HYDROLOGY AND EFFECTS OF MINING IN THE UPPER RUSSELL FORK BASIN, BUCHANAN AND DICKENSON COUNTIES, VIRGINIA

By J.D. Larson and John D. Powell

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the inch-pound units published herein to the International System of Units (SI):

Multiply inch-pound units	by	To obtain SI units
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
gallon per minute (gal/min)	0.06308	liter per second (L/s)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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HYDROLOGY AND EFFECTS OF MINING IN THE UPPER RUSSELL FORK BASIN, BUCHANAN AND DICKENSON COUNTIES, VIRGINIA

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ABSTRACT

Aquifer transmissivities estimated from pumping and slug tests at six observation wells in the Russell Fork basin decrease greatly with depth. Transmissivities also differ significantly between ridgetop and valley settings. Transmissivity (T) values at a ridge site range from about 0.30 feet squared per day (ft^2/d) near land surface to about 0.008 ft^2/d at a depth of 500 feet. T values in valley wells ranged from about 270 ft^2/d in alluvial material to about 0.15 ft^2/d in unweathered material below a depth of 60 feet. Estimated storage-coefficient (S) values of 0.00040 and 0.00048 were obtained from a weathered rock zone between 14 and 60 feet below land surface in a valley well. Aquifer tests suggest that the major aquifer system in the Russell Fork basin consists of the alluvial material and a veneer of weathered and highly fractured rock in the basin.

Flow-duration statistics obtained from a stream gage at Haysi, Virginia indicate a change in flow at the 95-percent exceedence level since the start of surface mining; flow increased from 4.0 (1928-50) to 8.9 cubic feet per second (1951-80).

Base-flow recessions for the Russell Fork at Haysi stream gage indicate a change in ground-water depletion rate from 34 to 59 days per log cycle of discharge for the pre-1950 (0-percent mined) to the post-1950 (5-percent mined) period. This change produced a change in diffusivity from 28,500 ft^2/d (pre-1950, negligible surface mining) to 16,500 ft^2/d (post-1950, 5 percent of basin mined). Based on analysis of individual recessions for five gaging stations, diffusivity ranges from 28,500 ft^2/d for Russell Fork at Haysi before mining, to 10,100 ft^2/d for Barton Fork near Council, Virginia, which has 19.5 percent of its area disturbed by surface mining.

1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 Purpose, Scope, and Methods of Study

EVALUATING THE IMPACTS OF SURFACE COAL MINING ON THE WATER RESOURCES OF AN AREA REQUIRES AN UNDERSTANDING OF THE HYDROLOGIC FRAMEWORK.

Hydrologic data from the upper Russell Fork basin provide information for development of a conceptual model of the local flow system and the hydrologic framework. Ground-water levels, water-quality data, precipitation data, streamflow data, and selected basin characteristics are used to define the total hydrologic system in the upper Russell Fork basin.

Petroleum shortages in the early 1970's produced an upsurge in coal production as an alternative source of energy. These production increases occurred simultaneously with changes in environmental regulations governing mining activities. Industry and regulatory agencies need to know both the local hydrologic framework and basic hydrologic concepts in order to understand the natural and man-made factors affecting the hydrologic system.

This report presents the results of a study of the upper Russell Fork basin of the Appalachian Plateau Province (fig. 1.1-1)--a typical coal-area basin. The report (1) describes the ground-water and surface-water hydrology and water quality in a river basin draining a coal-producing area in southwestern Virginia; (2) describes the effects of mining on the hydrologic system; and (3) provides a conceptual understanding of the hydrologic system.

Ground-water levels, aquifer tests, water-quality data, precipitation data, and streamflow data (pre- and post-mining), are evaluated in order to understand the hydrologic system and possible impacts of surface mining. Methods of determining aquifer properties from streamflows are shown.

The Virginia Division of Mineral Resources, as part of this study, mapped the geology in the Prater and Vansant quadrangles to complete the geologic framework for the area. Virginia Polytechnic Institute and State University, Department of Fisheries, provided data on basin characteristics. Field studies began in December of 1980. Eight observation wells were drilled (June-October 1981) and four gaging stations were constructed (July 1981). Data for the observation wells and short-term gaging stations are analyzed for October 1981 through September 1982. Records for the Russell Fork gaging station at Haysi are analyzed for 1926 to 1982. Discharge and water-quality data were obtained at 28 surface-water sites. Streamflow, precipitation, and water-quality data for sites included in this report are published by the U.S. Geological Survey (1982), and ground-water quality is discussed (Rogers and Powell, 1983).

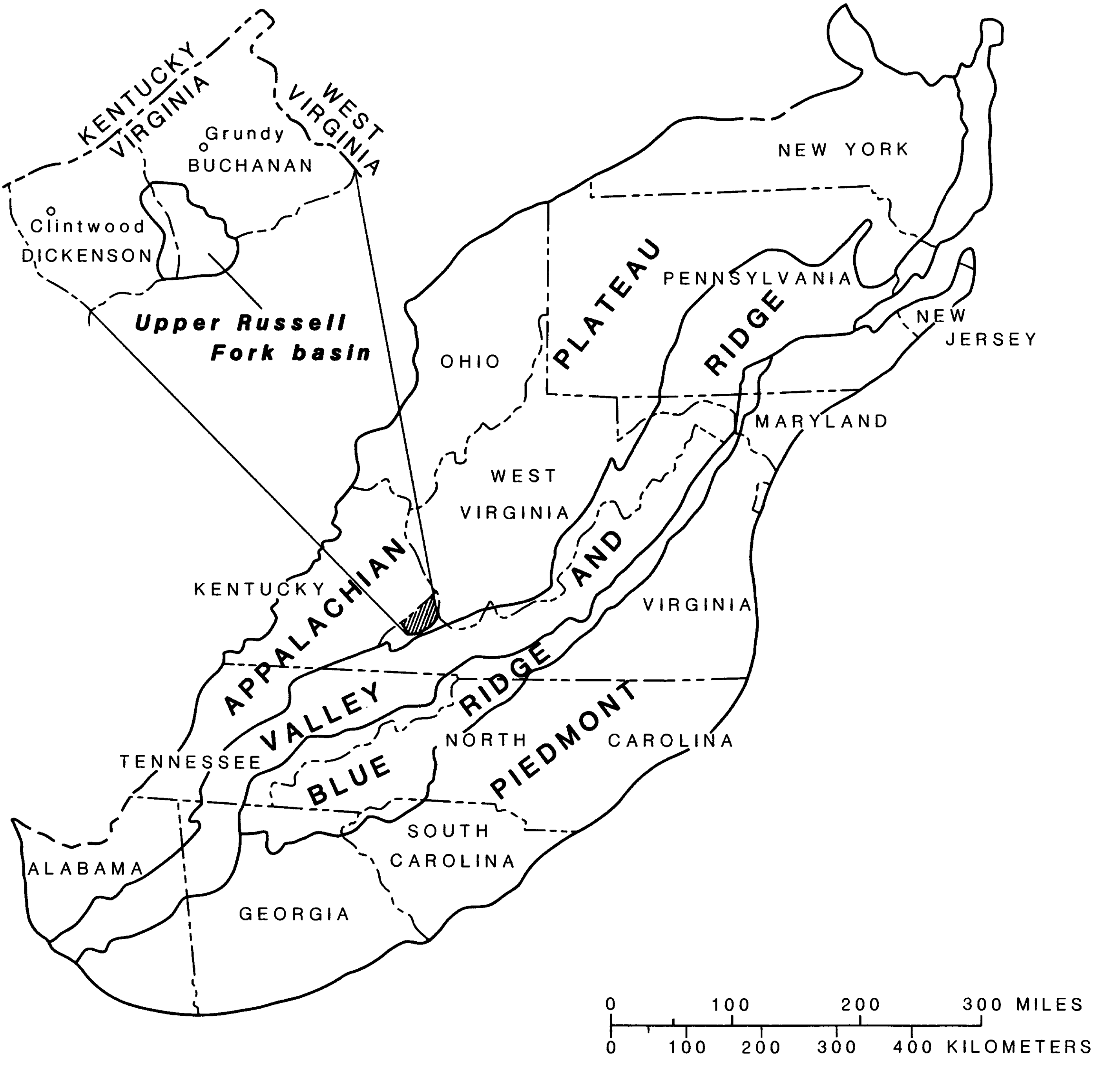


Figure 1.1-1 -- Physiographic provinces and location of upper Russell Fork basin.

1.2 Location of Area

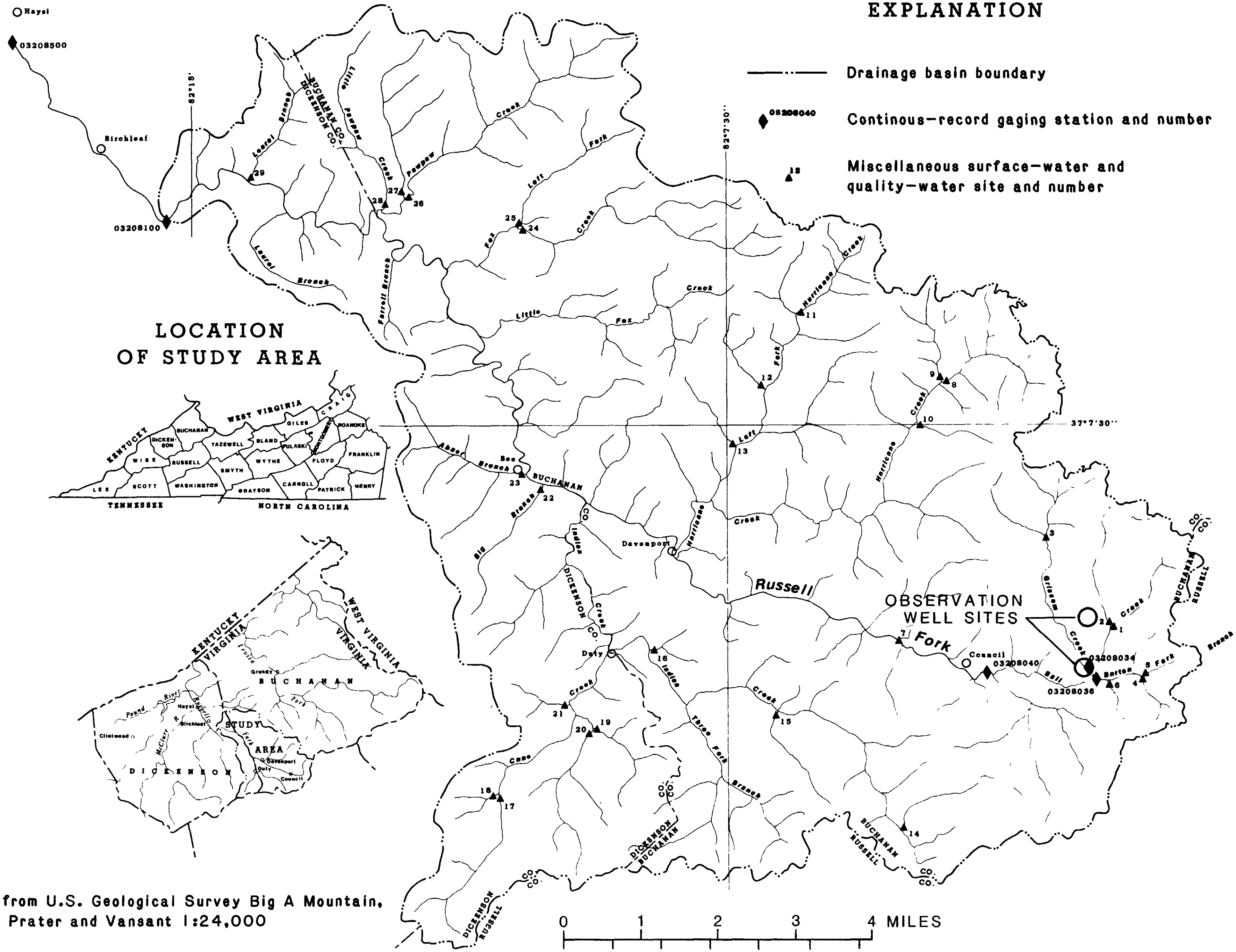
UPPER RUSSELL FORK BASIN REPRESENTS A TYPICAL HYDROGEOLOGIC SETTING IN A COAL-PRODUCING AREA OF VIRGINIA

A part of the upper Russell Fork basin of Buchanan and Dickenson Counties, Virginia, was selected for study because it meets the criteria needed to evaluate the ground-water and surface-water hydrology of a river basin draining a coal-producing area in southwestern Virginia.

