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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

METHODOLOGY FOR HYDROLOGIC EVALUATION OF A POTENTIAL SURFACE MINE: EAST TRAIL CREEK BASIN, BIG HORN COUNTY, MONTANA

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

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CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSION FACTORS

U.S. customary	Multiply by	International system
acres	4.047×10^{-1}	square hectometers
	4.047×10^{-3}	square kilometers
acre-feet	1.233×10^{3}	cubic meters
cubic feet per second	2.832×10^{-2}	cubic meters per second
cubic feet per second per square mile	1.093×10^{-2}	cubic meters per second per square kilometer
feet	3.048×10^{-1}	meters
feet per mile	1.894×10^{-1}	meters per kilometer
feet-tons per acre per inch	1.735×10^{-1}	megagram-meters per square hectometer per millimeter
gallons per minute	6.309×10^{-2}	liters per second
inches	2.540×10^{1}	millimeters
	2.540×10^{-2}	meters
miles	1.609	kilometers
millibars	1.020	grams per square centimeter
pounds per cubic foot	1.602×10^{-2}	grams per cubic centimeter
square miles	2.590	square kilometers
tons	9.072×10^{-1}	megagrams
tons per acre	2.242	megarams per square hectometer
tons per square mile	3.503×10^{-1}	megagrams per square kilometer

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

ABSTRACT

Permit applications made to the Office of Surface Mining 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 about 1,990 acres near the junction of Trail Creek and East Trail Creek, and the adjacent area in the drainage basin of East Trail Creek, about 30 square miles, Big Horn County, Montana. The study area is representative of the hydrologic problems that exist in a semiarid environment of the northern Great Plains.

The premining hydrology and geology of the study area are described primarily as a basis for evaluation of potential changes that may occur. Data for soil-moisture relations in seven soil-vegetation types show that differences in void space and surface available for water storage are important factors in planning reclamation. Estimates are also made of runoff volumes and peak discharges for flow magnitudes of specified recurrence intervals using a parametric model developed for the State of Montana. The shallow aquifers and their hydraulic characteristics are described in the study area. Methods for estimating erosion and sediment yield in the study area by means of the Universal Soil Loss Equation (USLE) and reservoir sedimentation surveys are described.

Changes in topography that may occur with the removal of coalbeds and replacement of the overburden are shown to be generally minimal. The postmining peak discharges before revegetation may be 2 to 6 times greater than the premining discharges and runoff volumes may be 2 to 3 times greater than premining volumes. However, after vegetation is reestablished, postmining discharges and volumes may be less than the premining values. Soil loss per acre is estimated to be about 27 percent less after mining and reclamation because of elimination of short steep slopes and the increase in vegetation cover after the fifth year of reclamation. Changes in ground-water levels will be greatest to the east, upgradient from any potential surface mine. However, replacement wells could be completed at greater depths.

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, March 13, 1979). This report considers methodology for assessing the effects of mining and reclamation on the hydrologic system of a 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. The East Trail Creek site in the Tongue River basin of southeastern Montana is representative of the northern Great Plains and is the demonstration site used in this report (see location map, figure 1).

This report is one of a series of three reports that present methodology for assessing effects of surface mining and reclamation on the hydrologic system of a mined area. One of the other reports (Frickel and others, 1981) addresses a potential mine site in the semiarid Great Divide basin of south-central Wyoming. Another report (Shown and others, 1981) pertains to a potential mine site in the arid part of the San Juan basin in northwestern New Mexico.

Objectives and Scope of Report

The primary objective of this report is to provide regulatory authorities with examples of methodologies which can be used to assess 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 and to define their limitations; some consistency

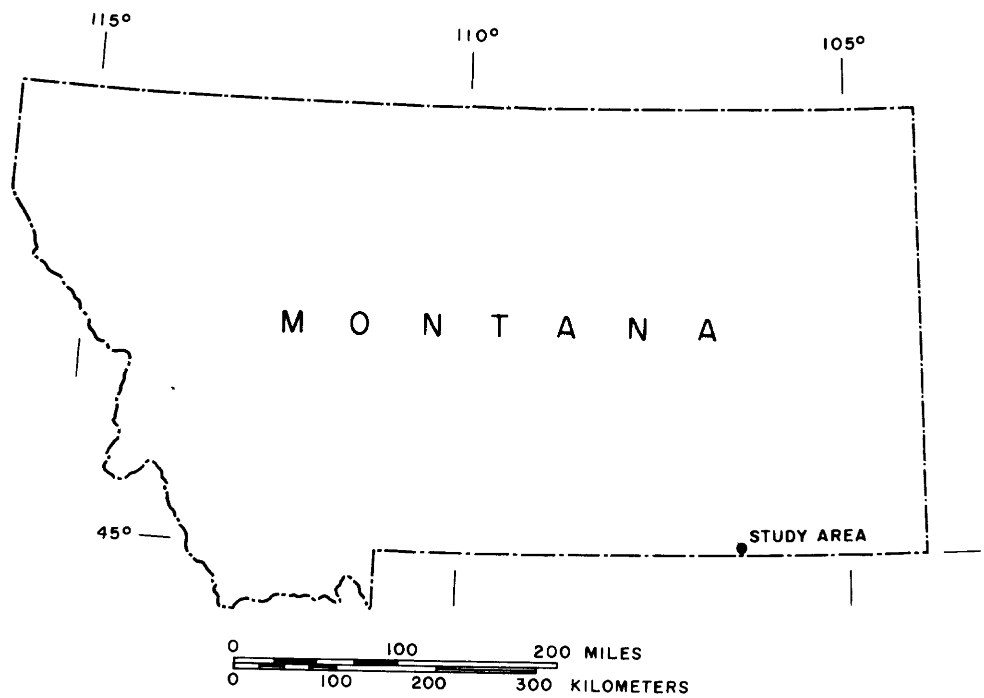


Figure 1.--Index map of Montana showing location of study area.

then can 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 that 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, 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, 1979, p. 15317). The permit area and the adjacent area comprise the study area.

The authors have designated an arbitrary permit area near the mouth of East Trail Creek (plate 1) and the adjacent area as the remainder of the East Trail Creek basin, upstream from the permit area. A potential for adverse impacts to the hydrologic system exists throughout the drainage basin.

Location

The permit area selected for a demonstration of hydrologic assessent methods is located in T. 8 S. and T. 9 S., R. 43 E. and R. 44 E., Big Horn County, Montana (plate 1). The permit area occupies about 1,990 acres (3.1 square miles near the junction of Trail Creek and East Trail Creek (plate 1)). The adjacent area is the remainder of the East Trail Creek basin that lies upstream from the permit area; it occupies about 30 square miles.

Topography

The topography of the permit area is made up of a dissected plateau with moderately steep valley-side slopes and flat interstream ridges. Slopes along the valley margins are moderate where alluvial fans and colluvial deposits have been deposited. Valley floors are relatively flat where alluvium has been deposited, although the stream gradients are relatively steep. The drainage pattern in the flat-lying, sedimentary rocks is predominantly dendritic.

Geology and Coal Resources

The geology of the study area has been mapped (Culbertson and Klett, 1979). Rocks exposed on the surface are the Tongue River Member of the Fort Union Formation of Paleocene age, and the overlying Wasatch Formation of Eocene age. The Wasatch Formation crops out along the drainage divides on the perimeter of the basin. Both rock formations are composed of sandstone, siltstone, shale, and coal beds, and are nearly flat-lying. The valley floor of East Trail Creek is underlain by alluvium, which is 30 to 40 feet thick, and is composed of unconsolidated sand, silt and clay (fig. 2).

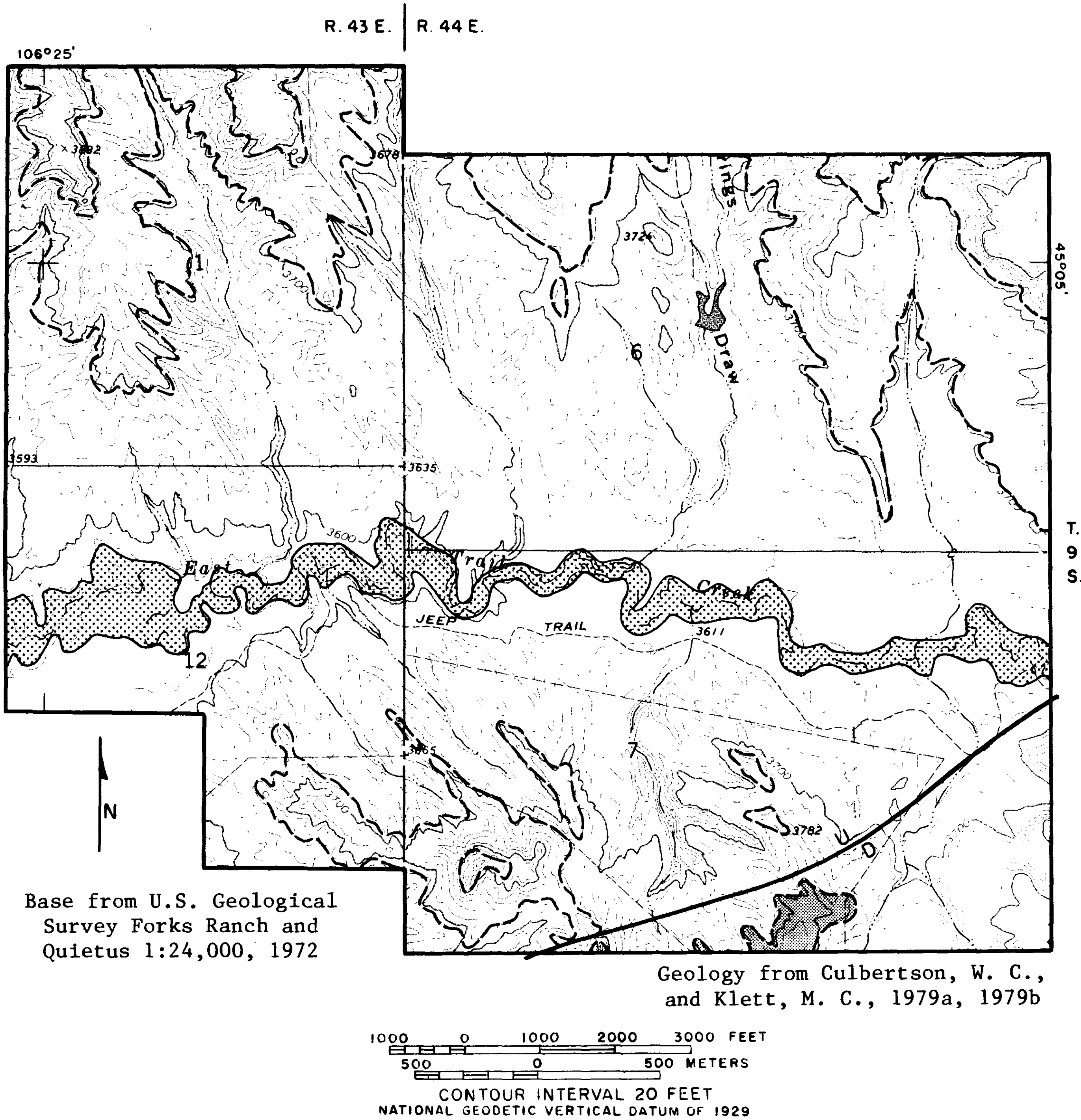
Coal-bearing rocks in the East Trail Creek basin comprise all of the Tongue River Member of the Fort Union Formation and the lower part of the Wasatch Formation. The principal coal bed in the Fort Union Formation is the Anderson coal bed, which is 26 to 33 feet thick in the study area. The Dietz coal bed, which is 9 to 12 feet thick, also may be recoverable and it is 50 to 100 feet below the Anderson coal bed. The coal beds above the Anderson bed are, in general, thin or of poor quality, or of limited extent.

Coal-bearing strata are nearly flat-lying except in the vicinity of a large northeast-trending normal fault that passes through the study area (fig. 2). Rocks on the south side of the fault have been displaced downward as much as 260 feet. The Anderson coal bed is so deep southeast of the fault that only a narrow strip adjacent to the creek bottom is under less than 200 feet of overburden (Culbertson and Klett, 1979a, 1979b).

Soils and Vegetation

The area has surprisingly diverse vegetation for the relatively low annual precipitation, about 15 to 20 inches. Geologic, edaphic, and topographic factors contribute to this diversity. Soils range from sandy to clayey and deep to shallow, and slopes range from flat to steep. In response to these factors, such diverse vegetation types as non-salt-tolerant, non-drought-tolerant ponderosa pine savannah, and drought and salt-tolerant shadscale occur within a few tenths of a mile. Vegetation species typical of montane habitats to the west, and of the Great Plains to the east, and of salt-desert-shrub areas to the southwest of the study area are present.

High, flat tablelands that form some of the drainage divides have sandy to loamy soils that have developed from a sandstone capping



EXPLANATION

Fault. U, upthrown side; D, downthrown side

Outcrop trace of coalbed

Quaternary alluvium. Unconsolidated sand, clay, and gravel

Wasatch Formation of Eocene age. Sandstone, siltstone, shale, and coalbeds

Tongue River Member of Fort Union Formation of Paleocene age. Sandstone, siltstone, shale, and coalbeds

Figure 2.--Geologic map of the permit area.

material. These ancient soils have stands characterized by needle-and-thread and big sagebrush (figs. 3 and 4 and table 1). Other abundant species present are western wheatgrass and blue grama.

Ponderosa pine-bluebunch wheatgrass typically occurs just below the perimeter of the tablelands (fig. 3 and 4). Coarse-textured soils of this site have developed in colluvium formed as the tablelands have been reduced in areal extent by geologic erosion. Species present here, that are common in more moist portions of the eastern Great Plains, are little bluestem and sideoats grama.

Two mapping units are shown (fig. 3) for midslopes between the ponderosa pine-bluebunch wheatgrass type and western wheatgrass-silver sagebrush type on the alluvial valley floor. The main criterion for separating the big sagebrush-blue grama type from shadscale-greasewood type was the larger amount of bare soil exposed in the latter. Also, the shadscale-greasewood type usually occurs on steeper slopes that represent the more highly erodible clay and silty shale beds of the Fort Union Formation.

Sampling sites 1 and 7 (fig. 3) were in the big sagebrush-blue grama type. Vegetation yields were medium to low. In general, the type may be described as a grassland with scattered shrubs.

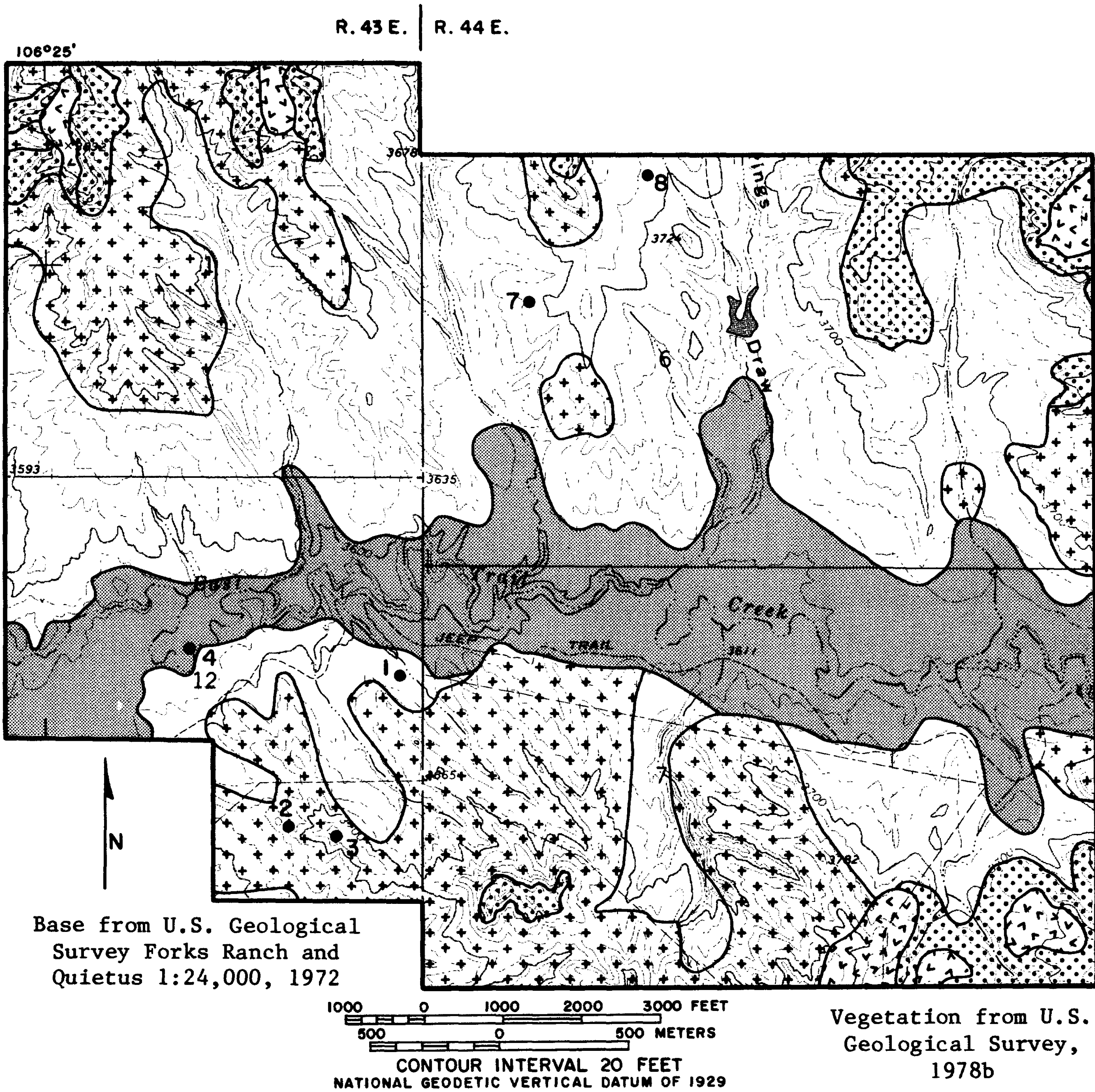
Sampling sites 2 and 3 (plate 1) were in the shadscale-greasewood type; productivity of this type, in pounds per acre, is higher than might be expected. Range condition, or species composition in relation to climax vegetation, is lower than for most other types. More shrub species occur on these sites than in other plant communities.

