter alternative are possible changes in perennial flow rates and continuing costs of structure maintenance.

Vegetation and Reclamation

Applicable Regulations

Information about revegetation that may be required in a permit application is listed in the following parts of the Surface Mining and Reclamation Regulations (Federal Register, March 13, 1979):

Subchapter	Part
K	816.11 Revegetation: general requirements
	816.12 Revegetation: use of introduced species
	816.14 Revegetation: mulching and other soil stabilizing practices
	816.117 Revegetation: tree and schrub stocking for forest land
	816.133 Postmining land use

The assumption was made that the permit area eventually would be returned to a loblolly pine plantation, which would require several years to establish. It was further assumed that a herbaceous cover would be established using procedures recommended by the U.S. Environmental Protection Agency (1976), as soon as possible after mining and reconstruction of the land surface including topsoiling is completed. Pine seedlings would be interplanted later in the stand of herbaceous vegetation.

The soils would be tested for lime and fertilizer requirements prior to seeding of a suitable mixture of species, with Bermuda grass being the dominant species. Immediately after seeding, a straw mulch at the rate of 2 tons per acre would be applied and anchored mechanically to stabilize the surface and conserve moisture until the seedlings became established.

A long growing season, warm temperatures, and abundant precipitation will facilitate rapid establishment of vegetation and result in only a short period when the soil is bare. Live plant cover is expected to be about 50 percent by the end of 2 months after planting and 95 percent at the end of the first year.

Surface runoff and erosion probably would occur during the short time that the soil is barren, but would decrease as vegetation cover and volume increases. Runoff for various stages of vegetation development during reclamation is difficult to quantify from existing data. However, the amount of overland flow will continue to decrease as mulch or litter accumulates and should cease to occur by the time the area becomes reforested, assuming that the reconstructed soils will be hydrologically similar to the present soils.

Data collected at other locations indicate the effect on streamflow when trees were felled and ground cover was left relatively undisturbed. At Coweeta, in North Carolina, where this treatment was applied and regrowth of trees was allowed, streamflow, expressed as a percentage of mean annual precipitation, was 47, 15, 15, 14, and 11 percent greater than the flow from an untreated watershed for the 5 years studied (Hibbert, 1967). Hornbeck and others (1970) reported a 40-percent increase in streamflow the first year after a similar treatment was applied in New Hampshire. In the Coweeta study, evapotranspiration amounts increased each year and were 36, 41, 41, 43, and 46 percent of the annual precipitation, as compared to 57 percent average evapotranspiration from the untreated watershed for the 5 years.

Postmining Hydrologic Systems

Because of the scope and associated time constraints of this study, no data were collected, and no analyses of hydrologic systems were done on mine-reclamation areas. Rather, in keeping with the main concept of the Federal regulations (Federal Register, March 13, 1979) of protection of the hydrologic balance, it was assumed that the area would be reclaimed in ways that would lead to reestablishment of a hydrologic system similar to the premining system. Some of the assumptions may not be in accordance with normally used reclamation practices; however, they serve the purpose of this report, which is to demonstrate methodology.

The hydrologic system that is most extensively analyzed and discussed in the remainder of the report is based on the assumptions that follow. As discussed in the Soils and Water Relations in Soils section, the first assumption is that about 10 feet of the present soil material or other permeable material from the Coker Formation would be placed back on top of graded spoil. A second assumption is that Coker Formation spoil would be put back on top of Pottsville Formation spoil, and the Coker Formation spoil would be graded to conform to the general configuration of the landscape.

The Coker Formation spoil should be very permeable, because of the destruction of the clay layers and of the consolidated basal bed during mining. Water that drains from the soils should trickle freely to the base of the formation where it would move laterally to the channels. This discharge from the base of the Coker Formation spoil would be much more responsive to rainfall events than premining discharges, and floods would recede faster.

A third assumption is that the prominent clay layer at the top of the Pottsville Formation would be replaced to restrict the amount of ground water that enters the Pottsville Formation spoil. The Pottsville Formation spoil beneath the clay layer should be permeable, but the permeability will vary according to: (1) The type and particle-size distribution of rock fragments and pulverized materials; and (2) the degree of compaction.

A different hydrologic system would result if the reclamation is done as follows: (1) Sandy soil material would be replaced on the surface, as in the previous alternative; and (2) the remaining spoil from the Coker Formation and the spoil from the Pottsville Formation would be put back in mined-out areas as a nonhomogeneous mixture. Also, under this alternative, the clay zone at the top of the Pottsville Formation would not be restored, so more ground water would percolate through spoil than with the hydrologic system discussed previously.

Surface Water

Applicable Regulations

The parts of the Surface Coal Mining and Reclamation Regulations (Federal Register, March 3, 1979) that specify the types of postmining surface-water information required in a permit application or to meet design standards are listed in the premining surface-water section of this report. These regulations require that hydraulic structures be designed to hold or convey volumes and discharges produced by 24-hour precipitation events of specified frequencies, except for overland flow diversions for which design storm duration is not specified, and for temporary bridges which must pass the discharge resulting from a 6-hour storm.

Estimates of Design Discharges and Runoff Volumes for Postmining Conditions

The requirement that discharge frequency be based on frequency of the precipitation event implies that the U.S. Soil Conservation Service method or some physical-process model be used to estimate design discharges for such structures, because these methods can accommodate the specified precipitation amounts as input, while regression models usually do not include precipitation parameters. In addition, regression models available for the Loblolly Branch area cannot account for the effects of changes in vegetative cover and soils that may result from mining and reclamation activities. The use of a physical-process model was beyond the scope of this study.

Peak discharges and runoff volumes for postmining conditions were estimated for Loblolly Branch sites A and B (fig. 2) with the U.S. Soil Conservation Service method. Application of this method under premining conditions indicated that it should give reasonable estimates, if values for the basin lag parameter, computed with equation 16, are adjusted to account for the subsurface component of upland flow. Basin lag values for postmining conditions were evaluated with the procedure and the lag ratios shown in table 11. This procedure assumes that the lag ratios derived for premining conditions also apply to postmining conditions. The validity of this assumption depends on how closely the reclaimed soils match premining soil conditions. The other required parameter values were assigned on the basis of basin conditions expected to exist immediately after reshaping of the spoils has been completed and through the early part of the vegetation-reestablishment period.