The Russell Fork basin is located within Buchanan and Dickenson Counties in southwestern Virginia (fig. 1.2-1). This drainage basin was selected for study because it is a typical hydrogeologic basin in a coal area and meets the criteria for evaluating ground-water and surface-water hydrology.

The criteria considered for selection of the study area were (1) availablity of long-term streamflow data (USGS gaging station 03208500 at Haysi, 1926-present); (2) adequate data concerning geologic framework (access to recently drilled core holes); (3) mixture of mined and unmined subbasins (0 to 56 percent of basin areas disturbed by surface mining); (4) geologic and topographic similarity to other stream basins in the coal-producing area of southwestern Virginia; and (5) low population density.

The drainage area of the Russell Fork above the gaging station at Haysi, Virginia, is 286 mi^2 (square miles). Study emphasis was on the following subbasins: upper Russell Fork (86.5 mi^2) above the gaging station near Birchleaf; Russell Fork above the gaging station at Council (10.2 mi^2), and detailed studies of Grissom Creek (2.83 mi^2) and Barton Fork (1.23 mi^2). Gaging-station locations, miscellaneous measurement sites, and two well-cluster sites are shown on figure 1.2-1.



Base from U.S. Geological Survey Big A Mountain, Duty, Prater and Vansant 1:24,000

Figure 1.2-1 -- Study area and location of data-collection sites.

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2.0 GEOLOGIC SETTING

2.0 GEOLOGIC SETTING

2.1 Geology

THE UPPER RUSSELL FORK BASIN IS UNDERLAIN BY GENTLY DIPPING BEDS OF SANDSTONE, SILTSTONE, AND COAL

The upper Russell Fork basin is underlain primarily by gently dipping beds of sandstone, siltstone, and coal of Early and Middle Pennsylvanian age. A small outlier of sedimentary rocks of Early Cambrian to Early Pennsylvanian age is exposed at the eastern edge of the basin. Holocene alluvium and colluvium commonly overlie older rocks in valley bottoms and on hillsides.

Most rocks of the upper Russell Fork basin are included in the Norton Formation of Early and Middle Pennsylvanian age. This formation lies stratigraphically between the underlying Lower Pennsylvanian Bee Rock Sandstone Member of the Lee Formation, and the overlying Middle Pennsylvanian Gladeville Sandstone. The Norton Formation is predominantly sandstone (over 50 percent) in the study area with siltstone, shale, and coal beds comprising the remainder. Small outliers of Middle Pennsylvanian Wise Formation which overlie the Gladeville Sandstone are found on the higher ridgetops. Small outcrops of the underlying Lee Formation are found where extensive faulting has brought this formation to the surface. The oldest rocks exposed in the basin are Early Cambrian to Early Pennsylvanian age. These crop out on the eastern edge of the basin where the Appalachian Plateau Province is in contact with the adjoining Valley and Ridge Province. The youngest rock material present (Quaternary age) is alluvium in the valley bottoms and colluvium on hillsides. Thicknesses of these deposits range from 0 to 30 feet.

Figure 2.1-1 shows a geologic section across the northern part of the Russell Fork basin prepared by the Virginia Division of Mineral Resources. Rock identifications are based on samples from exploratory core holes. Strata dip gently to the northwest at about 50 feet per mile.

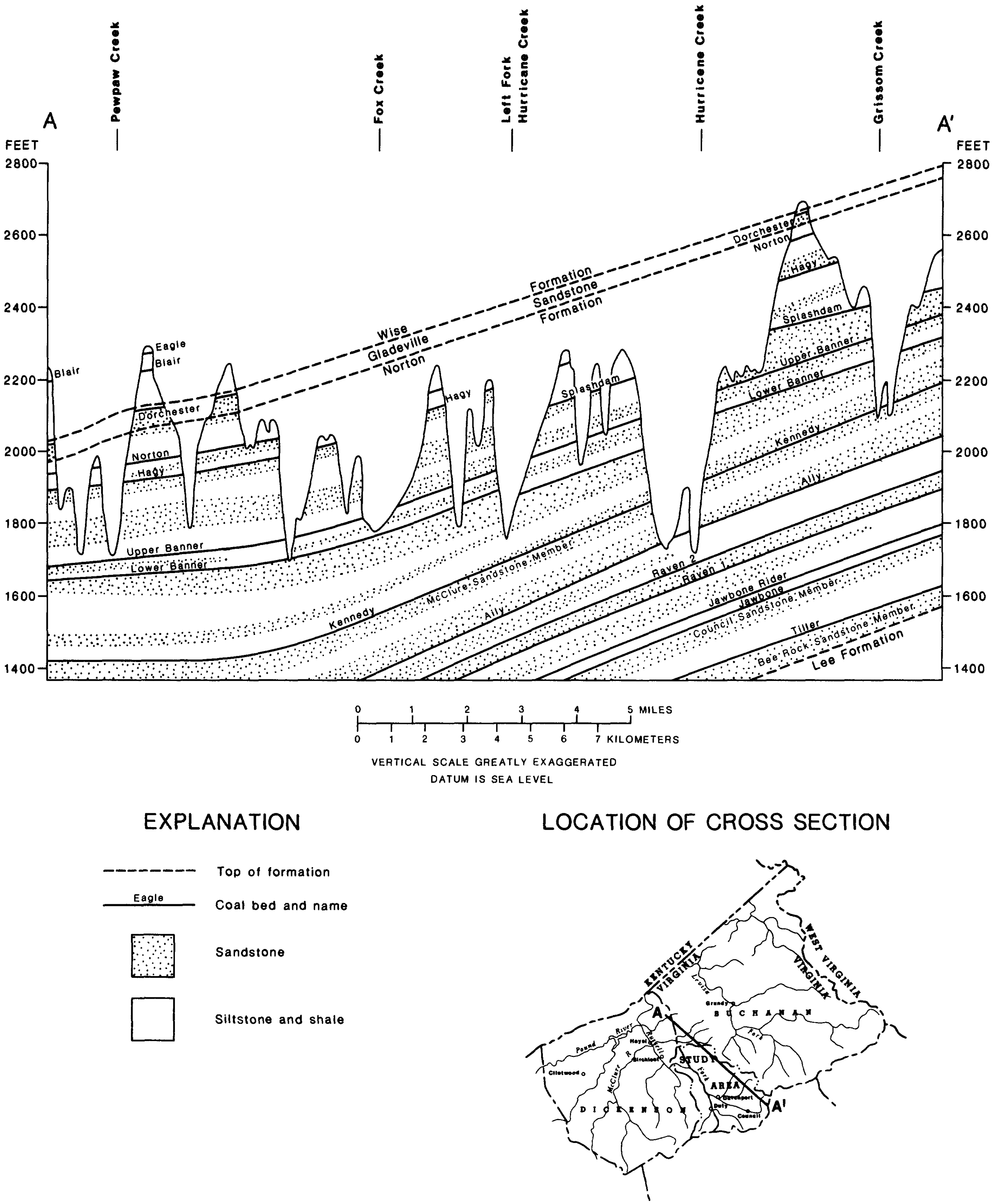

Figure 2.1-1 -- Section across upper Russell Fork basin showing stratigraphic positions of sandstone, siltstone, shale and major coal beds.

2.2 Linear Features

RUSSELL FORK FAULT IS MAJOR LINEAR FEATURE IN UPPER RUSSELL FORK BASIN

The Russell Fork Fault is the major linear feature in the upper Russell Fork basin. Additional linear features are present.

The major linear feature in the Russell Fork basin is the Russell Fork Fault (fig. 2.2-1). This feature extends southeastward from Bee, Virginia to the headwaters of the basin, parallel to the mainstream of the Russell Fork. It is a strike-slip fault with the northern section of the fault displaced about 4 miles to the east of the southern section (Englund, 1971). The Virginia Division of Mineral Resources delineated additional linear features within the basin as shown on the figure. Only the most prominent lineaments as seen from various high altitude and satellite photographs of the area are shown. Most tributary stream valleys appear as minor linear features.

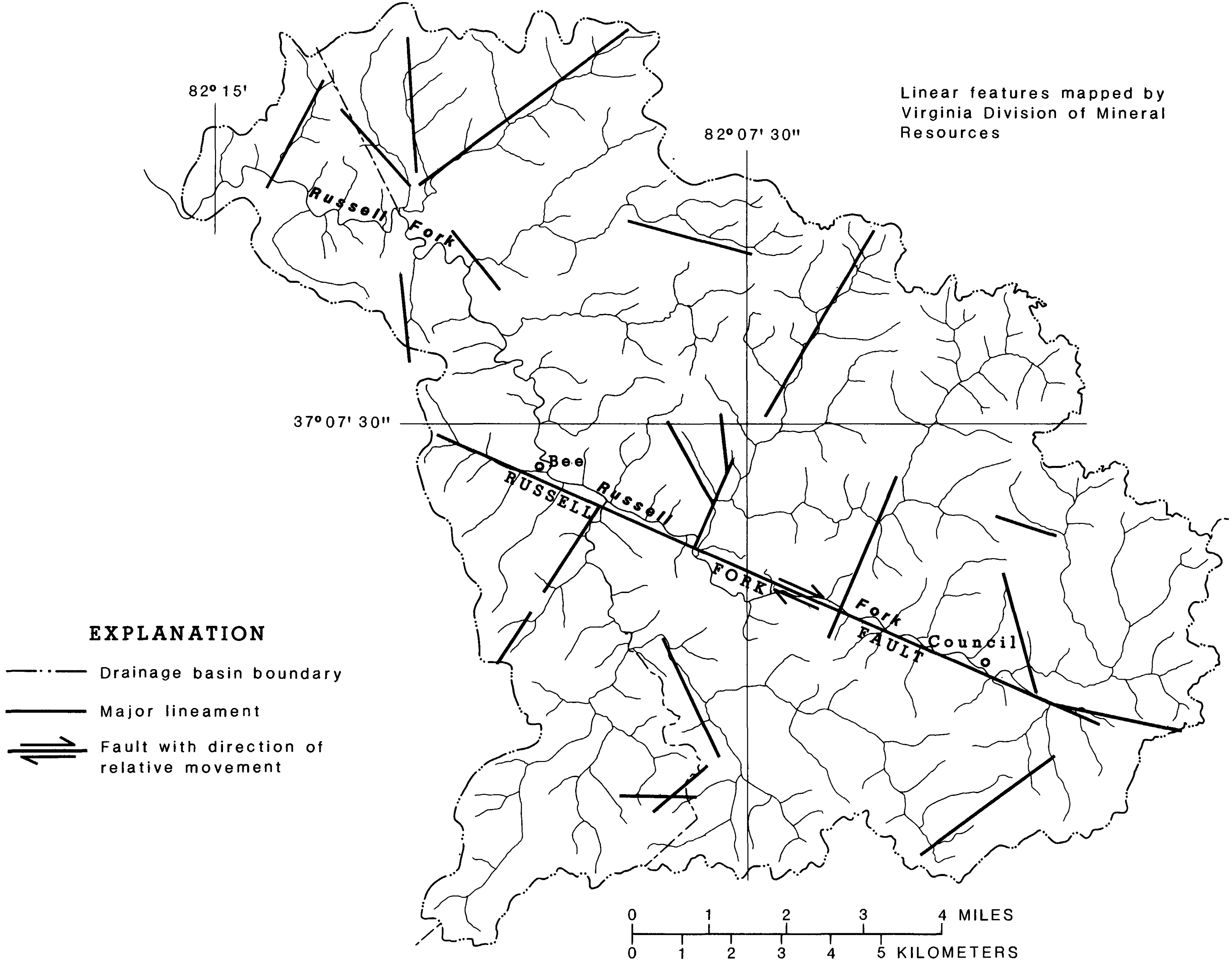

Figure 2.2-1 -- Major linear features in upper Russell Fork basin.