The most productive of the plant communities sampled, the western wheatgrass-silver sagebrush (site 4, plate 1), occurs on alluvium along the major drainages. Occasional flooding and shallow ground water contribute to high productivity and produce excellent range condition.

Using a weighted average based on extent of vegetation types and carrying capacity for each, it is estimated that about 13,000 acres of this land would be required to support 300 cows, with some additional development of hay meadows.

Climatological Information

Climatological information that may be requested by the regulatory authority in a permit application is listed in subchapter G, part 779.18 of the Surface Coal Mining and Reclamation Regulations (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 on precipitation amounts for storms of selected recurrence intervals and durations to



Base from U.S. Geological Survey Forks Ranch and Quietus 1:24,000, 1972

Vegetation from U.S. Geological Survey, 1978b

EXPLANATION

Big sagebrush–blue grama; western wheatgrass, needle-and-thread, and bluebunch wheatgrass abundant in places.

Shadscale–greasewood; steep slopes with shallow soils.

Western wheatgrass–silver sagebrush.

Needle-and-thread–big sagebrush.

Ponderosa pine–bluebunch wheatgrass.

Figure 3.--Vegetation map and sampling locations on permit area.

determine erosion rates; data on snowfall depths and water content; and data on the length of the growing season or frost-free period to assess reclamation potential.

The East Trail Creek basin, in which the permit area is located, is influenced by continental climate and convective thunderstorms in the summer months. The nearest weather station is Otter 9SSW, which is located about 1.5 miles northeast of the basin (NE¼, sec. 31, T. 8 S., R. 45 E.) at an elevation of 4,100 ft (NGVD of 1929). This station is located in terrain similar to the permit area and adjacent area; their records for the period 1961 through 1976 are used to characterize the climate of the study area.

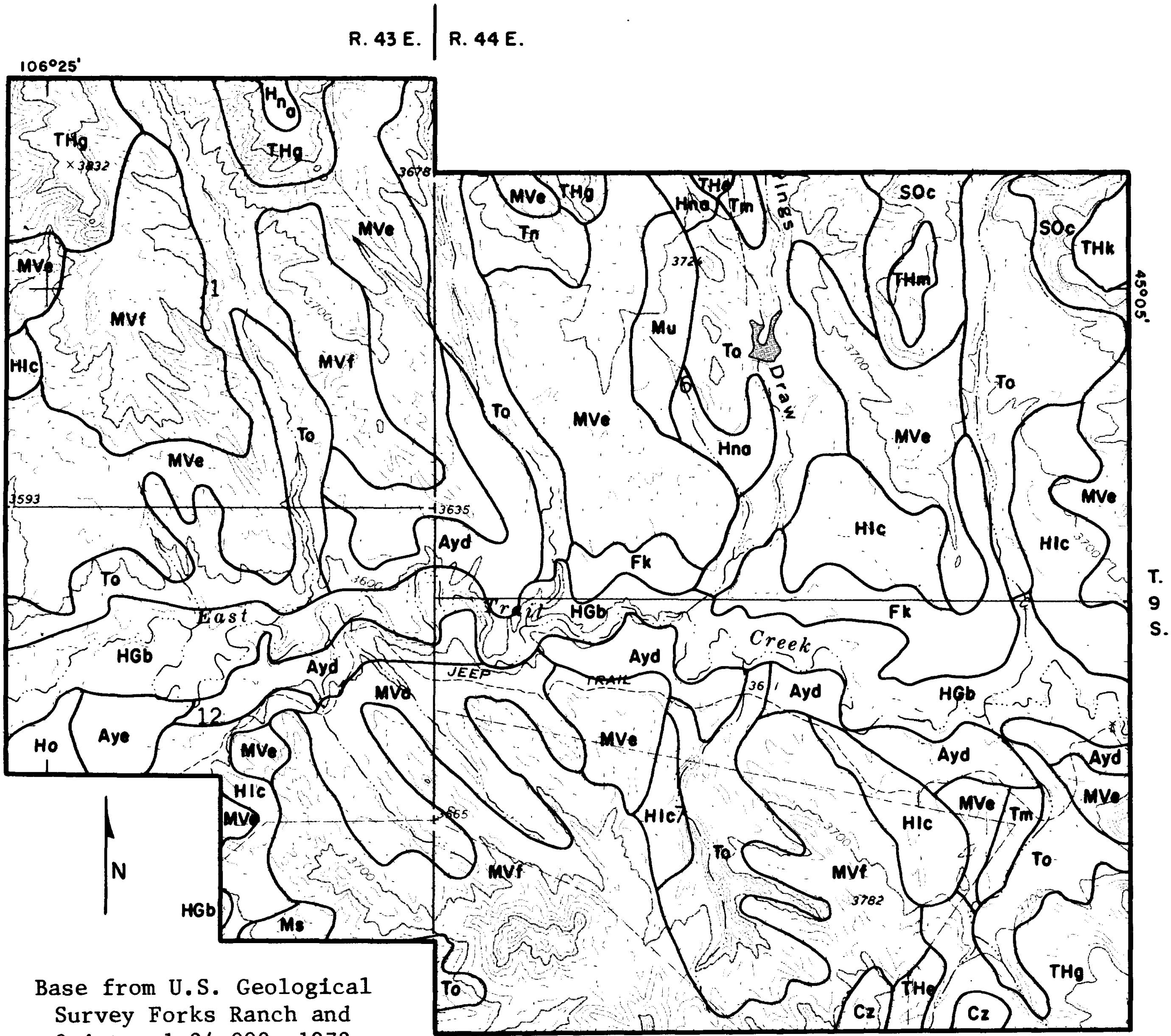
The mean annual precipitation for the station Otter 9SSW is 18.9 inches, with the wettest months being April, May, and June when a total of 8.87 inches fall. For purposes of reclamation, definition of the growing season is the logical way to divide the year; the growing season is generally considered to be the period when temperatures favor plant growth (Toy and Munson, 1978). In the East Trail Creek basin, the mean length of growing season is about 124 days from May 21 to September 20 or the interval between the last spring frost and the first fall frost (Toy and Munson, 1978). Length of growing season is influenced by topography, exposure, and altitude, but the mean value is a reasonable index in evaluating reclamation potential. Mean growing season precipitation at Otter 9SSW is about 9.5 inches.

Monthly temperature averages and extremes are shown in figure 5 (U.S. Bureau of Land Management, 1978). Mean monthly temperature minimums are greater than 32°F in May through October for Otter 9SSW. There are only 3 months--June, July, and August--when no temperatures below 32°F have been recorded.

Intensity of precipitation is more important to individual flood peaks and volumes and erosion rates than total precipitation amount. Therefore, the 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.

PREMINING HYDROLOGY OF THE STUDY AREA

Assessment of hydrologic processes in a semiarid 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 30 to 40 inches annually. For example, it is common for basins that receive 12 to 15 inches of annual precipitation to yield less than 0.5 inches as streamflow, and even less as recharge to ground-water aquifers. Most of the annual precipitation falling on a potential



Base from U.S. Geological Survey Forks Ranch and Quietus 1:24,000, 1972

Soils from SCS, 1977b

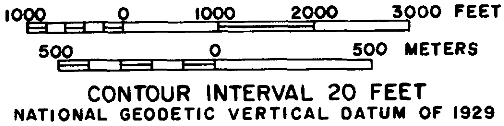


Figure 4.--SCS soils map of the permit area.

Table 1.--*Explanation for Soil Conservation Service (SCS) soil survey map shown in figure 4*

Ayd	Arvada silty clay loam
Aye	Arvada-Bone clays
Cz	Cushman loam, undulating
Fk	Fort Collins loam, 2 to 4 percent slope
HGb	Haverson and Lohmiller soils, channeled
Hlc	Heldt silty clay loam, 4 to 8 percent slope
Hna	Hydro loam, 0 to 8 percent slope
Ho	Hysham loam, 0 to 2 percent slope
Ms	McRae loam, 4 to 8 percent slope
Mu	Midway silty clay loam, undulating
MVa	Midway silty clay loam, rolling
MVe	Midway-Thedalund complex, rolling
MVf	Midway-Thedalund complex, hilly
SOc	Shale outcrop-Midway complex, steep
THe	Thedalund-Midway complex, rolling
THg	Thedalund-Rock outcrop complex, hilly
THk	Thedalund-Travessilla loams, rolling
THm	Thedalund-Wibaux complex, rolling
Tm	Thurlow silty clay loams, 1 to 4 percent slope
Tn	Thurlow silty clay loam, 4 to 8 percent slope
To	Thurlow-Midway silty clay loams, 4 to 15 percent slope

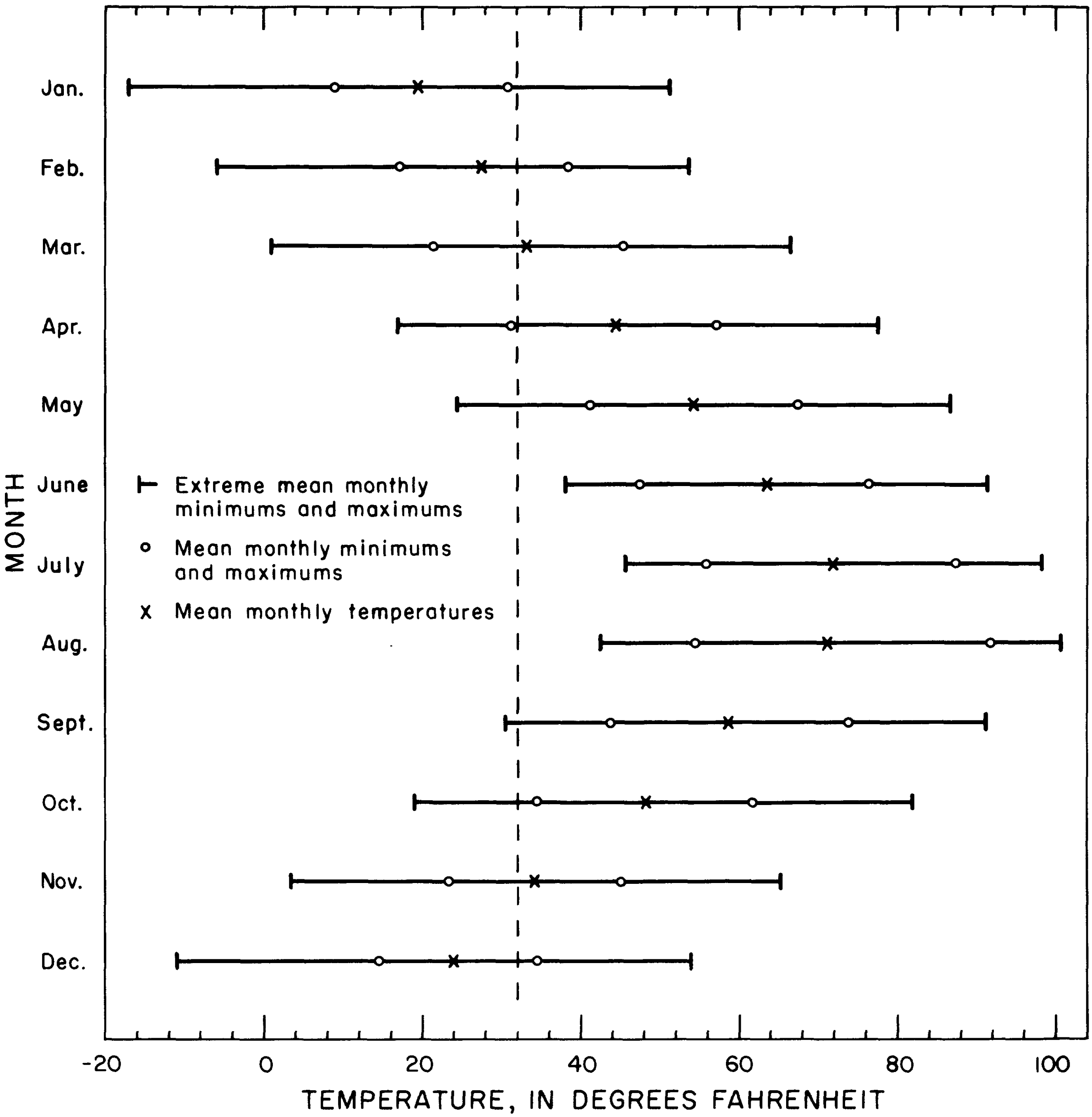


Figure 5.--Mean monthly extremes, mean monthly minimums and maximums, and mean monthly temperatures at Otter 9SSW, 1961-1976 (adapted from U.S. Bureau of Land Management, 1978).

Table 2.--*Estimated precipitation amounts, in inches, for selected storm recurrence intervals and durations for East Trail Creek basin, Montana**

Storm duration	Storm recurrence, years					
	2	5	10	25	50	100
	Precipitation amount, inches					
30 minutes	0.51	0.75	0.87	1.10	1.30	1.40
1 hour	.65	.95	1.10	1.40	1.60	1.80
3 hours	.79	1.10	1.28	1.62	1.85	2.00
6 hours	.95	1.25	1.50	1.90	2.10	2.35
12 hours	1.20	1.48	1.88	2.23	2.52	2.70
24 hours	1.30	1.80	2.20	2.70	2.90	3.30

*(From Miller, J. F., Frederick, R. H., and Tracey, R. J., 1973)

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 efficient use of soil moisture is important for reclaiming disturbed areas, by increasing reestablishment of plant cover and reducing erosion.

Hydrology of the Permit Area

Moisture Relations in Soils

Moisture regimens in soils, which function as reservoirs for water used by native vegetation, are a product of the semiarid climate characteristic of the East Trail Creek study area. Approximately one-fourth of the moisture arrives as snow during the period when vegetation is dormant (U.S. Department of Agriculture, 1941). 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 spring and early summer rains. Peak storage probably occurs near the end of the snowmelt period. 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.

The 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 that the 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 of the voids in the soil are filled. Void-moisture capacity is computed from the volume weight using the following equation and assuming that the specific gravity of the soil particles is 165.44 lb/ft^3:

$$VMC = (\frac{62.4}{VM} - 0.377)\ 100$$

where

VMC is the void-moisture capacity, in percentage of dry soil weight, and
VW is the soil volume weight, in pounds per cubic foot.

This relationship is presented graphically in figure 6. 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 7, has one-half the adsorptive surface per unit of weight as 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 sample of soil 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 $10^{4.40}$ lb/in^2 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 $10^{3.15}$ lb/in^2.

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 .01422 lb/in^2. Drainage continues to the moisture-retention capability (MRC) level where 10 molecular layers remain adsorbed and the retention force is 3.16 or $10^{.50}$ lb/in^2. The retention force increases from $10^{-1.85}$ to $10^{-1.46}$ and gradually to $10^{-1.04}$, $10^{-.28}$, and finally to 3.16 lb/in^2 as drainage slows proportionately. The final large increase results in drainage becoming insignificant at the MRC level where the retention force is

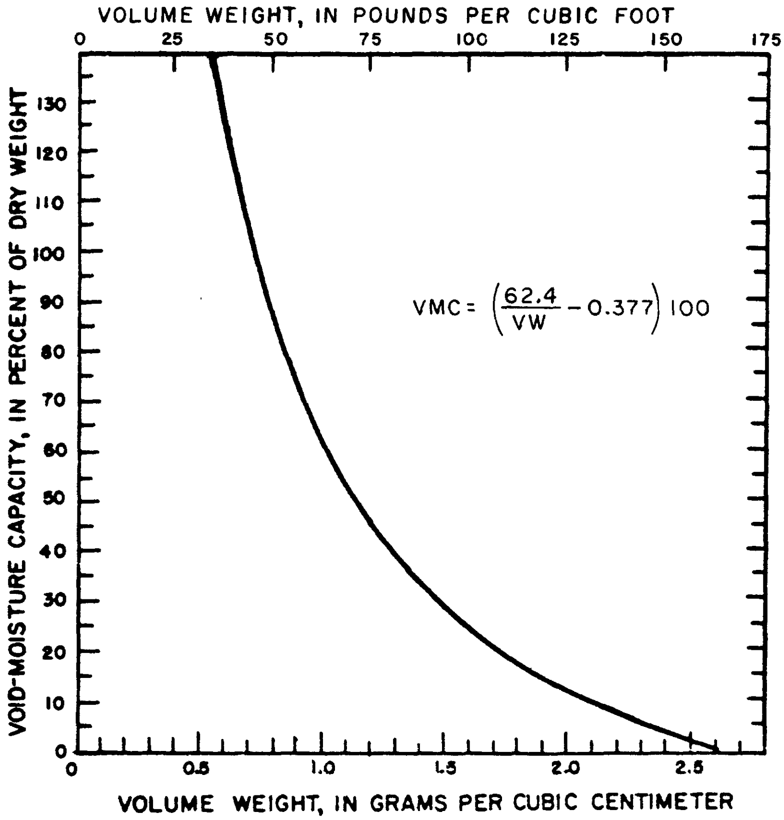


Figure 6.--Relationship used to determine void-moisture capacity (VMC) of soils from volume weight (VW).

$10^{.50}$ or 3.16 lb/in^2. During this process, the retention force increases 2.46 times as each molecular layer of water is desorbed. The logarithm, base 10, 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 average size of voids 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. 8) that permits estimation of rates of infiltration within plus or minus 0.35 in/hr. Since void size and adsorptive surface are controlling factors, the relationship is applicable anywhere.