Average basin slope was calculated from a map of the reshaped topography (fig. 10) prepared by the technique described in the section of this report titled Changes in Topography. It was assumed that the reshaped land would be seeded immediately to grass interplanted with tree seedlings. Because establishment of grass cover occurs relatively rapidly in this area, pasture in fair condition seemed the appropriate land-use category for selection of the proper CN value.

Infiltration characteristic of the soil is one of the most important factors that affects rate and quantity of runoff. It is very difficult, if not impossible, to predict what the postmining soil conditions will be because there are few data to indicate general changes in soil conditions that occur from overburden replacement and shaping. Type of soil material, its moisture content at time of placement, method of placement, method of seedbed preparation, and so forth, will influence resulting infiltration rates, increasing it in some combinations, decreasing it in others.

It previously has been assumed in the report that at least 10 feet of sandy subsoil material and topsoil would be used as top dressing over mine spoils in Loblolly Branch basin. Even if this is done, it is probable that the restructured surface soils would have lower water-transmitting capacities than the present soils. It seems unlikely that the topography could be restructured without leaving soils more compacted than they are in their natural state. Soils in this area that have been subjected to severe compaction by machines and animals may have as little as one-fourth the drainable water capacity of uncompacted soils (fig. 6). At some point, the subsurface flow route that precipitation now takes to channels would be so severely restricted that it would be an insignificant segment of the flow system. This restriction would render the lag adjustment procedure invalid and would result in larger peak-discharge estimates.

Assuming that increased compaction of restructured soils would place them in the infiltration range of Hydrologic Soil Group C, and that the land-use category would be pasture in fair condition, the CN value for the drainages above sites A and B (fig. 2) in Loblolly Branch basin would be 79 (U.S. Soil Conservation Service, 1973, table 2). The reader is cautioned that these are severe conditions selected for the purpose of structure- or channel-design flows.

Holtan and others (1965) suggest that potential water-storage volume (V, total porosity minus antecedent moisture content) of soils at the beginning of a storm represents a quantity similar in concept to the potential maximum-retention parameter (S in eqs. 14 and 15) of the U.S. Soil Conservation Service method. Assuming this is true, the quantities S and V may be used to evaluate the appropriateness of the selected CN value. The water content of soils in Loblolly Branch basin seems to be near their water-retention capacity, or field capacity, a large percentage of the time. The value of V for these soils may be considered as total porosity minus the water content at the soils' water-retention capacities, or the sum of the slowly and rapidly drainable water volumes (fig. 6). The magnitude of V for the compacted soil shown in figure 6, which is here assumed to represent postmining soils, is about 25 percent of V for the uncompacted soil (assumed to represent premining soils). The value of S (eq. 15) for a CN of 79 is about 35 percent of the S values for the CN's used for premining conditions (55 and 58). If S and V are considered analogous, a CN value of 79 seems to represent soil conditions that reasonably can be expected to exist for the first year or so after mining in Loblolly Branch.

CN values, hydraulic lengths of basins, drainage areas, and average basin slopes for the assumed postmining topography of Loblolly Branch are listed in table 13. Estimated peak discharges and runoff volumes for postmining conditions at Loblolly Branch sites A and B are listed in table 14. Peak discharges were computed by the procedure described in TP-149 (U.S. Soil Conservation Service, 1973).

Comparison of premining estimates and postmining design estimates shows that the 2-year precipitation event would produce peak discharges that are 4.8 to 6.8 times larger than premining peaks (fig. 8 and table 14). For higher recurrence-interval storms, estimated postmining peaks are 2.7 to 4.1 times greater than premining peaks. Estimated postmining runoff volumes are 2 to 3 times larger than premining volumes. These large differences reflect the significant hydrologic consequences of soil compaction and the changing of the vegetative cover from forest to grassland. However, the validity of these large differences is critically dependent on the selection of CN values that accurately reflect actual postmining hydrologic conditions. The selection procedure leaves ample opportunity for error.

The estimated postmining discharges should not be considered "final." These estimates are based on certain assumptions described earlier, including the assumed conditions existing "immediately after reshaping of the spoils and through the early part of the vegetation reestablishment period"; this is a "worst condition" scenario. However, it is reasonable to expect that the reclaimed site will revert back toward the pine-forest condition that existed before mining. The passage of time should result in some reduction of soil compaction, redevelopment of the duff layer on the surface soils, and greatly increased vegetative-cover density. Peak discharges should gradually decrease; within a period of 10-20 years, the discharge regime could be very similar to the regime that existed prior to mining.

Surface-water responses will be significantly altered from the premining regime, and from the early postmining regime just discussed, if the Pottsville and Coker Formations are not replaced separately, and if the clay layer between them is not replaced and compacted during reclamation. As reported by Curtis (1979), surface mining increases subsurface storage because of increased porosity and particle or fragment surface area in spoil, compared to unmined bedrock.

The additional storage created in the Pottsville Formation spoil would decrease peak discharges and flood volumes and would increase base flows. Such results have been reported by Curtis (1977, 1979) in Kentucky and West Virginia, and by T. P. Brabets in Illinois (U.S. Geological Survey, written commun., 1981), in comparing flows from unmined watersheds with flows from partially-mined watersheds.

