UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

METHODOLOGY FOR HYDROLOGIC EVALUATION OF A POTENTIAL SURFACE MINE: THE TSOSIE SWALE BASIN, SAN JUAN COUNTY, NEW MEXICO

By L. M. Shown, D. G. Frickel, R. F. Hadley, and R. F. Miller

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METRIC CONVERSION FACTORS

U.S. customary	Multiply by	International system
acre	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
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
pounds per cubic foot	1.602×10^{-2}	grams per cubic centimeter
pounds per square inch	7.030×10^{1}	grams per square centimeter
square feet	9.290×10^{-2}	square meters
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

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ABSTRACT

Permit applications made 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 the permanent regulations of the Surface Mining Control and Reclamation Act of 1977. Methodologies for assessment of the effects of mining and reclamation on the hydrologic system are presented for a potential permit area of 640 acres in the Tsosie Swale basin, a small tributary of Escavada Wash in northwestern New Mexico. Escavada Wash is the principal tributary of the upper Chaco River, which is the stream that drains much of the San Juan structural basin. Tsosie Swale represents an arid climatic area and a low relief landscape with a sandy mantle that is moderately vegetated with shrubs and grasses.

Premining soils, vegetation, geology, and hydrology of Tsosie Swale are described as a basis for evaluation of changes that may occur. Soil-moisture-vegetation relations show that the most grass cover occurs where 1 to 2 feet of sandy surface soils are underlain by fine-textured, less-permeable layers that perch soil moisture.

Estimates are made of premining and postmining peak discharges and runoff volumes by the empirical Soil Conservation Service (SCS) method and by a basin-characteristic model. The SCS method was found to be superior because it considers infiltration rates. Postmining peak discharge estimates are 30 to 70 percent of premining estimates, and runoff volumes are 30 to 70 percent of premining values.

Methods are demonstrated for estimating soil loss by use of the Universal Soil Loss Equation (USLE) and by simulation of an intense rainstorm on a microwatershed. Estimates of sediment yield from the basin for premining conditions are made using reservoir-sedimentation surveys and a watershed-factor rating method. USLE soil-loss estimates and a sediment delivery ratio is used to estimate postmining sediment yield. Estimated postmining sediment yield is about 50 percent of the premining estimate.

Changes in the topography resulting from removal of coalbeds and expansion of the overburden are shown to vary from a lowering of part of the permit area as much as 20 feet, to raising of other parts as much as 20 feet. The primary factors responsible for the reductions in streamflow and sediment yield are the assumptions that the minor areas now consisting of badlands and

alluvial plains, from which runoff is high, would be eliminated, and the whole area would be covered with about 2 feet of sandy soil.

INTRODUCTION

With increased emphasis on coal as an energy source for the Nation, it is anticipated that leasing and production of Federal coal will rapidly accelerate. There are many potential coal mining areas in the western United States that have been leased or will be leased in the near future under the new Federal coal management program established in 1979. When permit applications are made to the Office of Surface Mining to mine these near-surface coal deposits by surface-mining methods, mining and reclamation plans must be evaluated for compliance with permanent regulations of the Surface Mining Control and Reclamation Act of 1977 (Federal Register, Mar. 13, 1979). This report considers methodologies for assessing the effects of mining and reclamation on the hydrologic system of the mined area, and adjacent area that may be affected by the mining operation.

The coal fields in western United States occur in a wide range of physical environments from the semiarid Great Plains of Montana and North Dakota in the north to arid Colorado Plateau sites of New Mexico in the Four Corners region. One such arid site in northwestern New Mexico was selected as the subject of this report. (See location map, fig. 1.)

This report is one of a series of four reports that consider methods for assessing hydrology of potential surface mine sites. One report (Hadley and others, 1981) addresses the East Trail Creek site in semiarid southeastern Montana, where winter and spring precipitation dominates. Another report (Frickel and others, 1981) addresses the Red Rim site in south-central Wyoming, where winter precipitation only dominates. The third report (Shown and others, 1981) addresses the Loblolly Branch basin site in the humid southern Appalachian region of Alabama.

Objectives and scope of report

The primary objective of this report is to provide regulatory authorities with examples of methodologies available for adequate assessment of the effects on the hydrologic system at a potential mine site and adjacent areas. Regulatory authorities need this information in their review process to determine the adequacy of permit applications for mining and reclamation.

The hydrologic data base at specific potential mine sites will vary from almost no data to very detailed, depending on station distribution in the hydrologic network, and past demand in the area for basic data and topical investigations. Methodologies used to estimate the effects of land disturbance on hydrology must be tailored to fit available data. A second objective of this report is to describe various methods of hydrologic assessment

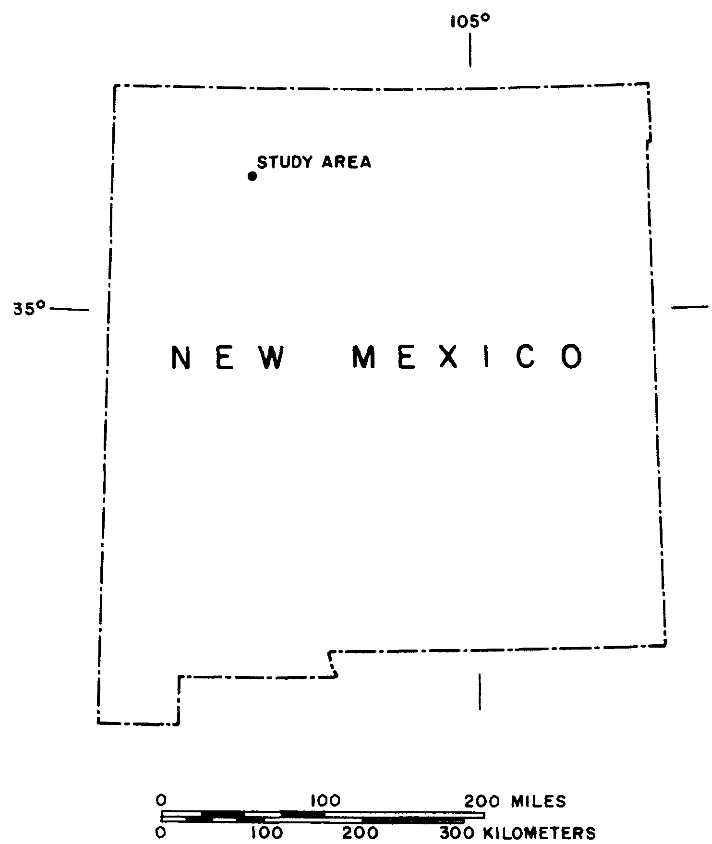


Figure 1.--Index map of New Mexico showing location of study area.

and to define their limitations; some consistency can then be attained in applying these methods in the permit review process.

In some cases, the data base and knowledge of hydrologic processes do not exist to make an adequate assessment of changes that will occur as a result of mining and reclamation. The third objective of this report is to consider the need for hydrologic research in potential mine areas, and areas that are presently being mined and reclaimed. Basic data and research needs are identified in this report, which may refine the predictive capability of hydrologists who are responsible for evaluating consequences of mining.

DESCRIPTION OF THE STUDY AREA

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, Mar. 13, 1979, p. 15320). The permit area is defined as the area where surface coal mining and reclamation will 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, Mar. 13, 1979, p. 15317). The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is geodetic datum derived from a general adjustment of the first order level notes of both the United States and Canada, formerly called "mean sea level."

Location and name

The permit area that was selected for use as a demonstration of hydrologic assessment methods in this report is sec. 18, T. 22 N., R. 10 W., San Juan County, New Mexico, which is 3 miles north of the northernmost boundary of Chaco Canyon National Monument. The study area includes the permit area and associated adjacent areas that comprise a small drainage basin 1.28 square miles in size (fig. 2). The basin in the headwaters is part of a tributary to Escavada Wash; their confluence is about 2 miles downstream from the lower end of the basin. Escavada Wash is the principal tributary of the upper Chaco River, the main stream of the region.

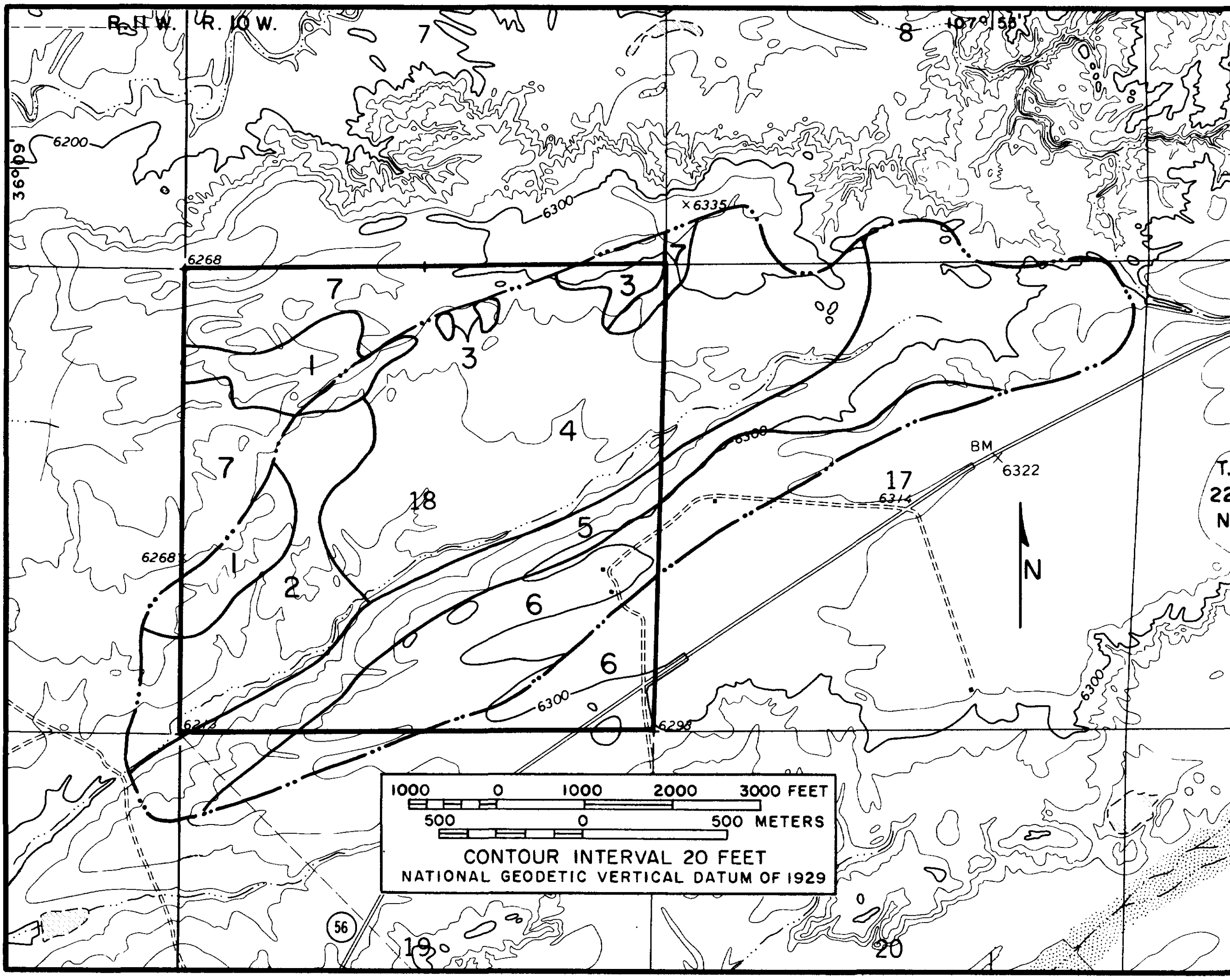
The stream draining the basin is unnamed on the U.S. Geological Survey Pueblo Bonito 7½-minute quadrangle map, but it has been informally named Tsosie Swale (Hejl, Ong, and Dewey, 1979). That is the name that will be used in this report. The basin is located on a mesa between Ah-shi-sle-pah Wash to the north, and the lower end of Kimbeto Wash to the south.

Topography

The basin is moderately dissected and has low relief of about 100 feet between the headwater divide and mouth of the basin. The mesa on which the basin lies is characterized by several landforms including hillslopes, dunes and badlands (fig. 2). The drainage pattern is moderately incised and discontinuous, because of wind-deposited sandy materials in the drainageways.

Geology

The study area is located in the San Juan Basin, an asymmetrical structural and topographic depression roughly 125 miles long north to south, and 100 miles wide east to west, in northwestern New Mexico and southwestern



Base from U.S. Geological
Survey Pueblo Bonito NW
1:24,000, 1966

EXPLANATION

Area No.	Landform
1	Badlands
2	Dune-mantled hillslope
3	Blowout
4	Dune and interdune overlying alluvial plains
5	Hillslope with sandy mantle
6	Mesa with sandy mantle
7	Longitudinal dunes
———	Permit area boundary
—··—	Drainage divide

Figure 2.--Landform map of Tsosie Swale basin and permit area.

Colorado. In the southwestern quadrant of the central basin, where the study area is situated, the unfaulted sedimentary formations dip gently to the northwest at angles less than 2 degrees (Baltz, 1967).

A geologic map of the permit area showing surficial materials, bedrock exposures, and coal zones, is shown in figure 3; it was derived from mapping of the Pueblo Bonito NW quadrangle done by Schneider and others (1979). Table 1 contains the explanation for this map; it is a modification abstracted from Schneider and others (1979).

Much of the area is mantled with Quaternary (pre-Pinedale) sandy alluvium (Qgs, fig. 3) containing a few gravel particles less than 0.5 inch in size. Geologic logs of cores taken by the U.S. Water and Power Resources Service (1980) show this alluvium to be 9 feet thick at drill hole DH-1K, and 2 feet thick at DH-2K on the permit area (fig. 3). Southwest winds have worked the surface of these deposits everywhere and, in the northwest corner of the permit area, stabilized longitudinal dunes have been formed by the winds (fig. 2). Eolian sand deposits (Qes, fig. 3) mantle most of the remaining part of the area including portions mapped as exposures of Cretaceous sedimentary rocks (Kk and Kf, fig. 3). These deposits occur as stabilized, low, broad-crested dunes of variable thickness. The sand was derived from sandy alluvium (Qgs) and from loosely consolidated bedrock.

The Kirkland Shale is the uppermost sedimentary formation exposed on the permit area (Kk, fig. 3). Consisting of silty and sandy mudstone with some carbonaceous laminae, the formation is only about 17 feet thick at core hole DH-1K, but is about 88 feet thick at DH-2K (U.S. Water and Power Resources Service, 1980).

The Fruitland Formation underlies the Kirkland Shale with the contact arbitrarily placed at the top of the highest coal or carbonaceous bed. The formation outcrops in the southwest part of the permit area, occurring primarily as badlands (figs. 2 and 3). Reported to be 152 feet thick at DH-1K and 115 feet thick at DH-2K, the formation consists of interbedded sandstone, mudstone, siltstone, and coal (Schneider and others, 1979). Individual beds thicken, thin, and pinch out, often within a few hundred feet. The coal beds are the most continuous rock units and can be traced for several miles in places.

The top of a massive sandstone bed below the lowermost Fruitland coal bed arbitrarily marks the contact between the Fruitland Formation and the underlying Pictured Cliffs Sandstone. Core hole DH-1K penetrated about 140 feet and DH-2K about 13 feet of the upper part of the Pictured Cliffs Sandstone, which consisted predominately of fine- to medium-grained, massive-bedded, silty sandstone.