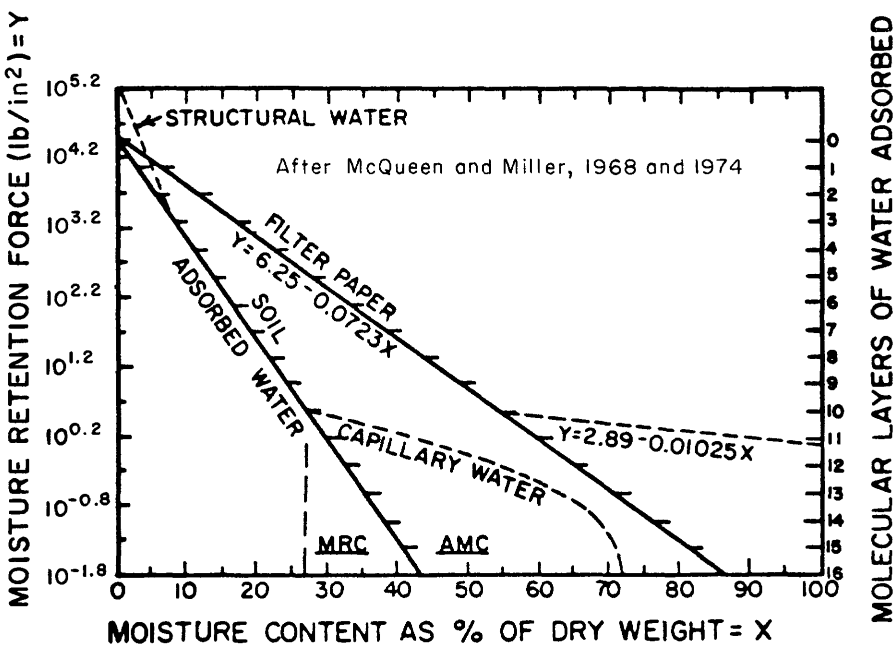


Figure 7.--Calibration relationships for determining moisture-retention force from moisture content of standard filter papers at equilibrium with moisture in samples of soil, and graph illustrating similar relations in soil with one-half the adsorptive surface.

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 as shown in figures 15 through 21 (Appendix I). Adsorbed moisture (AMC) 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 depth of the soil increment. The result is the amount of water expressed as a depth of water in inches (in).

Study Sites

Soils associated with plant communities occupying the various habitats occurring naturally in the area were sampled. Locations of the sampling sites are shown in figure 4. All the measurements required to

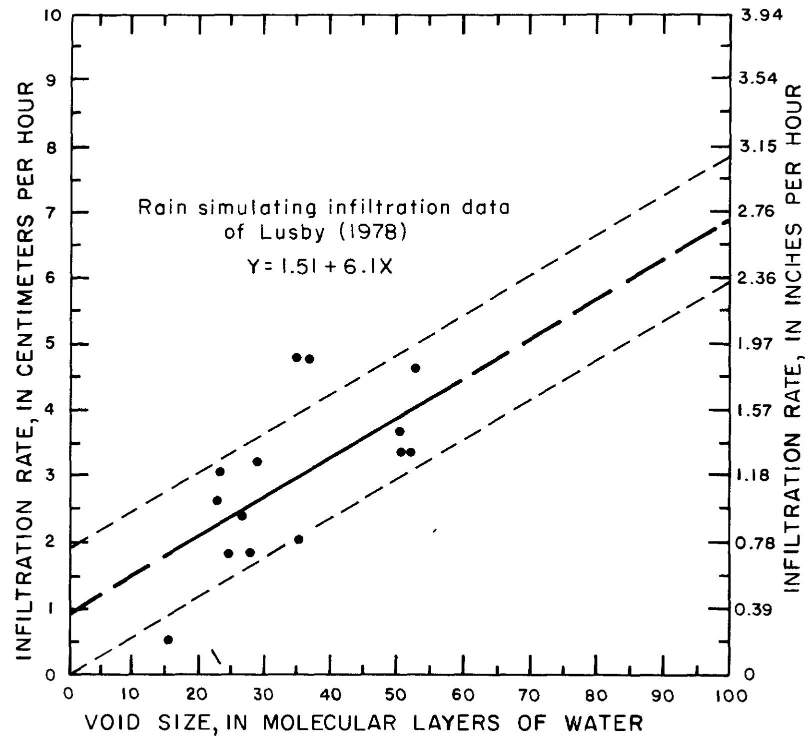


Figure 8.--Relationships between size of voids and rate at which water infiltrates into soils.

define moisture relations were obtained using the method of McQueen and Miller (1968).

Habitats ranging from flood plains to hilltops were sampled in the East Trail Creek study area. Sites are grouped on the basis of gross similarities in geomorphic position so that soil variables influencing use of water by vegetation could be determined. This information will be useful for determining if factors essential to reproducing the habitat can be reestablished when soil materials are repositioned after coal has been removed. Some soil conditions are such that more productive habitats can be created by reconstructing soils in a different manner following completion of mining.

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 along a transect 100 paces long. The data for cover and average moisture-retention forces at the time of sampling are summarized in Appendix I.

Surface Water

Runoff volume and peak discharge measurements are not usually available for streams that traverse potential mine sites; estimated flow 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, adequate rainfall and discharge data are not available during the early stages of a project, when the model is needed for planning. These models also require considerable data to describe the watershed, and use large blocks of computer time. Persons applying these models must be skilled in computer programming, mathematics, modeling techniques, and hydrology. Physical-process models are most useful for extending length of streamflow records and predicting effects of changes 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, require statistical techniques to relate physical characteristics of a watershed to hydrology. Geometric, geomorphic, land use, and climatic characteristics are used most often because they are readily available. These models are developed with data from numerous sites in a relatively homogeneous area, and are used to predict flow characteristics at ungaged sites. Models can be developed that predict either streamflow peaks and volumes, but volume data often are unavailable, especially for smaller watersheds. Accuracy of these models is a measure of how well selected watershed characteristics describe streamflow characteristics. Accuracy is usually expressed as the statistical standard error. Model accuracy also depends on the accuracy of input data and hydrologic homogeneity of the area of regionalization. In using a parametric model at an ungaged site, it is important that the size of the ungaged watersheds be within the size range of watersheds used to develop the model. While parametric models are not as versatile as physical-process models, they are relatively easy to use and often provide all the needed information.

One type of 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, the authors believe that channel dimensions, after an appropriate transition period, reflect changes in the flow regime caused by land use changes and stream regulation. However, the relative effect of the several processes which form 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). Use of these equations requires field training to identify the same reference levels that were used to develop the equations. Channel geometry provides a rapid method of estimating streamflow characteristics at ungaged sites with reasonable accuracy, especially on perennial streams.

The U.S. Geological Survey has numerous publications which describe parametric models for estimating magnitude and frequency of floods for various areas using both watershed characteristics and channel geometry measurements. Some that may have application at East Trail Creek 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 been modified to more accurately reflect conditions in some States 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 results obtained by this method.

Estimates of Peak Discharges.--Premining stream discharges should be estimated with methods that are based on streamflow records, if possible, rather than with empirical formulas. This would usually entail using parametric models developed for a broad geographical area that includes the permit area. Johnson and Omang (1976) have published the following equations for the State of Montana:

$$Q_2 = 2.18\ A^{0.551}\ S^{-0.520}\ p^{1.58}\ F$$

$$Q_5 = 31.7\ A^{0.484}\ S^{-0.553}\ p^{1.08}\ F$$

$$Q_{10} = 112\ A^{0.455}\ S^{-0.576}\ p^{0.860}\ F$$

$$Q_{25} = 388\ A^{0.429}\ S^{-0.597}\ p^{0.640}\ F$$

$$Q_{50} = 855\ A^{0.412}\ S^{-0.611}\ p^{0.503}\ F$$

$$Q_{100} = 1{,}745\ A^{0.396}\ S^{-0.624}\ p^{0.378}\ F$$

where

Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100} are flow magnitudes in cubic feet per second, having the specified recurrence intervals,
A is drainage area above the site, in square miles;
S is main channel slope, in feet per mile;
p is mean annual precipitation, in inches;
F is an areal factor to reduce unexplained variances in the models.

Drainage area (A) and channel slope (S) should be measured on the largest scale topographic maps available. The drainage boundary should be delineated on the map and the area measured with a planimeter. Main channel slope is the slope of the channel between points that are 10 percent and 85 percent of the distance from the desired site to the drainage divide. Above each stream junction, the main channel is the one that drains the largest area. The length measured should be the meander length of the channel, and not the length of the stream valley. The stream should be extended on the map to the basin divide. Certain electronic planimeters can be used to very accurately measure the length of a line. 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.

Mean annual precipitation (p) is the areally-weighted average value for the basin and can be determined from prepared isohyetal maps. Johnson and Omang (1976) provide such maps for Montana. Mean annual precipitation for East Trail Creek basin is 15.8 inches.

Because the same equations are used for the whole State, they give more accurate results for some regions than others. The areal factor, (F), is a coefficient applied to the equations to improve results for the various regions of the State. The value of the coefficient is the average of residuals obtained from the multiple regression process. For East Trail Creek basin, the value of the areal factor, (F), is 0.65 for all equations.

Using the areal factor value of 0.65 and a mean annual precipitation value of 15.8 inches, the equations for East Trail Creek basin reduce to

		Standard error of estimate, in percent
Q_2	$= 111\ A^{0.551}\ S^{-0.520}$	+125 to -55
Q_5	$= 406\ A^{0.484}\ S^{-0.553}$	+108 to -52
Q_{10}	$= 782\ A^{0.455}\ S^{-0.576}$	+108 to -52
Q_{25}	$= 1{,}475\ A^{0.429}\ S^{-0.597}$	+113 to -53
Q_{50}	$= 2{,}227\ A^{0.412}\ S^{-0.611}$	+121 to -55
Q_{100}	$= 3{,}220\ A^{0.396}\ S^{-0.624}$	+130 to -56

The accuracy of these equations is stated as the standard error of estimate, in percent. This is the range of error to be expected as the difference between computed and actual discharges in about two-thirds of the cases. Johnson and Omang (1976) suggest that these relatively high standard errors may be misleading in some cases; omission of two or three data points would significantly decrease the standard error, but would have little effect on the equation.

Hedman and Kastner (1977) have published equations relating streamflow characteristics to channel dimensions for use in the Missouri River basin. The equations that apply to East Trail Creek basin are:

Equation	Standard error of estimate, in percent
$Q_2 = 5.01\ W^{1.497}$	+72, -42
$Q_5 = 21.4\ W^{1.314}$	+41, -29
$Q_{10} = 47.1\ W^{1.212}$	+34, -26
$Q_{25} = 112\ W^{1.101}$	+37, -27
$Q_{50} = 198\ W^{1.027}$	+44, -31
$Q_{100} = 334\ W^{.959}$	+54, -35

where

Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100} are flow magnitudes, in cubic feet per second, having the specified recurrence intervals; and W is channel width at the active channel reference level (see Hedman and Kastner, 1977, for definition of "active channel").

Standard errors of estimate of these equations are considerably lower than those of Johnson and Omang (1976). In developing these equations, some ephemeral and intermittent streams were included and recent studies indicate that the equations give good results for ephemeral streams in Wyoming and Montana (E. R. Hedman, personal communication, 1979). Use of these equations would also eliminate the need to adjust discharges for the affects of stock ponds, changes in land use, and flow regulation. They were not used to estimate discharges in this report because channel width measurements were not available for the East Trail Creek basins.

Hedman and Kastner (1977) also included equations based on basin characteristics (drainage area and 2-year, 24-hour precipitation). These equations have standard errors of estimate similar in magnitude to those of the Johnson and Omang (1976) equations.

For illustrative purposes, discharges were determined at points A through I as shown on plate 1, using the Johnson-Omang equations. East Trail Creek carries basically ephemeral flows, although some reaches experience more persistent but small flows at certain times of the year. Peak discharge estimates shown in table 3 were computed with the Johnson and Omang (1976) equations, using 15.8 inches and 0.65 as value for annual precipitation (P) and the areal factor (F), respectively. The drainage areas and main channel slopes were measured on 1:24,000 scale maps. The estimates were made assuming that flows have not been reduced by detention in stock ponds or diversions for irrigation.

Peak discharges in East Trail Creek are affected by 15 to 20 stock ponds that have been constructed in the basin. These ponds are in generally good condition and control about 38 percent of the basin. Therefore, values in table 3 for sites A, B, and E should be adjusted downward to account for the effect of these ponds. Rigorous analyses of pond capacity, evaporation, and seepage losses, etc., are probably not justified in light of the very high standard errors of estimate associated with the discharges in table 3. A simplified approach as follows should be adequate in this case.

Values in table 3 represent the condition of little or no control in the basin. The other extreme would be total control of the areas above the ponds. In such case, it is assumed that each pond is large enough to always retain all runoff from the area above it, thus reducing the contributing areas to sites A, B, and E by the amount of controlled area. The peak discharges can then be recomputed using the reduced drainage area and the channel slope value listed in table 3. For example, at site A, the drainage area below the ponds is 20.6 square mile and the channel slope is 27 feet per mile, from table 3. The estimated 2-year peak discharge from the area below the ponds is

$$Q_2 = 111\ (20.6)^{0.551}\ (27)^{-0.52} = 105\ \text{ft}^3/\text{s after rounding.}$$

Table 3.--*Estimated peak discharges for sites on East Trail Creek*
[Q = peak discharge, in cubic feet per second]

Site[1/]	Drainage area (mi^2)	Main channel slope (ft/mi)	Flow magnitudes Q_2 (ft^3/s)	Q_{10} (ft^3/s)	Q_{25} (ft^3/s)	Q_{100} (ft^3/s)
A	33.5	27	140	580	930	1,660
B	25.8	36	105	435	700	1,250
C	0.85	102	9	50	85	170
D	1.09	95	11	60	100	185
E	1.41	99	12	65	110	210
F	0.70	212	6	30	50	165
G	0.50	118	6	35	65	125
H	0.39	194	4	25	40	80
I	0.15	136	3	20	35	70

[1/] See plate 1 for location of sites.

Peak discharge estimates for sites A, B, and E under the condition of total control are compared in table 4 with corresponding estimates from table 3. Actual discharges from these sites should fall somewhere between these two values in table 4 depending on how frequently the ponds spill. Ranchers and land managers should be contacted to obtain some idea of how much water ponds normally contain; how often they are empty or full; and what percentage of runoff events cause the ponds to spill. From this information, the degree of control can be determined and discharge values adjusted accordingly. If this information is not available or is considered unreliable, an average of the two values in table 4 may be used. It would seem that the ponds probably spill during less than one-half of the runoff events, and therefore, peak discharges would be most like those of the controlled condition.

Runoff Volumes.--As with peak discharges, estimates of premining runoff volumes should be based on streamflow records, if possible. The only published model for estimating runoff volume in the East Trail Creek area is Hedman and Kastner's (1977) equation for mean annual runoff. It is

	Standard error of estimate, in percent
$Q_A = 77.0\ W^{1.587}$	+58, -37.

Table 4.--*Comparison of estimated peak discharges for controlled and uncontrolled conditions at sites A, B, and E*
[Q = peak discharge, in cubic feet per second]

Site	Uncontrolled flow magnitudes				Controlled flow magnitudes			
	Q_2 (ft^3/s)	Q_{10} (ft^3/s)	Q_{25} (ft^3/s)	Q_{100} (ft^3/s)	Q_2 (ft^3/s)	Q_{10} (ft^3/s)	Q_{25} (ft^3/s)	Q_{100} (ft^3/s)
A	140	580	930	1,660	105	465	755	1,365
B	105	435	700	1,250	75	330	535	975
E	12	65	110	210	5	35	60	125

where

Q_A is the mean annual runoff, in acre-feet, and

W is the channel width at the active channel reference level.

This equation was developed for perennial streams; its use on East Trail Creek, which is only marginally perennial, is not recommended.

Craig and Rankl (1978) developed a relation between peak discharge and volume of runoff from individual runoff events for 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 ft^3/s.

The average standard error of this equation is 55 percent. Because storm hydrographs from basins in the East Trail Creek area are probably very similar in shape to those from nearby Wyoming, this equation can be used to estimate storm runoff volumes for East Trail Creek. Runoff volumes that may be expected from storms producing the peak discharges listed in table 3 are listed in table 5. It should be noted that these volumes do not 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

Table 5.--*Estimated runoff volumes associated with selected peak discharges at sites in East Trail Creek*
[V = storm runoff in volume, in acre-feet; Q = peak discharge, in cubic feet per second]

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_{100} (ft^3/s)	V (ac ft)
A	140	10.0	580	35.0	930	52.9	1,660	88.0
B	105	7.8	435	27.1	700	41.2	1,250	68.6
C	9	0.9	50	4.1	85	6.5	170	11.9
D	11	1.1	60	4.8	100	7.5	185	12.8
E	12	1.2	65	5.1	110	8.1	210	14.3
F	6	0.6	30	2.6	50	4.1	165	11.6
G	6	0.6	35	3.0	65	5.1	125	9.1
H	4	0.4	25	2.2	40	3.3	80	6.1
I	3	0.3	20	1.8	35	3.0	70	5.5

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).

The first year of record at USGS gaging station 06307560 at the mouth of East Trail Creek shows no flow on 287 days (U.S. Geological Survey Water Data Report, 1978c). This would suggest that downstream flows are not dependent on any minimum flow from East Trail Creek.

Surface-Water Quality.--Water samples collected at the East Trail Creek near Otter station have been analyzed for common ions and heavy metals since January 1977 except during periods of no flow (U.S. Geological Survey Water-Data Report, 1978c). Streamflow in East Trail Creek is generally surface runoff from the basin, and composition of the water is representative of the ions available from surficial material (U.S. Geological Survey, 1978b). Constituents that predominate are sodium, magnesium, and sulfate with relatively minor amounts of heavy metals. Concentrations of major constituents are not abnormally high for streamflow of this region.

Measured sediment concentrations at the time of chemical constituent sampling indicate low suspended-sediment discharge from the East Trail Creek basin. This conclusion is also substantiated by the sediment surveys of small reservoirs in the basin, some with over 35 years of record. The period of record at the East Trail Creek near Otter station is not long enough for meaningful interpretations of chemical quality or suspended-sediment discharge data.

Ground Water

Much of the information that is available in the study area on the occurrence of ground water was collected in connection with an investigation of the Hanging Woman Creek area by the Geological Survey, Montana Water Resources Division District (U.S. Geological Survey, 1978b). Twenty-nine wells and springs were inventoried in the study area and thirty additional observation wells were drilled to provide information on ground-water levels, aquifer characteristics, and chemical quality of ground water (U.S. Geological Survey, 1978b).

Characteristics of Overburden Aquifers

The permit area is underlain by several aquifers. The uppermost unconfined aquifer is composed of alluvium that has been deposited in the valley of East Trail Creek and is mostly clay and fine gravel with some silt and sand. Four test holes drilled in sec. 12, T. 9 S., R. 43 E. indicate that the alluvium has an average thickness of 34 ft. Water levels in the wells in the alluvium range from 7 ft below the land surface near the stream channels to 24 ft near the valley side slopes in sec. 12, T. 9 S., R. 43 E. (U.S. Geological Survey 1978b).