3.0 SURFACE-WATER HYDROLOGY

3.0 SURFACE-WATER HYDROLOGY

3.1 Water Budget

A WATER BUDGET INDICATES THAT ABOUT ONE THIRD OF TOTAL RUNOFF IS GROUND-WATER DISCHARGE

Streamflow hydrographs for Russell Fork at Haysi were separated into direct runoff and base-flow for 1971-1980 and 1982. These separations indicate that about 35 percent of total runoff is derived from the ground-water system. Monthly averages indicate that maximum runoff occurs in March, and minimum runoff occurs in September for both runoff components. Based on the water budget, about 50 percent of precipitation evapotranspirates.

Total water gain and loss for a basin may be estimated using a water budget. Assuming that ground-water and surface-water divides coincide and that precipitation is the only source of water, a water budget may be stated as P=Q + E, where P is precipitation, Q is total basin runoff, and E is evapotranspiration. This equation assumes no changes in ground-water and surface-water storage for several years of record. Precipitation averaged about 40 inches per year in 1971-1980 and 1982. Average streamflow at the Haysi gage represented about 19.5 inches of runoff per year; thus, 20.5 inches or about 50 percent of total precipitation on the basin is lost to evapotranspiration.

The streamflow hydrograph for Russell Fork at Haysi, which measures total basin runoff above the gaging station, was subdivided by inspection into direct overland runoff and base-flow runoff (ground-water discharge to the stream) for 1971-1980 and 1982. Figure 3.1-1 shows base flow and total runoff on an annual basis and the 11-year average. Figure 3.1-2 shows the average monthly values for base flow and total runoff for the same period of record. The average base-flow runoff for the 11-year period was about 7 inches per year, which equals 35 percent of the 19.5 inches of total runoff per year.

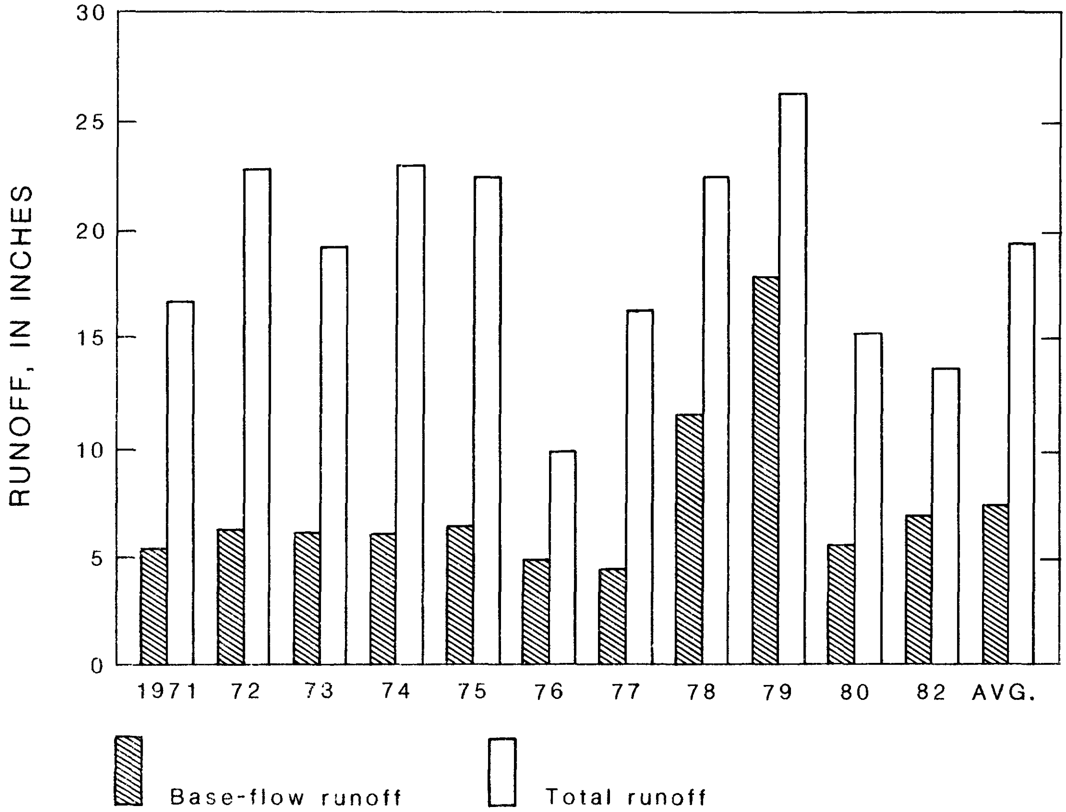

Figure 3.1-1 -- Base flow and total runoff from the Russell Fork basin, 1971-80, 1982 and 11-year average.

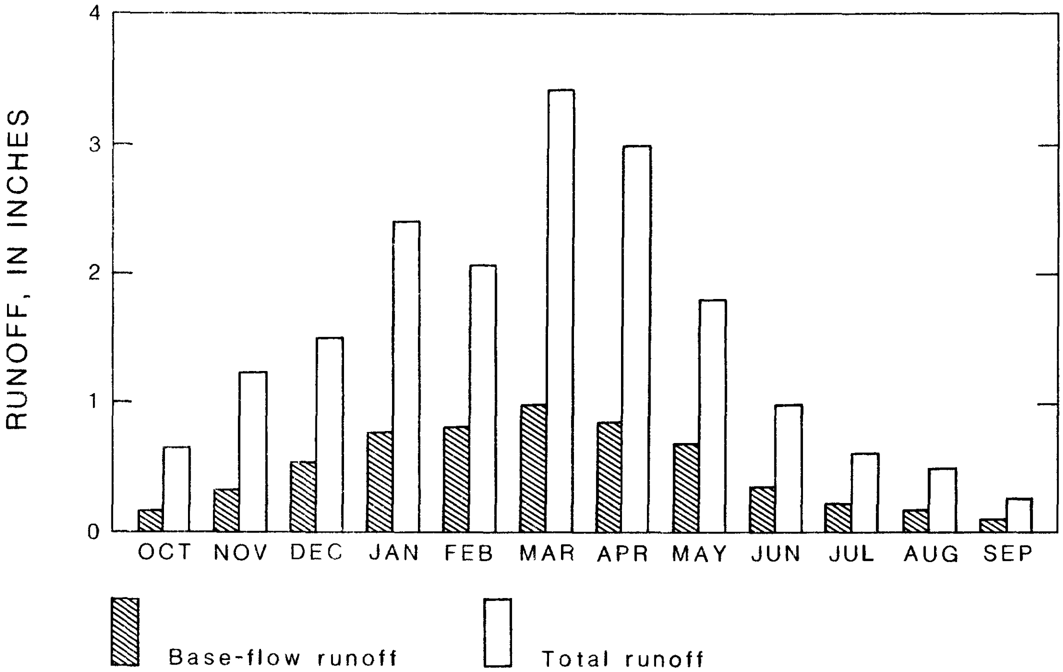

Figure 3.1-2 -- Average monthly base flow and total runoff from the Russell Fork basin, 1971-80 and 1982.

3.2 *Streamflow*

3.2.1 *Correlation between gaged and ungaged sites*

STATISTICS FROM A GAGED STATION ARE USED TO DEVELOP STREAMFLOW STATISTICS FOR UNGAGED BASINS

Graphs that correlate streamflow data from ungaged streamflow sites with data from concurrent continuous-record gaging stations provide a method for obtaining flow statistics. Six streamflow measurements were used to develop streamflow statistics in ungaged basins.

Streamflow measurements were made at selected sites and correlated with concurrent flow at a continuous-record gaging station located within the same basin in order to estimate streamflow statistics for subbasins not having continuous-record gaging stations. Figure 3.2.1-1 shows this type of correlation for Hurricane Creek above left Fork and Russell Fork at Haysi. Six measurements (August 1981 to October 1982) at each site are correlated with flows at the Haysi gage.

The Q_{50} streamflow for Russell Fork at Haysi is 135 cubic feet per second (ft^3/s). This statistic means that 50 percent of the time, the Russell Fork streamflow is greater than or equal to 135 ft^3/s. Horizontally across from where the Russell Fork Q_{50} line intersects the correlation line is the Q_{50} value for the ungaged site. The estimated Q_{50} streamflow for Hurricane Creek is about 0.67 ft^3/s. This correlation gives estimated flow statistics for a stream, as shown on the figure. Caution must be used when obtaining flow statistics beyond the range of measurements for an ungaged basin.

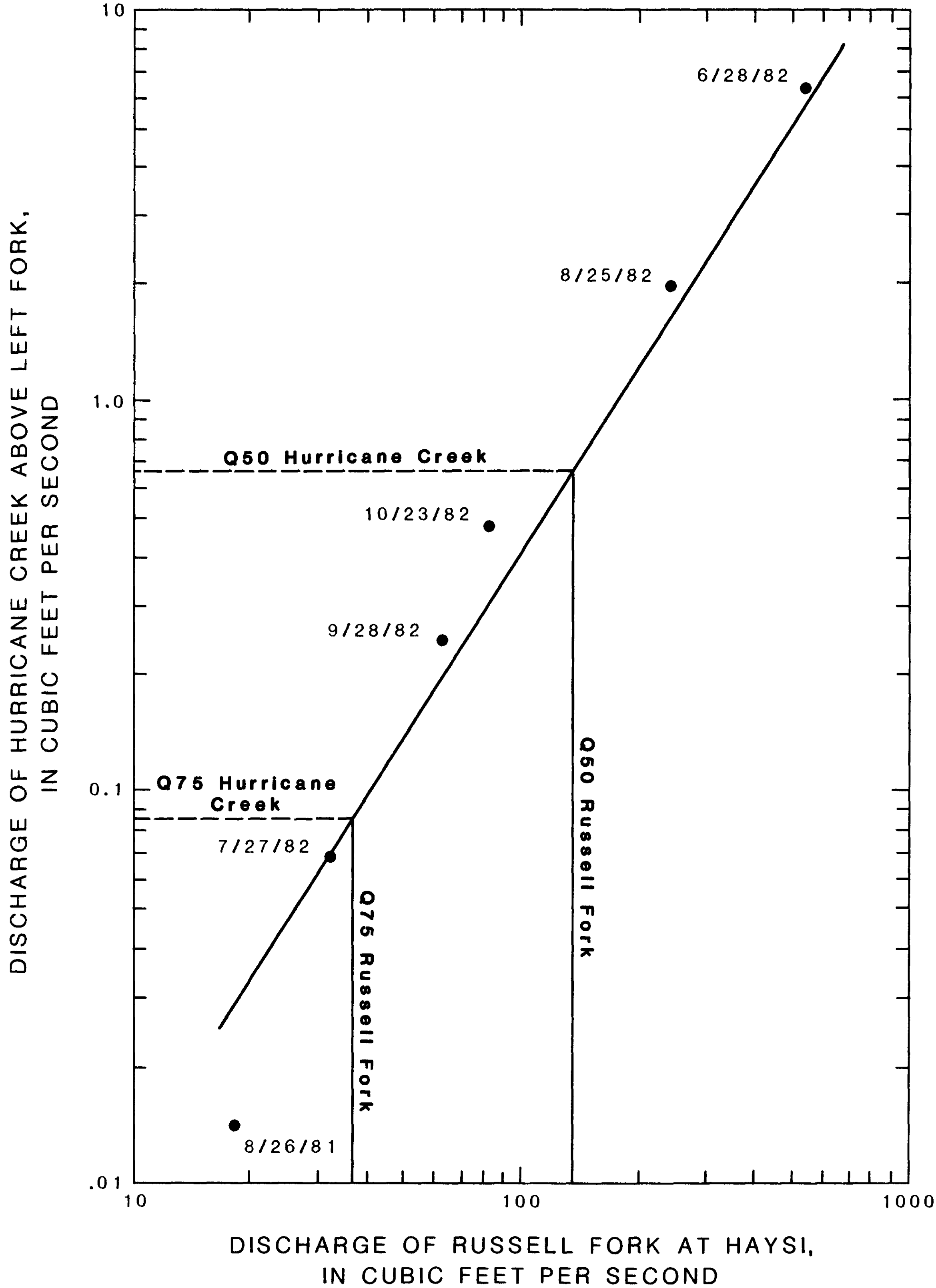

Figure 3.2.1-1 -- Streamflow correlation of Russell Fork at Haysi, Va. and Hurricane Creek.