Coal resources

The Fruitland Formation is the main surface-mineable, coal-bearing stratum on the permit area. According to logs obtained by the U.S. Water and Power Resources Service (1980), there are five coal beds greater than 2.5 feet thick at core hole DH-1K (fig. 3). The thickest bed is 9.4 feet thick; the total thickness of coal is 26 feet and the bottom of the lowest coal is at 125.5-foot depth. Only four beds of coal exist at core hole DH-2K (fig. 3). Three beds are greater than 10 feet thick, and the thickest is 14.8 feet. Total thickness of coals greater than 2.5 feet thick is 40.2 feet and the bottom of the lowest coal is at a depth of 206.4 feet.

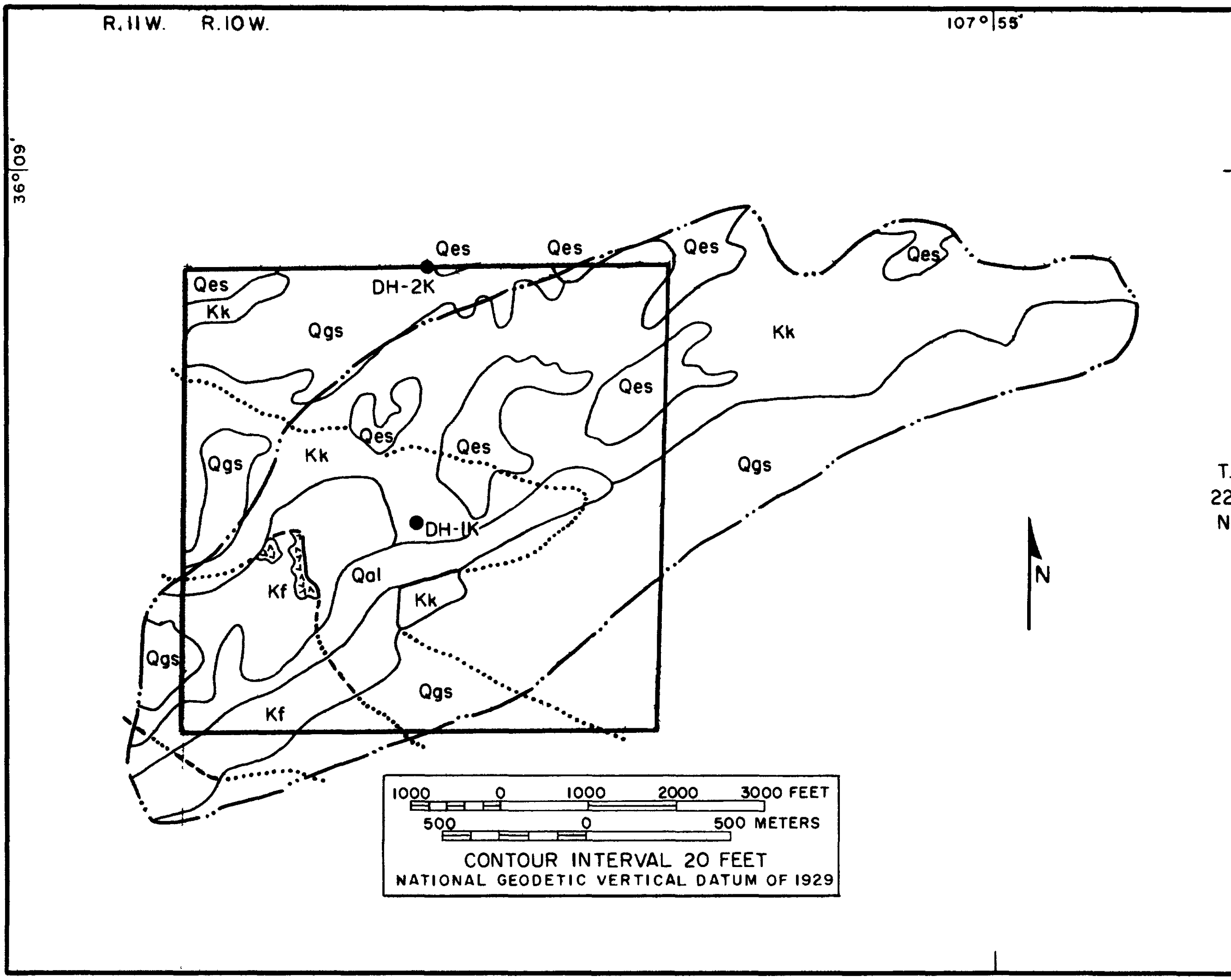
The U.S. Geological Survey (1980) estimated that total measured and indicated coal resources were 28,484,000 tons for the permit area. The estimate includes all coal beds greater than 2.5 feet thick that occur within 200 feet of the surface.

Soils and vegetation

Vegetation of the Tsosie Swale basin (fig. 4) is a part of the southernmost extent of typical northern desert shrubs such as big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*), and rubber rabbitbrush (*Chrysothamnus nauseosus*). Galleta (*Hilaria jamesii*) and ring muhly (*Muhlenbergia torreyi*), also abundant, are typical only of the southern part of northern desert shrublands. Other species present in significant amounts include alkali sacaton (*Sporobolus airoides*), which is the dominant species on dunes, Greenes rabbitbrush (*Chrysothamnus greenei*), and blue grama (*Bouteloua gracilis*).

Vegetation cover has been measured by U.S. Geological Survey (1980) at representative sites in the general vicinity of the study area; the validity of transferring the measurements to the study area was verified by using aerial photographs. Measurements were made of percentage areal cover of vegetation, mulch, rock, and bare soil by the first-contact, point-quadrant method (Levy and Madden, 1933). A frame containing 10 vertical pins was placed at three-step intervals requiring about 530 feet to obtain 600 pin contacts in each vegetative type.

Vegetation and mulch cover in this area is sparse to moderate because of low annual precipitation, spring winds, summer heat, and many years of excessive grazing. Cover consisting of vegetation, mulch, and rock ranged from a low of 12 percent on the barren badlands, where there was a sparse cover of shadscale and alkali sacaton, to a high of 45 percent for the big sagebrush-galleta type. Cover on the alkali sacaton and alkali sacaton-greasewood types was 32 and 33 percent respectively, and cover on the Greenes rabbitbrush-blue grama type was 40 percent. Even though cover is somewhat lacking, enough exists to stabilize the sandy soils, so wind and water erosion is only slight to moderate.



Base from U.S. Geological Survey Pueblo Bonito NW 1:24,000, 1966

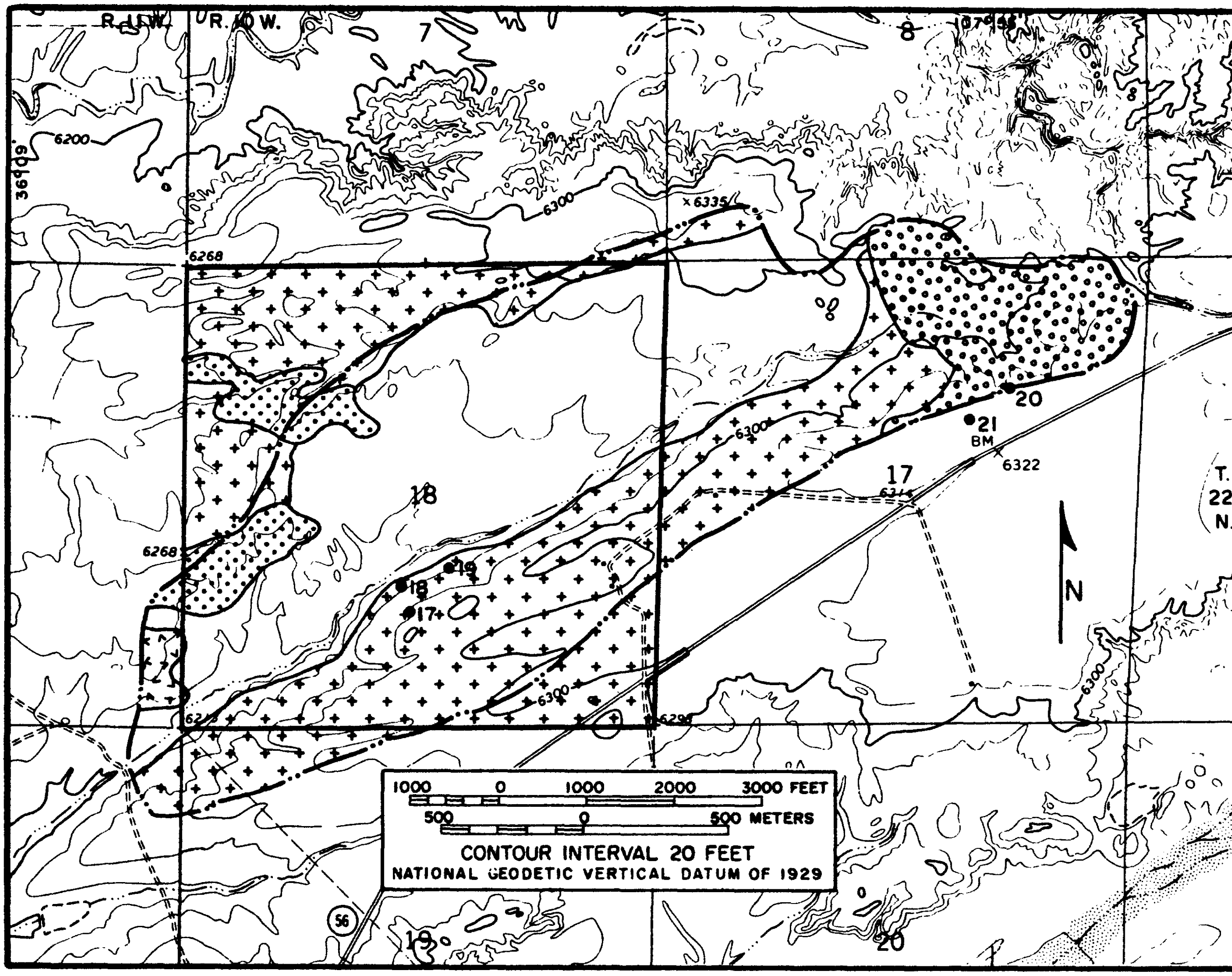
Geology from G. B. Schneider and others (1979)

Figure 3.--Geologic map of the permit area and Tsosie Swale basin, showing bedrock exposures, surficial materials, and coal zones.

Table 1.--*Explanation for geologic map of Tsosie Swale basin and permit area*

[Abstracted and slightly modified from Schneider and others, 1979]

QUATERNARY
EOLIAN SAND--Fine to coarse sand in cross-stratified sheets and dunes; sand was derived from alluvial deposits and from loosely consolidated bedrock.
ALLUVIUM--Sand, silt and clay.
GRAVELLY SAND--Alluvial deposits which are pedimentlike, occurring as sheets sloping toward Chaco River.
CRETACEOUS
KIRTLAND SHALE--Silty and sandy mudstone and some swelling clay; forms badlands showing grotesque erosional forms.
FRUITLAND FORMATION--Highly variable sequence of intercalated sandstone, siltstone, mudstone, and coal; forms badland topography.
GEOLOGIC CONTACT.
COAL ZONE--Solid line is contact between Kf-Kk drawn on uppermost coal, dotted where zone is concealed, dashed where inferred.
PERMIT AREA BOUNDARY
DRAINAGE DIVIDE
CLINKER--Rock fused and baked by coal burning on surface and underground.
CORE HOLE drilled for the Bureau of Land Management by Water and Power Resources Service.



Base from U.S. Geological Survey Pueblo Bonito NW 1:24,000, 1966

Vegetation from U.S. Geological Survey (1980)

EXPLANATION

BARREN

GREENES RABBITBRUSH — BLUE GRAMA

ALKALI SACATON

ALKALI SACATON — GREASEWOOD and ALKALI SACATON — RUBBER RABBITBRUSH

BIG SAGEBRUSH — GALLETA

PERMIT AREA BOUNDARY

DRAINAGE DIVIDE

●18 SOIL SAMPLING SITES

Figure 4.--Vegetation map of Tsosie Swale basin and permit area — 1976.

Soils associated with Greenes rabbitbrush-blue grama and big sagebrush-galleta types (fig. 4) have been identified and described by the Soil Conservation Service (SCS) (written communication, 1978) as Doak-Nageezi association. The Doak series underlies level parts of the mesas (fig. 4) and is associated with Greenes rabbitbrush-blue grama type. Doak soils typically have a brown loamy, fine-sand surface layer about 6 inches thick, underlain by clay loam subsoil about 32 inches thick. There is additional loamy soil to a depth of 120 inches.

Nageezi soils are found on gently sloping areas of mesas, and are loamy soils about 18 inches thick, underlain by loamy to fine sandy loam soil material to a depth of 60 inches or more.

The soil of the big sagebrush-galleta type (fig. 4) and of the longitudinal dunes area (fig. 2) in the northwest part of the permit area is apparently Shiprock series, which is an inclusion typically found with Doak-Nageezi association. Shiprock soils have a loamy sand surface layer about 12 inches thick, which is underlain by a sandy loam layer about 24 inches thick. Additional sandy soil material occurs to a depth of 120 inches.

The Huerfano-Tasaya-Uffens complex is saline-sodic soil associated with alkali-sacaton type (fig. 4). Huerfano soil is a shallow, fine-textured, silty clay loam to clay occurring on alluvial plains. It underlies low dunes which characterize most of the alkali sacaton type. Tasaya and Uffens soils comprise the dunes, which are stabilized by alkali sacaton. These soils have fine sandy loam surface layers about 4 inches thick overlying clay loam subsoils which are 20 to 40 inches thick. The soil associated with the greasewood-alkali sacaton type (fig. 4) is probably a deep Tasaya soil.

High erosion rates prevent significant soil development in the badlands. Shallow, fine-textured, saline-sodic soil materials found in the badlands are the result of weathering of siltstone, mudstone, and bentonite.

Climatological information

Climatological information that may be requested by regulatory authorities in a permit application is listed in subchapter G, part 779.18 of the Surface Coal Mining and Reclamation Regulations (Federal Register, Mar. 13, 1979). This includes: (1) average seasonal precipitation; (2) average direction and velocity of prevailing winds; and (3) seasonal temperature ranges. In addition, it would be useful to have data for precipitation amounts of storms of selected recurrence intervals and durations to assist in determining runoff and erosion rates; data on snowfall depths and water content; and data on length of the growing season or frost-free period, to assess the reclamation potential at the site.

The Tsosie Swale basin, in which the permit area is located, is shielded from shallow intrusions of extremely cold air in winter by distant mountains to the north and west. The mountains also block the study area from receiving moist Pacific air flows. The study area is also at the extreme northwestern edge of continental penetration by moist air from the Gulf of Mexico. These factors are important in the prevailing arid climate at the study area.

The nearest weather station with a long-term record is located at Chaco Canyon National Monument, about 8.5 miles southeast of the study area, at an elevation of 6,175 feet. This station is used to characterize the climate of the study area. All climatological data from the Chaco Canyon weather station are assumed to be directly applicable to the study area, which is at an altitude of about 6,300 feet.