Alluvium and colluvium mantle the underlying Tongue River Member of the Fort Union Formation on the valley floor and foot slopes in the permit area. The Tongue River Member contains a water-table aquifer and shallow confined aquifers. Although the Tongue River Member underlies the entire permit area, the lenticular sandstone, siltstone, and channel sand that contain many confined and semi-confined aquifers are quite limited in areal extent (U.S. Geological Survey, 1978b).

The Anderson and Dietz coalbeds, which are mineable by surface methods in the permit area, occur within the Tongue River Member of the Fort Union Formation and are continuous shallow aquifers in the study area. These coalbeds are generally confined above and below by black carbonaceous shale or clayey siltstone (U.S. Geological Survey, 1978b). Part of the water in the Anderson coalbed discharges into alluvium along Trail Creek.

The Lebo Shale Member of the Fort Union Formation, which is 240 feet thick, separates the Tongue River Member from underlying aquifers. The Lebo Shale Member has a low hydraulic conductivity and, therefore, the underlying aquifers are not likely to be affected by surface mining in the permit area.

Water in the alluvium moves down-valley; however, much of it is evaporated from small pools where the water table intersects the land surface or transpired by phreatophytic vegetation where the depth to water is shallow. The potentiometric surfaces in the Anderson coalbed and adjacent alluvium (fig. 9) and in the Dietz coalbed (fig. 10) are similar to the configuration of the local topography. The water levels in the Dietz coalbed are about 30 to 50 ft lower than in the Anderson coalbed in the permit area although the configuration of both potentiometric surfaces are similar. The fault that crosses the southeast corner of the permit area undoubtedly retards the flow of ground water. An area that has deeper water levels with progressively deeper aquifers is generally considered to be a recharge area (U.S. Geological Survey, 1978b).

Drawdown and recovery tests were completed by the Montana Bureau of Mines and Geology in the alluvium and Anderson and Dietz coalbeds (U.S. Geological Survey, 1978b). Discharges from two wells in the alluvium were 4.4 and 17.7 gallons per minute during tests; discharge from the Anderson coalbed aquifer during mine tests ranged from 0.3 to 10.0 gallons per minute; and discharges from three tests in the Dietz and Canyon coalbeds ranged from 0.3 to 10.5 gallons per minute.

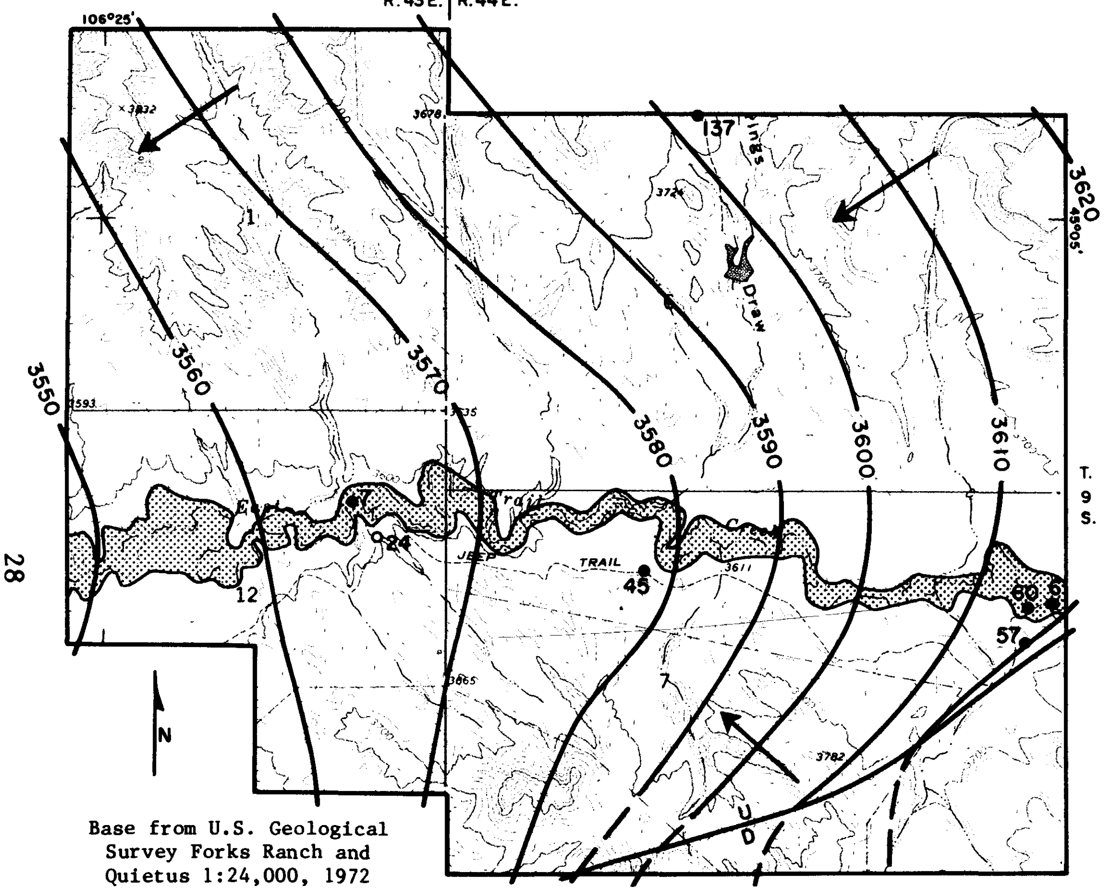
Ground-Water Quality

Chemical analyses of ground water in the East Trail Creek basin were made by the Geological Survey, Montana District, and samples were obtained from the upper part of the Tongue River Member of the Fort Union Formation (U.S. Geological Survey, 1978b). Samples were collected from a developed spring, 12 stock wells, and 16 test wells that tap aquifers in the sandstone and coal. Sampling depths range from the land surface at the spring to 273 feet below land surface. Dissolved solids concentrations for all the samples range 438 to 9,460 milligrams per liter (mg/L). The concentrations of dissolved solids in all but three samples, most concentrations of dissolved sulfate, and several concentrations of iron and manganese from samples collected in the study area are greater than the recommended maximum concentrations for drinking water. Data on ground-water quality are limited in the permit area.

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.



Base from U.S. Geological Survey Forks Ranch and Quietus 1:24,000, 1972

Geology modified from Culbertson, W. C., and Klett, M. C. (1979a, 1979b). Hydrology from U.S. Geological Survey (1978b)

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

EXPLANATION

ALLUVIUM - Mostly flood-plain deposits of silt, clay, fine gravel, and colluvium. Maximum thickness 40 feet

WASATCH FORMATION AND TONGUE RIVER MEMBER OF THE FORT UNION FORMATION, UNDIVIDED - Sandstone, siltstone, shale, and coal

U/D Fault. U, upthrown side; D, downthrown side

—3580— POTENTIOMETRIC CONTOUR - Shows altitude of water surface in Anderson coalbed and alluvium near Anderson coal outcrop. Dashed where approximately located. Contour interval is 10 feet. Datum is NGVD of 1929

●12 TEST WELL or STOCK WELL - Number is depth to water, in feet below land surface, 1973-77. Well obtains water from Anderson coalbed

○31 TEST WELL or STOCK WELL - Number is depth to water, in feet below land surface, 1973-77. Well obtains water from alluvium near Anderson coal outcrop

← DIRECTION of water movement in Anderson coalbed

Figure 9.--Hydrologic map showing potentiometric surface of Anderson coalbed of Tongue River Member of Fort Union Formation in permit area.

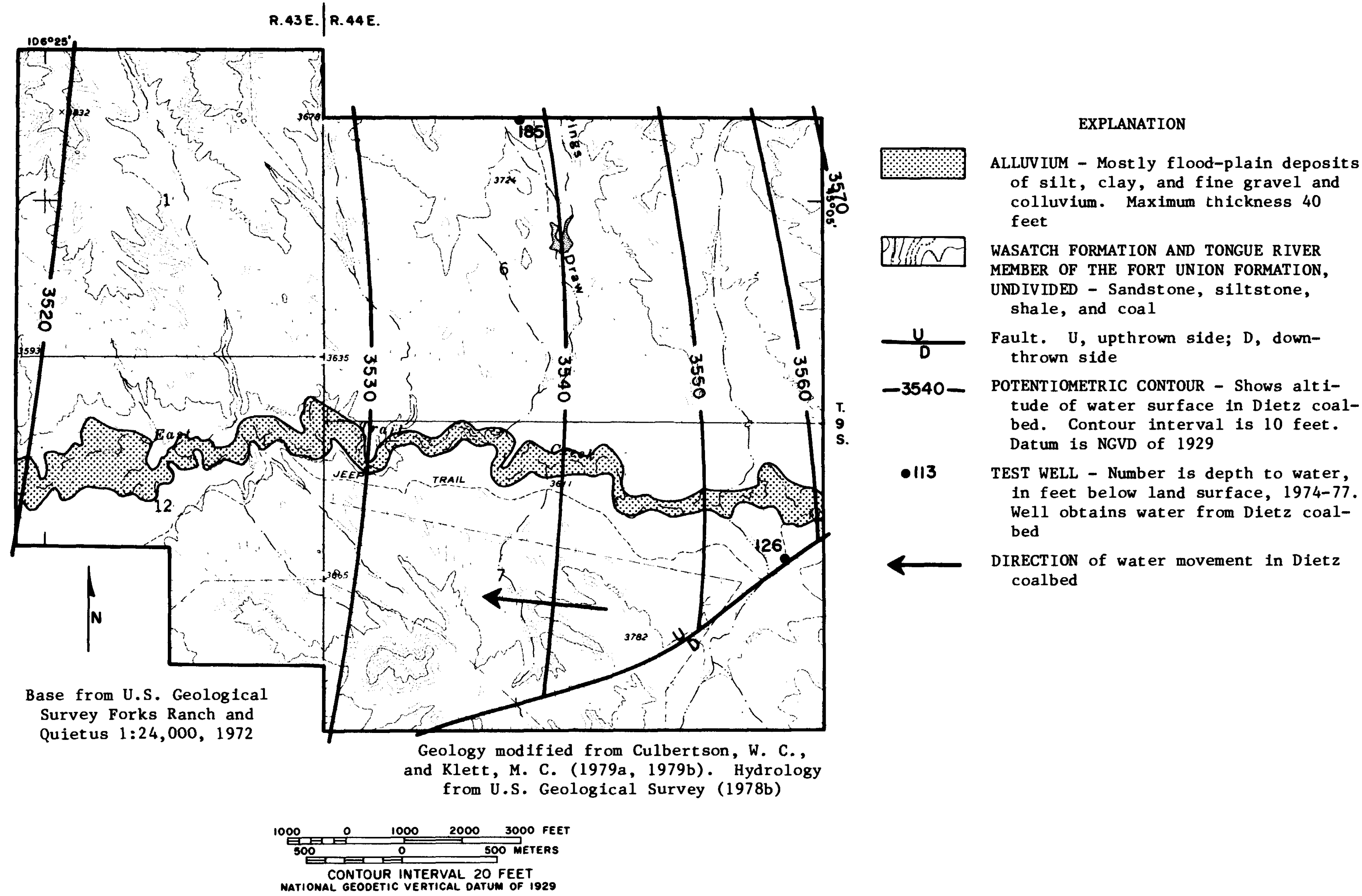


Figure 10.--Hydrologic map showing potentiometric surface of Dietz coalbed of Tongue River Member of Fort Union Formation in permit area.

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) (1977a) 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 as shown in figure 19, page 107. 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 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.

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.

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 is useful as a guide in estimating a value for sediment-delivery ratio.

Surveys of stock ponds in small watersheds similar to those on the permit area would 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).

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 adjacent area upstream from the permit area are listed under site B in tables 3, 4, and 5.

Ground Water

The East Trail Creek adjacent area is underlain by several aquifers. The shallowest aquifers are alluvium of Holocene age, Anderson clinker of Holocene (?) age, and the Tongue River Member of the Fort Union Formation of Paleocene age. The 240 feet thick Lebo Shale Member of the Fort Union Formation separates the Tongue River Member from underlying aquifers, which include the Tullock Member of the Fort Union Formation, upper Hell Creek aquifer, Fox Hills lower Hell Creek aquifer, Judith River Formation, Eagle Sandstone, Muddy Sandstone, and Madison Group. Because the Lebo Shale Member has a low hydraulic conductivity, the underlying aquifers are not likely to be affected by surface mining at the permit area. The Wasatch Formation of Eocene age is present on ridges in the adjacent area, but is unsaturated and is not considered in discussions of ground water.

The uppermost unconfined (water-table) aquifer at the adjacent area consists of alluvium containing fine colluvium and coarser material along East Trail Creek. Alluvium occurs beneath the valley bottoms; colluvium, which is mostly unsaturated, mantles the Tongue River Member adjacent to the valleys.

The Anderson, Dietz, and Canyon coalbeds, which occur within the Tongue River Member of the Fort Union Formation, appear to be the most continuous shallow aquifers penetrated by drill holes at the study site. These coalbeds are generally confined above and below by black carbonaceous shale or clayey siltstone. The nearest hydrologic boundaries of the Dietz and Canyon coalbeds are outcrops 12 to 15 mile northeast of the study area. Part of the water in the Anderson discharges west through the clinker into alluvium along Trail Creek. The slightly folded Anderson generally plunges westward, extending in the subsurface to the Hanging Woman Creek and Tongue River valleys, which are discharge areas for water not discharged to the alluvium along East Trail and Trail Creek (U.S. Geological Survey, 1978b).

Sediment Yields

The U.S. Geological Survey (1978b) has estimated the annual sediment discharge near the mouth of East Trail Creek (site A, plate 1) to be .02

to .03 acre-ft/square mile (1186 ± 237 tons/year, based on specific weight of 65 pound/cubic feet). The estimate was made by using a modification of the Pacific Southwest Inter-Agency Committee (PSIAC, 1968) method. The modification entails the preparation and use of a source-area sediment yield map and a channel classification map to estimate the sediment yield from the basin (Frickel, Shown, and Patton, 1975). The PSIAC (Shown, 1970) method can also be used to make estimates of sediment yield from small basins (.02 to 7.5 square mile). Application of the method on newly mined and reclaimed areas is unproven. In addition, subjective ratings of nine climate and watershed factors make the method less useful for monitoring sediment yields during land-use changes than does a quantitative method such as the USLE.

Examination of aerial photographs and analysis of the source-area sediment yield map and channel classification map (U.S. Geological Survey, 1978b) indicates that 600 ± 164 tons per year of sediment are yielded to East Trail Creek from the permit area and from adjacent drainage areas that are north, south, and west of it (see plate 1). Subtracting 600 tons from 1,186 tons leaves an estimate of 586 ± 221 tons per year of sediment being discharged onto the permit area by East Trail Creek at point B in plate 1.

POTENTIAL EFFECTS OF MINING AND RECLAMATION

The potential effects of surface mining on the hydrologic system may be similar to the effects caused by other types of land disturbances or land use. The major effects that will change the hydrology of the disturbed area are: (1) topographic and land-form changes, (2) soils and soil-moisture characteristics, (3) types and amount of plant cover, (4) quantity and quality of streamflow, (5) erosion and sediment-yield changes, and (6) quantity and quality of ground water and change in aquifer characteristics.

Changes in Topography

Postmining terrain maps provide an estimate of the surface topography of a mined area following reclamation (fig. 11). 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. The thickness of the replaced overburden is assumed to have increased by 20 to 25 percent due to the increase in void space in the fractured 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.

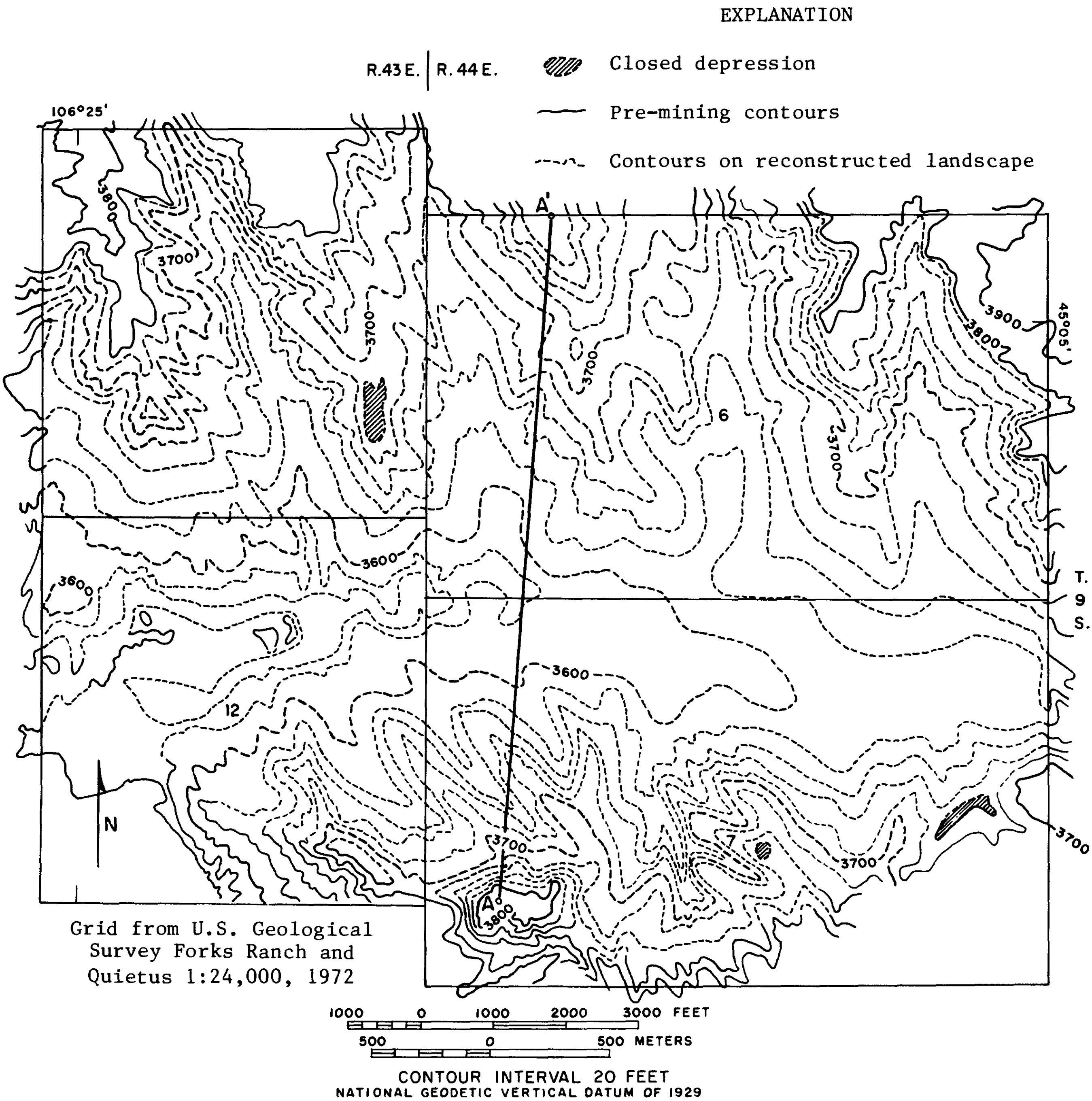


Figure 11.--Map showing reconstructed landscape resulting from the mining of coalbeds less than 200 feet deep and replacement and grading of the overburden. A bulking factor of 20 percent was applied to the overburden thickness.

