Land Reclamation Division, and Marilyn K. Kastens, U.S. Bureau of Land Management.

DATA COLLECTION AND METHODOLOGY

Geomorphic, hydrologic, and erosion data were collected along three hillslope transects at the Spring Creek area (hillslope transects SCA, SCB, and SCC, fig. 2) and along two hillslope transects at the Cow Camp Creek area (hillslope transects CCA and CCB, fig. 3). Geomorphic data included aspect, hillslope length, altitude, hillslope gradient, and hillslope-profile characteristics. Hydrologic data included precipitation, snowpack depth, snowpack-water content, and soil-water content. Erosion data included rill density and soil-surface altitudes. Some additional data were collected including vegetation cover and onsite observations of soil texture and soil ice layers.

Geomorphology

Each reclaimed hillslope was surveyed from the local surface-runoff hydrologic divide to the hillslope toe with a Zeiss Ni2 self-leveling level. The surveys were made along a linear transect that generally followed the steepest line on the hillslope. Aspects of the hillslope transects were determined using a Brunton compass. Hillslope transects were plotted on Peabody Coal Company 1:4,800 scale maps with 10-ft contour intervals from which altitude ranges were determined. Hillslope length (slope distance) was determined with a tape measure. Hillslope gradient, horizontal distance, and profile characteristics were determined from the survey data. The hillslope transects were monumented with wooden survey stakes and iron rebar, and the transects served as references for additional data collection and other observations.

Hillslopes at the Spring Creek area generally had a westerly aspect and lengths between 750 and 1,280 ft (table 1). Hillslope transects SCB and SCC were on laterally straight hillslopes (straight contour lines) and transect SCA was on a laterally convex hillslope (contour lines convex in the downhill direction) (fig. 2). Because the hillslope morphology changed from laterally straight to laterally convex, transects SCA and SCB shared a common position for the upper 300 ft but were divergent on the mid-hillslope and lower hill-slope segments. Longitudinal hillslope profiles are shown in figures 4-6.

Altitudes ranged from about 6,890 to 7,125 ft along the transects at the Spring Creek area. Mean hill-slope gradients, determined as the ratio of altitude difference to horizontal distance of the hillslope, were between 0.17 and 0.23 ft/ft. Reclamation dates (year of topsoil replacement and seeding) were 1986 for hill-slope transect SCC and 1987 for most of transects SCA and SCB. The upper 300 ft of transects SCA and SCB was reclaimed in 1986.

Hillslopes at the Cow Camp Creek area generally had a southerly aspect and the lengths of transects CCA and CCB were 800 and 670 ft (table 1). Transect CCA was on a laterally straight hillslope. Transect CCB was on a hillslope that was laterally straight throughout the upper segment; but at the middle segment, transect CCB crossed a small, diagonal-trending, hollow-like

Table 1. General characteristics of the hillslope transects

Hillslope transect	Aspect (degrees)	Hillslope length (feet)	Altitude range (feet)	Mean Hillslope Gradient (foot per foot)	Date of reclamation	Mean total-vegetation cover, 1989 (percent)
			SPRING CREEK AREA			
SCA	284	1,280	7,105-6,890	0.17	[1]1987	76
SCB	256	1,020	7,105-6,900	0.20	[1]1987	74
SCC	246	750	7,125-6,955	0.23	1986	80
			COW CAMP CREEK AREA			
CCA	154	800	7,140-6,970	0.22	[2]1985	86
CCB	161	670	7,140-6,995	0.22	1985	91

[1]Upper 300 feet of hillslope was reclaimed in 1986.

[2]Lower 50 feet of hillslope was reseeded in 1988.

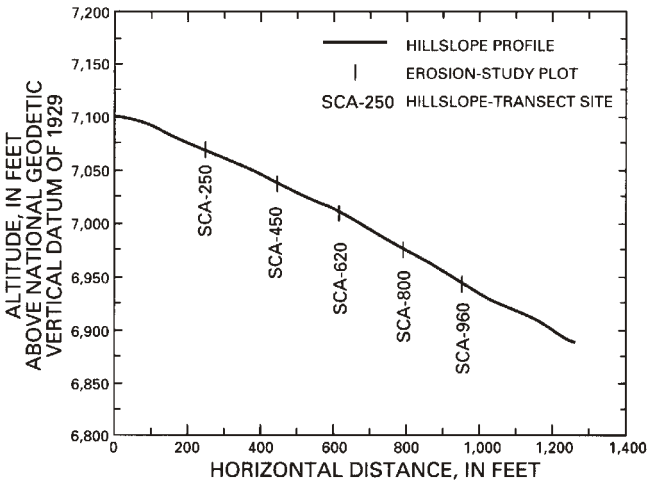

Figure 4. Longitudinal profile of hillslope transect SCA.