ESTIMATED FLOW-DURATION STATISTICS FOR UNGAGED SITES OBTAINED BY STREAMFLOW CORRELATION

Flow-duration statistics were estimated for 28 small ungaged sites using flow data from the Russell Fork gaging station at Haysi.

A flow-duration curve is a cumulative-frequency curve that indicates the percentage of time specified discharges were equaled or exceeded during a given time period. The low- or base-flow segments of these curves are useful in assessing the effects of geology and man's activities on the hydrologic system.

Flow-duration statistics (Q_{50}, Q_{60}, Q_{75}, and Q_{90}) are estimated for 28 ungaged streamflow sites draining the upper Russell Fork basin utilizing data from the gage on Russell Fork at Haysi. Table 3.2.2-1 lists flow statistics, basin area, and percent of area disturbed by surface mining. The table is sorted into increasing mining and basin size. In the table, estimated flow statistics compare flow data for basins of differing areal extent. The r^2 value on the table is a correlation coefficient, which statistically shows the closeness of fit of the measurements with the correlation curve. The closer the r^2 value is to 1.0, the closer the data points are to the curve.

Table 3.2.2-1 -- Estimated streamflow statistics for 28 miscellaneous measurement sites in the upper Russell Fork basin.

Map No.	Stream Name	Area (mi^2)	Percent[1] mined	Flow Duration $(ft^3/s)/mi^2$				r^2
				Q50	Q60	Q75	Q90	
6	Barton Fork Trib.	0.174	0	0.155	0.120	0.045	0.0172	.97
10	Parrett Fletcher Branch	0.483	0	0.312	0.215	0.053	0.0144	.86
13	Ivy Lick Branch	0.744	0	0.278	0.176	0.032	0.0067	.96
15	Puncheon Camp Branch	0.80	0	0.237	0.177	0.060	0.0212	.81
14	Little Indian Creek	1.01	0	0.274	0.211	0.082	0.0326	.89
22	Big Branch at Bee	1.10	0	0.131	0.095	0.029	0.0090	.79
2	Nance White Branch	1.13	0	0.137	0.095	0.024	0.0070	.93
3	Grissom Creek	1.44	0	0.238	0.161	0.038	0.0097	.95
27	Hackney Hollow	1.44	0	0.180	0.081	0.004	0.0002	.97
23	Abner Branch at Bee	2.01	0	0.162	0.117	0.035	0.0109	.92
8	Hurricane Creek	1.760	1	0.396	0.250	0.046	0.0090	.99
26	Paw Paw Creek	4.12	1	0.531	0.291	0.030	0.0036	.99
12	Boyd Branch	0.677	2	0.320	0.166	0.014	0.0014	.94
29	Laurel Branch at Viers	1.43	2	0.233	0.147	0.026	0.0048	.99
28	Little Paw Paw Creek	1.36	3	0.428	0.261	0.042	0.0073	.99
25	Left Fork abv Fox Creek	1.70	4	0.350	0.208	0.030	0.0047	.98
24	Fox Creek abv Left Fork	3.68	7	0.489	0.296	0.047	0.0078	.99
7	Big Branch	0.972	9	0.254	0.183	0.055	0.0174	.94
11	Left Fk. Hurricane Creek	1.18	9	0.708	0.500	0.139	0.0406	.92
21	Cane Creek Trib.	0.64	10	0.115	0.089	0.032	0.0125	.93
17	Cane Creek	1.735	11	0.196	0.123	0.022	0.0046	.90
9	Left Fork	0.887	15	0.809	0.459	0.057	0.0078	.94
5	Barton Fork	0.327	26	0.183	0.143	0.055	0.0214	.92
19	Left Fork abv Tiller Fork	1.02	31	0.377	0.284	0.100	0.0362	.92
18	Cane Creek Trib.	0.462	32	0.054	0.025	0.002	0.0002	.98
1	Ball Creek	0.912	36	0.439	0.378	0.217	0.1282	.91
4	Jackson Fork	0.31	39	0.316	0.264	0.138	0.0741	.97
16	Indian Creek Trib.	0.393	56	0.592	0.534	0.368	0.2595	.79

1. The percent of a basin disturbed by surface mining is referred here as percent mined.

3.2 Streamflow

3.2.3 Flow recession

BASE-FLOW RECESSION CURVES SHOW GROUND-WATER DISCHARGE AND SEASONAL VARIATION DUE TO EVAPOTRANSPIRATION

A base-flow recession curve from a streamflow hydrograph is a measure of the rate of decline in ground-water storage within a basin.

Flow recession is the rate of streamflow decrease; during base-flow periods, it approximates the decline in ground-water storage in a basin. Recession curves are developed by selecting straight-line segments of stream hydrographs that show flow after storm events and transposing these segments onto a straight line through the range of discharges observed.

Figure 3.2.3-1 is a streamflow hydrograph for Barton Fork near Council, Va., for the period October 1981 to September 1982. As shown in the figure, the recession lines are drawn when the hydrograph changes slope after a peak. The April and June-July recession lines illustrate the change in slope of recessions due to seasonal losses due to evapotranspiration. The June-July recession line is steeper, indicating loss of water from evapotranspiration. The April recession line is flatter, indicating minimal effects from evapotranspiration.

Barton Fork near Council, Va.

PERIOD OF RECORD : Oct. 1, 1981 to Sept. 30, 1982

AREA : 1.23 square miles

SURFACE MINING DISTURBANCE : 29%

AVERAGE DISTANCE FROM STREAM TO DIVIDE : 940 feet

DECAY RATE PER LOG CYCLE : 81 days

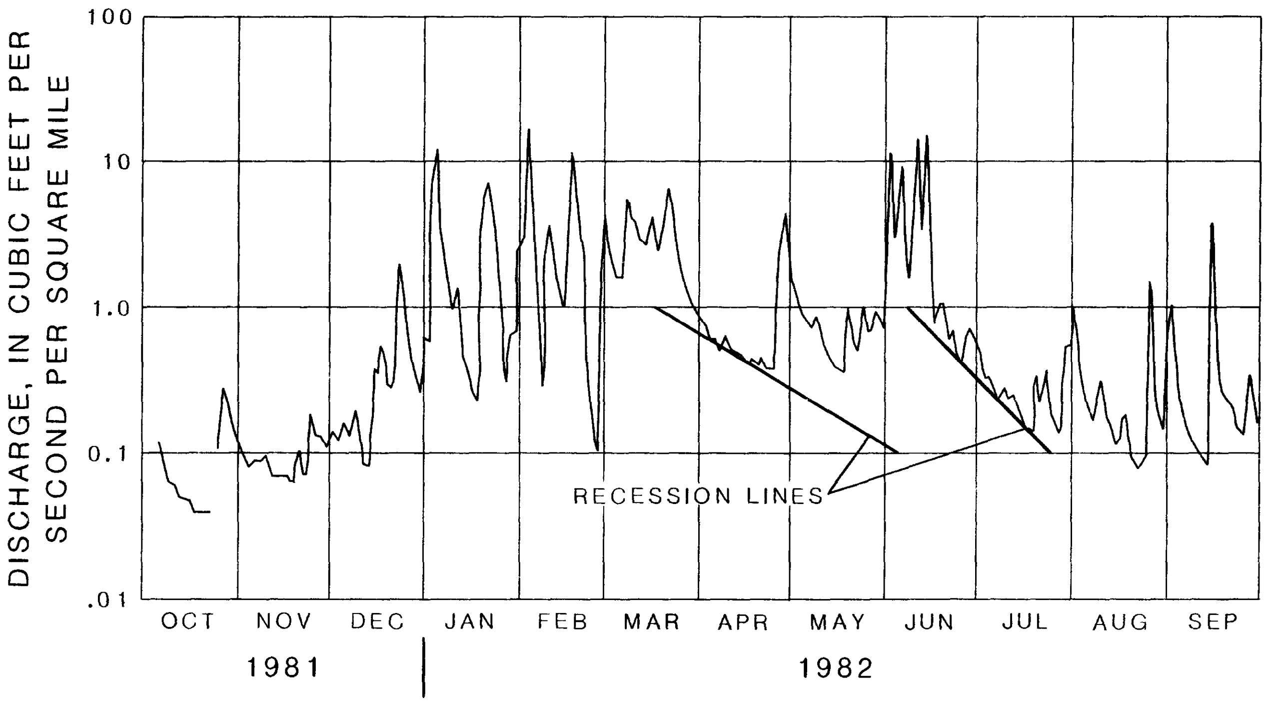

Figure 3.2.3-1 -- Streamflow hydrograph for Barton Fork near Council, Va., showing recessions.

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4.0 GROUND-WATER HYDROLOGY

page 25 follows

4.0 GROUND-WATER HYDROLOGY

4.1 *Observation Wells*

4.1.1 *Description*

OBSERVATION WELLS WERE INSTALLED IN A VALLEY BOTTOM AND ON A RIDGETOP TO EVALUATE DIFFERENT HYDROLOGIC ENVIRONMENTS

Eight observation wells were installed in the Grissom Creek subbasin to evaluate the various hydrogeologic environments present in the area. Three wells were installed in a valley bottom to monitor water levels and to conduct aquifer tests in alluvium, weathered rock, and unweathered rock. Five wells were drilled on a ridgetop to monitor water levels and to conduct aquifer tests on the weathered material and unweathered rock to the depth of the first coal bed, a sandstone-siltstone contact, and three coal-bed zones.

Eight observation wells were drilled in the Grissom Creek basin. Three wells are located in the valley bottom near the mouth of Grissom Creek and five wells are located on a ridgetop between Grissom Creek and Nance White Branch. The observation wells were constructed so that water levels and aquifer properties at specific-depth intervals below the ridgetop, and in the alluvium, weathered bedrock, and unweathered bedrock in the valley could be determined. Construction features and locations of the observation wells are shown in figure 4.1.1-1.

Two wells (14E40, 14E41) were drilled and one well point (14E44) was installed near the gaging station at the mouth of Grissom Creek. Well 14E40 was drilled and cased through the alluvium to a depth of 14 feet using an 8-inch diameter bit. Water inflow to the hole increased with depth in the alluvium. After 6-inch diameter casing was installed and grouted, drilling continued to a depth of 60 feet with a 6-inch bit. A gradual increase in water inflow was encountered to the Jawbone coal bed of the Norton Formation. A minor increase in water inflow occurred below the Jawbone coal bed. Well 14E41 was similarly drilled to a depth of 60 feet; after 6-inch casing was installed and grouted, drilling continued with a 6-inch diameter bit to a depth of 125 feet. Very little water was encountered below the cased section of the hole. Well 14E44 is a 2-inch diameter well point driven into alluvium near the bank of Grissom Creek; the water level was 2 feet below land surface. An unused well (14E42) at the site also was used as an observation well; the well is 60 feet deep and has 4-inch casing to a depth of 14 feet.