The technique involves the 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. The topographic data from the base superimposed maps may be added or subtracted to construct the desired surface.

The procedure for preparing a postmining terrain map is as follows:

1. The limits of minable coal for each coalbed are established from the 200-feet overburden contour and geologic maps. All subsequent mapping is confined with these limits.

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

3. An overburden thickness map is constructed by subtracting the upper coal surface elevation (structure contour map) from a standard topographic map elevation of the surface. Two or more coalbeds require the intermediate step of adding upper coalbed thicknesses to the structure contour map of the lowest coalbed.

4. An expanded overburden thickness map is made to account for bulking of replaced overburden. Each contour representing a depth of overburden was increased 20 percent. Thus, the 100 feet thickness became 120 feet; the original 120 feet thickness became 144 feet, etc. New 20-foot contours were then fitted among the irregular intervals.

5. Surface topography of the replaced spoil is constructed by adding the expanded overburden thickness to the map of the base of the lowest coalbed.

6. The final map is constructed by adjusting the topography of the reclaimed surface to the adjacent existing topography of the unmined area; (see fig. 12).

Because of expansion of the replaced overburden, the reclaimed surface on the permit area would not be greatly different from the premining topography. Nonetheless, the comparison of premining and postmining surface elevations along a cross section indicates that the surface would be lowered 0 to 15 feet across most of the area (see fig. 12). This is a result of the coal being relatively thick with respect to overburden thickness. For example, if there is 100 feet of overburden overlying 30 feet of coal, the replaced overburden (expanded by 20 percent) would be 120 feet thick, and the new surface would be 10 feet lower than the unmined surface. Figure 12 also shows that the reconstructed surface would be smoother and slopes would be, in general, longer and have slightly reduced gradients with respect to the premining topography.

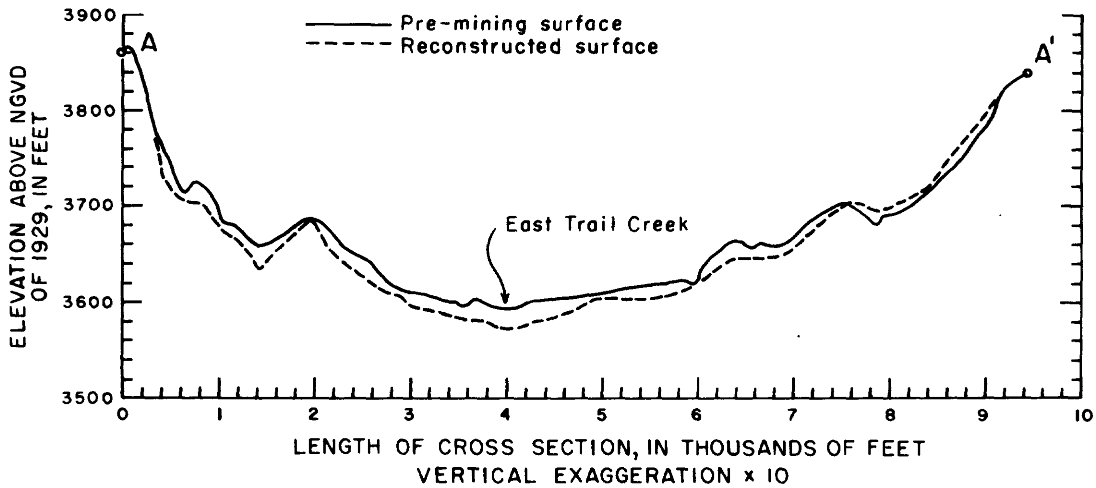


Figure 12.--Cross section showing changes in topography resulting from surface mining. The overburden was assumed to be replaced on a cut-by-cut basis and was graded smooth. Location of the cross section is shown in figure 11.

Construction of the postmining terrain map demonstrated a potential problem along the stripping limit boundary of the lower coalbed which does not appear on the final map. The situation is likely to be common to most areas with two or more coalbeds where the deeper bed can be mined only in part of the area. The economic limit of mining the lower bed will be at the point where the overburden is very thick (160 to 180 feet). Upslope from this limit, only the upper coalbed will be mined. This upper deposit is likely to have a much thinner layer of overlying rock. When the expanded rock is replaced, the terrain downslope of the original boundary will be higher than that immediately upslope of the boundary. A steep sided trench results along the stripping limit boundary. Since this problem would be taken care of during actual mining, such a trench is not shown on the map (fig. 11).

Soils and Vegetation

Soil materials can be selectively removed from the land surface and repositioned in a sequence and at depths that will result in optimum use of available water. Both the soil and vegetation maps (figs. 3 and 4) provide a first approximation of areas with grossly similar soil materials. Water-retention characteristics of soils associated with different kinds of plant cover are defined in the section on water relations in soils. The relationship between plant cover and position in the landscape to soil series in the area can be defined by platting the sampling locations on the SCS soils map (plate 1 and fig. 4). This information can be used to determine amounts of various kinds of soil material available for repositioning. Soils can then be reconstructed in a manner that will result in optimum use of available water.

Some soil materials are particularly suitable for topsoil if the area is mined. Course- to medium-textured soils and alluvium mapped as Haverson, McRae, and Fort Collins loam (fig. 4) are examples of such suitable materials. The presence of silver sagebrush with big sagebrush and grasses (fig. 16, Appendix I) provides on-site evidence of the occurrence of this type of soil. These relatively coarse materials would facilitate infiltration and storage of water until it can penetrate and be adsorbed by finer-textured materials beneath. This kind of top dressing should be especially considered for areas that will have the steepest slopes.

Large amounts of fine-textured materials underlie the alluvial terraces along East Trail Creek. These areas are mapped as Greeley, Lohmiller, or Arvada-Bone Clay soils. Greasewood occurs with grasses on these soils and can be used as an indicator of areas where they occur. These soil materials tend to be saline and sodic, especially at greater depths. The more sodic soils also have the least plant cover, so plant cover could be used as criteria for selecting the best available material from this source. The more saline-sodic materials from poorly vegetated areas or deep in the profile would be poor materials for topsoil. These materials have much less potential for agricultural purposes than if range vegetation is to be reestablished. Several species of range vegetation are more tolerant of these conditions than domestic crops. Water from rain and snow over time will wash salts out of soil at the surface down into soil to the normal depth of wetting (Branson, Miller, and McQueen, 1962).

Soils occurring on gently sloping uplands, and in swales draining those areas, also have high potential for replacement on the surface of spoil materials with regard to revegetation. These soils are included in the big sagebrush-blue grama type (fig. 3). Thedalund soils are present on uplands with Arvada soils occurring in grass-covered swales (fig. 4). These soil materials are similar to the fine-textured alluvial materials. They, in fact, provide evidence of the productive potential of fine-textured materials stored in deep alluvial terraces. If these materials or similar materials in alluvial terraces are replaced over spoil, they should be placed in areas with the least slope to prevent erosion.

The surface part of these soils, which contains grass roots, characteristically is most resistant to deterioration of soil structure. Preservation and replacement of these materials at the surface will result in adequate infiltration rates and reduce erosion. Shrubs that occur with grass on these areas present an obstacle to proper removal of this valuable soil horizon. Destruction of shrubs with a disk plow, prior to scraping this soil material off the surface will facilitate movement and replacement of the materials.

Preservation of soil materials from steeper areas would not be practical. Because of their variability, materials of different texture would be scraped up and stored together. As a result, it would be difficult to predict how these materials would interact with water.

Water-retention characteristics of the various soil materials available for use have been defined (fig. 15 to 21, Appendix I) on the basis of data obtained from individual auger holes. The data should be grossly applicable to areas with similar landform and plant cover. Removal, and storage, or replacement of materials can, therefore, be based on this information. Data derived from these sampling sites can also be used to determine how available soil materials should be replaced over reshaped spoil. Sequence and depth to which available materials are redeposited will have specific influence on water relations in restructured soils, and the kinds and amounts of plant cover that can be established.

Optimum amounts of soil materials, for replacement on reshaped spoils, can be determined on the basis of amounts of water available to soils from snow and rain and consideration of the water-retention capacity of available soil materials. Amounts of water that soils might be required to store to support vegetation can be determined from data acquired from various soils sampled on upland sites. Data acquired from sites on foot slopes and gently sloping uplands provide an indication of amounts of water that could be stored in repositioned upland soils. Sites 7 and 17 (plate 1), as well as sites 14 and 18 (plate 1) provide the most reliable information because available void space limits amounts of water that can be stored. The difference between water stored at the retention-capacity level and minimum levels of storage is 7.5 and 5.4 inches (191 and 137 millimeters) in sites 7 and 17, respectively (fig. 19). Under similar conditions, 3.2 and 2.7 inches (82 and 68 millimeters) of water can be stored in foot-slope soils at sites 14 and 18 (fig. 21). If voids in excess of retention capacity are filled with water, totals of 16.9 and 13.6 inches (429 and 346 millimeters) can be stored at sites 7 and 17 (fig. 19) in the Thedalund soil, while totals of 8.2 and 7.0 inches (208 and 179 millimeters) can be stored at sites 14 and 18 (fig. 21) in foot-slope areas. Average maximum levels of stress achieved in the later two sites are less than in the sites with more void capacity. Total plant cover is also greater at the sites with the least void capacity. With the same amount of water applied to each of these soils, storage will exceed retention-capability levels sooner in the foot-slope soils with the least total void capacity. Any water in excess of 3.2 and 2.7 inches (82 and 68 millimeters) (sites 14 and 18, fig. 21) will be stored at lower levels of force in the foot-slope soils while this does not occur on the sloping uplands until 7.5 and 5.4 inches (191 and 137 millimeters) of water (sites 7 and 17, fig. 19) are stored. As a result, mid and tallgrasses predominate on the foot-slope soils, while mid and shortgrasses occur with big sagebrush on gently sloping uplands. Total plant cover is also greater on foot slopes.

Evidence thus indicates that limiting void capacity, so water must be stored in excess of retention-capability levels, can result in more efficient use of limited water resources. The average water-retention capability of foot-slope soils is in the range of 15 percent by weight, while gently sloping uplands can retain approximately 20 percent. Medium-textured alluvium stored in deep terrace deposits contains materials with retention capabities varying from 10 to 20 percent. If just enough of this medium-textured material is placed over compacted fine-textured soil, the productive environment of foot-slope soils could be established on upland areas. Such materials deposited to a depth of 0.6 meters or 2 feet would come close to approximating the desired habitat. If this were done, productive grasses, like little bluestem, prairie sandreed, and bluebunch wheatgrass, could be established. If permeable materials are deposited to greater depths, less productive but more drought-resistant grasses, like western wheatgrass, green needle-grass, and blue grama, would probably predominate. Reestablishment of sagebrush on reconstructed soil would result in reduced forage production. Winterfat is a species of shrub would thrive on such deeper well-drained soil materials.

Low areas designed to carry runoff water produced on gently sloping uplands will need greater depths of soil material than upland areas. Data derived from sites 13 and 16 (plate 1 and Appendix 1) are indicative of storage requirements. As water passes through soils placed in low areas, the soil particles tend to reorient and compress to approximately the water-retention capability level. This results in slow penetration of water to depth. Establishment of rhizomanous grasses indigenous to swales, such as western wheatgrass, would improve soil structure and facilitate infiltration. The resulting root mass would also inhibit erosion. There is evidence that water penetrates fine-textured soil occurring naturally in swales to a depth of 4.9 feet. Fine-textured materials, with water-retention capacities of up to 30 percent, thus, are suitable for replacement in drainageways. Under natural conditions, drainageways are wide with gentle slopes and occur as tributary valleys to the main valley.

If alluvial materials now stored in terraces are utilized on upland areas, the main valley could be made wider at the flood plain level, particularly if coal is not removed from beneath the actual flood plain. If the existing channel were made wider, the channel could be caused to meander back and forth across the area. This could be done by reshaping the channel. Frequent flooding of the total area could be induced by placing compacted dikes across the channel to divert water onto the flood plain. A drain in each dike would prevent water from ponding behind the dikes. Miller and others (1969) found that drainage was essential to optimum forage production in flooded areas. Western wheatgrass would be the most suitable plant material for establishment on the flood plain because it is capable of withstanding inundation by up to a foot of sediment (Hubbell and Gardner, 1950). Silver sagebrush would probably reestablish itself here from seed derived upstream. This shrub would reduce flow velocity. It would also provide cover for wildlife.

Surface Water

Estimation Methods

The 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 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 flows through reservoirs and channels. Tables and graphs have been developed to simplify use on small watersheds and for special situations (SCS, 1973, 1975). The list of hydrologic soil-cover complexes has been expanded to describe a wider variety of conditions.

A computer program has been developed to simplify the use of the SCS method on more complex projects (SCS, 1965). Its use should be considered when watersheds are larger than 2,000 acres; there are many subareas with different runoff characteristics; reservoirs are present; or 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, 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. Condition refers to a range of vegetation 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 can 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-moisture condition is used. The CN for the basin 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 that 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 the peak discharges, depending on the size and complexity of the project. The SCS State Conservationist of Montana supplied the procedures to be used in Montana. The values required are drainage area, in square miles; CN; time of concentration, T_c, in hours; 6-hour and 24-hour design precipitation. Time of concentration is determined from the equation

$$T_c = \frac{\ell^{0.8} \times (S + 1)^{0.7}}{1140\ Y^{0.5}}$$

where

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

ℓ = greatest flow length in basin, in feet, and
Y = average basin slope.

As an example of the use of this method and in order to compare results with other methods, the SCS method was applied to basins C through I in the permit area for premining conditions. Drainage areas and greatest flow lengths were measured on 1:24,000 scale maps. Basin slope was determined by the summation of contour lengths method. The parameter values used are listed in table 6. Values of 6-hour and 24-hour precipitation amounts for various recurrence intervals were obtained from table 2. The resulting runoff volumes and peak discharges, listed in table 7, were obtained from graphs supplied by the State Conservationist. Flows must be routed through basins as large as those above sites A and B. The channel cross-section data required for routing were not available for this study; therefore, postmining discharges could not be estimated by the SCS method for sites A and B.

In the column headings in table 7, Q_{pn} represents the discharge, and V_{pn} represents the volume produced by the n-year precipitation event; n represents the 2, 10, 25, and 100-year intervals shown in the headings. In a strict hydrologic sense, these values are not comparable to the premining discharges obtained with the Johnson-Omang equations (table 3); however, the two sets of discharges are compared to show that extremely different values may result from the two methods.

The frequency curves estimated by the two methods are shown in figure 13 for sites D and I. For the East Trail Creek area, the SCS method gives considerably larger discharges than the Johnson-Omang equations. The SCS discharges also exceed the Johnson-Omang values with the standard error added. In general, the SCS peak discharges (table 7) are 2 to 6 times greater than those computed with the Johnson-Omang equations (table 3). Additional information is needed to judge which of these methods more accurately estimates actual discharges at the East Trail Creek sites.

Closer agreement between the two methods could be obtained by decreasing the CN values for the SCS method. The CN values used were selected on the basis of the best land-use and soil information available at the present time, but without the benefit of field inspection of the basins. Revision of these values should be made only if additional or more detailed soil and land-use data become available, or after sufficient years of discharge data are obtained in the area to verify the revised CN values. They should not be changed simply to make the resulting discharges agree more closely with the discharges estimated by another method, unless this other method is known to estimate the actual discharges in the area of question with acceptable accuracy.

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 which are solved on a digital computer. Since 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

Table 6.--*Parameter values for SCS method--premining conditions*
[CN = curve number value; T_c = time of concentration]

Site	Drainage area (mi^2)	Greatest flow length (ft)	Average basin slope (percent)	CN	T_c (hours)
C	0.85	10,770	15.5	81	0.87
D	1.09	11,830	15.0	80	0.99
E	1.41	11,405	11.3	80	1.10
F	0.70	10,875	11.9	78	1.10
G	0.50	7,605	9.7	80	0.86
H	0.39	6,230	18.4	80	0.53
I	0.15	4,915	13.9	80	0.51

Table 7.--*Premining runoff volumes and peak discharges calculated by the SCS method for sites in East Trail Creek*

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)
C	48	9.97	207	33.55	320	49.41	460	60.27
D	47	11.04	222	40.11	348	59.88	508	86.04
E	56	14.29	267	51.89	422	77.46	615	111.30
F	19	5.60	111	22.40	185	34.36	280	50.40
G	23	5.07	110	18.40	173	27.47	260	39.47
H	24	3.95	116	14.35	178	21.42	263	30.78
I	9	1.52	46	5.52	70	8.24	103	11.84

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.