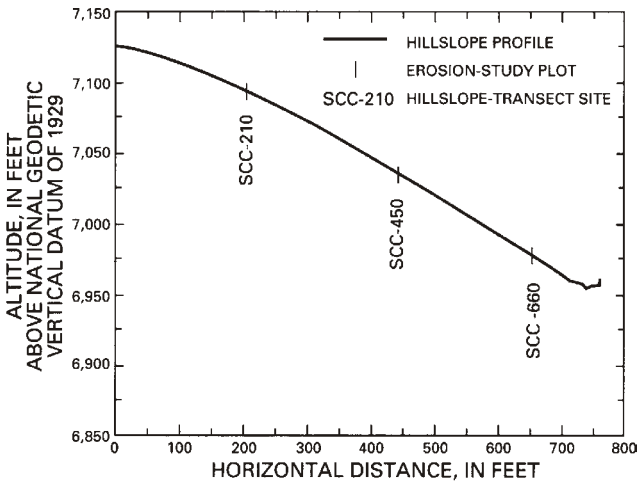

Figure 6. Longitudinal profile of hillslope transect SCC.

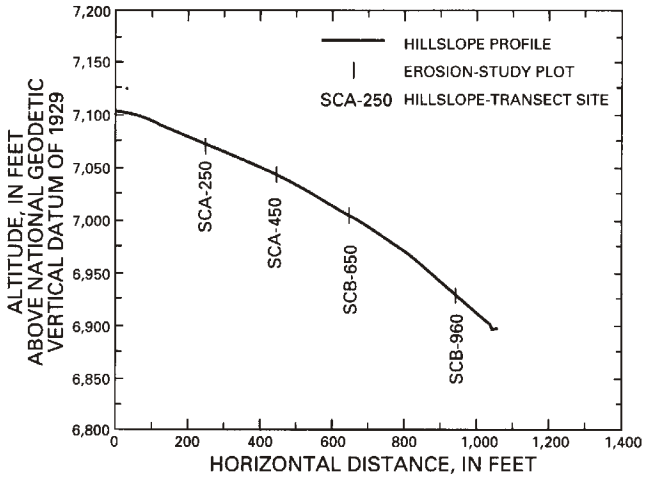

Figure 5. Longitudinal profile of hillslope transect SCB.

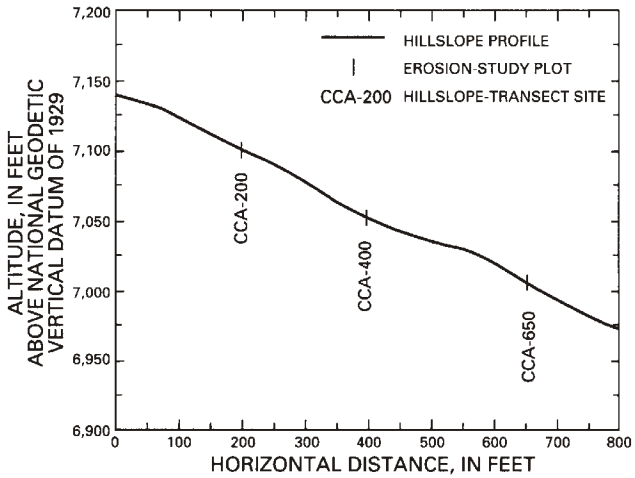

Figure 7. Longitudinal profile of hillslope transect CCA.

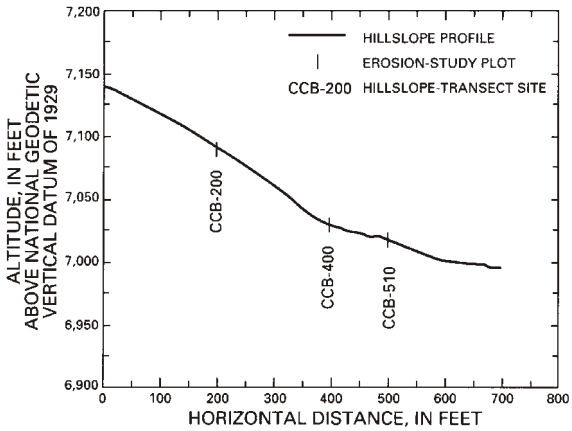

Figure 8. Longitudinal profile of hillslope transect CCB

Longitudinal hillslope profiles at the Cow Camp Creek area are shown in figures 7 and 8.

Altitudes ranged from about 6,970 to 7,140 ft along the transects at the Cow Camp Creek area, and mean hillslope gradients for both transects were 0.22 ft/ft. The reclamation date for transects CCA and CCB was 1985; however, the lower 50 ft of transect CCA was reseeded in 1988.

The surveys also were used to determine local hillslope gradients calculated for 50-ft increments of the hillslopes. Cumulative hillslope length and local hillslope gradient for transects SCA, SCB, SCC, CCA, and CCB are listed in table 2.

Vegetation

Reclaimed hillslopes were seeded with a mixture of native and introduced grass, forb, and shrub species soon after topsoil was applied to the regraded spoil material. At the Seneca II mine study areas, reseeding generally was done in late autumn. For this study, vegetation cover was determined using a 10-point vegetation sampling frame (Cook and Stubbendieck, 1986, p. 58-60). The 10-point frame was placed in three locations for each hillslope station along the transect (at the station, 10 ft uphill from the station, and 10 ft downhill from the station). A "vegetation" observation was recorded when the sampler pointer intercepted either the plant canopy, stem, or base. The local total-vegetation cover (sum of live vegetation and vegetation litter) was determined from the 30 point measurements near each station (table 2). The mean total-vegetation cover for each hillslope transect was the average of the local total-vegetation-cover measurements (table 1). The vegetation cover on reclaimed hillslopes was predominantly grasses and forbs, but no species distinctions were made onsite.