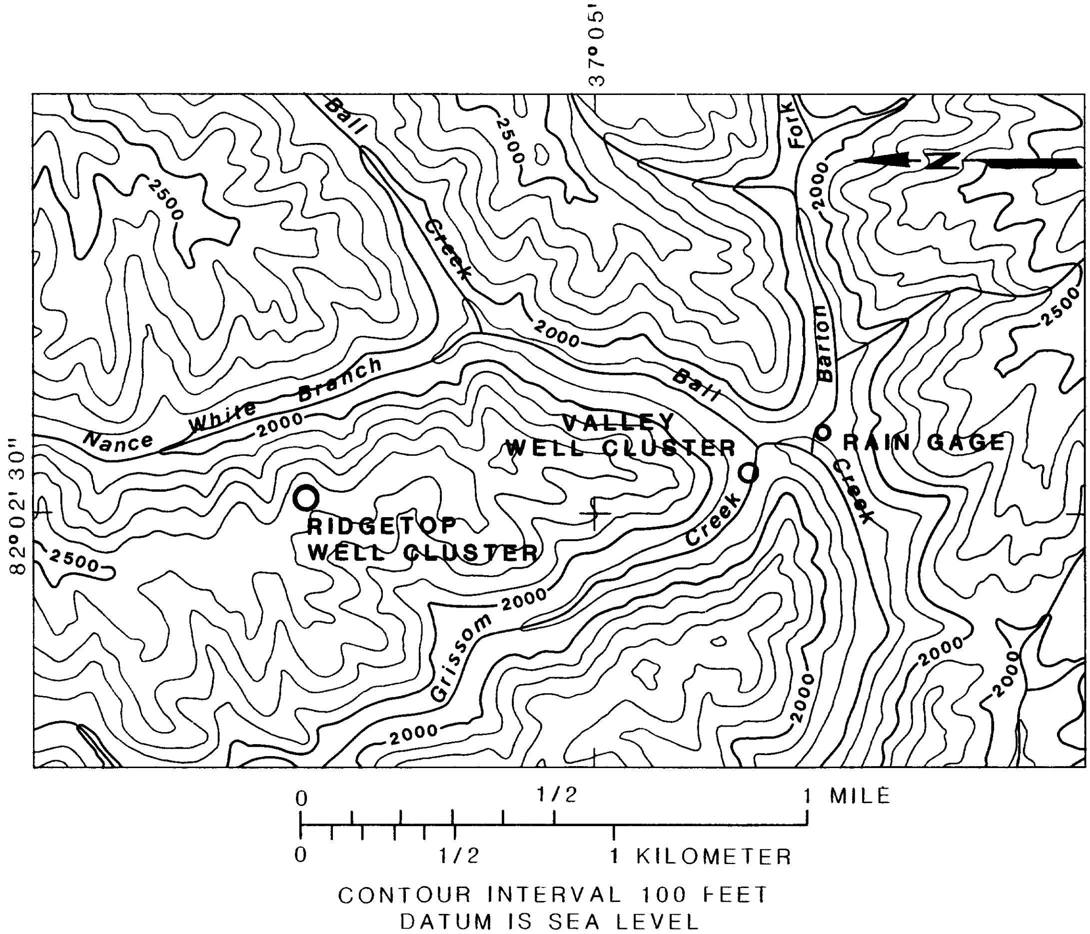
Five wells were drilled in a cluster on a ridgetop between Grissom Creek and Nance White Branch to monitor differences in water levels between major coal beds in the Norton Formation and to determine the hydraulic properties of the rocks. No measurable amount of water was produced during the drilling of any of the ridgetop wells. Two 8-inch diameter holes (14E25 and 14E26) were drilled to depths of 56 and 101 ft, respectively, and were cased with 4-inch diameter PVC pipe. In well

4.0 GROUND-WATER HYDROLOGY *(continued)*

4.1 Observation Wells (continued)

4.1.1 Description (continued)

14E25, casing was slotted from the bottom of the well (in the Upper Banner coal bed) to the bottom of the soil zone at a depth of two feet, a gravel pack was installed, and the casing was grouted in with a 2-foot cement cap to the surface. Well 14E26 had slotted PVC casing installed from 56 feet (below the Upper Banner coal bed) to the bottom, and a gravel pack was installed. The annular space between the casing and drilled hole was grouted with bentonite and cement from the top of the gravel pack to land surface. Well 14E26 does not reach the Lower Banner coal bed but is finished just below a sandstone-siltstone contact. Three additional 8-inch diameter holes (14E37, 14E38 and 14E39) were drilled to the bottom of coal beds. Six-inch casing was installed to the bottom of each. Cement grout was injected into the well and forced up the outside annulus to the surface. Drilling was continued into the next coal bed. The lower section of each well is an open hole. Well 14E39 is open from the bottom of the Lower Banner coal bed into the Kennedy coal bed at a depth of 243 ft. Well 14E38 is open from the bottom of the Kennedy coal bed into the Aily coal bed at 423 ft. and Well 14E37 is open from the bottom of the Aily coal bed through the Raven 1, 2, and 3 coal beds, to a depth of 582 ft.



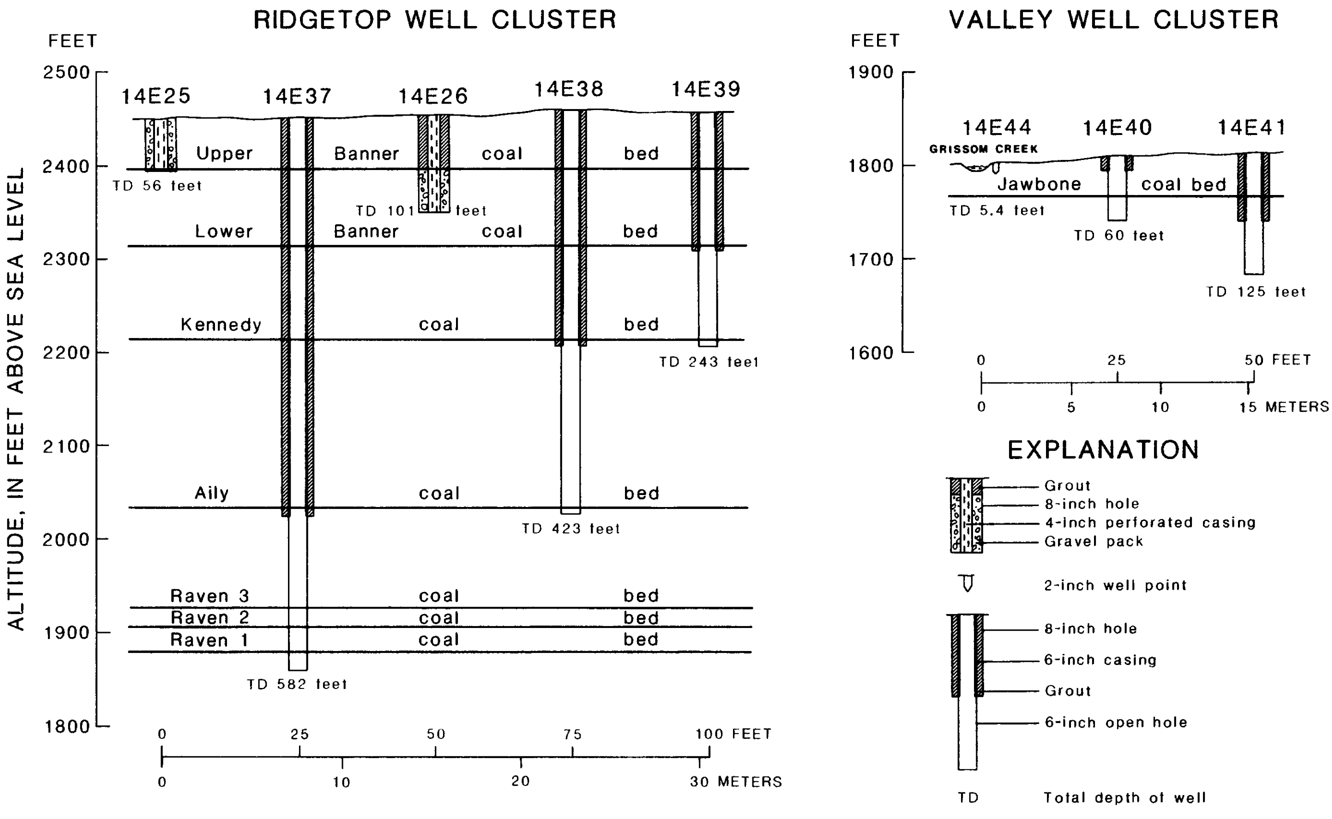


Figure 4.1.1-1 -- Construction features and location of observation wells.

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4.1 Observation Wells

4.1.2 Water-level fluctuations

WATER-LEVEL FLUCTUATIONS IN VALLEY OBSERVATION WELLS REFLECT CHANGES IN CLIMATIC CONDITIONS; RIDGETOP OBSERVATION WELLS TAP PERCHED WATER ZONES AT COAL BEDS

Water-level recorders were installed on three valley observation wells and five ridgetop wells in October-November 1981. Raingages were installed at Barton Fork, about 1,000 feet from the valley wells, and at Birchleaf, about 15 miles away. Water-level hydrographs and precipitation records for valley and ridgetop wells show some correlation of water-level response to rainfall and dry periods. The ridgetop observation wells tap a series of perched-water zones associated with coal beds.

Continuous water-level recorders were installed in three valley observation wells (14E40, 14E41, and 14E44) at the mouth of Grissom Creek in November 1981. Precipitation was measured at a raingage at the mouth of Barton Fork, approximately 1,000 feet from the wells. Precipitation also was measured at Birchleaf, Virginia, about 15 miles away. This record is used to supplement missing data records for May, June, and July 1982 at the Barton Fork raingage.

Hydrographs from the three valley wells and monthly precipitation totals for the period October 1981 through May 1983 are shown on figure 4.1.2-1. The top hydrograph is for a 5.4-foot long well point (14E44) installed in alluvium near the edge of Grissom Creek. The middle hydrograph is for a well (14E40) finished in the weathered zone (hole open from 14 to 60 feet). The bottom hydrograph is for a well (14E41) finished in unweathered sandstone and siltstone (hole open from 60 to 125 feet).

In general, water-level fluctuations correlate with variations in precipitation and evapotranspiration. The monthly magnitude of water-level fluctuation is greatest in the 60-foot deep well (14E40). Seasonal variations in water levels are evident in all three of the hydrographs.

Water-level recorders were installed on five ridgetop observation wells in October-November 1981 and operated through May of 1983. The figure shows the water-level hydrographs of the ridgetop wells. Those wells are location about 1/2 mile from the valley wells and about 3/4 mile from the raingage on Barton Fork. Water-level trends in the shallowest (14E25) and deepest (14E37) wells were similar. It appears that water-level fluctuations in 14E25 are directly related to rainfall and evapotranspiration--that is, water levels rise with increased precipitation but decline with increased evapotranspiration. The deep well is finished at an elevation below the adjacent stream valleys.

The peak water level on the hydrograph for well 14E37 is the result of a slug test where 20 gallons of water were injected into the well. Recovery to the projected static water level required more than 40 days, which indicates a very low transmissivity. The peaks on the hydrographs for wells 14E25, 14E26, and 14E39 recovered from similar slug injections in 1 to 5 days.

Each ridgetop well is open to a different coal bed or contact, and water levels in each well stand at different altitudes. Unsaturated zones were encountered between coal beds, indicating the presence of a series of perched water zones above the coal beds.