Table 13.--*Postmining parameter values for U.S. Soil Conservation Service method*

Site	Drainage area (acres)	Hydraulic length (feet)	Average basin slope (percent)	Curve number, CN
A	1,613	11,960	9	79
B	557	6,160	9	79

Table 14.--*Postmining design peak discharges and streamflow volumes estimated by the U.S. Soil Conservation Service method at the Loblolly Branch sites*

[ft^3/s = cubic feet per second; acre-ft = acre-feet]

	Recurrence interval of storms (years)			
	2	10	25	100
Basin A (computed lag = 0.8)				
Adjusted lag	1.5	2.2	2.3	2.5
Peak discharge (ft^3/s)	760	1,150	1,315	1,600
Runoff volume (acre-ft)	287	508	615	805
Basin B (computed lag = 0.5)				
Adjusted lag	0.9	1.3	1.4	1.5
Peak discharge (ft^3/s)	440	640	720	845
Runoff volume (acre-ft)	99	175	212	277

Quality of Surface Water

Sediment concentrations of the streamflow in Loblolly Branch basin are expected to be much greater during the mining and early reclamation phases as a result of surface runoff from barren soils and spoil banks. Sediment sampling of the streamflow from this basin or a similar one during mining would be required to evaluate the sediment concentrations.

Surface runoff and ground-water drainage from Pottsville Formation spoils prior to their reclamation probably will increase the concentrations of several chemical constituents of the surface waters, including aluminum, calcium, magnesium, manganese, iron, and sulfate. Sampling would be necessary to determine the magnitude of the increased concentrations.

As vegetation becomes well-established and the shallow ground-water flow system redevelops, quality of the streamflow gradually should approach that of premining conditions. This is based on the assumption that the Coker Formation spoils and the present soils would be placed back over Pottsville Formation spoils, with a compacted clay layer separating the two formations. This will permit the present shallow ground-water flow system to redevelop and reduce slope erosion and sediment concentration of streamflow. That system would reduce percolation of rainwater through Pottsville Formation spoil, where the water would become mineralized and eventually be discharged in Loblolly Branch either within the permit area or downstream. If the compacted clay layer is not installed, additional ground water moving through Pottsville Formation spoil will further increase discharge of chemical constituents to Loblolly Branch.

Ground Water

Mining and reclamation can produce significant changes in the aquifer system and the ground water. Severity of the adverse impacts would depend on the number and type of mitigating measures. Two assumed alternative plans for reclamation of the subsurface have been discussed in the postmining hydrologic system section; ground-water occurrence, movement, and quality will be affected differently by the two plans.

Ground-Water Movement

If the clay layer at the top of the Pottsville Formation spoil is replaced, ground water that would perch above the layer in the Coker Formation spoil would move toward Loblolly Branch and its tributaries and be discharged at springs and seeps along a line similar to the present spring line. Along the main stem of Loblolly Branch, this line will correspond closely with the edge of the mined area, except in the southwest corner of the permit area where the mine would extend downhill from the present contact of the Pottsville and Coker Formations (figs. 2 and 10).

Downward movement of any water that penetrates the replaced spoil would be stopped by the underclay remaining after the coal has been mined. The water then most likely would move toward Loblolly Branch and downvalley. Some water might enter unmined fractured Pottsville Formation and coal beds at the south and west edges of the permit area, but those edges should serve to train most of the water toward Loblolly Branch (figs. 2 and 10). Along the edges of the mined area next to the creek, the Pottsville Formation spoil would saturate up to a level where the water would enter the upper fractured and weathered zone of unmined Pottsville Formation. The water would move through this zone and discharge into Loblolly Branch. There will be no ground-water discharge until the replaced spoil becomes saturated, if the clay layer separating the Coker and Pottsville Formations is not replaced.

Quality of Ground Water

Disturbance of the Coker Formation during mining and reclamation should not affect the quality of ground water in the Coker, because of the lack of sulfide minerals in the formation. However, oxidation of the iron-sulfide minerals, pyrite and marcasite, in the Pottsville Formation spoil during mining and reclamation will produce sulfuric acid. Sulfuric acid reacts with other minerals, and this commonly results in increased concentrations of dissolved aluminum, calcium, magnesium, manganese, sulfate, and total iron in the water contained in and draining from the spoils. Such findings were reported by Puente and Newton (1979) for a 2-year hydrologic study on Crooked Creek in Jefferson County, Alabama, which is adjacent to Tuscaloosa County. There, the quality of streamflow upstream from an area of partially reclaimed surface mines was compared to quality of streamflow downstream from the mined areas. Mining had been in progress from 1970 until early 1976; most of the hydrologic data was collected between October 1975 and May 1977.

All of the streams in the Crooked Creek basin drain areas underlain by the Pottsville Formation. The Crooked Creek basin is situated about 1,000 feet lower in the Pottsville Formation than the Loblolly Branch basin, but the lithologies appear to be similar at both places (Puente and Newton, 1979; Puente and others, 1980). It is reasonable to assume that the quality of water from Pottsville spoil at Loblolly Branch would be similar to that from spoils at Crooked Creek.

Puente and Newton (1979) also reported that there were only small differences in the pH and bicarbonate concentration of streamflow above and below the influence of the mined area. They attributed this to neutralization of sulfuric acid by siderite ($FeCO_3$) and another unidentified carbonate mineral in the shale overlying the coal that was mined. This neutralization would be expected if the Loblolly Branch permit area was mined; however, the occurrence of siderite seems to be more sporadic there than in the Crooked Creek basin (J. G. Newton, U.S. Geological Survey, oral commun., 1980).

Erosion and Sediment Yield

Erosion and sediment yield from mining and reclamation will be controlled, chiefly, by the kind of earth material on the surface, the topographic form of the material, and the amount of vegetal cover on the surface. Because of drastic changes in these factors from the time that mining begins until reclamation of the area is accomplished some years later, erosion and sediment yield will be evaluated for various phases throughout this period of time.

Mining and Early Reclamation Phases

The Universal Soil Loss Equation was used to evaluate erosion for assumed various phases of mining and reclamation activities (table 15). Soil-loss units were delineated on the reconstructed topography map on the basis of slope gradients and slope lengths (fig. 12). A small basin, 0.21 square mile in area, was selected as an example area for which soil loss was evaluated for various phases of mining and reclamation assumed to occur within a year. The basin occurs wholly within soil-loss unit 1, and the basin divide and outlet at point D are indicated on figure 12. Parts of the basin that were outside the permit area and parts adjacent to perennial water were not mined; they include about 12 percent of the basin area, and sediment yield from that area was considered to be negligible.