Vegetation measurements were made at the Seneca II mine in August 1989. The age of a reclaimed vegetation community was determined by the number of elapsed growing seasons since the hillslope was reclaimed. For example, hillslope SCC was reclaimed in 1986 (table 1); therefore, the vegetation community was 3 years old when it was measured in August 1989.

Precipitation

Total precipitation (rain and snow) was measured at the Spring Creek and Cow Camp Creek areas with weighing-bucket precipitation gages. The precipitation gages operated continuously and provided daily precipitation data for the duration of the study. Total monthly precipitation data for December 1988 through June 1990 are listed in table 3. The precipitation gages at the Spring Creek and Cow Camp Creek areas are at about the same altitude (figs. 2 and 3) and are about 1.6 mi apart. Monthly and site-to-site precipitation variability is shown in figures 9-11.

Snowpack

Snow courses were established along all hill-slope transects for snowpack-depth, -density, and -water-content measurements. Snowpack measurements were made at 50- to 100-ft intervals along each transect and at sites where soil-water-content measurements were made using neutron-probe and time-domain reflectometry techniques. Snowpack-depth, -density, and -water-content measurements were made with standard U.S. Soil Conservation Service equipment and procedures (U.S. Soil Conservation Service, 1984). Density and water content were determined from bulk (composite) samples when the snowpack was thin or patchy. When density and water content were not measured, snowpack depth was measured with a ruler. To decrease variance from ground-surface and snow-surface irregularities, the average of three closely spaced ruler measurements was used to determine snowpack depth at each snow-course site.

Snowpack data from the Spring Creek and Cow Camp Creek areas are listed in tables 4 and 5 in the "Hydrologic Data" section at the back of this report. Snowpack depths varied seasonally, along a transect, and between the two study areas. Some snowpack

Table 2. Geomorphology, rill density, and vegetation cover of selected reclaimed hillslopes

[Rill densities are the sum of rill lengths per 100 square feet of hillslope area; --, no data]

Cumulative hillslope length (feet)	Local hillslope gradient (foot per foot)	Rill density, 1989 (feet per 100 square feet)			Local total-vegetation cover, 1989 (percent)
		Healing	Active	Total	
SPRING CREEK AREA, HILLSLOPE TRANSECT SCA					
0	--	0.00	0.00	0.00	43
50	0.05	0.00	0.00	0.00	87
100	0.12	0.52	0.52	1.04	60
150	0.16	0.00	0.00	0.00	87
200	0.15	0.00	0.00	0.00	--
250	0.15	0.00	0.00	0.00	93
300	0.14	0.00	0.00	0.00	--
350	0.15	3.01	0.00	3.01	97
400	0.14	2.04	0.00	2.04	--
450	0.20	0.91	1.09	2.00	100
500	0.18	2.04	1.25	3.29	--
550	0.16	3.33	2.87	6.20	53
600	0.16	1.72	5.47	7.19	--
650	0.15	2.48	4.54	7.02	67
700	0.22	1.01	2.36	3.37	83
750	0.22	7.82	0.00	7.82	--
800	0.18	6.32	0.00	6.32	93
850	0.19	4.47	0.56	5.03	--
900	0.19	10.90	2.00	12.90	63
950	0.20	10.27	3.61	13.88	--
1,000	0.23	7.65	4.71	12.36	70
1,050	0.19	10.88	2.06	12.94	--
1,100	0.17	6.90	0.00	6.90	73
1,150	0.16	2.52	7.90	10.42	--
1,200	0.16	6.04	3.11	9.15	73
SPRING CREEK AREA, HILLSLOPE TRANSECT SCB					
[1]0-300					
350	0.14	3.01	0.00	3.01	97
450	0.20	3.87	0.00	3.87	97
550	0.16	12.99	2.02	15.01	50
650	0.20	14.02	10.50	24.52	60
750	0.22	12.80	7.69	20.49	57
850	0.27	9.23	8.95	18.18	70
950	0.31	13.03	10.74	23.77	87

Table 2. Geomorphology, rill density, and vegetation cover of selected reclaimed hillslopes-Continued

Cumulative hillslope length (feet)	Local hillslope gradient (foot per foot)	Rill density, 1989 (feet per 100 square feet)			Local total-vegetation cover, 1989 (percent)
		Healing	Active	Total	
		SPRING CREEK AREA, HILLSLOPE TRANSECT SCC			
0	--	0.00	0.00	0.00	97
100	0.17	0.00	0.00	0.00	93
200	0.19	3.05	0.00	3.05	67
300	0.24	2.25	0.74	2.99	80
400	0.26	0.98	0.00	0.98	60
450	0.26	4.51	0.00	4.51	80
500	0.29	1.37	1.03	2.40	87
600	0.29	1.04	1.57	2.61	83
650	0.30	1.51	0.00	1.51	87
700	0.30	2.04	4.70	6.74	67
		COW CAMP CREEK AREA, HILLSLOPE TRANSECT CCA			
0	--	0.00	0.00	0.00	93
100	0.24	0.40	0.00	0.40	93
200	0.22	0.00	0.00	0.00	90
300	0.25	0.27	0.00	0.27	90
400	0.24	2.57	0.00	2.57	97
450	0.19	0.00	0.00	0.00	87
500	0.15	1.13	0.00	1.13	93
600	0.21	0.96	0.46	1.42	77
650	0.26	2.39	1.02	3.41	73
700	0.28	0.61	1.00	1.61	90
800	0.20	0.00	1.25	1.25	[2]65
		COW CAMP CREEK AREA, HILLSLOPE TRANSECT CCB			
0	--	0.00	0.00	0.00	90
100	0.22	0.00	0.00	0.00	90
200	0.28	0.84	0.83	1.67	93
300	0.34	0.92	0.00	0.92	93
400	0.32	1.28	0.00	1.28	97
450	0.13	1.27	0.00	1.27	90
500	0.17	3.14	1.11	4.25	83
600	0.20	1.84	1.01	2.85	93