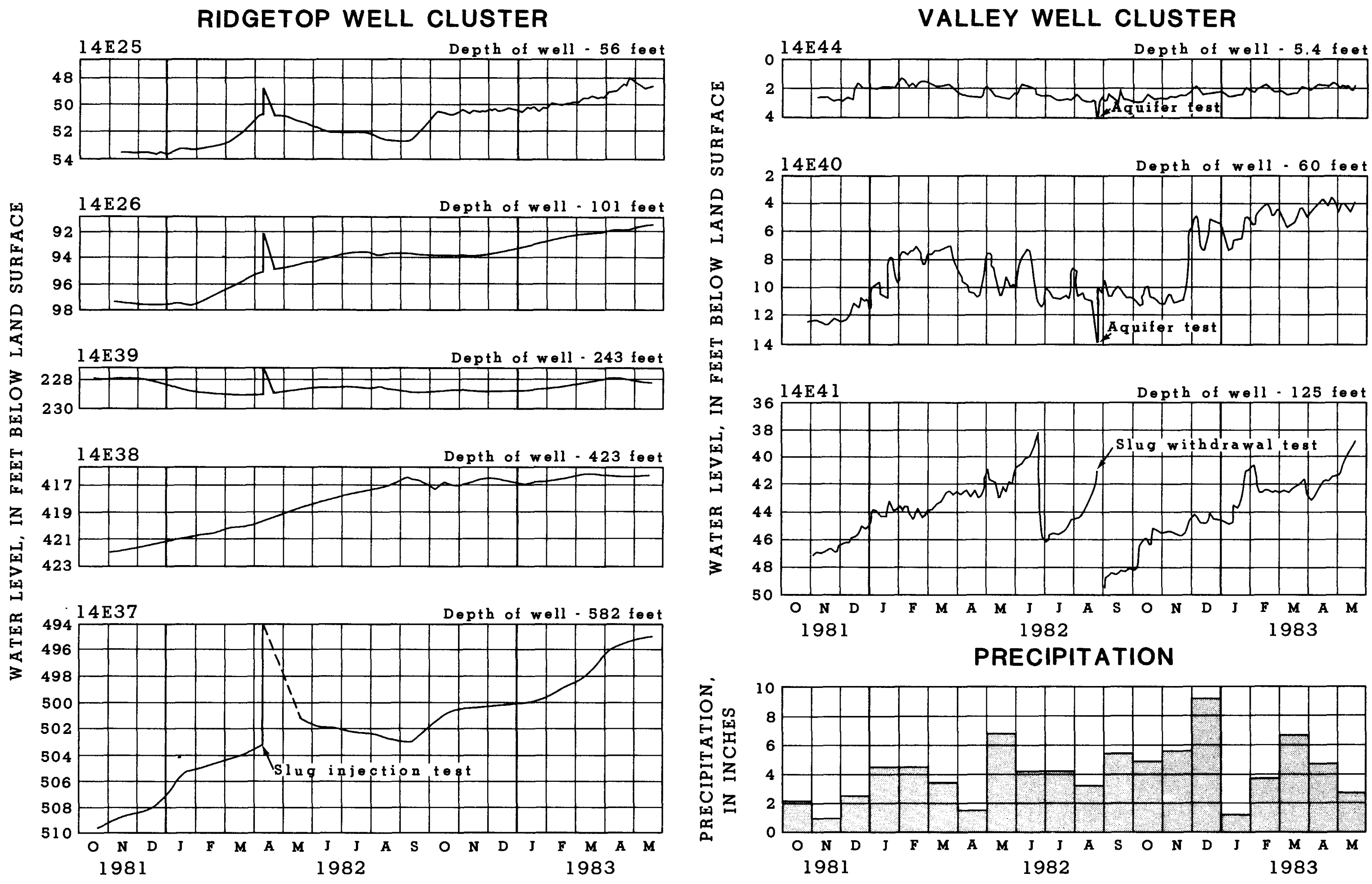

Figure 4.1.2-1 -- Water-level fluctuation in observation wells and precipitation.

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4.2 *Aquifer Hydraulic Properties*

4.2.1 *Aquifer tests of valley wells*

AQUIFER TESTS IN VALLEY INDICATE A WIDE RANGE OF TRANSMISSIVITIES

Aquifer tests of the valley observation wells at the mouth of Grissom Creek were conducted during the week of August 23-27, 1982. Estimated transmissivities ranged from 270 ft^2/d in the alluvial material, 120 to 140 ft^2/d in the weathered-bedrock zone, and about 0.15 ft^2/d in the unweathered bedrock. Storage coefficients from 4.0×10^{-4} to 4.8×10^{-4} were determined for the weathered-bedrock zone.

The movement of water within an aquifer depends, in part, on the hydraulic properties of the aquifer. Two principal hydraulic properties of an aquifer are storage coefficient and transmissivity.

Two techniques for determining aquifer hydraulic properties were used. The most common and widely used technique for determining aquifer properties is an aquifer test. It involves pumping a well for a period of time and measuring the changes in water levels in both the pumped well and adjacent observation wells. The other technique rapidly injects or withdraws a measured volume of water; this is followed by measurements of the water-level response to this change in volume over time. This latter procedure is known as a slug test.

Aquifer tests were conducted at wells in the bottom of the valley (14E40, 14E41, and 14E44) August 23-27, 1982. Pumping rates, length of tests, total drawdowns, and other pertinent information on the wells tested are provided in table 4.2.1-1. Two methods of analysis are used. One method (Cooper-Jacob, 1946, p. 529), consists of plotting water-level drawdown as a function of time on semilogarithmic graph paper (time is plotted on the logarithmic scale, as shown in fig. 4.2.1-1). This method was applied to a pumped well (14E40) and to an observation well (14E42) 35 feet away. Transmissivity values obtained were about 130 ft^2/d for the observation well and the pumped well. Both wells are finished in weathered bedrock and the Jawbone coal bed. A pumping test of the shallow 5.4 foot well point (14E44) was conducted, and the transmissivity was estimated to be about 270 ft^2/d for the alluvial material.

Another method of aquifer data analysis is the type curve matching technique. This method involves plotting time (t) and drawdown (s) on log-log paper (fig. 4.2.1-2) and matching this plot with type curves. Analysis of the shape of the curves for the aquifer test in the weathered bedrock in well 14E40 and 14E42, indicates a delayed yield from aquifer storage (Boulton, 1963, fig. 1). The curve for well 14E42 also fits the dimensionless type curves for non-dimension response to pumping a fully penetrating well in an unconfined aquifer (Stallman, 1965, figures 10 and 12). Transmissivities of about 120 ft^2/d for well 14E42 and about 140 ft^2/d for well 14E40 using the

Boulton equation, and about 120 ft^2/d for 14E42 using the Stallman equation were determined. Storage values for 14E42 were 4.0 X 10^{-4} by the Boulton method (where $S = 4Tt/r^2$) and 4.8 x 10^{-4} by the Stallman equation (where $S = Tt/r^2$). T is transmissivity in ft^2/d from the above equation, t is the time at the match point, and r is the radius from the pumping well to the observation well.

Well 14E41, which is finished in unweathered bedrock, was pumped for 9 minutes at 10 gal/min at which time the water level declined 95 feet. Analysis of the water-level recovery data using a slug test analysis method (Cooper and others, 1967, p. 267) provides an estimated transmissivity of 0.15 ft^2/d.

Analysis of aquifer- and slug-test data shows a rapid decline in the transmissive properties of the bedrock with depth. Drill cuttings from the wells indicate the presence of a zone of weathered bedrock that is conducive to the transmission and storage of ground water. The weathered zone is more highly fractured in addition to having openings created by the weathering process. The additional openings and voids allow for greater storage and movement of ground water.

Table 4.2.1-1. Aquifer test data for valley material.

Well no.	Pumping rate (gal/min)	Length of test (minutes)	Total drawdown (feet)	Remarks
14E40	11.5	320	6.89	
14E41	10.0	9	54.0	Slug-test analysis
14E42	11.5	320	6.79	Observation well for well 14E40
14E44	0.18	5	3.5	

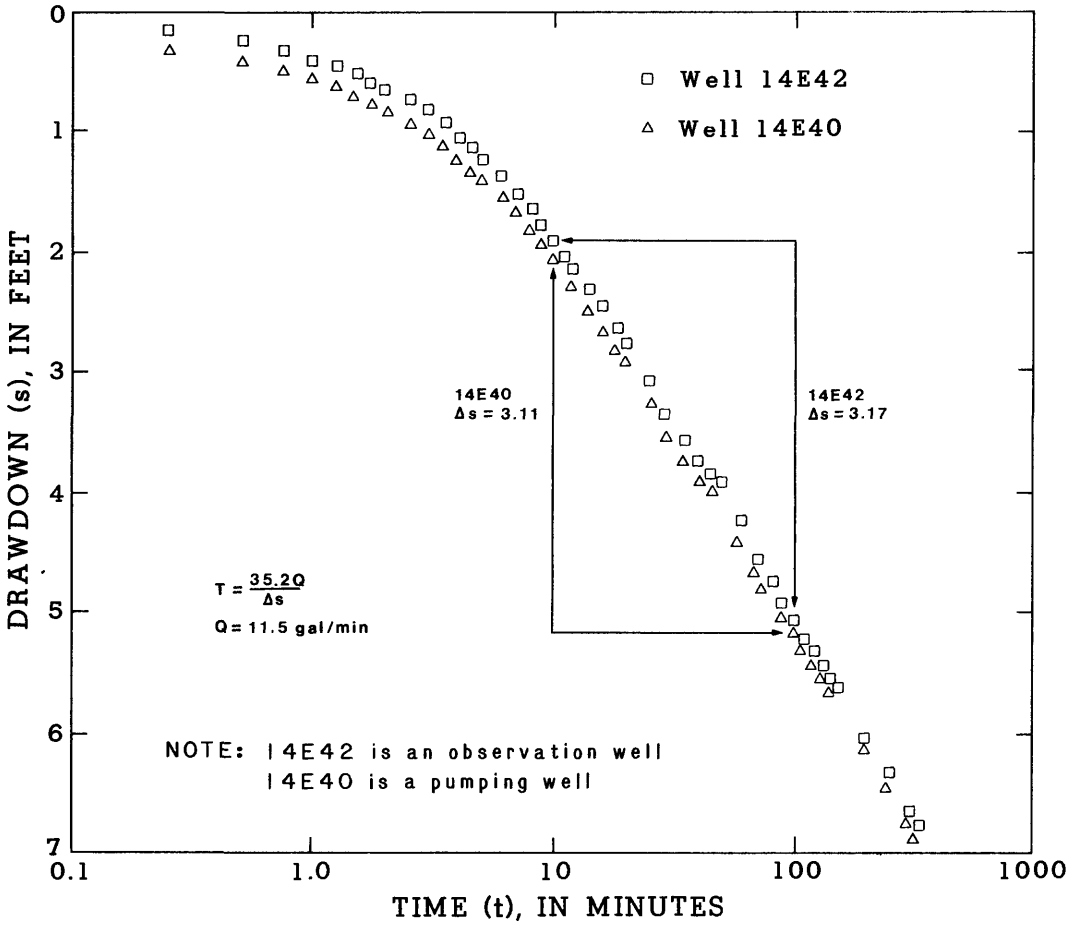

Figure 4.2.1-1 -- Aquifer-test analysis for valley wells by straight-line method.

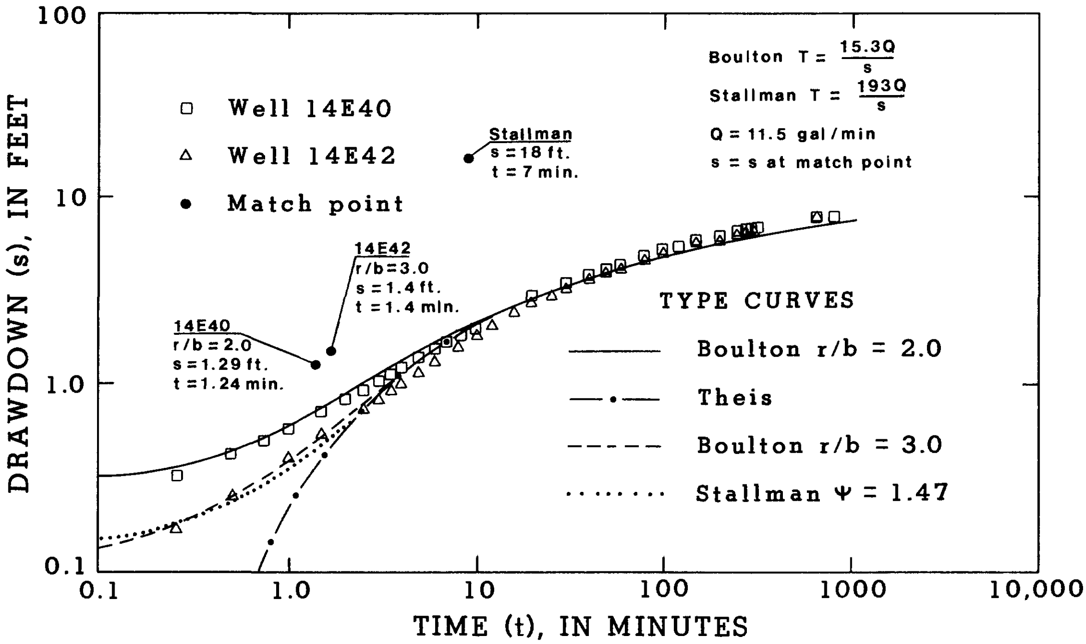

Figure 4.2.1-2 -- Aquifer-test analysis for valley wells by type-curve method.