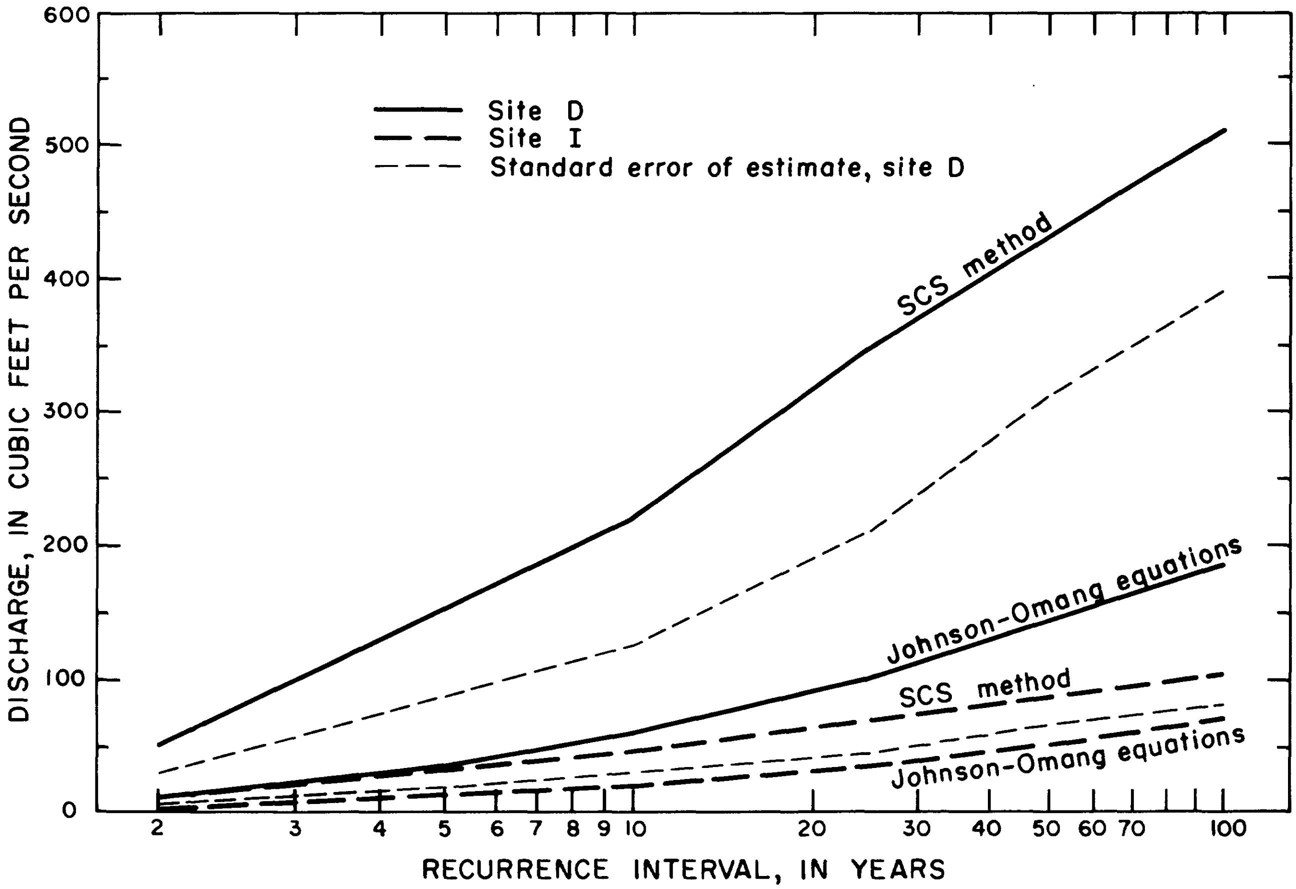


Figure 13.--Comparison of flood-frequency curves estimated by SCS method and Johnson-Omang equations for sites D and I.

Estimates of Design Peak Discharges and Runoff Volumes

The Johnson-Omang equations were developed with flood flows from basins that were virtually undisturbed by urbanization, regulation, or diversion; therefore, they should not be applied to basins that have been substantially altered by mining and reclamation activities. At this writing, the SCS method is the most feasible to use for design estimates from both convenience and data availability standpoints. 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 "Change in topography." Since vegetative cover will not have 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 runoff characteristics will be, because there are few data to indicate the magnitude of changes in infiltration characteristics 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, in some combinations increasing it; in some, decreasing it. It seems possible that the average infiltration rates for a basin may be about the same after mining as before. For lack of sufficient evidence to the contrary, and because the SCS method has been shown to give somewhat higher discharge estimates than some other methods, postmining infiltration rates are assumed to be, on the average, the same as before mining in East Trail Creek basin.

Using the previous considerations, peak discharges and runoff volumes were calculated for basins C through I in the permit area of East Trail Creek for postmining conditions. Drainage areas, greatest flow lengths, and average basin slopes were measured on the map of reconstructed topography shown in figure 11. The parameter values used are listed in table 8. The resulting runoff volumes and peak discharges are listed in table 9.

Comparison of the values in table 9 with the premining discharges obtained with the SCS method (table 7) gives some indication of the effects that mining will have on surface runoff. Postmining peak discharges are generally 2 to 6 times greater than the premining discharges and runoff volumes are 2 to 3 times greater than premining volumes. Because infiltration rates were considered to be the same for both sets of estimates, the increases reflect only the change from good and fair grass cover to no vegetative cover at all. Once vegetative cover is reestablished through the reclamation process, runoff rates should decrease and approach premining rates. In fact, it seems reasonable to expect that with some types of reclamation, postmining runoff rates could be somewhat less than premining rates. The previous discussion, which compared premining discharges estimated by the SCS method with those obtained from regression models, would also apply to the postmining estimates, as would any adjustment procedure devised from additional hydrologic information.

Erosion

Slopes

Numerous assumptions about reclamation were made in this section because a mine plan was not available. To some extent, the postmining conditions

Table 8.--*Parameter values for SCS method--postmining conditions*
[CN = curve number value; T_c = time of concentration]

Site	Drainage area (mi^2)	Greatest flow length (ft)	Average basin slope (percent)	CN	T_c (hours)
C	0.83	10,455	13.2	89	0.70
D	1.10	10,665	13.0	87	0.77
E	1.40	13,200	10.6	87	1.01
F	0.70	10,455	10.4	89	0.78
G	0.51	7,285	9.8	87	0.65
H	0.45	5,915	12.2	90	0.44
I	0.14	5,070	9.9	92	0.40

Table 9.--*Postmining runoff volumes and peak discharges calculated by the SCS method for sites in East Trail Creek*
[Q = peak discharge, in cubic feet per second;
V = storm runoff volume, in acre-feet]

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)
C	150	21.20	388	52.67	534	72.18	710	96.06
D	147	23.46	430	62.77	602	86.82	818	112.91
E	157	29.86	457	79.88	642	110.50	886	150.07
F	118	17.92	308	44.42	422	60.85	562	81.01
G	77	10.88	221	29.10	310	40.25	420	54.67
H	113	12.72	280	30.48	373	41.04	488	54.23
I	46	4.78	100	10.60	132	14.04	168	18.36

assumed are hypothetical, even though the actual land area, earth materials, and climatic variables are the same as the real premining conditions on the permit area.

In table 10, soil loss rates from the slopes of a small basin on the permit area, as computed with the USLE, are compared to the loss rates of

Table 10.--*Comparison of annual soil loss, as computed with the USLE, for a 518 acre basin on the permit area before mining and after mining and reclamation*[1]

[R = rainfall-runoff factor; K = soil erodibility factor; L = slope length, in feet; S = slope gradient, in percent; LS = topographic factor; C = cover factor; P = erosion-control practice factor]

Unit	R	K[2]	L (ft)	S (percent)	LS	Estimated ground cover (percent)	C	P	Soil loss tons/acre/yr	Proportion of basin area
						Before mining				
1	30	0.33	450	5.5	1.3	90	0.006	1	0.08	0.15
2	30	0.39	200	13	3.2	50	0.065	1	2.43	0.20
3	30	0.32	200	25	9.0	75	0.018	1	1.55	0.17
4	30	0.39	300	10	2.7	80	0.013	1	0.41	0.25
5	30	0.32	350	23	12.0	55	0.053	1	6.11	0.08
6	30	0.39	150	20	5.3	70	0.025	1	1.55	0.15
							Area weighted mean		1.59	
						After mining and 5-year reclamation period				
1	30	0.33	450	5.5	1.3	90	0.006	1	0.08	0.15
2	30	0.39	200	13	3.2	50	0.065	1	2.43	Trace
3	30	0.32	200	25	9.0	75	0.018	1	1.55	0.15
4	30	0.39	300	10	2.7	80	0.013	1	0.41	0.10
5	30	0.32	350	23	12.0	55	0.053	1	6.11	0.08
6	30	0.39	150	20	5.3	70	0.025	1	1.55	0.02
7	30	0.40	250	9	2.0	80	0.013	1	0.31	0.15
8[3]	30	0.39	800	11	5.6	75	0.018	1	1.18	0.10
9[4]	30	0.27	800	10	4.9	70	0.025	1	0.99	0.15
10[3]	30	0.40	250	9	2.0	80	0.013	1	0.31	0.10
							Area weighted mean		1.15	

1/ Location of basin is shown on figure 1.

2/ "K" values are from soil series lists provided by SCS; on unmined units only the surface soil values were used; on mined units mixing of A and B horizons was assumed and "K" values are profile averages.

3/ Sandy overburden with a computed "K" of .20 was substituted for soil on 15 percent of the area.

4/ Sandy overburden used on 55 percent of the area.

the same area after part of it was mined and was undergoing reclamation (fig. 14). Reclamation is assumed to have included the reconstruction of the landscape to the approximate original configuration. Slopes were reduced to gradient of 20 percent or less and smoothed before all available suitable A and B horizon soils were redistributed on the surface in about the same location they occupied before mining. Because soils of unit 2 (fig. 14) were thin and fine-textured and because the area was highly dissected, those soils were not stockpiled. Another assumption was that suitable sandy material from the overburden, as identified from analyses of core samples (USGS, 1978b), was used for topsoil on parts of the areas in units 8, 9, and 10, as indicated in the footnote of table 10.

The after-mining soil loss rates were computed for the fifth year after seeding of perennial grasses. It was assumed that by that time the grass would be fully established and in equilibrium with the environment and that soil aggregation and compaction (bulk densities) had returned to normal premining levels. Published "K" values (SCS, 1977a) therefore were used for both premining and postmining soils. The location, aerial extent, and general description of each soil series was determined from the Soil Survey of Big Horn County area of Montana (SCS, 1977b). "K" for the sandy overburden was computed using the Wischmeier, Johnson, and Cross (1971) nomograph with particle size and organic matter data obtained by Dollhopf, Jensen, and Hodder (1977) for sandy overburden at Colstrip, Montana. Estimates of vegetation cover for evaluating the premining factors in table 10 were made using first-contact point measurements done by the USGS (1978). Vegetation cover estimates for the fifth year of reclamation were based on data from reclaimed areas at Colstrip, Montana (DePuit, Coenenberg, and Willmuth (1978) as well as the USGS (1978) data.

Mean soil loss per acre would be about 27 percent less after mining and reclamation than before (1.59 vs. 1.15, table 10). The decrease is attributable to several factors: (1) Elimination of short steep slopes; (2) the replacement of thin, erosive fine-textured soils with sandy overburden; and (3) increasing the vegetation cover on areas formerly occupied by thin, fine-textured soils.

The total annual soil loss on this 518 acre basin would be 824 tons for the premining conditions and 596 tons for the fifth year of reclamation after mining. The premining sediment yield from the basin has been estimated by the USGS (1978) to be about 63 tons per year based on a specific weight of 65 lb/ft^3. This translates to a low sediment delivery ratio of 0.08, which means that 92 percent of the soil loss from the units of the basin is deposited where there are marked changes in slope gradients and in swales or on flood plains or low terraces. Applying that sediment delivery ratio to the postmining and reclamation soil loss results in a computed sediment yield of 48 tons per year. The actual sediment yield probably would be less, because this analysis did not account for sediment deposited in depressions in the landscape which result from differential settling of the

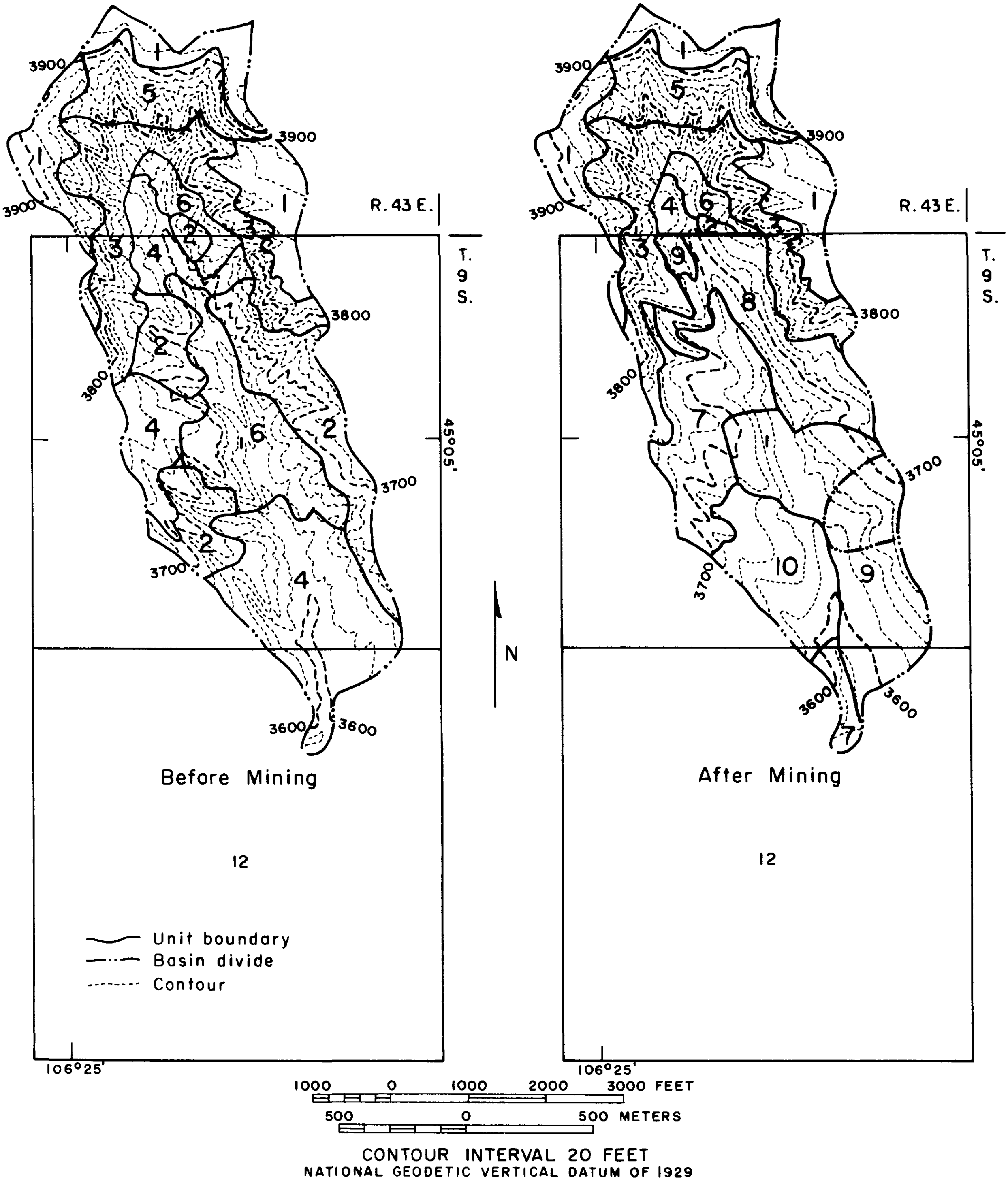


Figure 14.--Topographic maps of a 518-acre basin on the permit area before and after mining and reclamation. Delineated areas are soil-loss units for application of the USLE. A 48.5-acre subbasin is outlined in unit 9. Units 7, 8, 9, and 10 comprise the area that was mined.

replaced overburden; nonetheless, it can be concluded that the sediment yield from this basin and similar basins will be less after mining and reclamation than it was before.

Table 11 shows computed sediment yields from a small basin in unit 9 of figure 14. The yields are for progressive phases of reclamation over about a 3-year period, starting with when the topsoil has been redistributed. This type of analysis and the resulting total sediment yield for the 3-year period would provide data on sediment storage requirements of sedimentation ponds. At an assumed density of 70 lb/ft^3, the 141 tons of total sediment would occupy 4,028 cubic feet. Additional amounts of sediment yielded from new or graded spoil banks need to be included. The USLE is not presently applicable to slopes exceeding 50 to 60 percent. Slope gradients for raw spoil banks usually range between 60 and 100 percent; furthermore, the equation was developed for slopes less than 20 percent. Measurements of the volume of rills on slopes or the volume of sediment yielded to ponds or interbank depressions, as done by McKenzie and Stendick (1978), would be means of obtaining estimates of the amounts of material yielded from raw and graded spoils.

The data in table 11 show that the highest erosion rates and sediment yields occur during the spring rainy season and summer thunderstorm season, early in the reclamation period when vegetation cover is sparse or nonexistent. The rate of decrease in "K" over the 3 years may be optimistic in view of the fact that sandy overburden, with low organic-matter content, was the soil material on the basin.

Channel erosion was assumed to be negligible for both the mined and unmined basins considered in the analyses shown in tables 10 and 11. Most of the channels on the permit area, and especially in the unmined basin of figure 14, exist as old gullies now healed with vegetation and channel erosion is minimal. For the mined basins, it was assumed that the valley bottoms would be graded flat from side to side to provide wide waterways in which the flows would be shallow. Some channel erosion may well occur in response to flow hydraulics, particularly before vegetation becomes well established. Channel erosion would have to be evaluated by repeat surveys of cross sections placed at intervals along the entire channel length.