[1]Upper 300 feet of hillslope transect SCB is same as upper 300 feet of hillslope transect SCA.
[2]Lower 50 feet of hillslope was reseeded in 1988.

Table 3. Total monthly precipitation at the Spring Creek and Cow Camp Creek areas

[--, no data]

Water year	Total monthly precipitation (inches)											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
					SPRING CREEK AREA, PRECIPITATION GAGE 2							
1988	--	--	2.15	2.84	0.73	1.17	0.54	1.43	2.36	0.12	0.99	2.19
1989	0.07	2.01	1.18	0.90	2.40	0.93	0.27	1.14	0.50	1.56	1.02	1.25
1990	0.82	0.98	1.73	0.59	1.41	1.49	1.14	1.03	1.22	--	--	--
					COW CAMP CREEK AREA, PRECIPITATION GAGE 1							
1988	--	--	2.89	3.64	1.09	2.07	1.17	2.04	1.64	0.31	1.15	2.03
1989	0.08	2.30	1.98	1.40	2.95	1.79	0.35	1.27	0.71	1.48	1.08	1.31
1990	0.96	1.79	2.57	1.25	1.83	1.81	1.35	1.28	1.15	--	--	--

variability was due to different precipitation amounts at the Spring Creek and Cow Camp Creek areas (figs. 9-11), eolian transport, and partial melting. Snowpack-depth variability at two hillslope transects is shown in figures 12 and 13.

Additional observations were made during snow-course measurements. Soil beneath the snow-pack usually was thawed and damp or wet if the snow-pack was thicker than about 6 in., even when the air temperature was below freezing. Conversely, the soil beneath a thin snowpack was frozen when the air temperature was below freezing. Diurnal melting and runoff often were observed during mid-winter.

Soil Water

Soil-water content at the study site is affected by precipitation, snowpack-water content, topsoil and spoil texture, clay mineralogy, evapotranspiration, and antecedent conditions. Volumetric soil-water content was determined at several locations on the reclaimed hillslopes using a neutron-scattering technique and an electromagnetic technique. Soil-water content was measured at 1-ft-depth increments in the topsoil and underlying coal spoil using a neutron-emitting CPN 503 Hydroprobe. Soil-water content was measured in the upper 11.8 in. Of topsoil using a Tektronix 1502-04 time domain reflectometer. McKin and others (1980) neutron-scattering, electromagnetic, and other soil-water-measurement techniques.

The neutron-scattering technique (neutron probe) for measuring soil-water content is based on the thermalization (energy loss) of neutrons by collision with hydrogen atoms (McKim and others, 1980). Fast neutrons emitted by the Hydroprobe's 50-mCi Americium-241/Beryllium source are converted to slow neutrons following collisions with hydrogen atoms in the surrounding soil. The instrument determines the amount of hydrogen present from the number of slow neutrons detected and, assuming all hydrogen is in water molecules, calculates the amount of water in the surrounding soil. Water in the liquid, solid, or vapor phases is detected by the neutron-scattering technique. Hydrocarbons (coal fragments and other organic matter) in the soil can introduce error if they are present in sufficient quantities; however, it was assumed that hydrocarbon content was negligible at the measurement sites. Williams and Hammond (1988) discuss calibration and use of the neutron probe in coal spoil.

Soil-water-content measurements using the neutron-scattering technique were made in 2-in-diameter aluminum soil-water access tubes (SWAT's) inserted into 4- to 9-ft-deep auger holes. Soil-water-content measurements were made at eight SWAT's at the Spring Creek area (fig. 2) and five SWAT's at the Cow Camp Creek area (fig. 3). SWAT's were installed on a variety of geomorphic surfaces, but some SWAT locations were partly determined by the logistics of handling the

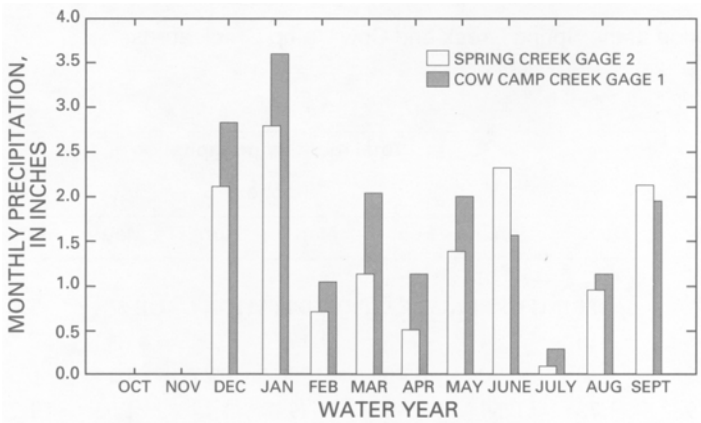

Figure 9. Monthly precipitation at the Spring Creek and Cow Camp Creek areas, water year 1988.