Average annual precipitation at the Tsosie Swale study area is about 8.8 inches, with the wettest months being July through October when half of the annual precipitation occurs. Late summer and early fall precipitation generally occurs as localized, often intense, thunderstorms which can cause flash floods and severe erosion. Monthly precipitation, in inches, for the study area is as follows:

January	0.39	July	1.19
February	.52	August	1.41
March	.60	September	1.15
April	.40	October	1.04
May	.60	November	.47
June	.38	December	.61

For purposes of reclamation, definition of the growing season is the logical way to divide the year; the growing season is generally considered to be the period when temperatures favor plant growth (Toy and Munson, 1978). In the Tsosie Swale basin, the mean length of growing season is about 106 days from June 5 to September 19, or the interval between the last spring frost and the first fall frost. Length of growing season is influenced by topography, exposure, and altitude, but the mean value is a reasonable index in evaluating reclamation potential. Based on data from the Chaco Canyon station, the Tsosie Swale basin has an average annual temperature of 49.7°F. Average monthly temperatures, in degrees Fahrenheit, are as follows:

January	27.5	July	73.1
February	33.5	August	70.8
March	39.5	September	62.8
April	48.0	October	51.3
May	57.0	November	37.6
June	66.5	December	29.0

Intensity of precipitation is more important to individual flood peaks and volumes and erosion rates than total precipitation amounts for individual storms. Therefore, estimated precipitation amounts for a variety of storm durations and recurrence intervals have been tabulated in table 2. The relation between storm intensity and erosion is discussed elsewhere in the report.

Table 2.--*Estimated precipitation amounts, in inches, at a point for selected storm recurrence intervals and durations for Tsosie Swale, New Mexico*[1/]

Storm duration	Storm recurrence interval (years)					
	2	5	10	25	50	100
30 minutes	0.5	0.7	0.9	1.0	1.2	1.4
1 hour	.6	.9	1.1	1.3	1.5	1.7
3 hours	.7	1.0	1.2	1.5	1.7	1.9
6 hours	.8	1.1	1.3	1.6	1.8	2.0
12 hours	.9	1.2	1.4	1.7	1.9	2.2
24 hours	1.0	1.4	1.6	2.0	2.2	2.4

[1/] From Miller and others (1976).

PREMINING HYDROLOGY OF THE STUDY AREA

Assessment of hydrologic processes in an arid environment must consider the relation of precipitation occurring as rain and snow and losses from evaporation and transpiration. Most sites are water-deficient, with potential water losses frequently exceeding precipitation by 40 to 50 inches annually. For example, it is common for basins that receive 8 to 10 inches of annual precipitation to yield less than 0.25 inches as streamflow, and even less as recharge to ground-water aquifers. An important exception is apparent from a 2-year streamflow record in the adjoining Ah-shi-sle-pah Wash basin. About 45 percent of the 8.2-square mile area above the gage consists of badlands that have caused the annual streamflow from the basin to exceed 2 inches (Hejl, Ong, and Dewey, 1979).

Most of the annual precipitation falling on a potential mine site is stored in the upper 2 to 3 feet of the soil mantle and used by vegetation, or returned to the atmosphere by evaporation from bare soil surfaces. Therefore, improving the efficiency of soil-moisture use is important in reclaiming disturbed areas. Improved efficiency can be accomplished by increasing the amount of plant cover and reducing erosion.

Hydrology of the permit area

Water relations in soils

Moisture regimens in soils, which function as reservoirs for water used by native vegetation, are a product of the arid climate characteristic of the Tsosie Swale study area. Approximately one-fourth of the moisture arrives as snow during the period when vegetation is dormant. Snow is subject to redistribution by winds; hence, the quantity that falls on a site is not necessarily available for infiltration and storage when the snow melts. Moisture stored in soils as a result of snowmelt is supplemented by water derived from summer and early fall rains. Maximum runoff from the surface probably occurs under conditions where an intense rainstorm occurs coincident with periods of maximum moisture storage in soils. Void space and quantity of surface available to store water are the two factors that control moisture relations in soils. These two factors are, therefore, the basis for the concepts, analyses, and interpretations presented here.

Retention force is determined from the moisture content of standard filter papers at equilibrium with moisture in samples augered from consecutive depth increments in soil profiles. All the soil obtained from each auger increment is retained, so volume weight (VW), or weight per unit volume, which is bulk density, can be determined. Amounts of void space influence infiltration and storage of water. Void moisture capacity (VMC) is a measure of the quantity of water contained when all voids in the soil are filled. Void moisture capacity values, in percent of dry weight, are computed, assuming that soil particles have a density of 165.44 pounds per cubic foot and using 62.4 pounds per cubic foot as the density of water. The equation used is:

$$\mathrm{VMC} = \left(\frac{62.4}{\mathrm{VW}} - 0.377\right) 100$$

This relationship is presented graphically in figure 5. The influence of differences in amounts of adsorptive surface in soils on quantities of water that can be retained, over the moisture range from saturation to oven dry were determined using the modeling technique proposed by McQueen and Miller (1974). The soil, for which a graphic model is presented in figure 6, has one-half the adsorptive surface per unit of weight compared to the filter paper. Amounts of water adsorbed as multimolecular films to external surfaces of soil particles, are consistently one-half the quantities adsorbed to surfaces of fibers in the paper.

A similar graphic model of moisture content-retention force relationships can be made for any soil sample, if moisture content and retention-force data are acquired under conditions where only adsorbed water is present. The line representing quantities of water adsorbed is extended down from $10^{4.40}$ pounds per square inch on the vertical axis through a point representing the moisture content of the soil and the retention force determined from the filter paper at equilibrium with the soil. Soils that contain expanding lattice clays, unlike the filter paper, can adsorb water within their structure. There is evidence (Miller and McQueen, 1972) that this occurs under conditions where retention forces exceed $10^{3.15}$ pounds per square inch.

Water adsorbed as multimolecular films tends to drain down from the adsorption-moisture capacity (AMC) level, where 16 molecular layers are adsorbed and the retention force is $10^{-1.85}$ or 0.01422 pounds per square inch. Drainage continues to the moisture-retention capability (MRC) level where

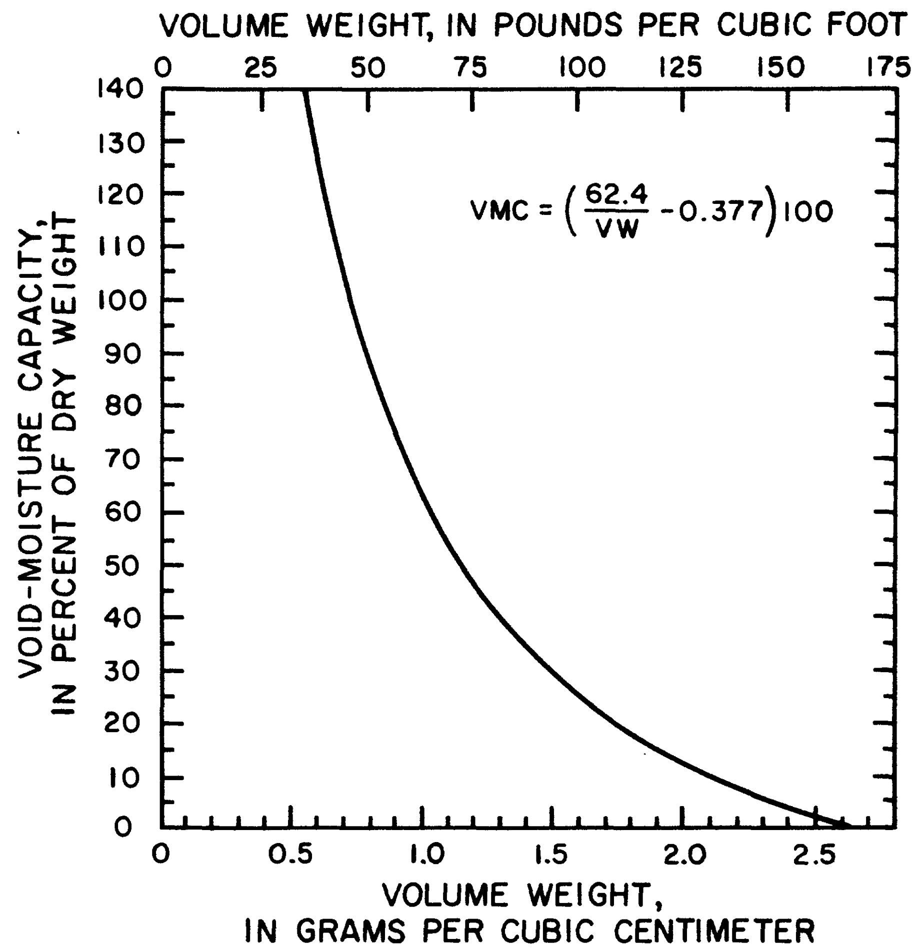


Figure 5.—Relationship used to determine void-moisture capacity (VMC) of soils from volume weight (VW).

10 molecular layers remain adsorbed and the retention force is 3.16 or $10^{.50}$ pounds per square inch. The retention force increases from $10^{-1.85}$ to $10^{-1.46}$; gradually to $10^{-1.04}$, $10^{-.28}$; and finally to 3.16 pounds per square inch, as drainage slows proportionately. The final large increase results in drainage becoming insignificant at the MRC level where the retention force is $10^{.50}$ or 3.16 pounds per square inch. During this process, the retention force increases 2.46 times as each molecular layer of water is desorbed. The logarithm of 2.46 is 0.391; therefore, the exponent of the retention force increases by 0.391 as each molecular layer is desorbed.

Molecular dimensions of void spaces in a given depth increment of soil can be used to approximate infiltration rates. The size of voids

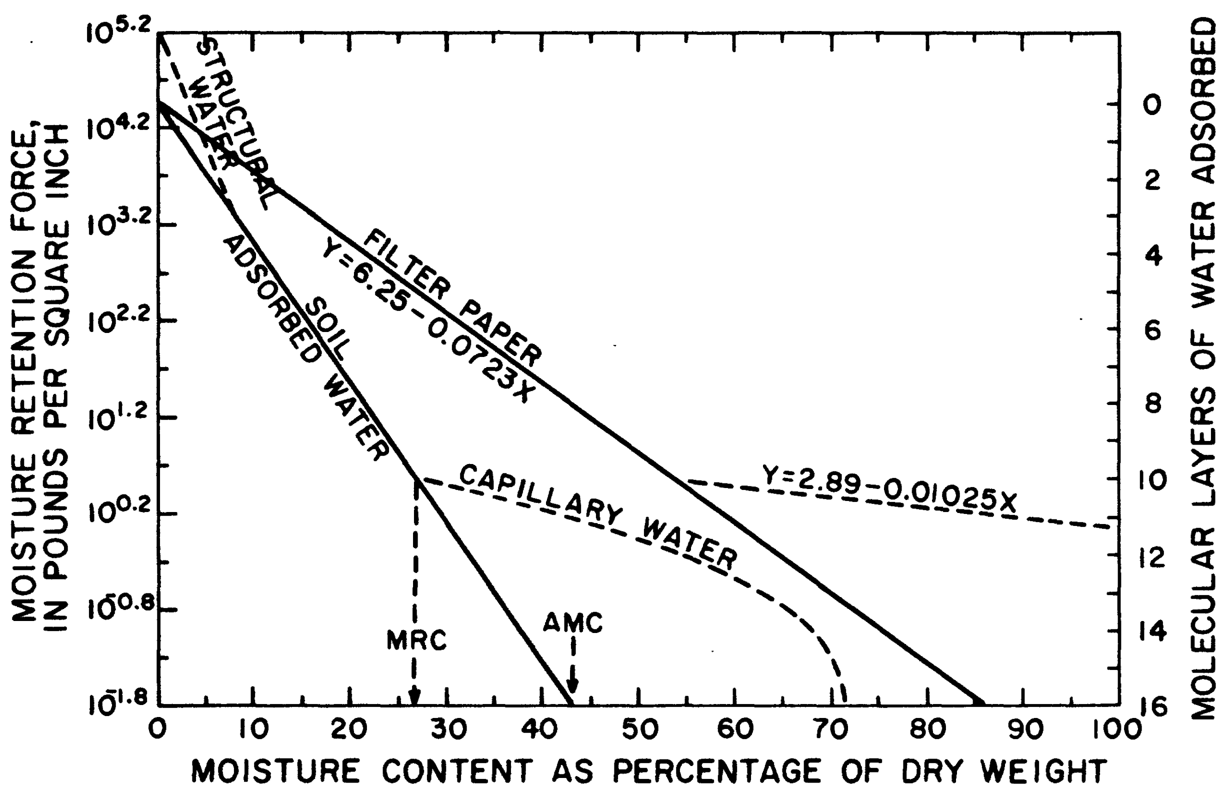


Figure 6.--Calibration relationships (modified from McQueen and Miller, 1968, 1974) for determining moisture-retention force from moisture content of standard filter papers at equilibrium with moisture in samples of soil. Lower lines are the moisture-retention relationships for a soil that has one-half as much adsorbtive surface per unit weight as filter paper. MRC is moisture-retention capability, and AMC is adsorption-moisture capacity.

available for infiltration and storage of water can be approximated in terms of molecular dimensions of water. This is done by dividing VMC values by MRC values and multiplying by 10, because 10 molecular layers are adsorbed at the MRC level. Infiltration data at sites where a large rainfall-simulating infiltrometer (Lusby and Toy, 1976) was used were made available by Lusby (written communication, 1976) for comparison with void-dimension data. The data plot has a linear relationship (fig. 7) that permits estimation of rates of infiltration within plus or minus 0.35 inches per hour. Because void size and adsorptive surface are controlling factors, the relationship is applicable to all soils in arid and semiarid areas.

Quantities of water that can be present in soils between the limits provided by VMC and minimum levels of storage (MS) are divided into adsorbed and drainable portions (figs. 12 through 14, Appendix I). Adsorbed moisture

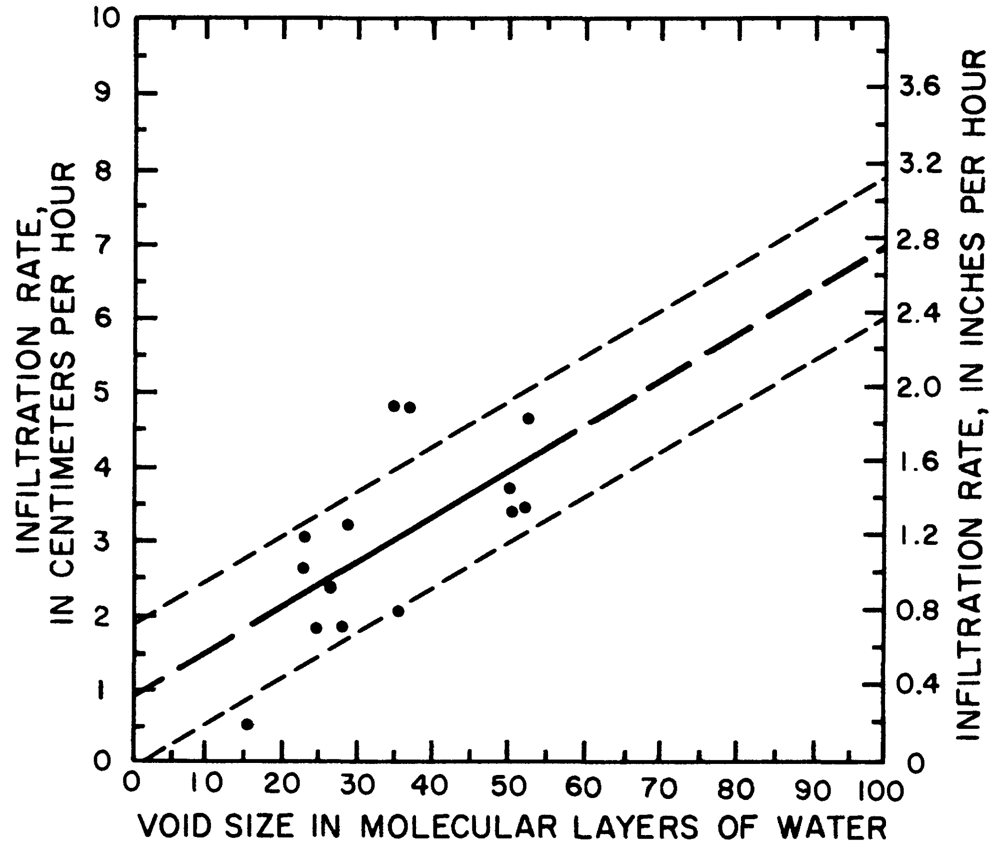


Figure 7.--Relationships between size of voids and rate at which water infiltrates into soils (from Miller and McQueen, 1978).

is computed as the difference between MRC and MS values; drainable moisture is computed as the difference between VMC and MRC values; both are computed to the depth where drainable moisture is capable of occurring. Moisture contents initially computed as percent of the dry weight of soil are converted to numbers indicating depths of adsorbed or drainable water; this is done by multiplying percent moisture by the average VW of the depth increment involved. The product of this multiplication is then multiplied by the length of the soil increment; the result is the amount of water, expressed as depth of water.