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 holding operations, and the soils are vulnerable to compaction by heavy earth-moving equipment when they are repositioned over the graded spoils. It is not known how completely the compaction is released by tillage operations, such as chiseling, ripping, or furrowing, nor is it known how long it would take natural processes, such as wetting and drying, to return the soils to normal uncompacted

Table 11.--*Sediment yields for progressive time periods from a 48.5 acre basin being reclaimed*[1/]
[R = rainfall-runoff factor; K = soil erodibility factor; LS = topographic factor;
C = cover factor; P = erosion-control practice factor]

Period/Condition	Estimated ground cover (percent)	Number of months	R	Estimated K	LS[2/]	C	P	Soil loss (tons)	Estimated sediment[3/] delivery ratio	Sediment yield (tons)
Late summer before fall seeding, graded, topsoiled, straw mulched	0	2	18.3[4/]	0.32[5/]	1.7	0.18	1	86.9	0.75	65
Fall and winter after seeding	0	7	2.1[4/]	0.32	1.7	0.24	1	13.3	0.75	10
Spring, seedlings establishing	25	3	9.6[4/]	0.30	1.7	0.18	1	42.7	0.75	32
Summer, vegetation developing	60	2	18.3[4/]	0.30	1.7	0.06	1	27.1	0.5	14
Second year, grass and weeds	70	12	30.0	0.28	1.7	0.04	1	27.7	0.5	14
Third year, mostly grass	80	12	30.0	0.28	1.7	0.017	1	11.8	0.5	6
							TOTALS	209.5		141

1/ Location of basin is shown on figure 1, unit 9.
2/ Based on average slope length of 350 ft and 7 percent gradient.
3/ Roehl (1963) curve used as guide; higher values in earlier periods because of lack of vegetation in waterways.
4/ Computed from monthly distribution of rainfall erosion index for Miles City, Montana; table 7 in Wischmeier and Smith (1978).
5/ K arbitrarily increased 20 percent from a value of 0.27 for unmined soils to account for decreased aggregation and slower permeability.

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 before reliable estimates of delivery ratios and sediment yields can be made 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 Yields

Sediment concentrations of some flows from the mine area; before, during, and after mining; are expected to exceed the regulatory limit of 45 mg/L (Federal Register, 1979). To meet this regulation, the flows will have to be detained in sedimentation ponds where most of the sediment will settle. Sediment discharges from upland areas, therefore, are expected to be much lower during mining and reclamation than before.

Potential exists for increased erosion of natural channels below sedimentation ponds if peak discharges of relatively clear water released from the ponds are excessive (perhaps exceeding the mean annual peak).

Flows of East Trail Creek would need to be routed through a diversion canal at one side of the valley floor while that area is being mined. The gradient of the canal would exceed that of the natural channel. A stable lining and (or) drop structures would need to be installed to prevent erosion and deposition problems in the canal and to prevent an increase in sediment discharge to East Trail Creek.

Comparing the reconstructed topography map of the permit area (fig. 11) with premining topography shown on the geologic map (fig. 2) indicates that the valley floor would be lowered 10 to 20 ft after mining where East Trail Creek enters the permit area. The resultant knickpoint in the gradient of the creek would cause headcut erosion to progress upstream from the mined area. Also, the base level to which the tributaries on the permit area are graded would be lowered, and that could cause downcutting of tributary channels. The sediment load of East Trail Creek would be increased drastically from such erosion. One solution would be to transport overburden to the valley floor from ridges that divide the tributary drainages on the permit area, and thus, restore the original valley gradient. The other solution would be to install stable linings and (or) drop structures where the channel gradients are increased as was proposed by the U.S. Geological Survey (1978a) for a mine to be developed near Decker, Montana.

Ground Water

The effects of surface mining on the area hydrology depend on the depth to which coalbeds will be stripped and the areal extent of mine development. Two mining alternatives assume mining of the Anderson coalbed of the Tongue River Member of the Fort Union Formation alone or mining of the Anderson plus one or two coalbeds below the Anderson.

Surface mining of the Anderson will drain the saturated overburden and the Anderson coalbed adjacent to the mined area. The mine floor will be lower in altitude; therefore, the hydraulic gradient will be from the alluvium to the mine in most surface-mined areas. Water in the alluvium could be diverted into a mine even though surface mining did not extend to the alluvium. Assuming a surface mine approximated by a well one-half mile in radius, mine inflow is estimated by a form of Darcy's Law to be less than 0.7 ft^3/s, using an average K of 3.0 ft/d (.9 m/d) determined from aquifer tests (U.S. Geological Survey, 1978b). However, this flow should gradually diminish to less than 0.1 ft^3/s as hydraulic gradients approach equilibrium conditions (U.S. Geological Survey, 1978b).

The area of greatest water-level decline in wells can be expected to the east, upgradient from any potential surface mine. Depending upon the extent of mining, 17 stock wells or springs could become dry. Replacement wells of similar yields could be completed in one or more water-bearing zones of the Tongue River Member. The water quality generally could be expected to be better than water from wells presently in alluvium although additional quality of water data are needed.

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.

(b) recharge rates, quantity, quality, discharge rates, rate and direction of movement, and geochemistry of the ground-water flow system.

(c) channel erosion and deposition.

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

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

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Appendix I - Moisture relations and vegetation data for East Trail Creek sites

NOTE: Values within the graphs are depths of water, in millimeters, that the soil can contain between the indicated water contents. Adsorbed water is retained between minimum annual storage (MS) and moisture-retention capability (MRC) contents. Drainable water is contained between MRC and void-moisture capacity (VMC) contents. Moisture-retention capability is similar in concept to field capacity and void-moisture capacity is the water content when the soil is saturated, and relates to porosity.

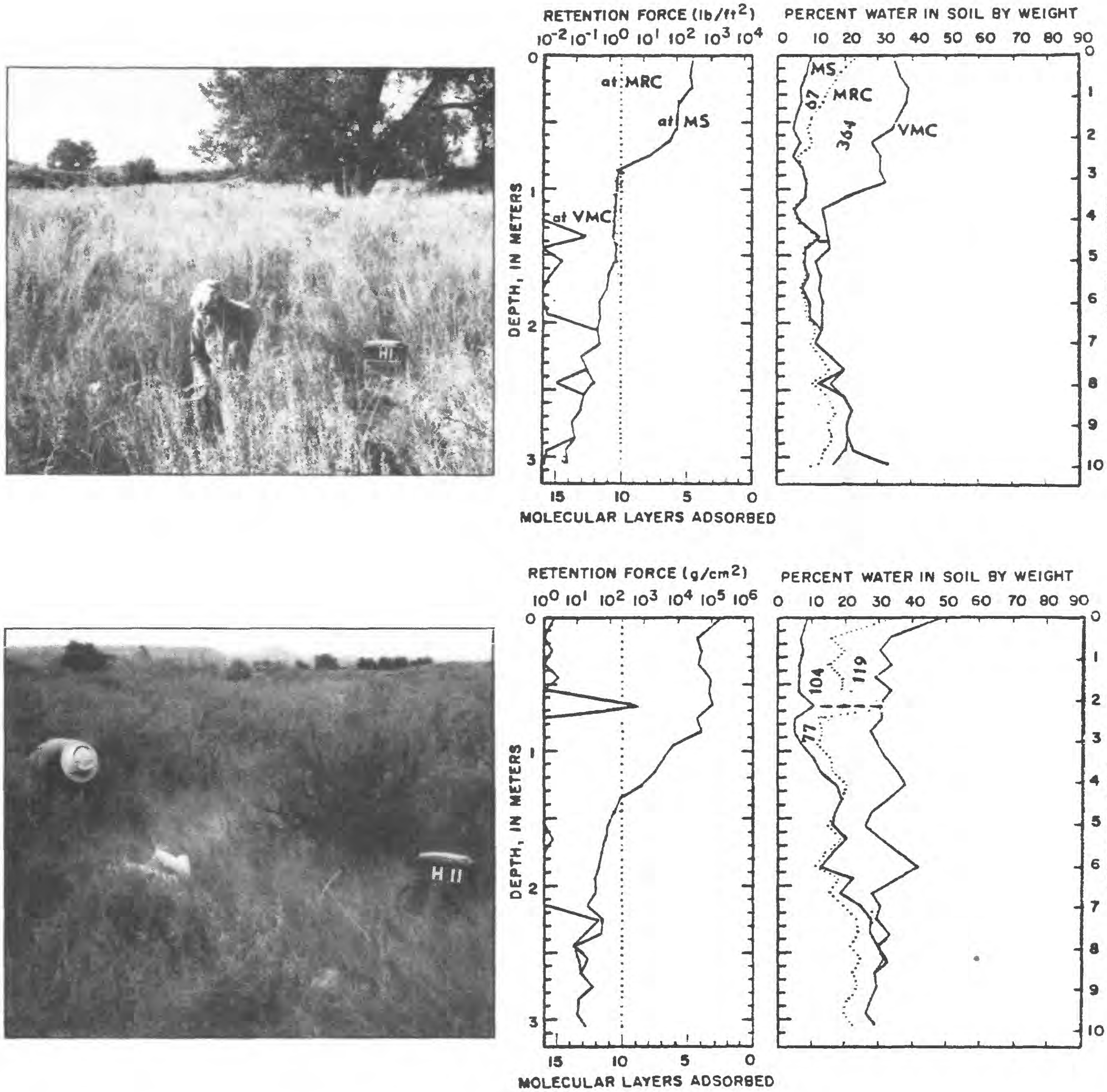

Figure 15.--Moisture relations in soils occurring on flood plains. View of site H1 is downvalley near left bank of Deep Creek. View of site H11 is toward north with trees marking the course of East Trail Creek. July, 1976.

Table 12.--*Types and percentages of cover and average moisture retention forces at time of sampling for flood plain sites*

Type	Site 1	Site 11
	cover (percent)	
Bare soil	0	5
Mulch	2	13
Forbs	3	1
Western wheatgrass	57	38
Silver sagebrush	38	2
Greasewood	0	27
Saltgrass	0	14
Average moisture retention force (lb/in^2)	2.64	7.29

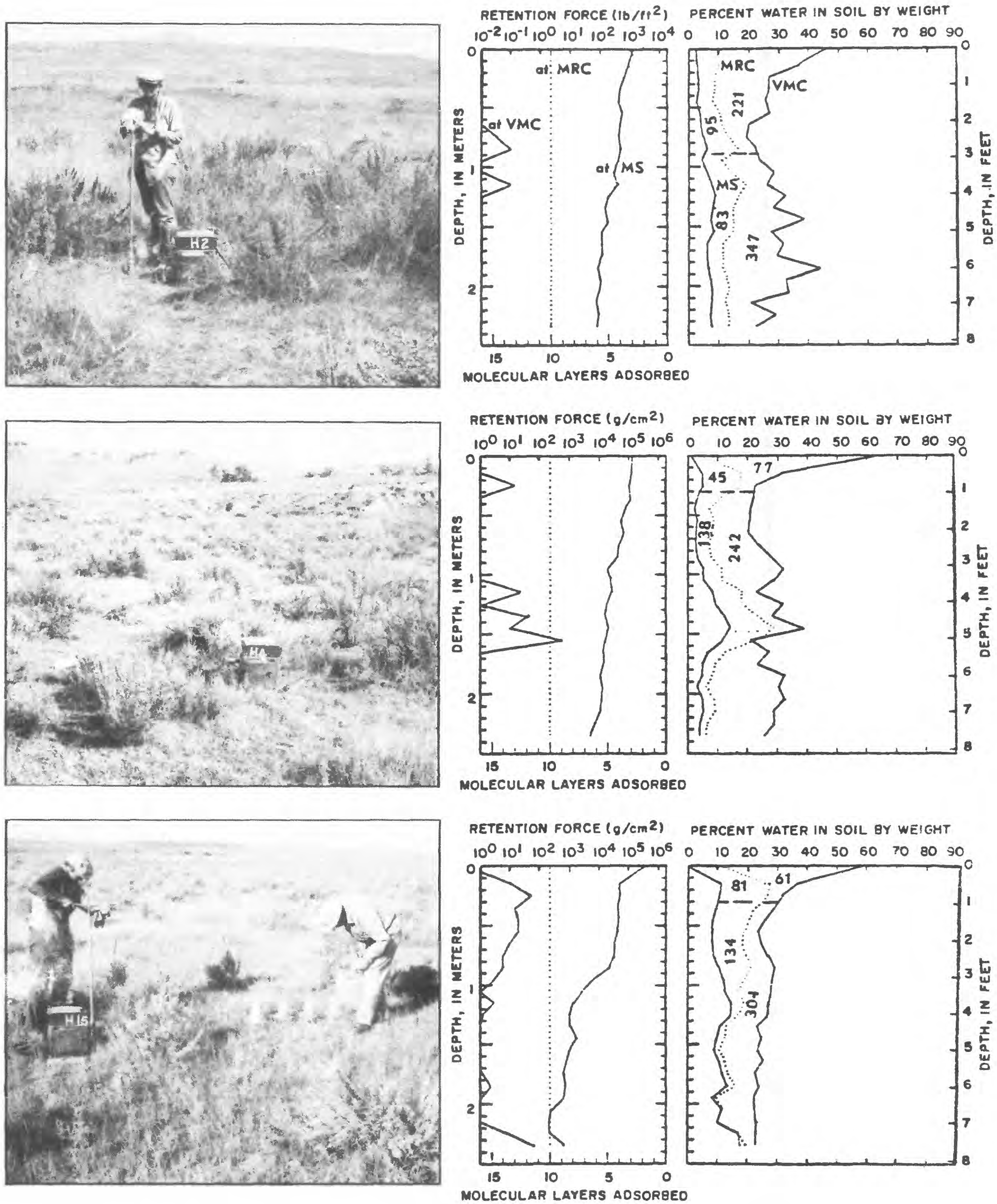

Figure 16.--Moisture relations in soils on alluvial terraces with silver sagebrush present. View of site H2 is toward southwest. View of site H4 is southeast up Trail Creek Valley. View of H15 is north. July, 1976.

Table 13.--*Types and percentages of cover and average moisture retention forces at time of sampling for alluvial terrace sites with silver sagebrush present*

Type	Site 2	Site 4	Site 15
	cover (percent)		
Bare soil	15	19	33
Mulch	6	16	18
Forbs	9	0	0
Silver sagebrush	18	4	14
Big sagebrush	0	14	4
Fringed sagebrush	0	0	3
Western wheatgrass	22	12	18
Needle-and-thread grass	23	0	0
Sandberg bluegrass	0	0	8
Cheatgrass	2	1	0
Blue grama grass	4	34	0
Prickly pear cactus	1	0	1
Average moisture retention force (lb/in^2)	356.19	391.65	51.63

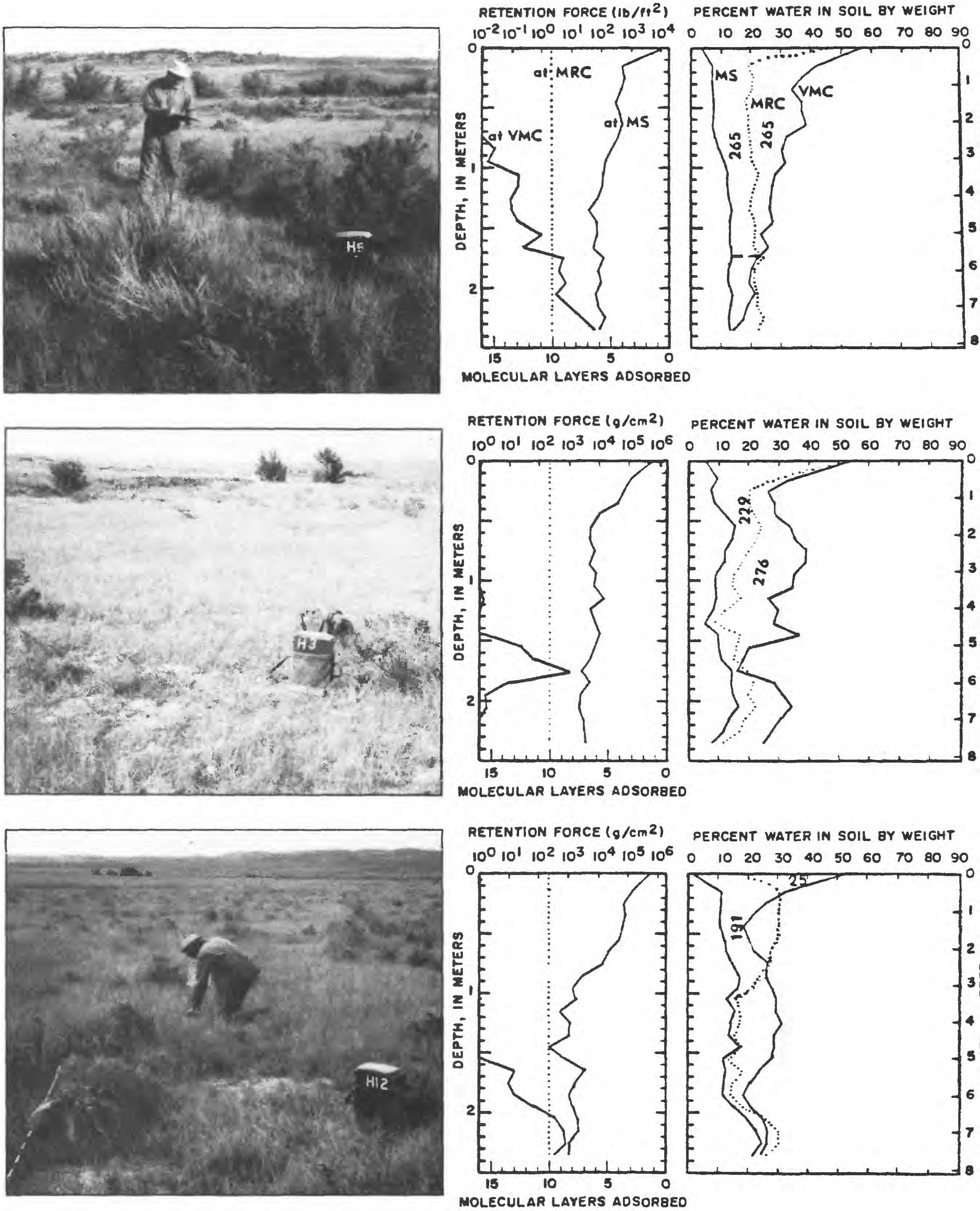

Figure 17.--Moisture relations in soils on alluvial terraces where greasewood is present. View of site H5 is north across East Trail Creek. View of site H3 is southeast up Trail Creek Valley. View of site H12 is south. July, 1976.