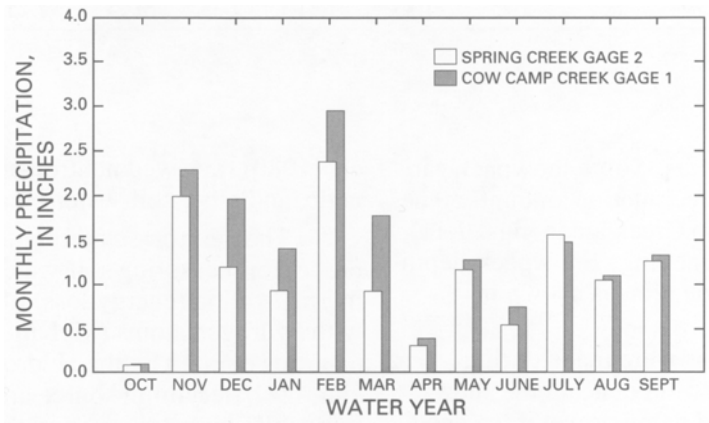

Figure 10. Monthly precipitation at the Spring Creek and Cow Camp Creek areas, water year 1989.

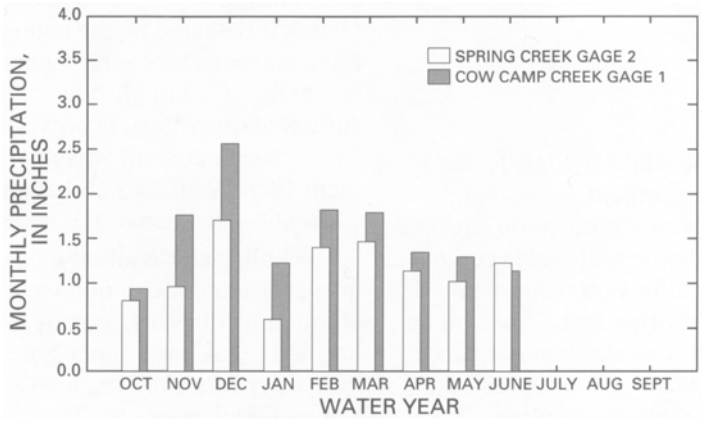

Figure 11. Monthly precipitation at the Spring Creek and Cow Camp Creek areas, water year 1990.

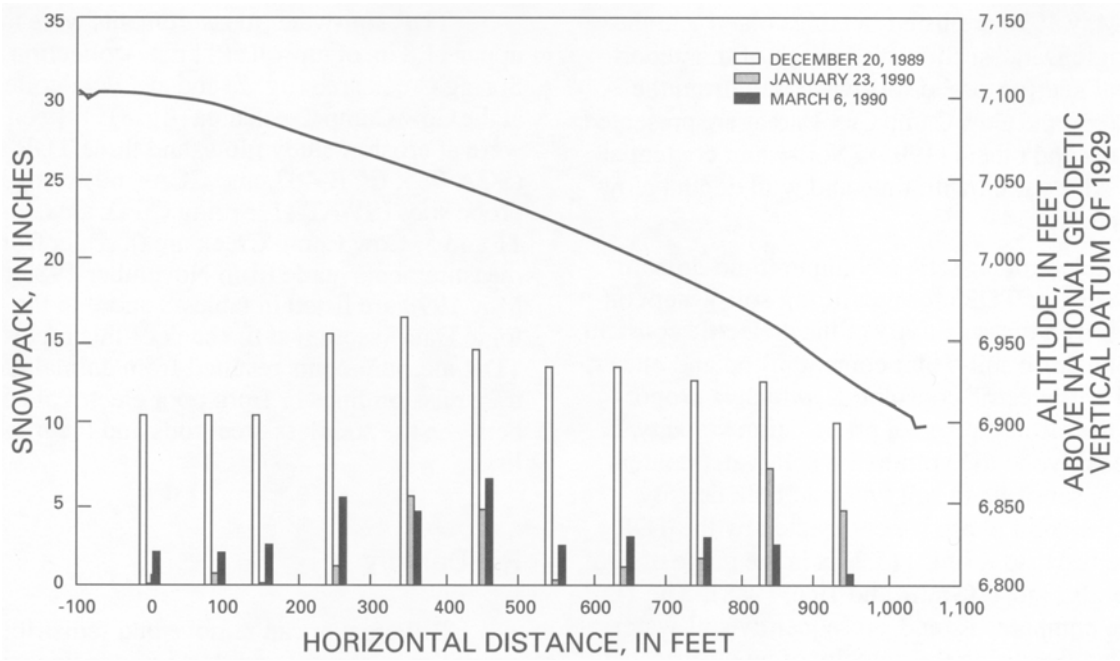

Figure 12. Snowpack depths along hillslope transect SCB, water year 1990.