Study sites

Soils were sampled that are associated with plant communities occupying the various habitats occurring naturally in the area. Locations of all except one of the sampling sites are shown in figure 4. All the measurements required to define moisture relations were obtained by using the method of McQueen and Miller (1968).

Habitats ranging from badlands to mesa tops were sampled in the Tsosie Swale study area. Sites are grouped on the basis of gross similarities in geomorphic position, so soil variables influencing use of water by vegetation could be determined. This information should be useful for determining if factors essential to reproducing the habitat can be reestablished, when soil materials are repositioned after coal has been removed.

Percentages of various types of ground cover (vegetation, mulch, and bare soil) occurring naturally in each habitat were determined from the first contact made with a pin at each pace along a transect 100 paces long in the immediate vicinity of each soil sampling site. Data for cover and soil-water relationships are summarized in Appendix I.

Dunes.--No dune areas were sampled on the study area, but information obtained by the U.S. Geological Survey (1980) at sites within one mile of Tsosie Swale is applicable. The dune areas shown on figure 2 are among the most productive, in terms of cover and forage, on the study area. This is the result of favorable soil-water relations caused by drainage constrictions at depths of 27 to 48 inches. Most of the water held in the sandy soil above the constrictions is readily available to the grasses and shrubs that stabilize the dunes. The constrictions in some of the soils result from a shift from sandy surface soils to loamy soils at depth. In other soils the constrictions are caused by clayey alluvium underlying the dunes.

Mesa.--The soils on the mesas have adequate porosity in the surface layer for moderate to rapid infiltration. The mesa, in general, is about equally as productive as the dunes, and the most productive site sampled on the permit area (site 20, fig. 4) was on the mesa. That soil has a severe reduction in porosity at 30 inches that causes "perching" of soil water.

Hillslope.--Soils sampled on hillslopes have variable amounts of porosity depending on whether they are developed on bedrock or alluvium. The most productive hillslope soil (site 18, fig. 4) is a highly porous and well-drained alluvial soil and most of the cover is grasses (see appendix table 11 and fig. 13).

Porosity is severely limited in a fine-textured alluvial soil (site 19, appendix fig. 13), and the porosity is near the surface, so much of the water held there is lost by evaporation. Even though this soil is only sparsely covered with broadscale saltbush, erosion potential is not great because of a 23-percent cover of rock fragments. Porosity also is limited in the hillslope soil developed on bedrock (site 17, fig. 4), but more of the water that enters this soil is available to vegetation, so both grasses and shrubs occur on that site.

Badlands.--A prominent feature of the badlands type (fig. 2) are bench-forming bentonite beds. Site 12 (appendix fig. 14), about one-half mile east of Tsosie Swale basin, is on a bentonite bed typical of the permit area. The soil at site 12 consists of finely weathered bentonite and the soil is devoid of porosity below about 10 inches. This is in contrast to a nearby site in a blowout that also has a very fine-textured soil that is mantled with sandy loam, but has some porosity to a depth of 3 feet. That soil, therefore, has three times more porosity (3.0 vs. 8.7 inches) and has a 37-percent cover of grasses and shrubs. This demonstrates the beneficial effect of a layer of coarse soil over fine material.

Surface water

Runoff volume and peak discharge measurements are usually not available at potential mine sites, and estimation techniques must be used for the planning and design of required erosion and water control structures. Several techniques are available for estimating streamflow characteristics. Each has its advantages and disadvantages, which must be considered with availability of data in the selection of the method to use at a particular site.

Estimation methods

Deterministic physical-process models are based on physical laws, and require measurements of initial and boundary conditions with other input data. If all conditions are adequately described, these models can provide highly accurate answers. However, because of the complexity of the processes being modeled, many simplifications and approximations must usually 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 the length of streamflow records and predicting the effects of changes imposed on the watershed. The U.S. Geological Survey is presently developing a precipitation-runoff modeling system for use on energy lands (Van Haveren and Leavesley, 1979).

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 most often used because they are most 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 is a measure of how well the selected watershed characteristics describe streamflow characteristics; it is usually expressed as the standard error of estimate. Model accuracy depends on accuracy of input data sampling error, as well as model error, or form of the regression equation. In using a regression model at an ungaged site, it is important that the data base used to develop the model 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 all the necessary information. However, because they are usually developed with data from relatively undisturbed basins, they should not be used to estimate streamflow characteristics for postmining conditions.

A special case of the parametric model that may have application to surface-mining areas, relates channel dimensions to streamflow characteristics (Osterkamp and Hedman, 1979). This technique is based on the assumption that a channel adjusts in size and shape to the size of flows that it carries. The theory holds that consistent channel features are formed by flows and that these features may be used as reference levels for measuring channel dimensions. Although it has not been verified, it is believed that channel dimensions, after an appropriate transition period, will reflect changes in the flow regime due to land-use changes and stream regulation. However, the processes that form the channel features are not fully understood; there is need for continued research in this area.

Equations relating channel geometry and streamflow characteristics have been developed for certain areas of the western United States (Hedman and Kastner, 1977; Hedman and others, 1972; Scott and Kunkler, 1976; Lowham, 1976). Persons wishing to use this method should receive field training first to learn to identify the same reference levels as were used to develop the equations. Channel geometry provides a simple means of estimating streamflow characteristics at ungaged sites with reasonable accuracy, especially on perennial streams. However, research is needed to determine the validity of this method in arid regions such as Tsosie Swale.

The U.S. Geological Survey has numerous publications that describe parametric models for estimating magnitude and frequency of floods for various areas using both watershed characteristics and channel-geometry measurements. Some of those that may have application at the Tsosie Swale site are cited in this report.

The Soil Conservation Service (SCS) (1972) has developed an empirical model that relates rainfall to direct runoff through a series of numbered curves. The proper curve is selected by consideration of soil type, land use, and antecedent soil-moisture conditions. The method was developed in the 1950's and is based on a large amount of plot and small basin runoff data. Parameter evaluation procedures have since been modified for some States to more accurately reflect local conditions, and evaluations for additional types of ground cover are now available. The method was developed to give consistent runoff volumes and peak discharge rates for the design of conservation structures on farms and ranches. Frequencies of the computed discharges are based on frequencies of the design precipitation events and may not correspond to frequencies of actual flood events. Streamflow data, if available, should always be used to check the reasonableness of results obtained by this method.

Estimates of peak discharges.--Estimates of premining stream discharges should be based on actual streamflow records, if available. This may be done by using parametric models developed for the area. Scott (1971) has published the following equations for the region of New Mexico that includes the Tsosie Swale area:

Equation	Standard error of estimate (Percent)	
	Average	Range
$Q_2 = 2{,}860\ A^{0.56}\ E^{-1.76}\ S_t^{-0.86}$	86	+118, -54
$Q_5 = 261\ A^{0.49}$	83	+113, -53
$Q_{10} = 411\ A^{0.47}$	82	+112, -53
$Q_{25} = 716\ A^{0.49}\ P^{-1.18}\ I^{2.57}\ T^{0.23}$	72	+96, -49
$Q_{50} = 915\ A^{0.49}\ P^{1.23}\ I^{2.74}\ T^{0.25}$	74	+98, -49

where

Q_2, Q_5, Q_{10}, Q_{25}, and Q_{50} are flow magnitudes, in cubic feet per second, having specified recurrence intervals in years.
A is the drainage area above the site, in square miles.
E is the mean basin altitude, in thousands of feet above sea level.
S_t is the area of lakes and ponds within the drainage basin expressed as a percentage of A and increased by 1.0.
P is the normal May through September precipitation, in inches, minus 3.0.
I is the maximum 24-hour 2-year precipitation, in inches.
T is the mean minimum January temperature, in degrees Fahrenheit.

Drainage area (A), area of lakes and ponds (S_t), and mean basin altitude (E) should be determined from the largest scale topographic maps available. The drainage area boundary should be delineated on the map and the area measured with a planimeter. Stereoscopic airphoto coverage is often useful for delineating boundaries in relatively flat areas. The surface area of lakes and ponds within the drainage areas may be measured with a planimeter or by counting squares of an overlying transparent grid divided into

0.01- or 0.04-square-mile areas. Recent aerial photography may provide the best means of locating and measuring stock ponds.

Mean basin altitude (E) is the average of altitudes at points 10 percent and 85 percent of the distance along the main channel from the proposed 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 extended to the basin divide and not the length of the stream valley. Certain electronic planimeters can give a very accurate measure of the length of line traced. If one of these is not available, channel length can be determined by stepping with a draftsman's dividers set at a small increment, preferably 0.1 mile or less. Altitudes at the 10 percent and 85 percent points are determined by interpolation between contour lines.

Normal May through September precipitation (P) is the basin average determined from a 1:500,000-scale-isoheyetal map prepared for New Mexico by the U.S. Weather Bureau (no date) using 1931 to 1960 data. The maximum 24-hour 2-year precipitation (I) can be determined from maps published by Miller and others (1973). The value of I for the Tsosie Swale site is given in table 2 of this report as 1.0 inch. The mean minimum January temperature (T) is the basin average determined from a map given by Von Eschen (1959) and reproduced by Scott (1971). The value of T for the Tsosie Swale sites is 14°F.

The accuracy of the equations is stated as the standard error of estimate, in percent. This is the range of error to be expected as the difference between the computed and actual discharges in about two-thirds of the cases.

Scott and Kunkler (1976) have published equations relating streamflow characteristics to channel dimensions for use in New Mexico. The equations that apply to the Tsosie Swale site are:

Equation	Standard error of estimate, in percent	
	Average	Range
$Q_2 = 1.70\ W^{1.67}$	82	+112, -53
$Q_5 = 5.86\ W^{1.55}$	63	+82, -45
$Q_{10} = 10.9\ W^{1.49}$	62	+80, -45
$Q_{25} = 21.2\ W^{1.42}$	68	+90, -47
$Q_{50} = 33.0\ W^{1.37}$	76	+101, -50

where

Q_2, Q_5, Q_{10}, Q_{25}, and Q_{50} are flow magnitudes in cubic feet per second, having the specified recurrence intervals in years; and

W is the channel width at the active channel reference level (see Scott and Kunkler, 1976, or Hedman and Kastner, 1977 for definition of "active channel"). Channel geometry measurements were not available for estimating discharges of Tsosie Swale.

The standard errors of estimate of these equations are somewhat lower than those of Scott (1971) which are based on basin and climatic characteristics. However, accurate estimation of discharges by the channel geometry method is dependent on the training and experience of the hydrologist. Note that many New Mexico gaging-station records are not long enough to adequately define the 100-year peak discharge; therefore, equations for Q_{100} could not be developed for either the channel geometry or the basin-characteristics method.

For illustrative purposes, discharges were determined at points A and B in figure 8. These estimates shown in table 3 were computed with the Scott (1971) equations, using 5.1 inch as the value for normal May through September precipitation; 1.0 inch as the maximum 2-year 24-hour precipitation; and 14 degrees as the minimum January temperature. Drainage areas, mean basin altitudes, and areas of lakes and ponds were measured on 1:24,000 scale topographic maps.

Estimates of runoff volumes.--No published equations exist for estimating annual volumes of runoff from the study area. H. R. Hejl (written communication, 1979) estimates that annual volume of runoff for Tsosie Swale is about 11 acre-feet per year. This is based on relative amounts of badland area in Tsosie Swale basin and the neighboring Ah-shi-sle-pah Wash basin where streamflow has been gaged for 2 years. A reasonable assumption is made that most of the streamflow in the two basins is contributed from the badlands and from alluvial plains consisting of impermeable fine-textured alluvium.

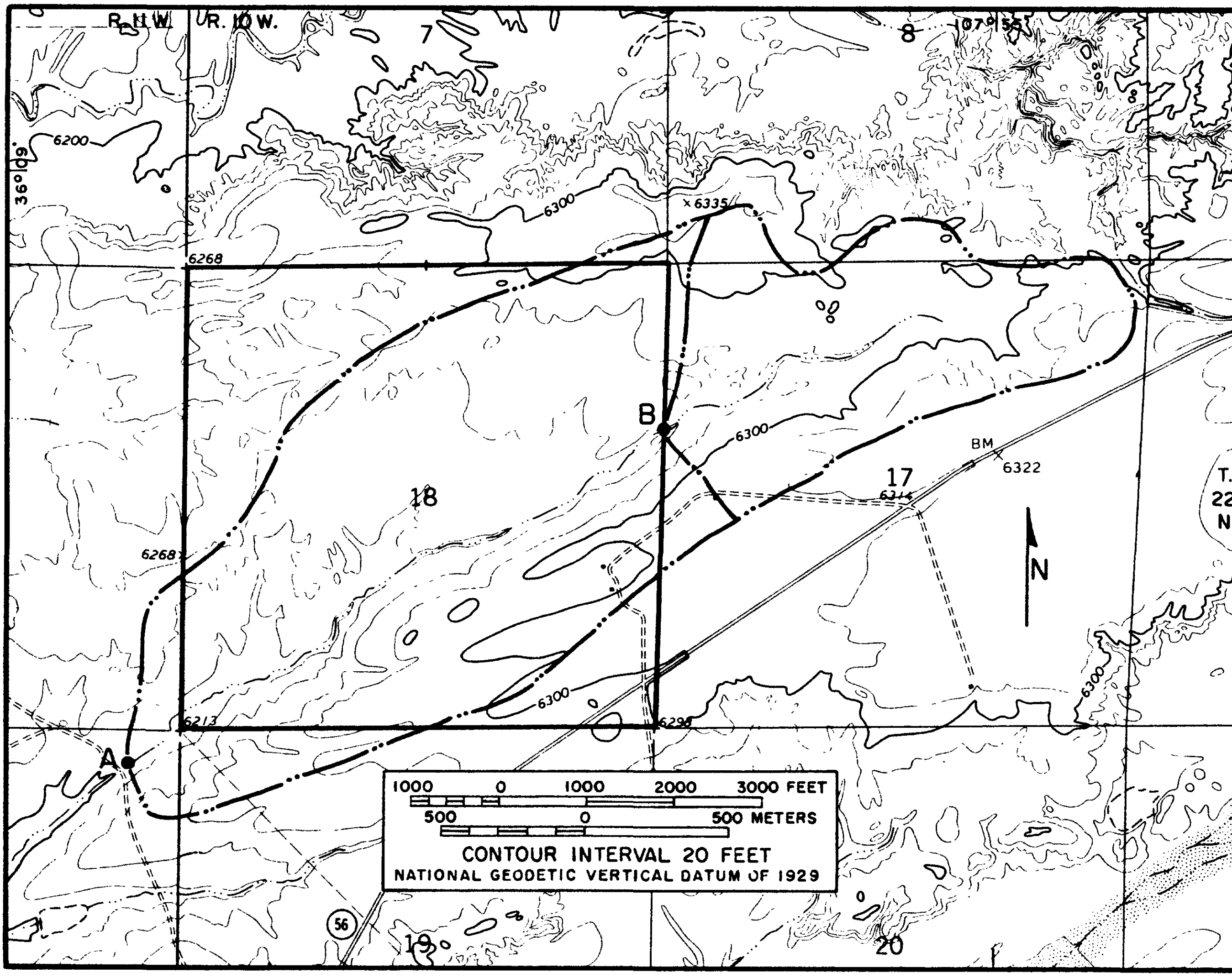
Craig and Rankl (1978) developed a relation between peak discharge and volume of runoff from individual runoff events in Wyoming. This equation is

$$V = 0.131\ Q^{0.878}$$

where

V is storm runoff volume, in acre-feet; and
Q is peak discharge, in cubic feet per second.