4.2.2 Aquifer tests of ridgetop wells

AQUIFER TESTS OF RIDGETOP WELLS INDICATE A DECREASE IN TRANSMISSIVITY WITH DEPTH

Instantaneous injections (slugs) of water were used to evaluate the aquifer properties of three ridgetop wells, (14E26, 14E39, and 14E37). Analysis of water-level responses, after injection, yield estimated transmissivity values of 0.29 ft^2/d at well 14E26 (101 feet deep), 0.088 ft^2/d at well 14E39 (243 feet deep), and 0.008 ft^2/d at well 14E37 (582 feet deep). Estimated storage coefficients are $1.0x10^{-2}$ for well 14E26, 1.0×10^{-5} for well 14E39, and 1.0×10^{-4} for well 14E37.

The volume of water in each well and absence of water encountered during drilling necessitated the use of slug tests to obtain transmissivity (T) and storage coefficient (S) for the ridgetop observation-well cluster. Slug-test data were analyzed using a curve-matching method presented by Cooper and others (1967, p. 267). This method involves plotting H/H_0 as a function of time on semilogarithmic graph paper where H is the head of water at time t after injection and H_0 is initial head at the time of injection (figure 4.2.2-1). Plots of these values are matched to a type curve of H/H_0 as a function of Tt/r_c2 at the point where $Tt/r_c2 = 1.0$ (T is transmissivity (ft^2/d), t is time in days and r_c is the radius of the well, in feet). The time (t) where $Tt/r_c2 = 1.0$ is used to calculate transmissivity (ft^2/d). Each type curve used in the analysis has a relative storage coefficient (S) for the aquifer as determined by the equation that defines the curve. According to Cooper and others (1967), this coefficient has questionable reliability because the curves differ only slightly with an order-of-magnitude change in storage. The result is presented here as a relative storage value.

Wells 14E26, 14E39, and 14E37 were injected with 3, 5, and 20 gallons of water, respectively, on April 8, 1982. As shown on the figure, well 14E26 has an estimated T of 0.29 ft^2/d and an S of 0.01, well 14E39 has an estimated T of 0.088 ft^2/d and an S of 0.00001, and well 14E37 has an estimated T of 0.008 ft^2/d and an S of 0.0001. Water encountered during drilling of the observation wells was restricted to coal beds and a thin (generally less than 1-foot thick) shale zone above the coal beds.

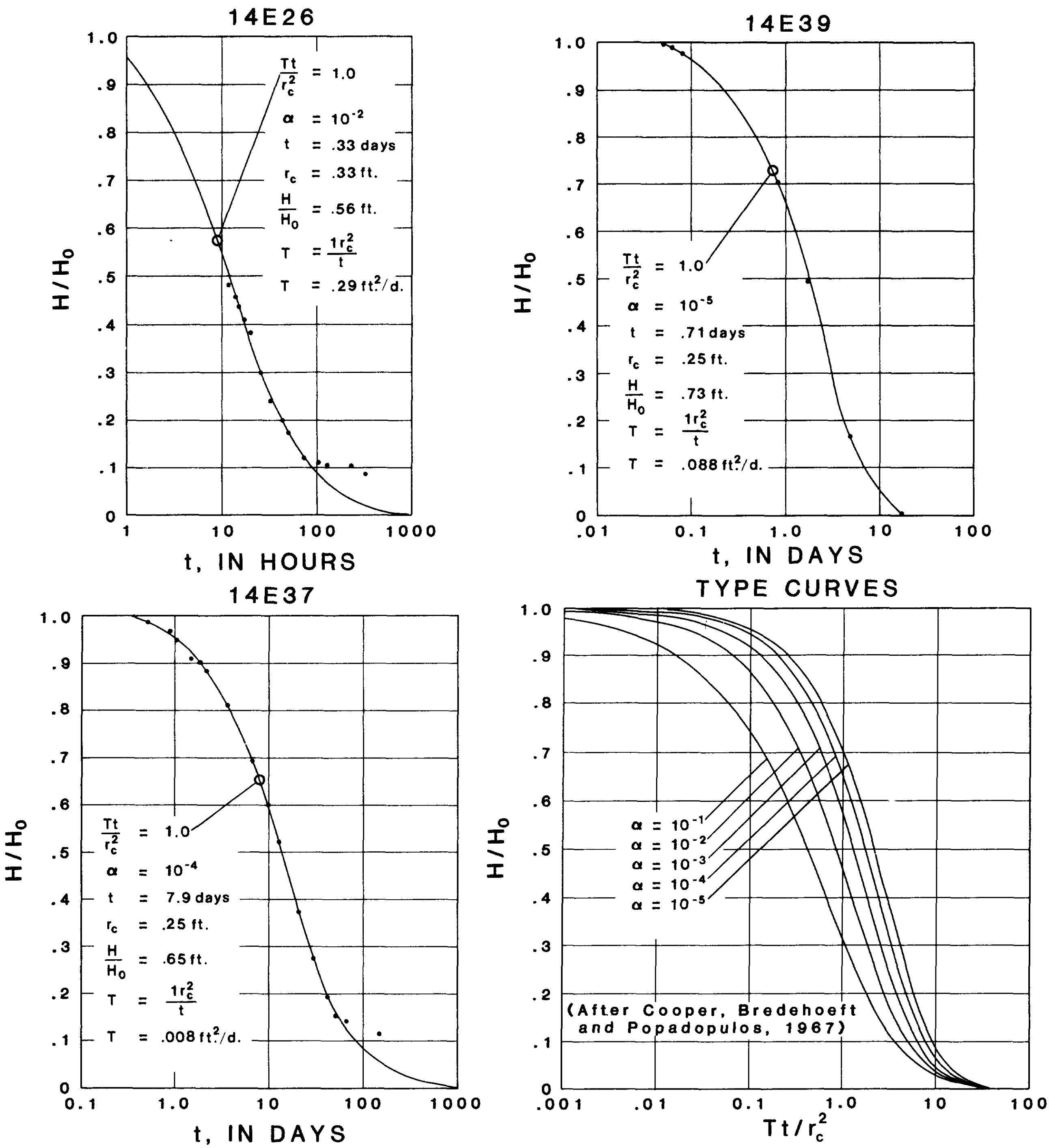

Figure 4.2.2-1 -- Slug-test results from ridgetop wells and type curves used in the analysis.

4.2.3 Aquifer properties from streamflow

ANALYSIS OF STREAMFLOW DATA YIELDS GENERALIZED AQUIFER PROPERTIES OF A BASIN

Streamflow recessions may be used to obtain average aquifer properties for a basin. Diffusivity (transmissivity divided by storage), can be determined from stream hydrographs. The technique of estimating diffusivity from stream hydrographs is shown.

Base flow is essentially ground water that discharges to a stream; thus, base-flow recession is a measure of declining ground-water storage in a basin. Rorbaugh (1964) derived an equation that estimates diffusivity for a basin by means of base-flow recessions. The Rorbaugh equation is $T/S = .933a^2/\Delta t$, where T is transmissivity, S is the storage coefficient, a is the average distance in feet from a stream to the divide in a basin, and Δt is the time required for discharge to decrease through one log cycle on the graph. The value of "a" is determined from the equation $a=A/2L$, where A is the basin area, in square feet; and L is the total length of stream channels in the basin, in feet.

Aquifer diffusivity values estimated from recession curves are approximate values because of the effects of the short recession periods observed in this study, evapotranspiration, and nonhomogeneity within the aquifers. According to Rorbaugh (1964), the rate of recession approaches a straight line $0.2\Delta t$ days after a storm. Observed recession stabilization times support this estimate.

Figure 4.2.3-1 shows a hydrograph for Grissom Creek for the period October 1, 1981 through September 30, 1982. A period during late March and early April 1982 shows a good recession and is used to illustrate the method of obtaining diffusivity from streamflow. A straight line is drawn along the slope of the hydrograph line as shown in the figure. In this case, the number of days for the line to decline from 1.0 $(ft^3/s)/mi^2$ to 0.1 $(ft^3/s)/mi^2$ is determined to be 56 days. Diffusivity in this case is then determined from the equation to be 24,800 ft^2/d, using 56 days for Δt and 1,220 feet for "a".

Grissom Creek near Council, Va.

PERIOD OF RECORD : Oct. 1, 1981 to Sept. 30, 1982

AREA : 2.83 square miles

SURFACE MINING DISTURBANCE : 0%

AVERAGE DISTANCE FROM STREAM TO DIVIDE : 1220 feet

DECAY RATE PER LOG CYCLE : 56 days

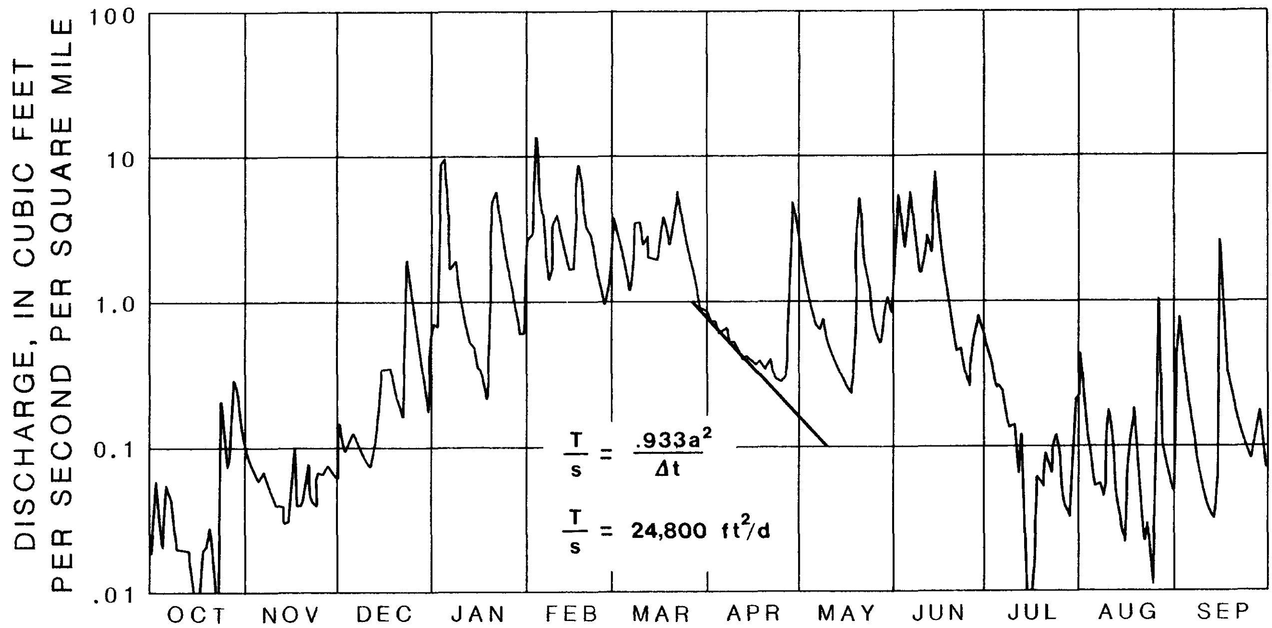

Figure 4.2.3-1 -- Streamflow hydrograph for Grissom Creek showing a recession period and diffusivity.