Table 14.--*Types and percentages of cover and average moisture retention forces at time of sampling at sites on alluvial terraces with greasewood present*

Type	Site 5	Site 3	Site 12
	Cover (percent)		
Bare soil	27	30	30
Mulch	2	10	4
Greasewood	12	10	4
Western wheatgrass	30	30	28
Blue grama grass	10	12	21
Sandberg bluegrass	3	1	0
Japanese bromegrass	10	0	4
Big sagebrush	3	0	4
Fringed sagebrush	2	0	0
Prickly pear cactus	1	3	4
Cheatgrass	0	1	0
Forbs	0	3	0
Saltgrass	0	0	1
Average moisture retention force (lb/in^2)	241.48	115.58	64.99

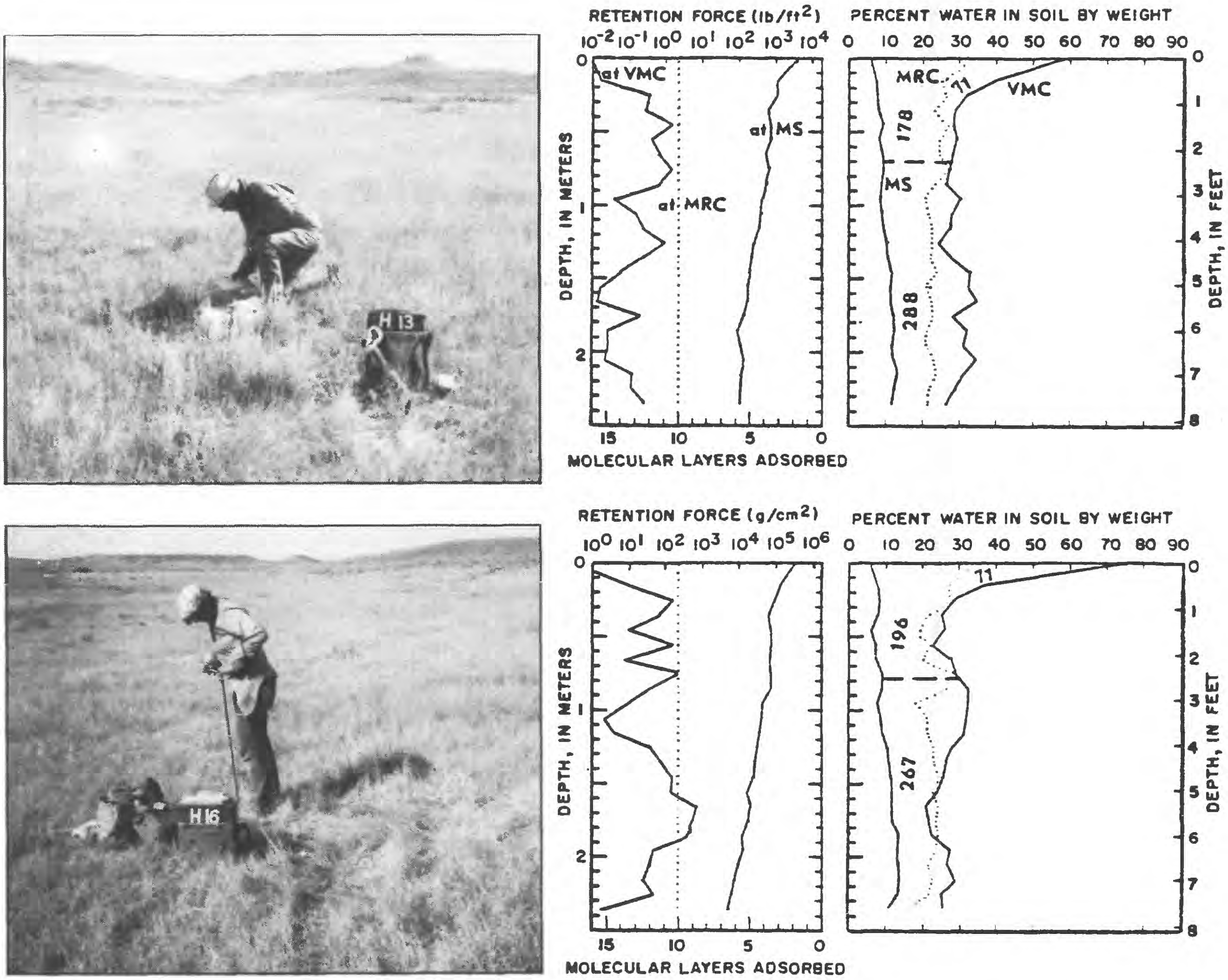

Figure 18.--Moisture relations in soils occurring in swales with a cover of grasses. View of site H13 is toward the southeast. View of site H16 is up a tributary valley toward the northwest. July, 1976.

Table 15.--*Types and percentages of cover and average moisture retention forces at time of sampling for sites in grass-covered swales*

Type	Site 13	Site 16
	Cover (percent)	
Bare soil	11	12
Mulch	9	6
Western wheatgrass	33	16
Japanese bromegrass	16	42
Green needlegrass	0	17
Blue grama grass	12	4
Winterfat	13	0
Prickly pear cactus	5	3
Forbs	1	0
Average moisture retention force (lb/in^2)	481.83	470.89

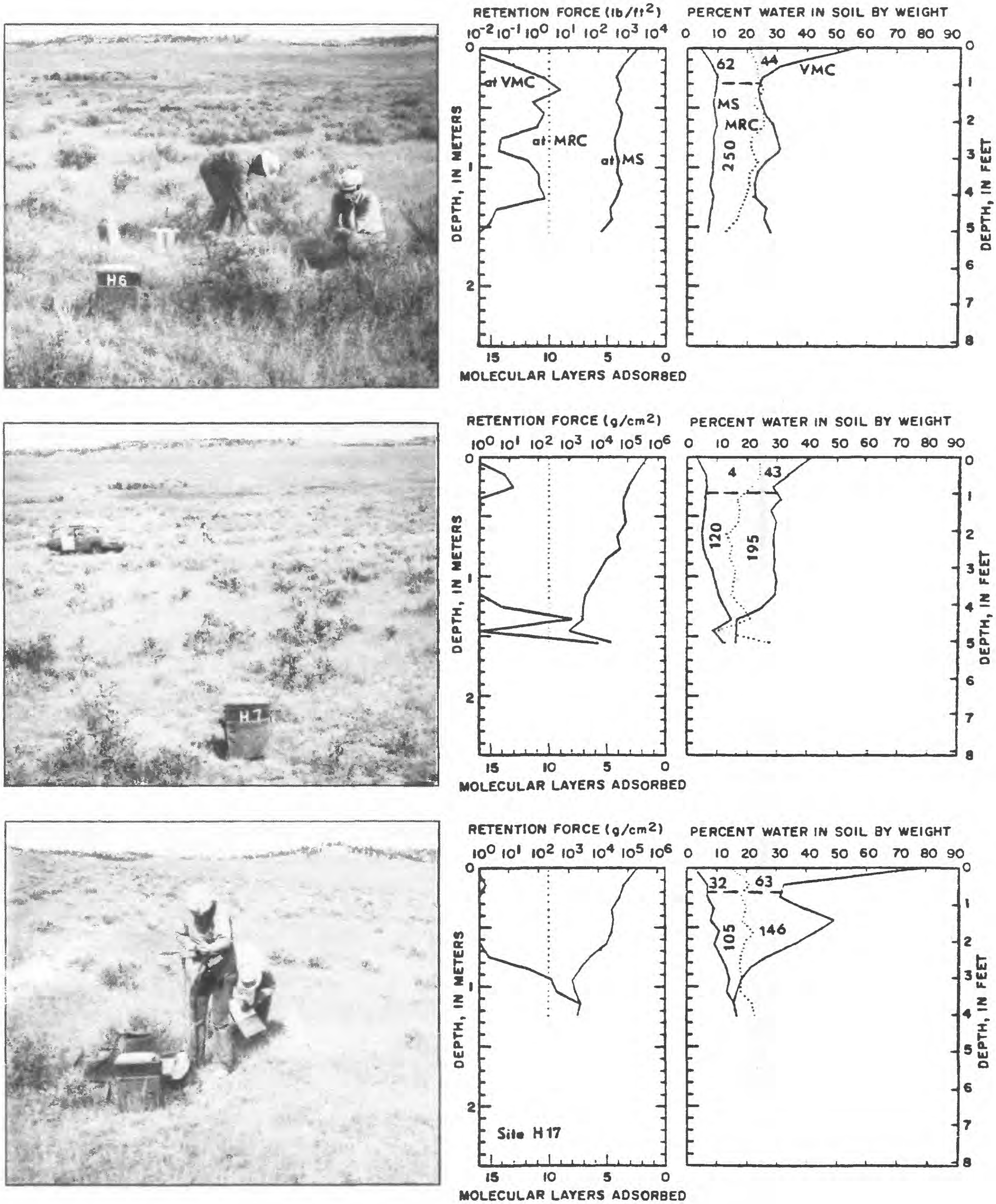

Figure 19.--Moisture relations in soils on gently sloping uplands. Views of sites H6 and H7 are northwest looking across East Trail Creek Valley, View of site H17 is toward the northwest. July, 1976.

Table 16.--*Types and percentages of cover and average moisture retention forces at the time of sampling on gently sloping uplands*

Type	Site 6	Site 7	Site 17
	Cover (percent)		
Bare soil	23	40	20
Mulch	6	4	4
Western wheatgrass	10	19	33
Green needlegrass	7	0	2
Hairy chess grass	5	0	0
Blue grama grass	7	15	10
Sandberg Bluegrass	12	2	1
Big sagebrush	13	13	15
Winterfat	7	0	4
Fringed sagebrush	10	2	4
Snakeweed	0	5	0
Prickly pear cactus	0	0	7
Average moisture retention force (lb/in^2)	649.98	341.11	178.16

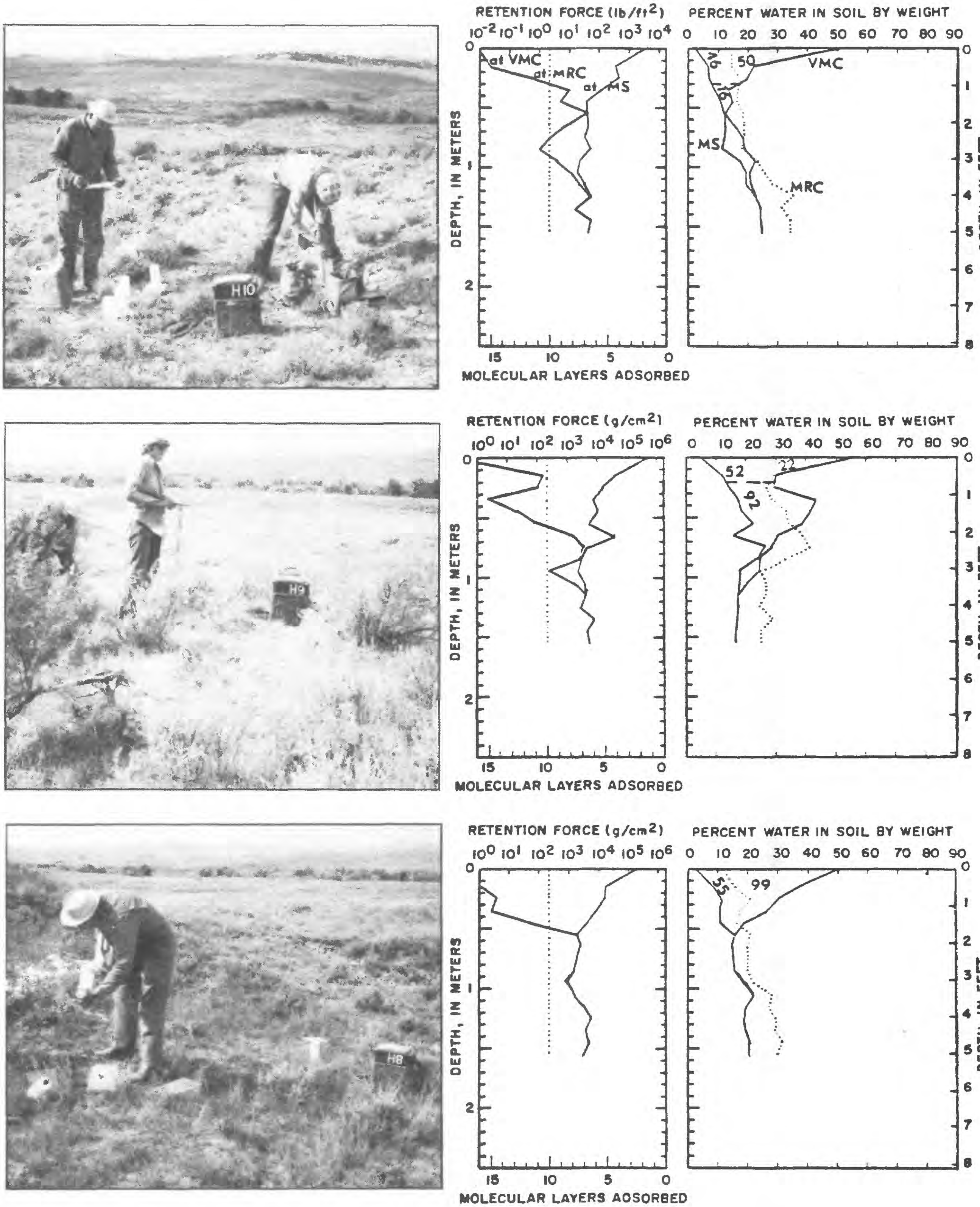

Figure 20.--Moisture relations in soils in breaks areas. All views are toward northwest looking across the East Trail Creek Valley. July, 1976.

Table 17.--*Types and percentages of cover and average moisture retention forces at time of sampling in the breaks*

Type	Site 10	Site 9	Site 8
	Cover (percent)		
Bare soil	38	42	39
Mulch	0	4	7
Broom snakeweed	9	1	12
Big sagebrush	6	15	10
Hoods phlox	5	0	0
Mountain muhly	29	0	0
Sandberg bluegrass	10	20	0
Blue grama grass	3	0	0
Greasewood	0	10	0
Western wheatgrass	0	8	0
Wild buckwheat	0	2	0
Bluebunch wheatgrass	0	0	31
Green needlegrass	0	0	1
Average moisture retention force (lb/in^2)	93.94	123.84	62.65

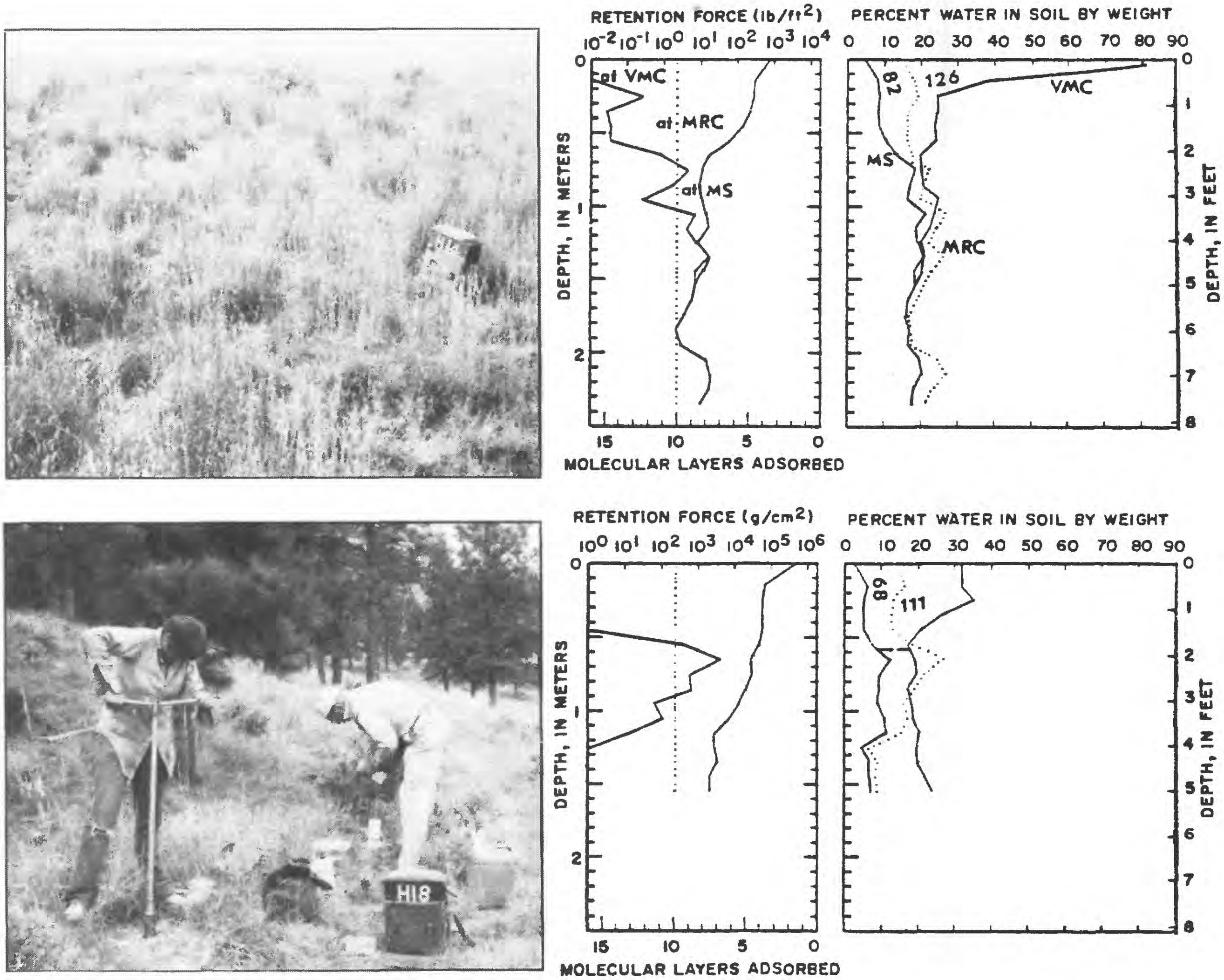

Figure 21.--Moisture relations in soils occurring on foot slopes below breaks areas. View of site H14 is toward the west. View of site H18 is toward the northwest. July, 1976.

Table 18.--*Types and percentages of cover and average moisture retention forces at time of sampling on foot slopes*

Type	Site 14	Site 18
	Cover (percent)	
Bare soil	19	25
Mulch	3	7
Little bluestem	54	3
Bluebunch wheatgrass	22	6
Prairie sandreed grass	0	6
Red threeawn grass	0	3
Side oats grama grass	0	4
Mountain muhly	0	5
Ponderosa pine	0	8
Juniper	0	3
Yucca	0	5
Prickly pear cactus	0	5
Rubber rabbitbrush	0	4
Big sagebrush	0	4
Silver sagebrush	0	4
Forbs	2	8
Average moisture retention force (lb/in^2)	62.07	220.24

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