The average standard error of estimate of this equation is 55 percent. Craig and Rankl (1978) also developed a mean dimensionless hydrograph with which they were able to synthesize hydrographs that were consistently in close agreement with measured hydrographs from semiarid, ephemeral streams in Wyoming, Arizona, and New Mexico. This suggests that a standard hydrograph shape may be used over a wide area on this type of stream. Furthermore, use of the above equation should also be valid over a wide area on ephemeral



Base from U.S. Geological
Survey Pueblo Bonito NW
1:24,000, 1966

EXPLANATION

permit area boundary

drainage divide, Tsosie basin
and subbasin

A● location on main channel where
streamflow was estimated

Figure 8.--Map of Tsosie Swale basin, San Juan County, New Mexico showing permit area and streamflow estimation sites.

Table 3.--*Estimated peak discharges for premining conditions at Tsosie Swale*
[Computed with Scott's (1971) equations]

Site	Drainage basin (mi^2)	Mean basin altitude (ft)	Area of lakes (mi^2)	Q_2 (ft^3/s)	Q_{10} (ft^3/s)	Q_{25} (ft^3/s)	Q_{50} (ft^3/s)
A	1.28	6,245	0	130	460	615	800
B	0.39	6,280	0	65	265	345	450

streams because peak discharge and runoff volume are both essential elements of a mean dimensionless hydrograph.

Craig and Rankl's (1978) equation was used to compute the runoff volumes listed in table 4 that may be expected from storms producing the peak discharges listed in table 3. It should be noted that the volumes do not necessarily have the same recurrence interval as the peak discharges, and do not provide estimates of mean annual runoff.

Estimates of low flows.--Regression models for estimating low flow characteristics have generally been unsuccessful except in a few geologically homogeneous regions of limited extent (Riggs, 1973). Most such attempts have resulted in relations of very poor accuracy.

A different method of estimating low flow characteristics is described by Riggs (1970, 1973). Discharge measurements of low flows at an ungaged site may be related to concurrent flows at a nearby gaging station at which the low flow-frequency curve is defined. Low flow characteristics at the gaging station then can be transferred through that relation to obtain estimates of characteristics at the measurement site; an example is given by Riggs (1970). This method may also be used to estimate mean monthly flows and mean seasonal flows (Riggs, 1973).

Streams in the report area are definitely ephemeral, carrying no flow about 90 percent of the time. Downstream flows are not dependent on any minimum flow from Tsosie Swale.

Surface water quality.--A sample of water was collected for chemical analyses on May 7, 1978, from a flow of 5 cubic feet per second in Tsosie Swale at location A (fig. 2) (Hejl, Ong, and Dewey, 1979). Samples were collected on Escavada Wash, about 1 mile upstream from the confluence with Tsosie Swale, during Spring, 1977 and 1978. Escavada Wash drains a much larger (about 200 square miles) and more diverse basin than Tsosie Swale, but the analyses of the Escavada Wash samples are more representative of 2- to

Table 4.--*Estimated runoff volumes associated with selected peak discharges at sites on Tsosie Swale*
[Computed with Craig and Rankl's (1978) equation]

Site	Q_2 (ft^3/s)	V (ac-ft)	Q_{10} (ft^3/s)	V (ac-ft)	Q_{25} (ft^3/s)	V (ac-ft)	Q_{50} (ft^3/s)	V (ac-ft)
A	130	9.4	460	28.5	615	36.8	800	46.4
B	65	5.1	265	17.6	345	22.2	450	28.0

5-year average values for quality of water variables in the upper Chaco River basin. This is proven by examination of data furnished by Hejl, Ong, and Dewey (1979) for several of the main washes in the upper basin including the 8.2 square mile Ah-shi-sle-pah Wash basin, which bounds Tsosie Swale and which consists of about 45 percent badlands. The badland areas produce much of the water, sediment, and chemicals in the surface runoff from all of the basins, but badlands comprise only about 3 percent of Tsosie Swale basin.

The sample from Tsosie Wash indicated water of good chemical quality. The calculated dissolved solids concentration was 152 milligrams per liter compared to a concentration of 350 milligrams per liter for the average of two samples from Escavada Wash. The Tsosie Swale water was sodium-calcium bicarbonate-sulphate type, with a pH of 7.5. The water from Escavada Wash was sodium bicarbonate-sulphate type, with a pH of 8.5. The pH of the Tsosie Swale sample was the same as the pH of other streams in the upper Chaco River basin, which had pHs ranging from 7.5 to 7.8. Calcium concentration of the Escavada Wash water (2.9 milligrams per liter) was lower than that of Tsosie Swale (8.0 milligrams per liter) and other streams in the upper Chaco basin where the average calcium concentrations ranged from 9.5 to 25 milligrams per liter. The sodium concentration of 40 milligrams per liter for the Tsosie Swale flow was less than the 112 milligrams per liter average sodium concentration of Escavada Wash flows and less than the average sodium concentrations of 86 and 180 milligrams per liter for samples from two other washes in the upper Chaco River basin.

Trace element and radiochemical concentrations were not determined for the Tsosie Swale sample. Analyses of samples from other streams in the upper Chaco basin indicated that concentrations of dissolved trace elements and radiochemical constituents were very low, but "total" concentrations were high, owing to high suspended sediment concentrations (Hejl, Ong, and Dewey, 1979). "Total" concentration is defined as the concentration of the dissolved phase of an ion, plus the concentration resulting from extraction or desorption of the ion from the surfaces of suspended sediment. The average suspended sediment concentration of the 2 samples from Escavada Wash, and 51 samples, over a 2-year period, from Ah-shi-sle-pah Wash, were an order of magnitude greater than the sediment concentration of the Tsosie Swale sample; the concentrations were 34,600, 54,800, and 4,020 milligrams per liter, respectively. The trace-element ions and radiochemical constituents that are adsorbed to the sediment particles will remain adsorbed as long as the sediment remains in an alkaline environment.

Ground water

Examination of aerial photographs taken in 1975 for the occurrence and density of phreatophytic vegetation indicates that ground water is practically absent in the surficial materials of the study area. Even on alluvium along the main watercourse of Tsosie Swale, sparsity of rubber rabbitbrush indicates an insignificant amount of ground water. Likewise, occurrence of widely spaced rubber rabbitbrush and greasewood plants on dunes indicates the presence of some perched soil moisture but no significant amounts of ground water.

The U.S. Geological Survey (Hejl, Ong, and Dewey, 1979) has investigated ground water at three observation wells completed in the Kirtland Shale overburden above the coal zone in the vicinity of the permit area. Yields to these wells were less than 1 gallon per minute and the highest hydraulic conductivity was less than 0.1 square foot per day.

Overburden well DH-3K, a mile north of the permit area, appears most applicable to the permit area. Quality of water in that well was extremely poor; it had a specific conductance of 18,000 micromhos per centimeter at 25°C, a calculated total dissolved solids content of 6,350 milligrams per liter, and a pH of 12.4. The wide disparity between the conductance and the calculated dissolved solids is unexplainable; the high conductance was measured in both the field and in the laboratory and a similar wide disparity was observed for a water sample from another overburden well in the vicinity of the permit area.

The U.S. Geological Survey (Hejl, Ong, and Dewey, 1979) reports that all of the Fruitland coal beds in core hole DH-2K (fig. 3) and at two other core holes which are within 1½ miles of the permit area are saturated. The combined transmissivities of the coalbeds in each of the three wells range from 3 to 11 square feet per day. Ground-water flow appears to be toward the northwest, parallel to the Chaco River. On Feb. 2, 1978, the water level in the core hole DH-2K well, which is open to the coal-bed aquifers, was at 91 feet below surface, which was 114 feet above the uppermost coal bed. Expected yields from the coal aquifers would be low.

The well at DH-1K (fig. 3) is completed in the Pictured Cliffs Sandstone. The sandstone has a transmissivity of about 3 square feet per day in this area and is low-yielding (Hejl, Ong, and Dewey, 1979). On Feb. 23, 1978, the water level in the well was at 94.5 feet below the surface, which was 85.5 feet above the top of the water-bearing zone.

Average values for analyses of about 20 samples each of ground water from the Fruitland Formation and the Pictured Cliffs Sandstone have been determined by Kim Ong (written communication, 1979) to be applicable to the waters in core holes DH-2K and DH-1K respectively. The average values are:

	Fruitland Formation	Pictured Cliffs Sandstone
Specific conductance, micromhos per centimeter--	6,920	6,020
Dissolved solids, milligrams per liter----------	4,240	3,420
pH, standard units------------------------------	8.8	8.9
Sodium, milligrams per liter--------------------	1,480	1,280
Sodium-adsorption ratio-------------------------	67	94
Boron, micrograms per liter---------------------	563	427

The yield and quality of these waters would be too poor for irrigation of areas being reclaimed, as determined with the USDA classification of irrigation waters (Richards, 1954).

Erosion and sediment yield

Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) has been developed over the past 30 years, primarily for use on cropland fields (Wischmeir 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 from slopes in mined and reclaimed areas. Additional research, however, is necessary to answer some unknowns about applicability of the method on mined lands.

Use of the method is limited to small areas such as permit areas, because considerable time and resources are needed to do the mapping and computations to assign values for the six factors of the equation. Preliminary procedures for applying the method on both mined and unmined land are given in a interim report prepared by the USDA-SCS (Soil Conservation Service) (1977) for the U.S. Environmental Protection Agency, Region VIII.

Rigorous analysis of the topography, especially of slope gradients and slope lengths, is necessary to delineate soil-loss units. Soil-loss units are areas of quasi-uniform slopes which are delineated on the basis of relief, drainage patterns, and land use on topographic maps with the aid of aerial photographs. USGS 7½-minute topographic maps at 1:24,000 scale with 20-feet contour intervals are largely inadequate for accurate slope analysis for most areas. Maps at 1:12,000 scale (1 inches = 1,000 feet) with contour intervals of 10 feet in the steeper areas and 5 feet in the flatter areas might be adequate in most places.

The most important reason for evaluating soil loss or erosion on the permit area is to have "baseline" values to compare with postmining values as a criterion for determining when reclamation has been accomplished.

Most of the permit and adjacent areas are mantled with locally derived, wind-worked sandy soils. These soils are permeable; therefore, runoff from them is almost nil. Even though the soils are fairly well stabilized by vegetation, some shifting by winds still occurs. Because of these factors, the slopes and drainage network are poorly developed; therefore, it appears impossible to evaluate the slope length and slope-gradient factors for the Universal Soil Loss Equation (Wischmeier and Smith, 1978) on the areas.

Sands are not a problem on the badland type (fig. 2) but the gradients of some of the slopes exceed those for which the equation has been verified. Slope lengths and gradients in the badlands would need to be measured either in the field or on large-scale (1 inch = 500 feet) topographic maps because the area is minutely dissected.

Sediment yield

The USLE can also be used in conjunction with sediment-delivery ratios to make estimates of the sediment yield from drainage basins. In such cases, amounts of sediment from gully or channel erosion, if significant, would have to be determined by some other method. The most reliable values for sediment-delivery ratios would be obtained from local or regional investigations in small watersheds where sediment yield was measured and the USLE was applied. Another alternative would be to use the curve relating sediment-delivery ratio to drainage area, published by Roehl (1963). Most sedimentation experts agree that the curve is not strictly applicable to western rangeland conditions, but it could be used as a guide in estimating a value for sediment-delivery ratio.

Surveys of stock ponds in small watersheds provide information about both sediment yields and sediment-delivery ratios that would apply to the permit area. Procedures for surveying small reservoirs are given in the Sedimentation Engineering Manual (Vanoni, 1975) and by Heinemann and Dvorak (1965). Methods for converting from volume to weight of sediment and for correcting for sediment trap efficiencies of the ponds are also given in the Sedimentation Engineering Manual (Vanoni, 1975).

Rainfall simulation

The results of rainfall-simulation studies conducted by G. C. Lusby (written communication, 1979) at the Bisti West study area about 15 miles northwest of the permit area are applicable to the badlands, dunes, and interdune alluvial plain areas shown in figure 2. Artificial rainfall was applied at an intensity of approximately 2 inches per hour in a 45-minute period to microwatersheds that were about 3,000 square feet in area. Frequency analyses indicated that a storm of that intensity would have a recurrence interval of about 150 years. Runoff, sediment production (soil loss), and concentrations of certain chemical ions in the runoff were measured.

No runoff or sediment was produced from the dry antecedent-moisture run on the deep dune microwatershed having an average slope of 8 percent. During the wet antecedent-moisture run, the equivalent of about 7 tons per square mile of sediment was produced. For the nearly flat alluvial plain watershed, the equivalent of 44 and 301 tons per square mile were produced during the dry and wet runs, respectively. Only a dry run was made on the badland watershed, which had an average slope of 33 percent. The resultant sediment production was equivalent to 3,227 tons per square mile. When appropriate specific weights (Vanoni, 1975) are applied to convert the above values to units of acre-feet per square mile, the values for those extremely intense simulated storms compare favorably with estimates of annual source-area sediment yields made on similar landforms in the area using the modification reported by Frickel, Shown, and Patton (1975) of the Pacific Southwest Inter-Agency Committee (PSIAC) method (1968).

Erosion observations

Little evidence exists of erosion by water on any of the dune or sand-mantled areas shown in figure 2. Examination of areas 2 and 5 of figure 2 on aerial photographs taken in 1975 show some evidence of rill erosion in the past, but the rills are now healed by vegetation. Slope and channel erosion occur in the badlands and some rilling and scouring occur in the four braided drainageways that are shallowly incised in the alluvial plain that underlies the dunes of area 4. A healed gully exists along the main channel across the lower part of area 2. Some sandy material is deposited by winds in the drainageways and gully of areas 4 and 2. Much of the material is transported out of the basin during flows.

Hydrology of the adjacent area

Surface water

The methods used to estimate streamflow characteristics of the permit area may also be used for the adjacent area. Estimates of premining peak discharges and runoff volumes for the portion of the adjacent area that lies upstream from the permit area are listed under site B in tables 3 and 4.