The phases considered in table 15 begin with premining dense forest and progress through various mining and reclamation operations to the early stages of grass-seedling development. The schedule of the phases was patterned after some example computations of soil loss in mining areas done by Haan and Barfield (1978). For this example, it was assumed that reclamation operations would be concurrent with mining, and that soils would be removed ahead of the pit and immediately be placed on graded spoil on the opposite side of the pit. The sources of the USLE factors and the computations of soil losses and sediment yields are explained in the footnotes to table 15.

The relation developed by Roehl (1962) from sediment-delivery ratio versus drainage-area data obtained at several southern and midwestern locations is for watersheds 0.01 square mile and larger in area and was used to obtain the sediment-delivery ratio shown in footnote 7 of table 15. The relation between drainage area and sediment-delivery ratio for the Piedmont Province (Roehl, 1962) was not used because the relation was developed for basins greater than 0.6 square mile.

Channel erosion for the phases occurring between June 1 and August 10 probably is not zero as indicated in table 15. Because the landscape and drainage system would be undergoing many changes due to earth-moving operations, it would be difficult to evaluate channel erosion for these phases.

The sediment-yield values shown in the right-most column of table 15, refer to the amount of sediment delivered at location D (fig. 12). These values, particularly the total of 13,456 tons, have implications regarding

Table 15.--*Soil-loss and sediment-yield estimates from subbasin D for progressive periods during mining and early reclamation*

[Footnotes are continued on next page; R = rainfall-erosivity factor; K = soil erodibility factor; LS = slope gradient and length factor; CP = combined cover and erosion-control practice factor; C_r = erosion-control factor for runoff-reduction practices: C_s = erosion-control factor for surface stabilization practices]

Period	Phase	Universal Soil Loss Equation factors								Estimated sediment-delivery ratio	Estimated channel erosion (tons)	Sediment[5] yield (tons)
		R[1]	K[2]	Slope length (feet)	Slope gradient (percent)	LS[3]	CP[4] ($C_r \times C_s$)	Soil loss (tons per acre)				
1/01 to 4/01	Dense forest	63	0.18	400	13	4.8	0.001	0.05	0.04[6]	0.39[7]	0.6[8]	2.4
				600	8	2.4	.001	.03				
4/01 to 6/01	Bare soil (after tree removal)	59.5	.24	400	13	4.8	.90[9]	61.7	43.2[6]	.52[10]	61[11]	2,712
				600	8	2.4	.90[9]	30.8				
6/01 to 8/10	Active mining (dumped and roughly graded soil)[12]	105	.31	100	10	1.4	1.2	54.7		.20[13]	0	1,290
6/01 to 8/10	Active mining (spoil banks, partially graded)[12]	105	.35	80	35	9.0	1	331		.20[13]	0	7,812
8/10 to 9/01	Regraded bare soil with diversion berms	31.5	.33	900	8.5	3.5	.58[14]	21.1		.52[10]	175[16]	1,295
9/01 to 11/01	Newly seeded to grass	49	.28	900	8.5	3.5	.58 x (.08)[15]	2.2		.52[10]		310
11/01 to 12/31	Grass development	42	.28	900	8.5	3.5	.58 x (.05)[17]	1.2		.25[18]		35
										Total sediment yield		13,456

[1] Computed using percentage distribution of annual R value for given dates as shown in table 5.1 (Haan and Barfield, 1978).

[2] Estimated values computed using nomograph of Wischmeier and others (1971).

[3] From figure 5.10 in Haan and Barfield (1978).

[4] Values from table 5.4, table 5.7, and figure 5.15 in Haan and Barfield (1978).

[5] Sediment yield computed by multiplying soil loss by mined area (118 acres) and by sediment-delivery ratio and adding on channel erosion. All material eroded from channel was assumed to be transported from the basin.

[6] Weighted according to 0.4 of area with slopes 400 feet and 13-percent gradients, and 0.6 of area with slopes 600 feet long and 8-percent gradients.

[7] From Roehl's (1962) curve of sediment-delivery ratio versus drainage area for pooled data from several physiographic provinces.

8/ Based on assumed rate of 0.01 foot of bank erosion along 1,800 feet of second-order channel with all of the material being transported out of the basin.

9/ Scraped and compacted by bulldozer and root-raked across slopes.

10/ Based on relation of sediment-delivery ratio and relief ratio using mean channel length (Roehl, 1962).

11/ Computed by assuming that 0.76 mile of perennial stream would widen an estimated 0.5 foot because of increased discharge.

12/ Spoil banks and high wall only covering one-third of basin area at any given time and newly placed soil only covering two-thirds of basin at any given time.

13/ Based on assumption that 80 percent of surface runoff from spoil area drains to interbank depressions or into sumps in mine pit where sediment is trapped.