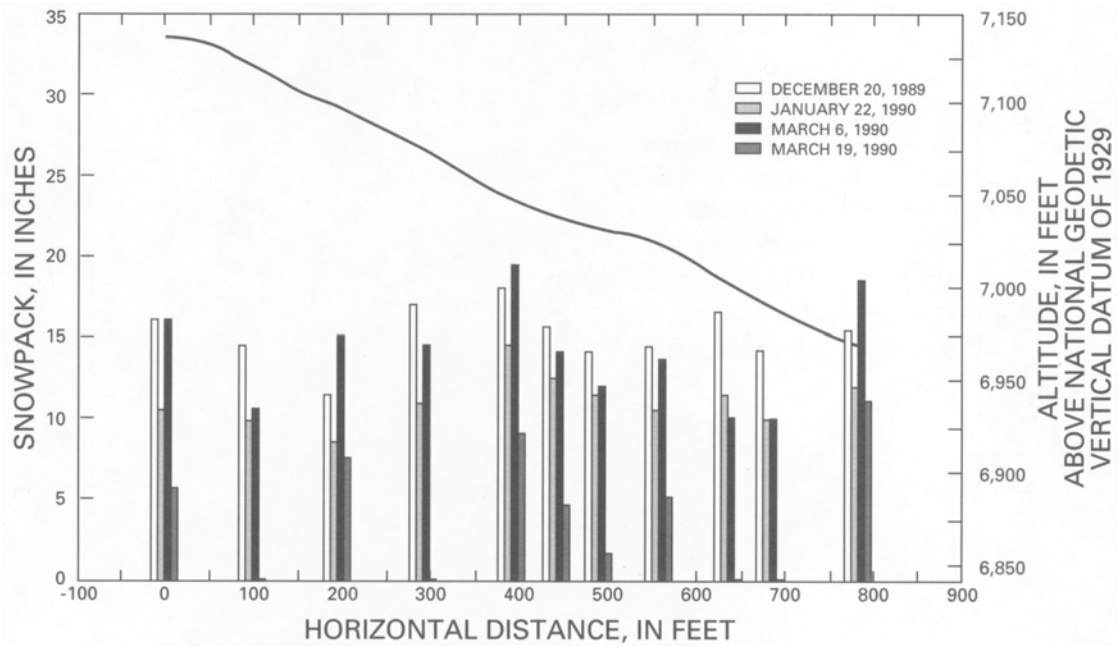

Figure 13. Snowpack depths along hillslope transect CCA, water year 1990.

trailer-mounted auger. Data from neutron-probe measurements made from November 1988 through May 1990 are listed in tables 6 and 7 in the "Hydrologic Data" section at the back of this report. Additional neutron-probe soil-water data from the Spring Creek and Cow Camp Creek areas are presented in Williams and others (1993). Soil-water content at most SWAT's varied with time and with depth below the surface (fig. 14).

The electromagnetic technique (time-domain reflectometry, or TDR) for measuring soil-water content is based on the sensitivity of the dielectric constant to the volumetric soil-water content (Topp and others, 1980). The dielectric constant, K, which is proportional to the electrical signal propagation velocity, is highly sensitive to the volumetric soil-water content but weakly sensitive to soil type and bulk density. Water in the solid phase is not detected by the TDR technique because K of ice (3.2) is in the range of K of soil minerals (3 to 4) (Smith and Tice, 1988). The TDR technique computes K, and subsequently soil-water content, by measuring the velocity of an electrical signal in a transmission line of known length. The TDR transmission lines over which K was measured were two parallel, 0.118-in-diameter stainless-steel rods inserted vertically into the topsoil. The rods were 11.8 in. long and were spaced 1.18 in. apart (W.N. Herkelrath, U.S. Geological Survey, oral commun., 1989). TDR soil-water measurements were made in the upper 11.8 in. of topsoil at 11 data-collection sites at the Spring Creek area (fig. 2) and at 7 data-collection sites at the Cow Camp Creek area (fig. 3). Fifteen TDR sites were at erosion-study plots, and three TDR sites (SCA-085, CCB-407, and CCA-569) were at neutron-probe sites (SWAT 11, Spring Creek area, and SWAT's 11 and 5, Cow Camp Creek area). Data from TDR measurements made from November 1989 through May 1990 are listed in tables 8 and 9 in the "Hydrologic Data" section at the back of this report. Missing TDR measurements resulted from animal damage to transmission lines or from poor electrical contacts between the stainless-steel rods and the transmission lines.

Rill Density

Rill erosion can remove and redistribute large quantities of topsoil and thus impede vegetation growth. Rills are small (generally less than 1 ft wide and 1 ft deep) parallel or bifurcating erosion channels. The occurrence of rills might be an indicator of the erosion history or erosion potential of a hillslope.