Ground water

The U.S. Geological Survey reports that there are several deep, high yielding water-bearing units or aquifers under the study area (Hejl, Ong, and

Dewey, 1979). They are the Cliff House Sandstone at 800 to 1,600 feet below land surface, Menefee Formation at 1,600 to 2,600 feet, Morrison Formation at 5,100 to 5,500 feet, and Entrada Sandstone at 6,000 to 6,500 feet. From a single 8-inch well, it could be expected that Cliff House Sandstone would yield 100 gallons per minute, Menefee Formation 50 gallons per minute, and Morrison Formation and Entrada Sandstone 400 gallons per minute each. The estimated specific conductances of these aquifers at the study area are as follows: Cliff House ranges from 1,500 to 4,000, Menefee from 1,500 to 4,000, Morrison from 3,000 to 5,000, and Entrada from 10,000 to 20,000 micromhos per centimeter (Hejl, Ong, and Dewey, 1979). The total dissolved solids concentrations of water in milligrams per liter is roughly 0.7 times the specific conductance. Wells would have to be drilled into the deep aquifers to determine actual water quality and yields at the study area.

Sediment yield

Sediment discharge at the lower end of the 1.28 square mile Tsosie Swale basin (location A, fig. 8) is low, owing to the large percentage of the basin that does not contribute much, if any, water or sediment. Much of the sediment that is produced by the badlands is deposited in the sand-choked drainageways immediately downstream from the badlands. Annual sediment discharge was estimated to be between 0.1 and 0.2 acre-feet per square mile. The estimate was made with the unmodified PSIAC (1968) method, which Shown (1970) found to be very reliable for estimating sediment yields from small basins in semiarid New Mexico. This estimate is in accordance with a measurement of 0.12 acre-feet per square mile per year of sediment deposition in a nearby stock pond, which traps the sediment from a smaller (0.44 square mile) but similar basin (U.S. Geological Survey, 1980).

A flow resulting from a spring storm was sampled by the U.S. Geological Survey (Hejl, Ong, and Dewey, 1979) for sediment content at the mouth of the basin on May 7, 1978. Flow at the time of sampling was about 5 cubic feet per second; sediment concentration was 4,020 milligrams per liter; and 99 percent of the sediment was less than 0.0625 millimeters in size.

POTENTIAL EFFECTS OF MINING AND RECLAMATION

Major potential effects of surface mining and reclamation that will change the hydrology of the permit area and adjacent area include: (1) Topographic and landform changes; (2) soils and soil-moisture characteristics; (3) types and amounts of plant cover; (4) quantity and quality of streamflow; (5) quantities of erosion and sediment yield; and (6) changes in aquifer characteristics and quality and quantity of ground water.

Changes in topography

Postmining terrain maps, such as the one for the study area in figure 9, provide an estimate of the surface topography of a mined area following reclamation. These maps are based on the concept of lifting out the overburden as one unit, removing the coal, and replacing the overburden in the same position it formerly occupied. Thickness of the replaced overburden is assumed to have increased by 25 percent due to the increase in void space in the fractured and pulverized rock.

This method provides a simple approximation of the reconstructed surface of a mined area without assuming a mining plan or calculation of overburden volumes moved about within the mined area. It should provide an adequate picture of an area for the anticipation of problems of drainage, slope, and reconstruction of surfaces adjacent to unmined lands.

The technique involves construction of a sequence of contour maps starting from basic geologic data. At each step, a map is drawn, based on the intersections of the contours of two superimposed maps. These intersections provide elevations of points from which contours can be drawn for the new map. Topographic data from the superimposed maps may be added or subtracted to construct the desired surface.

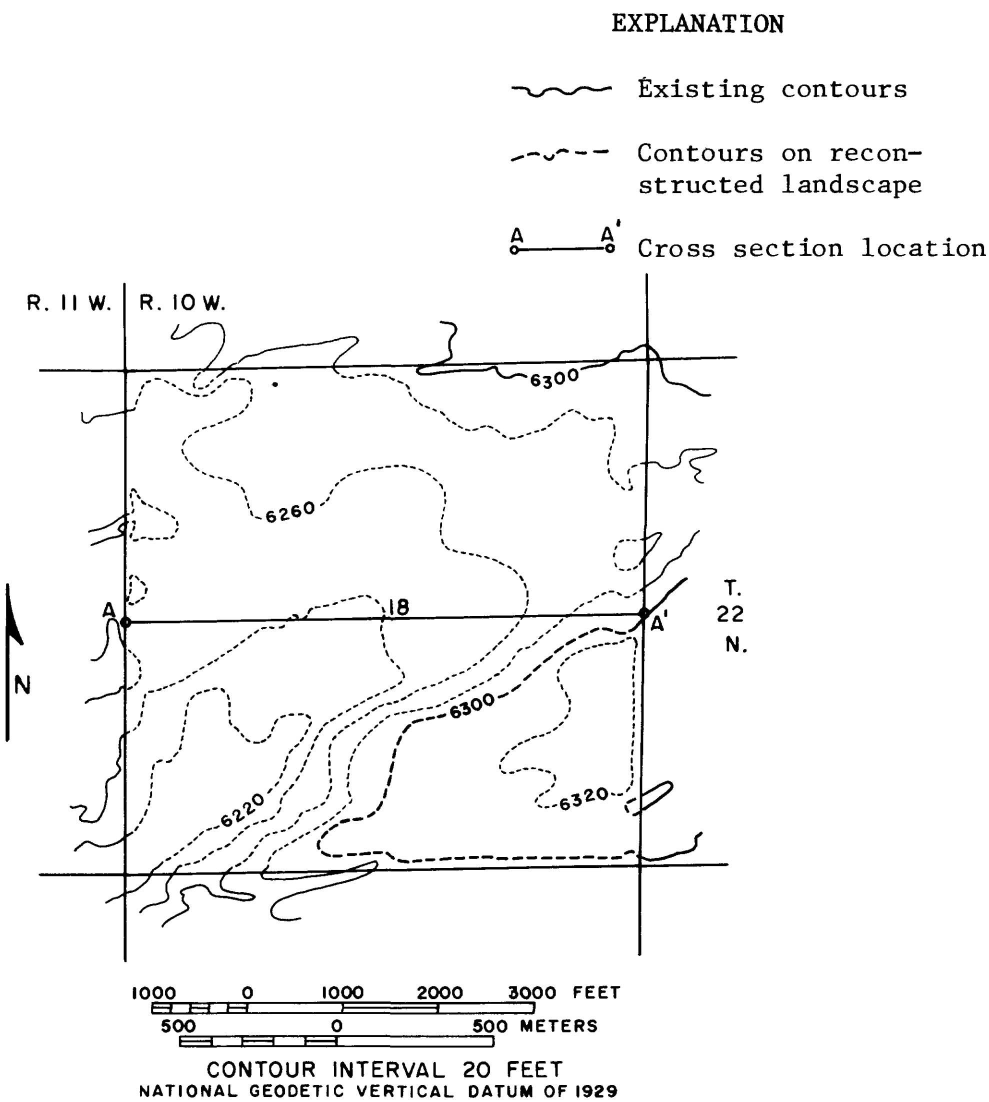
Due to expansion of the replaced overburden, the reclaimed surface may not be greatly different from the original topography. In many cases, increased depth of the spoil compensates for the thickness of the coal removed. In some instances, the postmining surface may be higher than the surface before mining. This situation occurs where the overburden is very thick and the coal beds are thin. For example, if there is 160 feet of rock above 20 feet of coal, the replaced overburden (expanded by 25 percent) would be 200 feet thick, and the new surface would be 20 feet higher than the original.

The procedure for construction of postmining terrain maps is:

1. The limits of minable coal for each coal bed are established from the 200 foot overburden contour and geologic maps; all subsequent mapping is confined within these limits.

2. The base of the coal-bed map is constructed by subtracting coal thickness from the upper coal surface map (structure contour map).

3. An expanded overburden-thickness map is constructed to account for bulking of replaced overburden by subtracting the upper coal surface (structure contour map) from a standard topographic map of the land surface and increasing this difference by the desired percentage (25 percent in this case). Two or more coal beds require the intermediate step of adding upper coal-bed thicknesses to the structure contour map of the lowest coal bed. If an overburden-thickness map already exists, the expanded overburden-thickness map is constructed by increasing the value of each thickness contour by the



Grid from U.S. Geological
Survey Pueblo Bonito NW
1:24,000, 1966

Figure 9.--Reconstructed landscape after mining to a maximum depth of 200 feet and replacement and grading of the overburden. A 25-percent expansion factor was used in computing the overburden thickness.

desired amount, say 25 percent. Thus, the 50 foot thickness became 62.5 feet; the original 100 foot thickness became 125 feet, and so forth. New regular 20-foot contours were then fitted among the irregular intervals of the expanded overburden map by interpolation.

4. Surface topography of the replaced spoil is constructed by adding the expanded overburden thickness to the base map of the lowest coal bed.

5. The final map is constructed by adjusting the topography of the reclaimed surface to the adjacent existing topography of the unmined area (fig. 10).

Elevations before and after mining along a transect across the permit area are compared in figure 10. The elevation difference shown along transect A-A is fairly representative of differences over the whole square mile; where some parts would be lowered, with a maximum lowering of about 20 feet; some raised with a maximum raise of about 20 feet, and some not changed.

The main drainageway in the reconstructed landscape is indicated along approximately the same course as it was prior to mining (fig. 9). However, the gradient of the drainageway is changed. It is flatter for about the first 0.25 mile from the east edge of the permit area, and increases for about the next 0.5 mile from about 50 feet per mile to about 75 feet per mile. The steepened reach of channel may need to be wider than other reaches to prevent the initiation of headcut erosion there.

Soils and vegetation

Sandy soil materials that cover shale and sandstone on the mesas and that have accumulated in deep dunes on lower areas would be the most suitable material for placement over repositioned spoil, after coal beneath the area has been mined. Previous work at the Bisti West EMRIA site, where the soils and vegetation are similar to Tsosie Swale, indicates that maximum forage production can be achieved per unit of water stored, if 2 feet of sandy loam material are deposited over compacted fine-textured material (U.S. Geological Survey, 1976). Under these conditions, water will be adsorbed to the surface of particles in excess of the 10 molecular layers adsorbed at the retention-capability level. In most years, amounts of water adsorbed will not exceed the maximum of 16 molecular layers that can be adsorbed as films. As a result, there will be no capillary rebound toward the surface from perched liquid water.

If there is insufficient sandy material to cover the mined area to a depth of two feet, a checkerboard pattern of soil placement would be a variable alternative. Two-foot deep interlocking patches of sandy soil placed over a continuous layer of compacted clay material would cause runoff from the areas of exposed clay to be intercepted by the sandy patches. This form of water harvesting would provide a habitat in which alkali sacaton or galleta would be very productive.

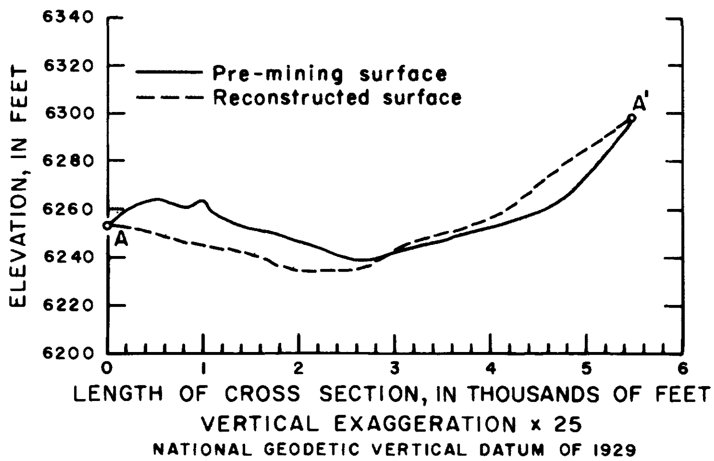


Figure 10.--Cross section showing changes in topography resulting from surface mining. The overburden was assumed to be replaced on a cut-by-cut basis and was graded smooth. Location of cross section is shown in figure 9.

Surface water

Estimation methods

Surface-mining regulations specify that hydraulic structures be designed to hold or convey volumes and discharges produced by precipitation events of specific durations and frequencies. This requirement indirectly specifies that the SCS method or some other physical-process model be used to estimate design discharges for these structures, because these are the only methods that base runoff and peak discharges on precipitation frequencies.

The SCS method is described in the SCS National Engineering Handbook, Section 4 (1972). The method estimates runoff volume and peak discharges produced by a specified amount of precipitation. It also includes procedures for developing hydrographs and routing them through reservoirs and channels. Shortcut procedures, in the form of tables and graphs, have been developed to simplify use on small watersheds and for special situations (SCS, 1973, 1975). In some States, SCS offices have expanded the list of hydrologic soil-cover complexes to more completely describe local conditions.

A computer program has been developed to simplify the use of the SCS method on more complex projects (SCS, 1965). Use of the program should be considered when: (1) watersheds are larger than 2,000 acres; (2) there are many subareas with different runoff characteristics; (3) reservoirs are present; or (4) when historical storm events need to be analyzed (SCS, 1975). A copy of the source program can be obtained through the National Technical Information Service (NTIS).

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

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

where

Q is runoff volume, in watershed inches,
P is the storm rainfall, in inches,
S is the potential maximum retention, in inches, and

$$S = \frac{1000}{CN} - 10$$

where CN is a "curve number" value based on soil, land use and condition, and antecedent soil-moisture conditions. Each different combination of these parameters is assigned a CN value based on experimental data. Evaluating CN can be laborious for a large basin with a variety of soils and vegetation types.

The first requirement is a map of the basin showing cover type and condition; the latter refers to a range of vegetation cover density. This map can be prepared as described in the vegetation section of this report. A second requirement is a map showing soils divided into four groups according to infiltration rates. If an SCS Soil Survey has been completed for the project area, it will indicate the infiltration range, called a "hydrologic soil group", of each mapped soil series. With this information, the required map of hydrologic soil groups can be easily prepared. If an SCS 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 for the desired antecedent soil-moisture condition. Usually, the average antecedent condition is used. The CN for the basins is the areally weighted average of the CN values of all the complexes.

The above procedure is greatly simplified if the area is small enough that only one cover type and one hydrologic group is present. However, in dealing with western energy lands, two or three of each is likely in a given basin. If the SCS method is to be used extensively, it would be helpful to digitize the soils map and the vegetation maps, so the laborious work of combining the map and determining the areas of the different soil-cover complexes could be done by computer.

The SCS method provides several procedures for calculating peak discharges, depending on the size and complexity of the project. The procedure described by the SCS (1973) for estimating peak discharges without developing a hydrograph was applied at sites A and B on Tsosie Swale for premining conditions.

Table 5.--*Parameter values for SCS method--premining conditions*

Site	Drainage area (mi^2)	Average basin slope (percent)	CN
A	1.28	5.3	84
B	.39	4.4	82

Parameter values required are: (1) drainage area, in acres; (2) CN; (3) 24-hour precipitation amounts, in inches; and (4) average basin slope, in percent. Drainage areas and greatest flow lengths were measured on 1:24,000 scale maps; average basin slopes were determined by the summation of contour-lengths method. Parameter values used are listed in table 5. Values of 24-hour precipitation amount for various recurrence intervals are listed in table 2. Discharges can be obtained from graphs developed by the SCS (1973).