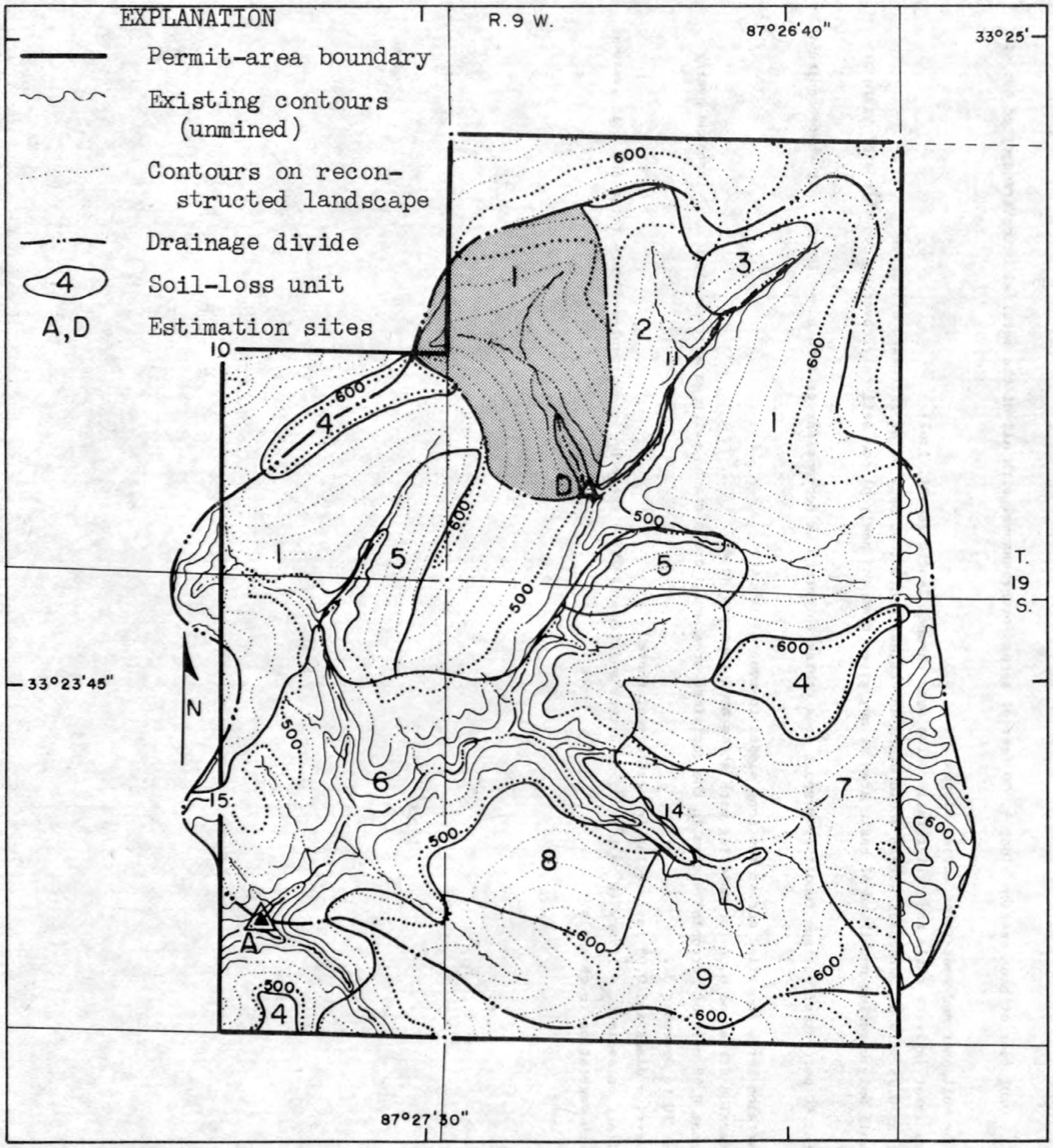
14/ Two equally spaced diversion berms installed across the long slopes to control runoff.

15/ Factor of 0.58 for diversion dikes and 0.08 for mulching with straw at 2 tons per acre.

16/ Computed by assuming that 0.58 mile of perennial stream in the reclaimed area would cut a channel with an average width of 2 feet and average depth of 0.75 foot from August 10 to December 31.

17/ Factor of 0.58 for diversion dikes and 0.05 for seeding in development phase.

18/ Based on vegetation effect on sediment delivery ($D_v = L^{-0.22}$; Holberger and Truett, 1976) where D_v is sediment-delivery ratio and L is average length of overland flow through vegetation to channels.



Grid from U.S. Geological Survey
Windham Springs 1:24,000, 1974

Mapped by D. L. Dunagan

1000 0 1000 2000 3000 FEET
500 0 500 METERS

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 12.--Soil-loss units on the permit area and on Loblolly Branch basin during reclamation period.

sediment-storage requirements of detention ponds. A unit weight of 1,750 tons per acre-foot for sandy sediment (Vanoni, 1975) translates 13,456 tons to about 8 acre-feet of volume.

The soil-loss and sediment-yield values developed in this section are for a sandy-loam soil. Importance of the surface material, particularly during early reclamation phases, cannot be overemphasized; for example, during the first year on a nearby reclamation area, severe rilling occurred on areas covered with clayey spoil, whereas there was scant evidence of erosion on areas covered with sandy and sandy-loam soils.

To the extent that it was applicable, a multiplicative relation proposed by Haan and Barfield (1978) was used for predicting the sediment-delivery ratios shown in table 16. The relation they propose for use in evaluating sediment yields from surface mines is:

$$D = D_a \cdot D_v \cdot D_c \cdot D_p$$

where

D is sediment-delivery ratio;

D_a is the term that accounts for the effect of drainage area on sediment-delivery ratio (the relations reported by Roehl (1962) or a similar one are used to evaluate D_a);

D_v is the term accounting for the effect of vegetation in the flow path on sediment discharge (a relation like that of Holberger and Truett (1976) has been proposed for evaluating this term);

D_c is a term that accounts for the effect of degree of channelization on sediment delivery (relations of basin relief-length ratio to sediment-delivery ratio (Roehl, 1962) are proposed for use to evaluate this term); and

D_p is the term that accounts for deposition in the mine pit or other significant detention locations, other than detention ponds (Haan and Barfield (1978) have developed a family of curves involving depth of water in the pit, detention time, and particle size that is used with a particle-size distribution curve to evaluate D_p).

The above equation proposed by Haan and Barfield (1978) is for use only on severely disturbed areas, such as construction sites or surface mines; validity of the equation remains to be proven. In most situations, the factors are not independent; for example, Haan and Barfield (1978) state that only in cases of very dense vegetation and highly aggregated exposed soils should the actual product of D_a and D_v be used, with the other term being unity.