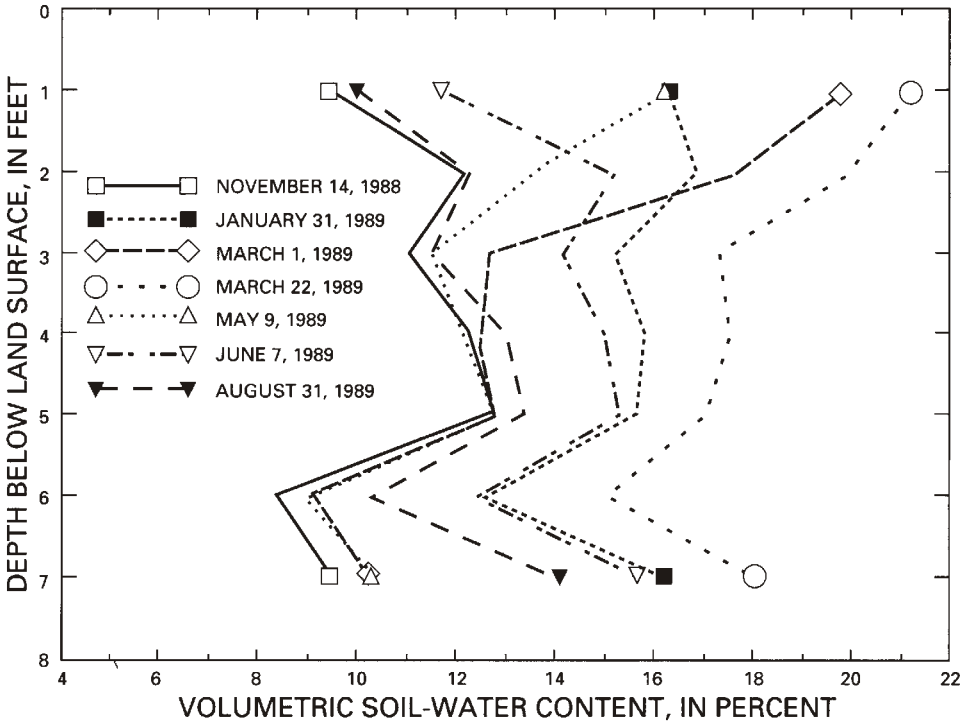

Figure 14. Variation in soil-water content with time and depth, soil-water access tube 14, hillslope transect CCA

Rills on the five reclaimed hillslopes were identified and mapped onsite in August 1989. Two types of rills were observedhealing and active. Healing rills formerly were the source of eroded topsoil; however, at the time of the study, healing rills were inactive sediment sources, and their channels were indistinct. Healing rills had subtle, smoothed channels, often were discontinuous after several feet, and usually had some vegetation growing in the rill. Active rills were the source of eroded topsoil when surface runoff was generated. Active rills had pronounced angular channels, often were continuous for several tens of feet, and usually had no vegetation growing in the rill.

Rill occurrence was quantified in 10- by 100-ft rectangular traverse areas located at 50-ft intervals along each hillslope transect. The traverse areas were oriented so that the long dimension was across (traverse to) the hillslope and the short axis was oriented down the hillslope. Individual rill lengths were measured, and the sum of all rill lengths was determined in each traverse area. The sum of all rill lengths (feet) divided by the traverse area (1,000 ft^2) determined the rill density (feet per 100 square feet) for a specific hillslope interval (table 2). Rill densities were determined for healing and active rills as well as for total rills (the sum of healing and active rill lengths).

Soil-Surface Surveys

Measurement of soil-surface altitude changes over a known time interval can provide a means to estimate soil loss where the actual eroded material cannot be collected (as in a flume). Several methods have been used to measure soil-surface altitude changes and, subsequently, to quantify soil loss. The erosion-pin method involves repeated measurements of the exposed length of an erosion pin permanently placed in the soil (Hadley and Lusby, 1967; Collins and Dunne, 1986). The principal disadvantages of the erosion-pin method are that the pin disturbs the soil when it is installed, and the pin influences the path and velocity of runoff near it.

Toy (1983, 1989) developed the linear erosion/ altitude measuring instrument (LEMI) method to avoid erosion-pin disturbance of the soil and runoff. The LEMI method involves measurements of the distance to the soil surface from a fixed point above undisturbed soil. A disadvantage of the LEMI method is that only one or two points usually are measured in a specific area.

Repeated soil-surface surveys made with a transit or level can be used to measure soil-surface altitude changes. However, transit surveys may not be accurate enough to detect small changes resulting from a single runoff event or an entire runoff season (Hadley, 1977). Inaccuracy results from surveyed points that may be spaced too far apart to define microtopographic detail or from optical limitations that are exaggerated when the distance between the instrument and rod is large. Another source of inaccuracy results from using a survey rod having a diameter wider than microtopographic landforms.

The erosion-frame method was developed to overcome some of the disadvantages of the erosion-pin, LEMI, and transit-survey methods. The erosion-frame method involves repeated soil-surface surveys in a monumented study plot with a transit and a modified survey rod. For this study, a 10- by 10-ft portable metal frame was assembled on each erosion-study plot where soil-surface altitude changes were measured. Each corner of the erosion frame was monumented and anchored with a section of rebar driven about 18 in. into the ground. Near each erosion-study plot, a fifth rebar section was driven about 30 in. into the ground and served as a vertical control for subsequent resur-veys. It was assumed that the fifth rebar section would not be affected by frost heave. The position and altitude of the fifth rebar section was referenced to fixed monuments (a powerline tower pad and a rock outcrop) on unmined land several hundred feet away. Five bolts at 2-ft intervals were placed along two opposite sides of the erosion frame. The paired bolts were anchor points for a surveyor's tape measure attached on opposite sides of the frame. A 2- by 10-in. board gangplank was placed across and above the erosion frame to prevent trampling in the erosion-study plot during surveying.