Resulting runoff volumes and design peak discharges are listed in table 6. The column headings, Q_{pn} and V_{pn}, represent the discharge and volume, respectively, produced by the n-year precipitation event. These volumes are not comparable to the values in table 3 in a strict hydrologic sense because the recurrence intervals for the discharges and volumes are not necessarily the same as the recurrence interval of the precipitation amount, which is an assumption inherent in the SCS method. The two sets of discharges, however, should be compared since they represent different answers to the same question.

Frequency curves estimated by the two methods are shown in figure 11 for the total drainage area above site A. The two methods give considerably different results at this site; discharges estimated by the Scott equations

Table 6.--*Runoff volumes (V_p) and peak discharges (Q_p) for 2-, 10-, 25-, and 100-year precipitation events calculated by the SCS method for sites at Tsosie Swale--Premining conditions*

Site	Q_p2 (ft^3/s)	V_p2 (ac-ft)	Q_p10 (ft^3/s)	V_p10 (ac-ft)	Q_p25 (ft^3/s)	V_p25 (ac-ft)	Q_p100 (ft^3/s)	V_p100 (ac-ft)
A	35	10.24	140	32.77	230	51.20	340	71.00
B	9	2.29	45	8.32	78	13.52	115	19.14

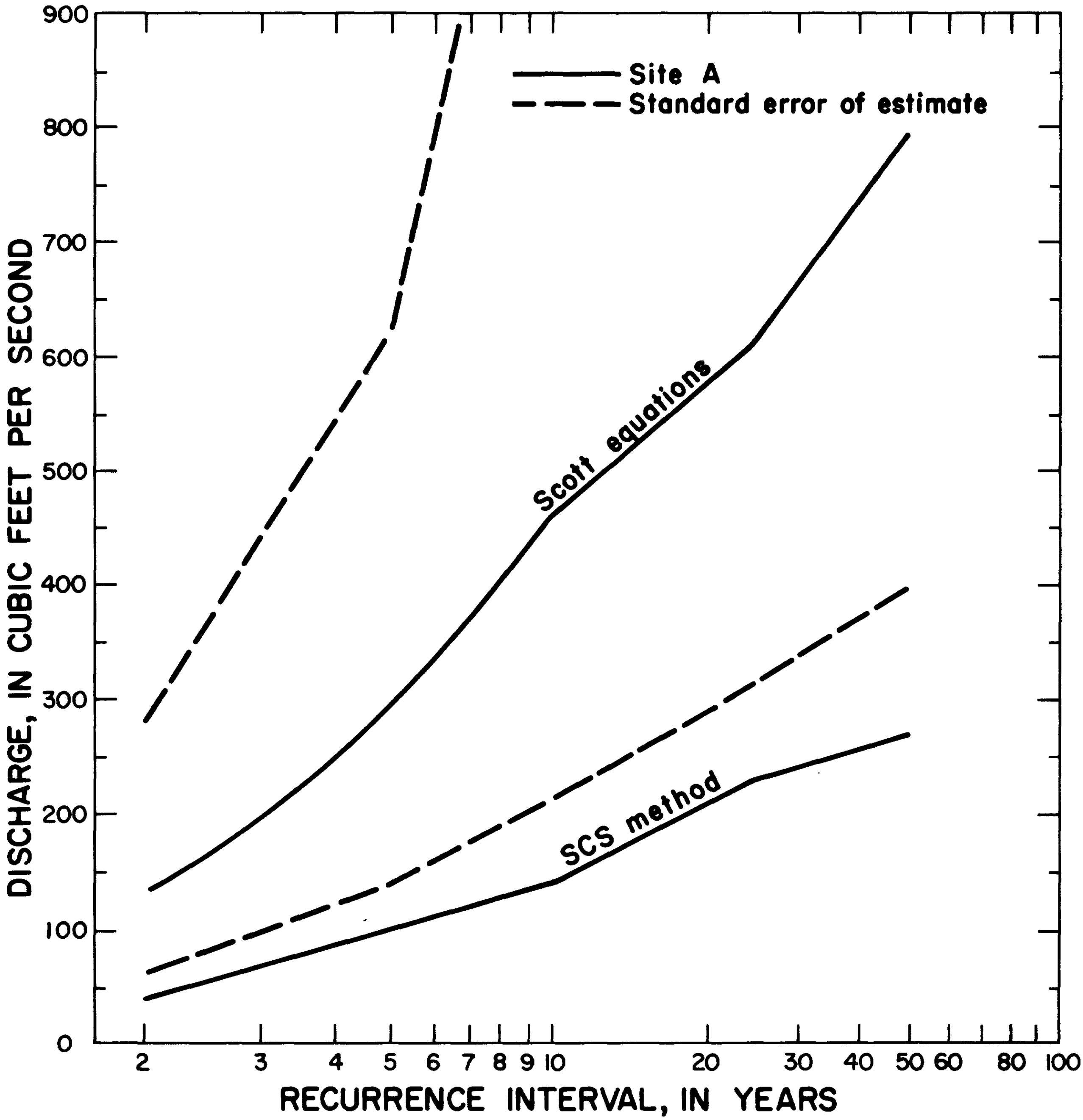


Figure 11.--Comparison of frequency curves estimated by SCS (1973) method and Scott's (1971) equations. Standard errors of estimate are for Scott's equations.

are an average of three times greater than those estimated by the SCS method. There are a number of factors that may contribute to these differences, some of which are inherent in the different basic approaches of the two methods.

One of the most important factors here lies in the ability of the methods to explain variability caused by the wide differences in infiltration characteristics of the soils of this area. The sandy soils have high infiltration rates, while the fine-textured soils in the badlands and alluvial-plain types have very slow infiltration rates and produce a large percentage of the runoff. Thus, runoff rates can vary greatly among basins depending on which soil type is predominate. None of the parameters in the Scott (1971) equations directly considers infiltration rates, so these equations are not likely to show the differences in runoff rates that these soil types produce. On the other hand, the SCS method does consider the variability of soils, though it uses only four categories of infiltration rates.

The fine-textured badland and alluvial-plain soils occur over only about three percent of Tsosie Swale basin, so relatively low runoff rates can be expected from this basin. The drainage area of the adjoining 8.2 square mile Ah-shi-sle-pah Wash basin consists of about 45 percent badlands. A channel-width measurement was available for that basin, so three estimation methods could be applied; channel geometry (Scott and Kunkler, 1976), basin characteristics (Scott, 1971), and the SCS (1973) method. The three methods gave approximately the same results for Ah-shi-sle-pah Wash basin. In this case, the SCS method seems to accurately account for the variability of the soils and probably gives the best estimate of the streamflow characteristics at Tsosie Swale; channel-geometry measurements on Tsosie Swale would further test this assumption.

The foregoing comparison of estimation methods points out that any method must be used with care, or considerable error can result. It is essential to determine the most important runoff-producing characteristics of a basin or area, and use the method that best accounts for the variability of these characteristics. It should also be noted that the U.S. Geological Survey is developing new methodology for hydrologic estimates in the San Juan Basin coal area based on data from a large, recently expended data-collection network.

Other models that satisfy the precipitation-input requirement of the surface-mining regulations for determining design peak discharges and runoff volumes are those that represent the various phases of the hydrologic cycle, with mathematical relationships that are solved on a digital computer. Because these models allow for the input of a variety of data on climate, soils, vegetation, and basin characteristics for the basin being modeled, they should give very good results provided there is sufficient data to adequately calibrate them.

In a cooperative effort, the U.S. Geological Survey and the Bureau of Land Management initiated a model development and implementation program.

A modular-design program package is being developed and will be maintained in a single computer-system library. Each module (set of subroutines) will define a component of the hydrologic cycle or contain routines for parameter optimization, data handling, and model-output analysis. Given a specific problem, the hydrologist will be able to select a main program routine and the specific modules that define his problem (Van Haveren and Leavesley, 1979). This modeling system is scheduled to be ready for application early in 1981.

Estimates of design peak discharges and runoff volumes

At this writing, the SCS method is the most feasible to use for design estimates for both convenience and data availability. These estimates should be based on basin conditions existing immediately after spoils are reshaped and before vegetation is reestablished. The major changes to be considered are basin slope, vegetative cover, and soils.

The average basin slope should be calculated from a map of the reshaped topography. If a contour map of the planned reconstructed topography is not available, an approximation may be prepared by the technique described in the section of the report titled "Changes in topography." Since vegetative cover has not been reestablished, the land-use category should be considered as barren or fallow for application of the SCS method.

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

It has been suggested in the soils section of this report that there is sufficient sandy soil material in the dunes and mesas to allow placement of a 1.5- to 2-foot-thick layer of this material over the total permit area as topsoil. This topsoil would be highly permeable and should reduce runoff from the reclaimed area to a minimum.

With this evaluation of the soil, a CN value of 75 was assumed for calculating runoff volumes and peak discharges for the postmining period before vegetation is reestablished. The CN value is moderately high, in spite of a highly permeable soil, because there is no vegetative cover. After vegetation becomes well established, a considerably lower CN value (50 to 70) may be appropriate, depending on the type and density of the plants.

Using the above consideration, peak discharges and runoff volumes were calculated for two areas above site A of figure 8. A_1 is for the total drainage area of Tsosie Swale including the area above site B. For A_2, it was assumed that discharges from above site B are diverted, so only the drainage areas between sites A and B are included. Drainage areas and average basin slopes were measured on the map of reconstructed topography shown in figure 9. Parameter values used are listed in table 7. The resulting volumes and discharges obtained from the graphs in TP-149 (SCS, 1973) are listed in table 8.

Comparison of the values for site A in table 8 with those in table 6 gives some indication of the effects that mining will have on surface runoff. Postmining peak discharges are 15 to 50 percent of the premining rates and runoff volumes are 30 to 70 percent of the premining values. The lower postmining rates reflect the assumption that the reclamation process will leave 1.5 to 2 feet of sandy topsoil with a high infiltration capacity over the permit area. Once vegetative cover is reestablished, runoff rates should decrease even further.

Ground water

Surface mining for coal would destroy water-bearing zones in the Kirtland Shale and water-bearing coalbeds in the Fruitland Formation, replacing them with crumbled shale and sandstone rubble, with a porosity estimated to be 30 percent greater than the original material and containing exposed soluble material (Hejl, Ong, and Dewey, 1979). Destruction of these saline, low-yielding water-bearing strata would be of negligible consequence, but the resulting fill of more porous material could become saturated with surface water percolating from natural or diversion channels. The quality of the water would deteriorate as a result of the exposed soluble materials in the replace overburden. Some means of lining or sealing channels in the reclaimed area will be needed to minimize or prevent flow losses, and to prevent development of a thick zone of saline ground water.

The supply of surface water for mining and reclamation use is probably inadequate because of low runoff. Ground water from deep aquifers, such as

Table 7.--*Parameter values for SCS method--postmining conditions*

Site	Drainage area (mi^2)	Average basin slope (percent)	CN
A			
A_1	1.32	4.2	77
A_2	.93	4.1	75

Table 8.--*Postmining-runoff volumes* (V_p) *and peak discharges* (Q_p) *for 2-, 10-, 25-, and 100-years precipitation events calculated by the SCS method for sites at Tsosie Swale*

Site	Q_p2 (ft^3/s)	V_p2 (ac-ft)	Q_p10 (ft^3/s)	V_p10 (ac-ft)	Q_p25 (ft^3/s)	V_p25 (ac-ft)	Q_p100 (ft^3/s)	V_p100 (ac-ft)
A								
A_1	5	3.52	48	17.60	92	31.68	157	47.87
A_2	1	1.49	25	9.92	55	18.85	100	29.26

the Cliff House Sandstone, Menefee Formation, or Morrison Formation, is a potential source of water to supplement available, good quality surface water (Hejl, Ong, and Dewey, 1979). Any ground water that is pumped to the surface will be poorer quality than the surface water, but blending of the waters may result in water that is suitable for mining and reclamation uses, such as dust control and irrigation.

A withdrawal rate of 400 gallons per minute from the Morrison Formation would cause a local cone of depression, but would have a negligible regional impact on the quantity and quality of water in that aquifer. Withdrawal from other deep aquifers at rates yielded by one 8-inch well would also not cause a significant regional impact on water in the aquifers.

Erosion

Redistribution of sandy soil materials from deep dunes and from the mesa (fig. 2), so that the whole area would be covered with 2 feet or more of those materials, plus decreasing the slope gradient of the badland areas, will reduce runoff and fluvial erosion after the area is reclaimed. Computations of soil loss using the Universal Soil Loss Equation (SCS, 1977) are shown in table 9 for dune and mesa soils. Soil-loss values shown are for two slope gradients and for reestablished cover of native grasses. Irrigation for at least 1 or 2 years after seeding would be required to establish the cover percentages shown in table 9 by, perhaps, the fifth year after seeding. Aldon (1978) reported on the benefits of straw mulches in preventing wind erosion on seeded mine spoils in New Mexico.

Research is needed to determine if soil erodibility or *K* factors used in the USLE are changed when the soils are disturbed during mining and reclamation operations. If they are changed, an accurate way of evaluating the changed *K* and for monitoring the value of *K* over time is needed. Certainly, the aggregation of soils is likely to be decreased by the moving operations, and the soils are vulnerable to compaction by heavy earth-moving

Table 9.--*Universal Soil Loss Equation computations for assumed soil, slope, and cover conditions after mining and reclamation*

[R = rainfall and runoff factor; K = soil erodibility factor; L = slope length factor; S = slope steepness factor; LS = topographic factor, determined from L and S; C = cover and management factor; P = erosion-control practice factor, value of one in this case]

Soil series	Assumed factors							Annual soil loss[1]	
	R	K	L (ft)	S (percent)	LS	Percent cover	C	tons/acre	acre-ft/mi^2
Doak and Nageezi loams									
(mesa soils)-------------	20	0.4	500	10	3.7	40	0.1	2.96	[2]1.18
	20	.4	500	2	.33	40	.1	.26	[2].11
Shiprock sandy loam									
(dune soils)-------------	20	.24	500	10	3.7	50	.065	1.15	[3].42
	20	.24	500	2	.33	50	.065	.10	[3].04

[1]Annual soil loss in tons/acre is the product of RK(LS)CP.

[2]A specific weight of 1,600 ton/acre-ft was used.

[3]A specific weight of 1,750 tons/acre-ft was used.

equipment when they are repositioned over the graded soils. It is not known how completely the compaction is released by tillage operations, such as chiseling, ripping, or furrowing, nor is it know how long it would take natural processes, such as wetting and drying, to return the soils to normal uncompacted states. Monitoring of soil bulk density and permeability in an area undergoing reclamation would shed some light on the subject.

A nomograph developed by Wischmeier, Johnson, and Cross (1971) may be useful for computing the *K* factors of replaced soils. Information about organic matter content and particle-size distribution, as well as information about the structure and permeability of the soils in place, and over time after placement, is necessary to effectively use the nomograph. Work by Gee, Gilley, and Bauer (1976) and by Young and Mutchler (1977) indicate that disturbances of soils that affect the degree of aggregation of soils cause the *K* factors to change. These effects are only partially accounted for in the nomograph. Investigations with rainfall simulators, such as those reported by Gilley and others (1977), on various soils would provide another means of evaluating *K* factors on areas that have been mined and reclaimed. Also, periodic use of rainulators on slopes during reclamation when the soils are reaggregating and vegetation is establishing would verify the use of the USLE on mined areas.

Data on channel erosion and on deposition rates in sedimentation reservoirs from areas representative of the permit area are needed to assess the reliability of estimates of delivery ratios and sediment yields for mined and reclaimed areas. This is true whether the USLE or other methods are used for evaluating sediment yield. Channel erosion would be best monitored by repeat surveys of monumented cross sections. A topographic survey of a sedimentation pond immediately after completion is the best approach in monitoring sedimentation rates.