Table 16.--*Annual postmining soil-loss and sediment-yield estimates from Loblolly Branch basin and reclamation for two kinds of cover*

[R = rainfall-erosivity factor; K = soil erodibility factor; LS = slope gradient and length factor; CP = combined cover and erosion-control practice factor; C_s = erosion-control factor for surface stabilization practices; C_r = erosion-control factor for runoff-reduction practices]

		Perennial grass cover[1/] [2/]								
Unit	Area (acres)	Universal Soil Loss Equation factors							Annual soil loss	
		R	K[3/]	Slope length (feet)	Slope gradient (percent)	LS	CP (C_s x C_r)		Tons per acre	Tons
1	686.4	350	0.25	911	8.5	3.5	(0.005) x 0.6[4/]		0.92	631
2	58.2	350	.25	500	9.3	3.1	(.005) x 1		1.36	79
3	15.7	350	.25	525	13.0	5.7	(.005) x 1		2.49	39
4	44.1	350	.25	250	0.5	0.13	(.005) x 1		.06	3
5	72.4	350	.25	725	11.3	5.4	(.005) x 1		2.36	171
6	278.7	350	.25	470	12.8	5.2	(.005) x 1		2.28	635
7	108.6	350	.25	867	9.0	4.0	(.005) x 1		1.75	190
8	61.4	350	.25	1,450	11.0	8.1	(.005) x 0.6		2.13	131
9	248.8	350	.25	568	6.8	1.9	.005		.83	206
						Total upland soil loss				2,085
						Upland sediment yield:	2,085 x 0.28[5/]			584
						Estimated channel erosion[6/]				184
						Basin sediment yield				768
						Loblolly pine plantation[7/]				
						Total upland soil loss				302
						Upland sediment yield:	302 x 0.28[5/]			85
						Estimated channel erosion[8/]				92
						Basin sediment yield				177

[1/] Fully established stand 3 year after seeding to grass and planting loblolly pine saplings in rows.

[2/] Factor values obtained from USLE tables and figures in Haan and Barfield (1978) unless otherwise indicated.

[3/] Computed using nomograph of Wischmeier and others (1971); the value is for a sandy-loam soil with 1.0-percent organic matter, medium granular structure, and moderate permeability.

[4/] C_r factor of 0.6 from figure 5.16 (Haan and Barfield, 1978) for two equally spaced diversion berms to reduce length of slopes that are as much as 1,450 feet.

[5/] From Roehl's (1962) relation of sediment-delivery ratio versus drainage area for Piedmont Province.

[6/] Based on assumed width, depth, and widening rates of second-, third-, and fourth-order channels shown in figure 12. All material assumed to be transported from basin.

[7/] Trees 20 years old and 30 feet tall. All values for USLE factors were the same except K and C_s. K was 0.19. Obtained by using nomograph of Wischmeier and others (1971) for sandy-loam soil with 1.25-percent organic matter, fine granular structure, and moderate to rapid permeability. C_s value of 0.001 form table 5.7 in Haan and Barfield (1978) was for a woodland estimated to have 80-percent canopy cover and 95-percent cover of litter.

[8/] Based on one-half the rate during period with grass cover due to increased stabilization of banks.

Advanced Reclamation Phases

The assumption was made that Loblolly Branch basin would be returned to a loblolly pine plantation after mining. In establishing a pine plantation, it is normal procedure to first seed a reclamation area to perennial grass to prevent erosion while the trees are becoming established. Annual rates of soil loss, therefore, were computed with the USLE under conditions of: (1) Fully established perennial grass cover 3 years after seeding, and (2) fully established loblolly pine stand 20 years old (table 16). The soil-loss units listed in table 16 are delineated in figure 12.

The period 3 to 4 years after the beginning of reclamation (table 16) was used for one set of conditions because of the findings of Curtis (1979) in Breathitt County, Kentucky. He found that sediment yields from small watersheds undergoing reclamation were highest during the first 6 months after mining; yields diminished by about one-half each in succession thereafter and reached relatively low levels within 3 years. The other set of conditions using a 20-year old loblolly pine stand was selected because it was assumed that, by that time, the forest litter layer would be developed fully and the soils would be reaching equilibrium organic-matter contents and bulk densities following the disturbances during the mining and early reclamation phases.

As indicated by the K values in table 16, soils were assumed to be uniform over the entire basin. These K values are larger than the ones used for the premining soil-loss analyses shown in table 11, because it was assumed that during the topsoil handling operations, some fine-textured subsoil with lower organic-matter content would get mixed in with the surface soils. Additionally, there would be some compaction of the soil during placement and grading that would not be released completely by ripping. A K value of 0.19 was used for the soil-loss computations for the loblolly pine plantation, as it was assumed that, by that time (17 years later), the organic-matter content would have increased; some of the clay would have been leached from the surface soils, and infiltration rates would be increased.

The reduced K and CP factors from the different kinds of cover result in a computed annual soil-loss rate of 302 tons under the loblolly pine cover, about one-seventh of the soil-loss rate of 2,085 tons under the grass cover (table 16).

The annual sediment yield from Loblolly Branch basin was computed to be 279 tons (table 12) before mining and 177 tons after mining and 20 years of reclamation (table 16). This difference occurred because, before mining, part of the basin was covered with a mixed pine-hardwood stand (fig. 3), part of the loblolly pine stand was young, and another part had been thinned. These conditions resulted in larger CP values before mining, than for the full, well-established stand of loblolly pine 20 years after mining (tables 12 and 16).

The scope and schedule of this report did not permit an evaluation of the accuracy of the soil-loss estimates made with the USLE nor the sediment-delivery ratios that were used to compute estimates of sediment discharge from basins. However, it is considered that the estimates of soil loss made for forested conditions, including a thick duff layer on the ground, are far larger than they would be if soil loss from plots along slopes actually was measured. Evidence of slope erosion is extremely sparse in any of the forested areas in Loblolly Branch basin and in the general vicinity. How can there be signficant long-term sheet and rill erosion when overland flow events are rare?