Soil-surface surveys were made along five traverses of each erosion-study plot. Soil-surface profiles were plotted from altitudes determined with a Zeiss Ni2 self-leveling level at 0.2-ft intervals along each of the five 10-ft traverses. The instrument was set up within about 30 ft of the erosion frame to minimize reading errors. A reinforced carpenter's scale with 0.01-ft graduations was used as the survey rod. The carpenter's scale had a very small cross-sectional area (0.15 by 0.6 in.), which permitted precise placement on microtopographic features. The reinforced carpenter's scale was light weight, which minimized damage to the soil surface. A total of 250 soil-surface altitudes, 50 per traverse, were determined for each soil-surface survey in the 100-ft erosion-study plot.

The initial soil-surface surveys were made at 16 erosion-study plots in September and October 1989. A second set of soil-surface surveys was made at each erosion-study plot in June 1990. Data from the soil-surface surveys are listed in tables 10 and 11 in the "Hydrologic Data" section at the back of the report. Soil-surface profiles from one erosion-study plot are shown in figure 15. The plotted profile orientation

is as if viewed looking toward the hillslope. The net soil-surface altitude change for each point (station) along an erosion-study plot traverse was the difference between the September or October 1989 altitude and the June 1990 altitude.

SUMMARY

Geomorphic, hydrologic, and erosion data were collected from five reclaimed hillslopes at the Seneca II mine near Hayden. Data presented in this report were collected during an investigation of hillslope-hydro-logic processes and soil loss at a representative reclaimed surface coal mine in northwestern Colorado. The Seneca II mine is producing coal from Cretaceous sedimentary rocks of the Williams Fork Formation. The climate of the region is semiarid, and a large amount of the 16-in. mean annual precipitation is snow.

Data were collected at two areas of the mine the Spring Creek area, reclaimed in 1986 and 1987, and the Cow Camp Creek area, reclaimed in 1985. The geomorphology of the reclaimed hillslopes was determined from surveys made onsite and from topographic maps. Cumulative hillslope lengths and local hillslope gradients were determined at 50- to 100-ft intervals along five surveyed hillslope transects. Aspect of the three Spring Creek area hillslopes was generally west and the altitude range of the hillslope transects was 6,890 to 7,125 ft. Hillslope lengths at the Spring Creek area were between 750 and 1,280 ft, and the mean hill-slope gradient was between 0.17 and 0.23 ft/ft. Aspect of *the* two Cow Camp Creek area hillslopes was generally south and the altitude range was about 6,970 to 7,140 ft. Hillslope lengths at the Cow Camp Creek area were 670 and 800 ft, and the mean hillslope gradient for both hillslopes was 0.22 ft/ft.

Vegetation cover was determined at 50- to 100-ft intervals along the hillslope transects with a 10-point vegetation sampling frame. Vegetation on

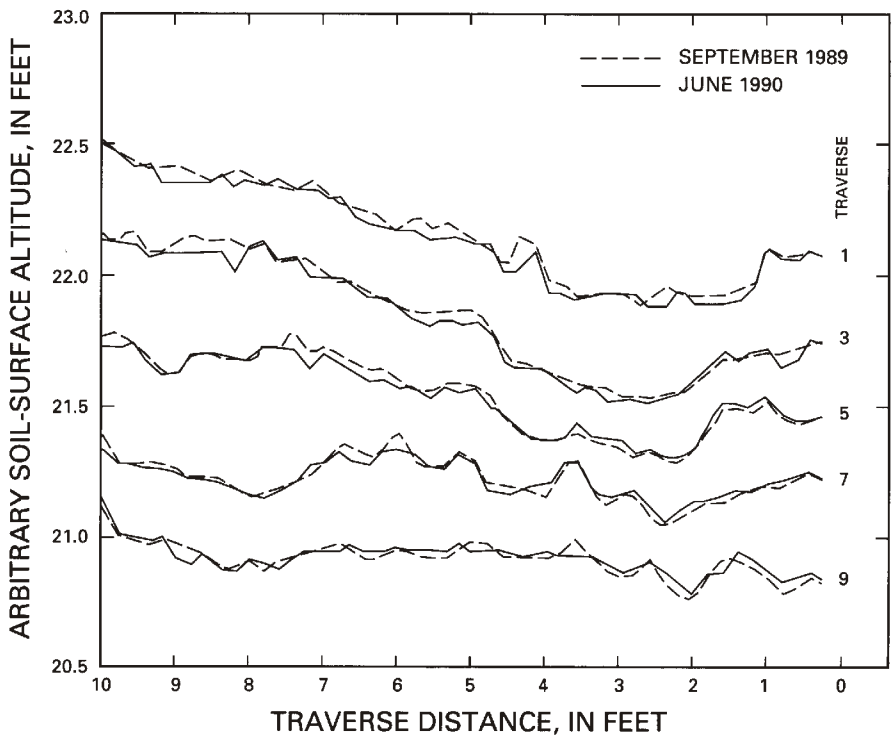

Figure 15. Soil-surface profiles from erosion-study plot SCA-620.