Sediment yield

During mining and reclamation, any flows from the permit area will have to be impounded until the sediment concentration decreases enough to meet Federal regulations (Federal Register, Mar. 13, 1979). All flows can be expected to have sediment concentrations exceeding 45 milligrams per liter.

Examination of the reconstructed topography map (fig. 9) indicates that the lower soil-loss rates for mesa and dune soils in table 9 would be applicable to about 90 percent of the area of Tsosie Swale basin with slope gradients of about 2 percent, and the higher rates to about 10 percent of the basin with slope gradients of about 10 percent. If it is assumed that 35 percent of the area would be covered by Doak and Nageezi soils and 65 percent by Shiprock and similar soils, the weighted-average soil loss for the basin would be 0.13 acre-foot per square mile. The sediment-delivery ratio versus drainage area relation of Roehl (1962) gives a sediment delivery ratio of about 0.4 for a basin of that size. Applying this ratio to the weighted-average soil loss results in an annual sediment yield of 0.05 acre-foot per square mile, which translates to 88 tons per square mile using a specific weight of 1,750 tons per acre-foot for sandy sediment.

Certainly, the sediment-yield rate would not be expected to exceed 0.09 acre-foot per square mile, which was the sediment yield measured by the authors using a pond survey at a nearby basin that is completely mantled with sandy materials. That basin has a drainage area of 0.89 square mile and has a much steeper main-channel gradient of 111 feet per mile, compared to 41 feet per mile for the Tsosie Swale basin.

RECOMMENDATIONS FOR RESEARCH

The Universal Soil Loss Equation (USLE) is suitable for estimating soil loss from slopes in mined areas, and can be used with an appropriate sediment-delivery ratio to estimate the sediment yield from a drainage basin. In this investigation, we discovered that 1:24,000 scale topographic maps with 20-foot contour intervals are inadequate for determining slope gradients and slope lengths. Maps that are 1:12,000 scale or larger with contour intervals of 10 feet in steep areas and 5 feet in flatter areas may be adequate in most places. A research effort is needed to develop a relationship for estimating sediment-delivery ratios for mined areas.

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

A related problem needing research is in regard to application of the SCS method, or any method that requires infiltration values to evaluate peak discharge and volume of discharge from a mined basin. The effects of several factors on infiltration rates need to be quantitatively defined. These factors include: (1) soil mixing, (2) breakdown of aggregates, (3) any layering that may occur during replacement, (4) compaction (bulk density), and (5) tillage treatments to alleviate compaction.

A number of types of data for mined areas are scarce, completely lacking, or not readily accessible, thus making it difficult to evaluate the hydrologic effects of mining and reclamation. If data were available for mines where reclamation is progressing, hydrologic relationships 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 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 of sufficient scale and contour interval to allow accurate measurements of slope and channel lengths and gradients, and delineation of closed depressions.

(2) Amounts of soil moisture and associated vegetation (cover and weight) for various landforms and for various soil types.

(3) Infiltration, quantity and quality of runoff, and sediment yield from microwatersheds on various landforms.

(4) Bulk density, organic-matter content, degree of aggregation, and amount of cover on these microwatersheds.

(5) Data for drainage basins in reclaimed areas.

(a) Quantity and quality of surface water, including sediment concentrations.

(6) Quantity and quality of ground water, including recharge and discharge.

(7) Channel erosion and deposition in diversion channels and below sedimentation ponds.

(8) Deposition rates in sedimentation ponds to provide reference sediment yields with which to evaluate sediment-delivery ratios.

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Appendix I

Vegetation and Soil-Water Relations Data for Tsosie Swale Basin

The values within figures 12 through 14 are depths of water, in milliliters, that can be contained in the soil profiles between the indicated water-content levels. VMC is void-moisture capacity, MRC is moisture-retention capability, and MS is minimum annual storage.

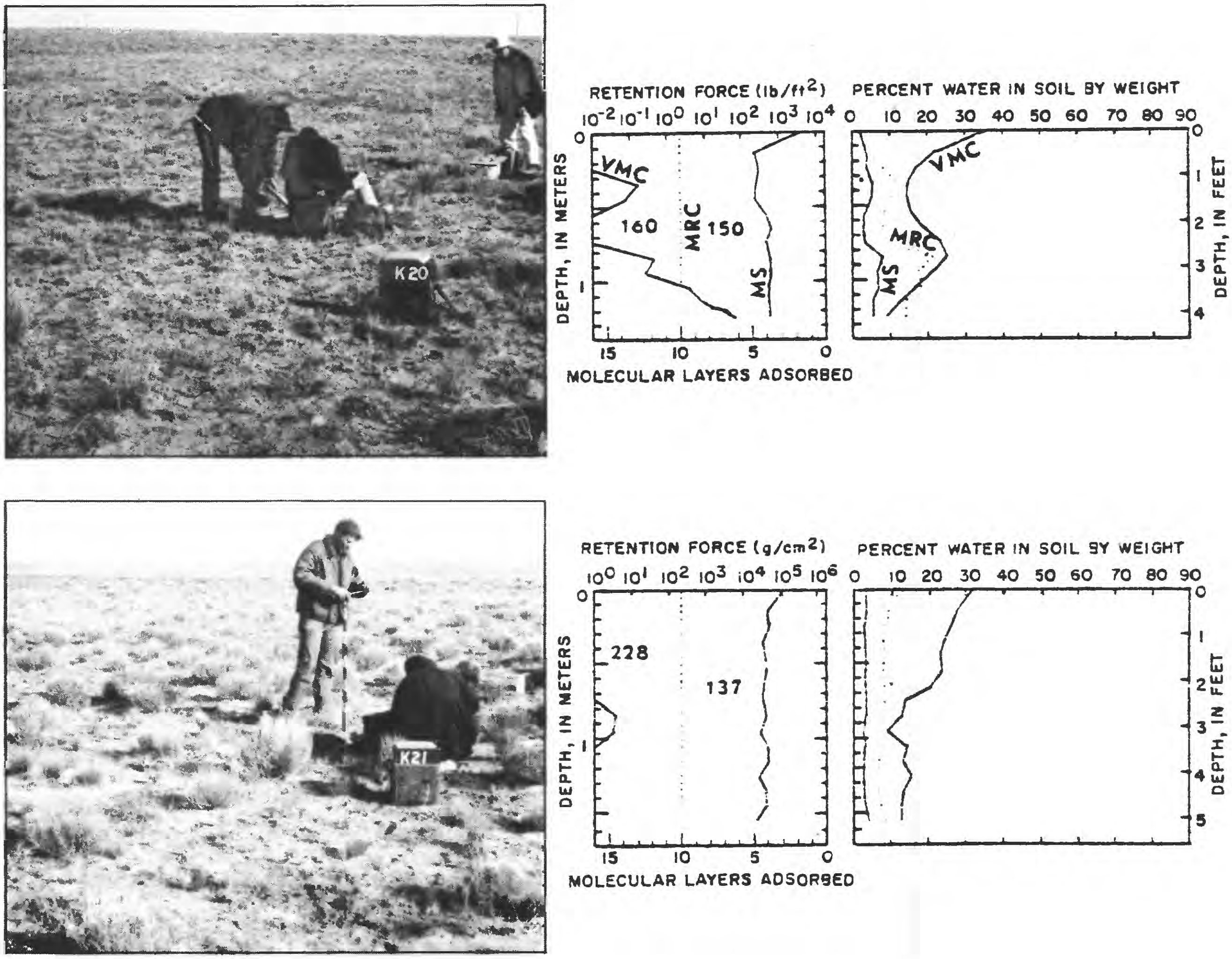

Figure 12.--Moisture relations in soils for sites on mesa. Views are toward south. October, 1976.

Table 10.--*Percent cover and bare soil at mesa sites*

Latin name	Common name	Site 20 Cover (Percent)	Site 21 Cover (Percent)
Shrubs			
Artemisia tridentata	Big sagebrush	0	0
Chrysothamnus greenei	Greenes rabbitbrush	4	15
Gutierrezia sarothrae	Broom snakeweed	0	3
Opuntia polycantha	Plains pricklypear	1	0
Grasses			
Bouteloua gracilis	Blue grama	7	7
Hilaria jamesii	Galleta	37	16
Forbs			
Salsola kali	Russian thistle	10	3
	Unidentified forbs	2	0
Total live cover		61	44
Mulch		0	0
Bare soil		39	56

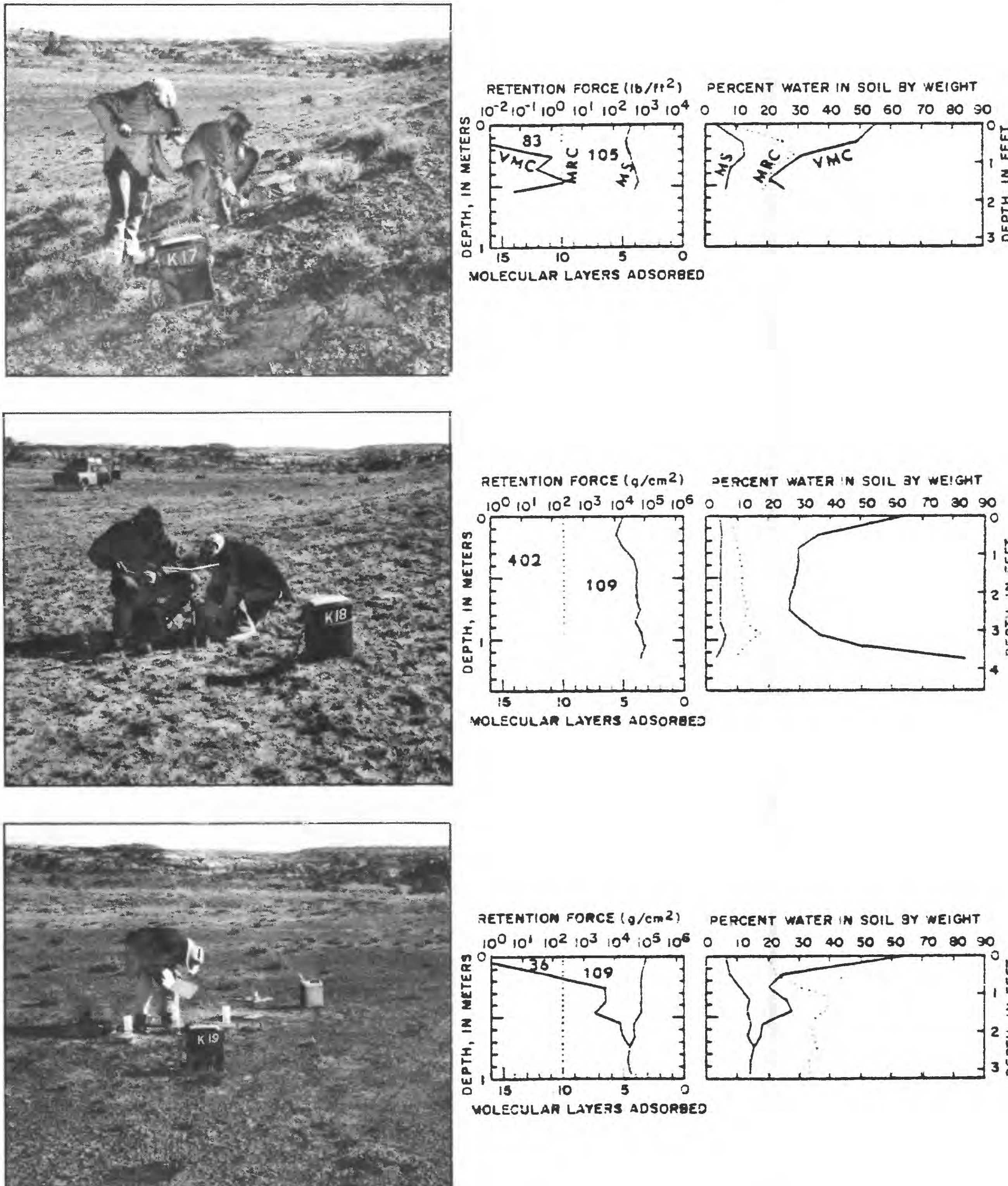

Figure 13.--Moisture relations in soils on hillslopes. Site 17 has a residual soil; sites 18 and 19 have alluvial soils. Views are all toward northwest. October, 1976.

Table 11.--*Percent cover and bare soil at slope sites*

Species		Site		
Latin name	Common name	17	18	19
Shrubs				
Atriplex confertifolia	Shadscale	17	0	0
Atriplex obovata	Broadscale saltbush	0	0	28
Grasses				
Hilaria jamesii	Galleta	6	22	0
Sporobolus airoides	Alkali sacaton	12	20	1
Forbs				
Salsola kali	Russian thistle	3	1	0
-----	Unidentified forbs	0	0	1
Total live cover		38	43	30
Mulch		0	0	0
Rock		40	8	23
Bare soil		22	49	47

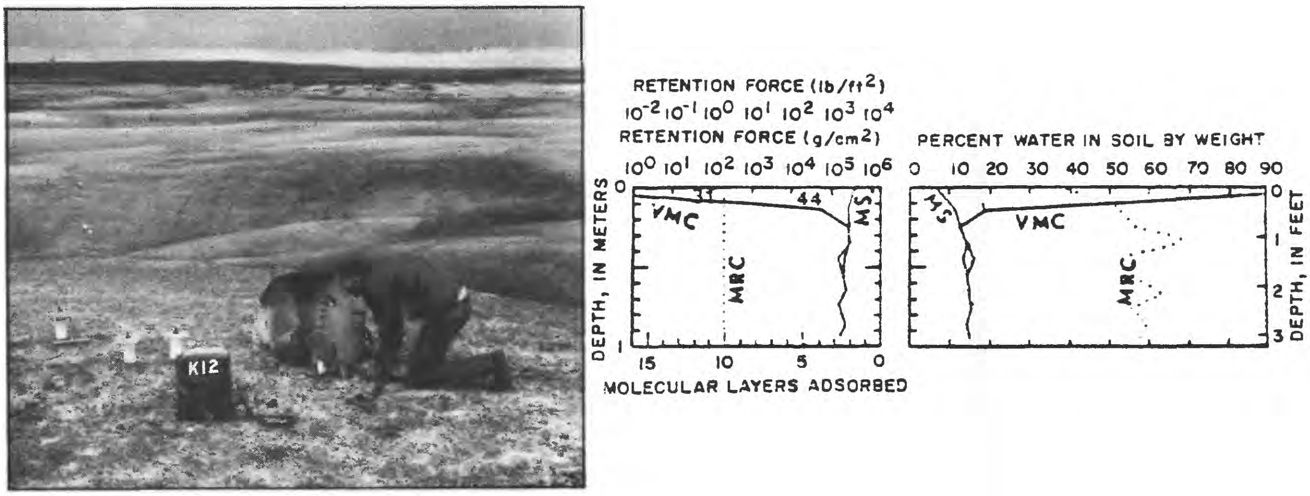

Figure 14.--Moisture relations for a soil on a bentonite bed in the badlands. View is toward north. October, 1976.

Table 12.--*Percent cover and bare soil at badland site*

Species	Site 12 Cover (Percent)
Shrubs-------------------------	0
Grasses------------------------	0
Lichen-------------------------	11
Total live cover----------	11
Mulch---------------------	0
Rock----------------------	9
Bare soil-----------------	80

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