It is recommended that soil-loss values be verified by another method in addition to the USLE, preferably direct measurement, to evaluate the accuracy of the values. Even without verification, the USLE method appears to be very useful for quantifying the degree of change in soil loss caused by different land uses or different aspects of the same use (tables 12, 15, and 16).

Puente and others (1980) report that suspended-sediment concentrations at the continuously-recording gaging station on Yellow Creek (fig. 1) range from about 0 milligrams per liter during low flows to about 1,600 milligrams per liter during high flows. Because the basin characteristics of Loblolly Branch are similar to those of Yellow Creek, a similar range of sediment concentrations probably occurs in the streamflow of Loblolly Branch. U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement Regulations (Federal Register, March 13, 1979) require that the effluent from detention ponds below disturbed areas not contain more than 70 milligrams per liter of suspended solids. Channel erosion may increase downstream from detention dams during larger flows because normal, premining flows have sediment concentrations greater than 70 milligrams per liter, and sediment concentration is one of the hydraulic characteristics of flow that affects channel stability. A complete hydraulic analysis, including flow characteristics, sediment concentrations, and properties of the bed and bank materials, would be needed to evaluate the amount of channel erosion that would occur. The DEPOSITS model developed at the University of Kentucky and discussed extensively by Haan and Barfield (1978) would be useful to determine the trap effciency of a detention pond and to predict flow and sediment variables below a planned sedimentation pond.

SUGGESTIONS FOR FUTURE STUDIES

Research, coupled with well-designed data-collection programs, is needed to provide an adequate understanding of the hydrologic effects of mining and reclamation in the Loblolly Branch basin and other humid region surface-mining areas. There also is need for research to further develop and verify techniques for evaluating the hydrology of potential mine sites and prediction of the effects of mining and reclamation on that hydrology.

Research is needed to define the exact flow routes and flow rates of water through deep, coarse-textured, soils in which part of the flow is rapid lateral flow (quickflow), and the remainder is deep percolation that supplies the aquifer at the base of the Coker Formation. Knowledge about the routes and rates of flows would determine the feasibility of attempting to reestablish that system following mining. Some related research would be to adapt and verify empirical, regression, and physical-process models for estimating peak flows and volumes of streamflow from mine and reclamation areas.

Investigations are needed in the Loblolly Branch area to determine recharge rates and movement of ground water in the Pottsville Formation under both premining and postmining conditions. This would include determination of the effect of mining on wells completed in the upper part of the Pottsville Formation that are not on the permit area. Also, the geochemistry of water moving through spoils derived from Pottsville rock needs to be studied.

The accuracy of soil-loss estimates made with the Universal Soil Loss Equation on unmined forested areas and on areas being mined and undergoing reclamation needs to be evaluated. In this investigation it was reaffirmed that 1:24,000-scale topographic maps with 20-foot contour intervals are inadequate for determining hillslope and channel gradients and lengths. Research results would determine what map scales and contour intervals would be adequate for lands with different slopes. Research also is needed to develop further and evaluate relationships for estimating sediment-delivery ratios, or otherwise accounting for sediment deposition on mining and reclamation areas.

Research is needed to evaluate the effects that stockpiling, mixing of horizons, redistribution, and mechanical treatment of soils have on the USLE K factors of soils. Soils of various textures should be investigated, and within texture groups, the effects of other factors, such as organic-matter content, degree of aggregation, bulk density, and possibly, type of clay, should be determined. If K is changed, the cause of the temporary or permanent change should be identified. The effects of natural processes and tillage operations in restoring a temporarily changed K to premining values should be quantified.

A related problem needing research is application of the U.S. Soil Conservation Service method, or any method that requires infiltration and permeability values, to evaluate peak discharge and volume of discharge from a mined basin. The effects of the following factors on infiltration and permeability rates need to be defined quantitatively: (1) Soil mixing; (2) aggregate breakdown; (3) any layering that may occur during replacement; (4) compaction (bulk density); and (5) tillage treatments to alleviate compaction.

Methods need to be developed for estimating channel erosion in small unmined forested basins, such as Loblolly Branch. This need arises, in part, from the premise that even though sediment yields from small basins are small, most sediment is derived from bed and bank erosion. Methods also are needed for estimating channel-erosion rates during mining and reclamation. Development of such methods would coordinate with studies of channel morphology and determinations of need for channel-stabilization practices on reclamation areas.

For downstream effects of mining and reclamation, research is needed to evaluate further detention-pond design models, such as the DEPOSITS model discussed in Haan and Barfield (1978). The discharge hydrograph and effluent sediment graph are two output factors of that model that are important for sediment effluent regulations and for channel stability below detention ponds.

A number of types of data for mined areas are scarce, completely lacking, or not readily accessible, making it difficult to evaluate the hydrologic effects of mining and reclamation. If data were available for mines where reclamation is progressing, hydrologic relations could be developed that would allow prediction of effects of mining on the hydrology of potential permit and adjacent areas. The following is an annotated list of some types of data for mined and unmined areas that would be useful. Most of the variables need to be monitored from the time of seeding until reclamation is accomplished and possibly longer for ground-water variables:

1. Topographic maps with scale and contour interval to allow accurate measurements of slope and channel lengths and gradients, and delineation of closed depressions for both mined and unmined areas.
2. Amounts of soil water and cover and weight of vegetation by species for various landforms and for various soil types.
3. Infiltration, quantity, and quality of streamflow and sediment yield from microwatersheds on various landforms for both mined and unmined areas.
4. Depth and porosity, organic-matter content, degree of aggregation of soils, and amount of ground cover on these microwatersheds.
5. Data for drainage basins in both mined and unmined areas including:
    a. quantity and quality of surface water, including sediment concentrations and bedload discharges;
    b. recharge rates, quantity, quality, and discharge rates of ground water, and;
    c. channel erosion and deposition.
6. Channel erosion and deposition in diversion channels and below sedimentation ponds.
7. Deposition rates in sedimentation ponds to provide reference sediment yields with which to evaluate sediment-delivery ratios.

SUMMARY

Permit applications to the Office of Surface Mining Reclamation and Enforcement for mining of near-surface coal deposits contain both mining and reclamation plans. These plans must be evaluated by regulatory authorities for compliance with permanent regulations of the Surface Mining Contol Act of 1977. Methodology for evaluation of the effects of mining and reclamation on the hydrologic system are presented for a potential permit area of 1,680 acres in the Warrior Coal Field, northwestern Alabama. This forested area is underlain by two to four thin beds of high-volatile A-bituminous coal with low to moderate ash content and low sulfur content. Much of the permit area lies within the drainage divide of Loblolly Branch basin, an unofficially named 2.48 square-mile perennial headwater tributary of Yellow Creek. Loblolly Branch is in a hilly area of the southern Appalachian Plateau that is mantled with various mixtures of largely unconsolidated sands, gravels, and clays.

The climate and premining geology, soils, vegetation, surface water, ground water, and water quality are described as a basis to evaluate changes that might occur in response to mining and reclamation. Published information about the area, data collected by the authors and colleagues in the area, and applicable published information for other humid areas are used in this description. Estimation techniques are used to develop data that are nonexistent.

Several assumptions are made about how the permit area would be mined and many assumptions involving two alternatives are made regarding reclamation. Notable assumptions are that: (1) Land use would be the same as before mining; (2) reconstructed topography would be similar to that before mining; and (3) highly permeable soils, from which subsurface flows emerge, and underlying permeable deposits, from which base flows emerge, would be reestablished.

Topographic changes are evaluated by applying a bulking factor to the overburden and interburden, by assuming that the material would be put back in the same stratigraphic position after the coal beds are removed and that it would be graded smooth and the reclaimed edges would be blended into the adjacent unmined area. Because the overburden is relatively thick with respect to the coal beds, the reconstructed surface generally would be raised 1.5 to 21 feet; in one place, a head-of-a-hollow fill would raise the surface 65 feet.

A wide-range gravimetric (filter-paper) method and pressure apparatus methods for obtaining data for defining soil-water retention curves are discussed. The filter-paper method is used in this report to evaluate soil-water relations; graphical models of soil porosity are developed for the generally coarse and highly porous soils. Vulnerability of the soils to compaction and the effects of compaction on porosity and on the soil-water flow system are demonstrated.

Data resulting from several methods for quantifying the multilayered vegetation cover of the area are given, and these data are discussed with respect to the transfer of interception and evapotranspiration values to ungaged areas. Some of these data and a vegetation and land-use map of the area were utilized in some of the methods for estimating streamflow and soil loss.

Regression and empirical methods for evaluating premining streamflow characteristics are compared. Estimates of peak discharges made with four methods are divergent, particularly for recurrence intervals of 2, 5, and 10 years; divergence is less for 25-, 50-, and 100-year discharges. It is concluded that the most accurate estimates of peak discharges for an ungaged basin would be obtained by relating some discharge measurements on the ungaged stream to concurrent discharges at a gaging station in the area that has a period of record for 3 to 5 years or more.

Methods that account for the effects of geology, soils, and vegetation on streamflow produce more reliable estimates of discharges; these methods are necessary to evaluate potential changes in streamflow resulting from mining and reclamation. The U.S. Soil Conservation Service method accounts for effects of soil and vegetation conditions on streamflow; it was used to make estimates of premining streamflow volumes and postmining flow volumes and peak discharges. A further justification for using the U.S. Soil Conservation Service method is that it apparently gave the closest estimates to actual premining discharges; however, further research is needed to verify the procedure and validity of adjusting basin lag values in the U.S. Soil Conservation Service method (as in this report).

The Universal Soil Loss Equation (USLE) is used to estimate soil loss for: (1) Premining forested conditions; (2) various phases during mining and early reclamation; (3) the third year of reclamation with perennial grass cover; and (4) the twentieth year of reclamation with a closed stand of loblolly pine. Published relationships for predicting sediment-delivery ratios are used to estimate sediment yield from small basins under these four conditions.

Soil losses and sediment yields are low for premining conditions, are large during mining, decrease sharply during early reclamation phases, and are very low after 20 years of reclamation. There would be more than a 4-fold decrease in sediment yield between the third and twentieth years of reclamation. Sediment yield is about 1.6 times greater before mining from a small subbasin with various forest covers resulting from wood utilization and reforestation practices than the yield would be from the basin with uniform loblolly pine cover 20 years after mining. A premining estimate of sediment yield for Loblolly Branch basin, using the USLE and a sediment-discharge ratio, is about 2.5 times larger than an estimate made with the flow duration-sediment rating curve method. There is scant evidence of erosion on this well-forested basin, so the estimate made with the USLE method probably is larger than the actual sediment yield. The estimates made with the sediment-rating curve may be smaller than the actual sediment yield because the bedload portion is not considered with that method.

Several areas for research were identified during this study:

1. Quantification of the proportion of shallow ground water that moves through the soils to channels, and the remaining portion that moves through the underlying Coker Formation to channels, would be helpful in reclamation planning for a mine site with similar conditions.
2. More knowledge is needed about the premining and postmining ground-water hydrology and geochemistry of the coal-bearing Pottsville Formation.
3. A method for predicting channel-erosion rates before and after mining would help in identifying sediment-source areas.
4. A field evaluation of bulk density, porosity, and erodibility of spoils and soils on reclamation areas would improve predictions of postmining soil-water relations, streamflow characteristics, and sediment yield.

Data are lacking or are insufficient for a number of aspects of surface mining in the southern Appalachians. Some of the more pressing data needs for unmined, active mine, and reclamation areas are: (1) Topographic maps of adequate scale and contour interval to permit accurate measurements of hillslope and channel lengths and gradients; (2) data on streamflow, quality of surface water and discharge, and quality of ground water; (3) data on hillslope and channel-erosion rates and deposition in detention ponds; and (4) sediment concentration and bedload-discharge data.

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