4.3 Conceptual Ground-Water Flow System

RESULTS FROM AQUIFER TESTS INDICATE MAJOR AQUIFERS ARE ALLUVIUM AND WEATHERED BEDROCK

A conceptualization of the ground-water system shows that ground-water flow occurs primarily within the colluvium-alluvium cover on the hillslopes and valley floor, and within the coal beds and weathered bedrock. Results of aquifer tests indicate that these materials are the major aquifers in the study area. The tests indicate that transmissivity decreases with depth. The principal component of flow in the ridgetop and hillslope areas is primarily downward. Seeps associated with coal beds are a result of lateral flow within the beds toward the edge of the hillslope. Most ground water flows laterally and upward toward the valley floor.

A conceptualization of the ground-water system in the study area is shown in figure 4.3-1. Ground-water flow primarily is within the colluvium-alluvium cover on the hillslopes and valley floor, and within the coal beds and weathered bedrock. Results of aquifer tests indicate that these units are the major aquifers. The same tests indicate the estimated transmissivity of colluvium-alluvium and weathered bedrock to be about 270 and 130 ft^2/d respectively, as compared to less than 1.0 ft^2/d for underlying unweathered bedrock. Flow in the ridgetop and hillslope areas primarily is downward through weathered bedrock. Small amounts of ground water move downward through fractures and intersticial openings in the unweathered bedrock to coal beds. Seeps are associated with coal beds that lie between shale and an underclay.

The higher transmissivity of coal beds results in some lateral ground-water flow within the coal beds toward the edges of hillslopes. Seeps along the edges of hillslopes and perched zones of ground water within the ridge result from this lateral flow. Water moving downward along hillslopes discharges locally to a stream in the valley floor. Ground-water flow is either to or from the stream, depending on the hydraulic gradient between the stream and aquifer material. Ground-water flow that does not discharge directly to the stream continues downgradient as underflow beneath the stream.

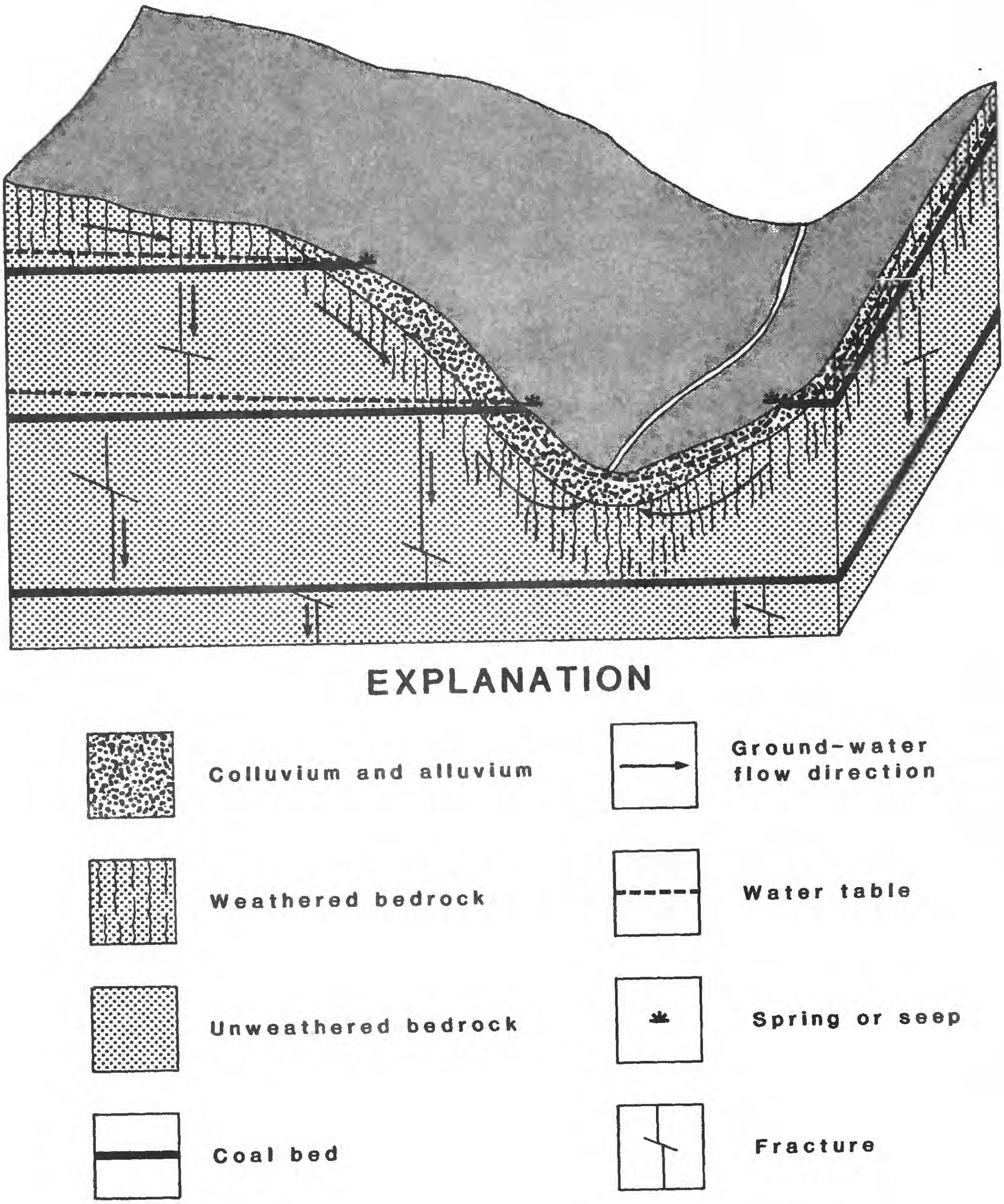

Figure 4.3-1 -- Conceptual ground-water flow system in the study area.

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5.0 WATER QUALITY

5.0 WATER QUALITY

5.1 Ground-Water and Surface-Water Quality

WATER QUALITY DURING LOW FLOW IS DIRECTLY RELATED TO GROUND-WATER QUALITY

In the Barton Fork basin (mined), surface water is a calcium-sulfate type at both high and low flows. In the Grissom Creek basin (unmined), water at high flow is also a calcium-sulfate type, but, during low flow is a calcium-bicarbonate type very similar to the quality of ground water in observation wells.

Chemical analyses from the five ridgetop observation wells (see section 4.1) plot in the calcium-bicarbonate field on a trilinear diagram (fig. 5.1-1). Data for well 14E37 (the deepest well, 582 ft) plot in the sodium-bicarbonate field. These data are consistent with data of Rogers and Powell (1983) that indicate that wells 50 to 150 feet deep throughout the area yield calcium-bicarbonate water.

Water-quality data for streams are also plotted on figure 5.1-1. Data for Grissom Creek samples, collected during high flows, plot in the calcium-sulfate field, whereas data collected during low flows plot in the calcium-bicarbonate field. Data representing water quality in Barton Fork at both high flow and low flow plot in the calcium-sulfate field. These data are consistent with the findings of Rogers and Powell (1983) who observed that stream water in unmined basins is a sulfate type at high flows and a bicarbonate type at low flows, whereas stream water from mined basins is a sulfate type at high and low flows.

A relationship between surface water, ground water, and mining in the study area can be seen in the trilinear diagram. Water-quality data representing low flows in the unmined Grissom Creek basin plot near water-quality data representing ground water from observation wells; high flows in this basin plot in the calcium-sulfate field. These plots may result from flushing of the weathered-rock zone where sulfides are oxidized to sulfates by precipitation. The plot of the Barton Fork low-flow data in the calcium-sulfate field demonstrates the effect of surface mining on the quality of ground water and, therefore, stream-water quality. Water-quality data representing low flows plot closer to the bicarbonate field than do water-quality data representing high flows, demonstrating a trend similar to that seen in the Grissom Creek basin data.

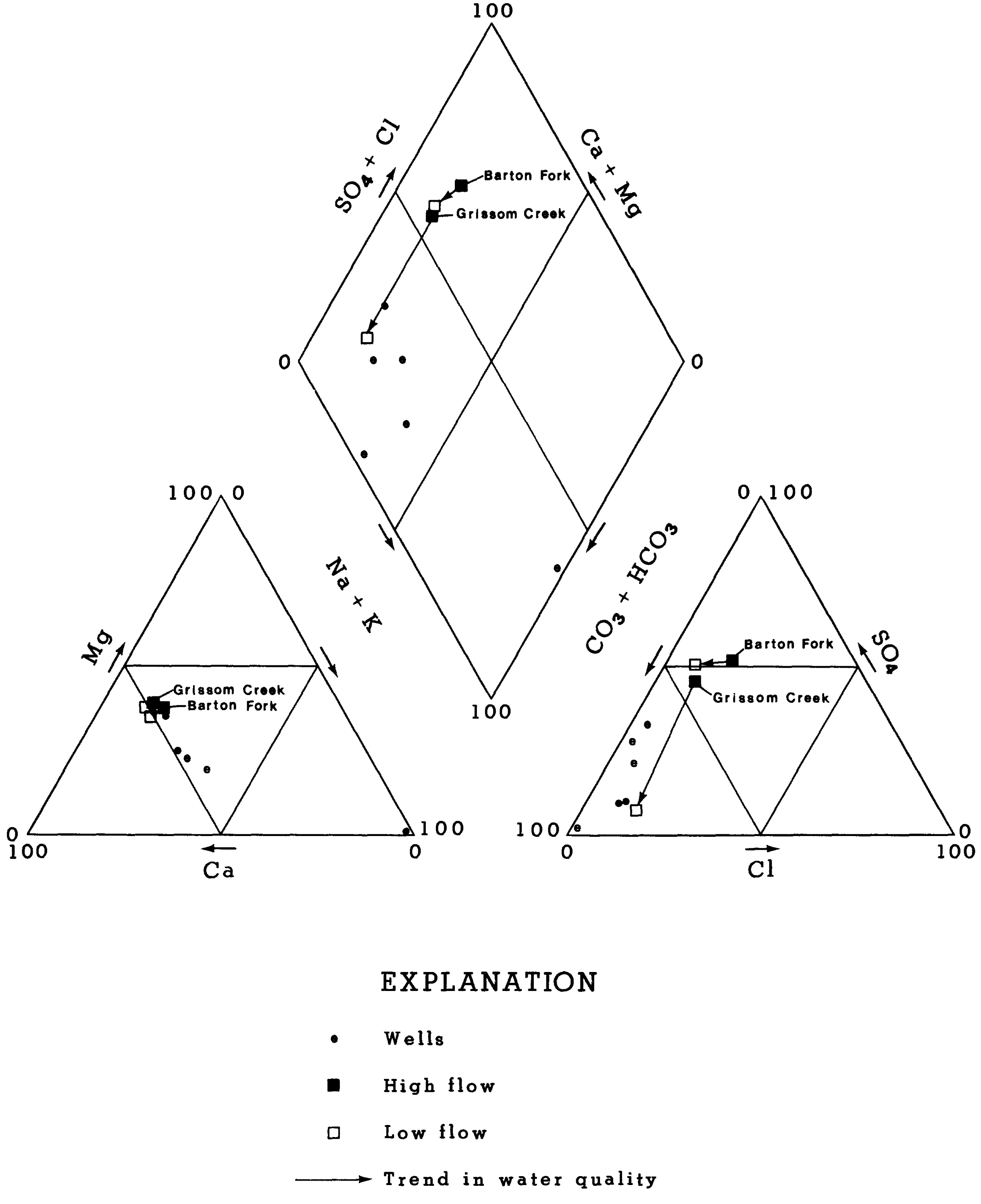


Figure 5.1-1 -- Ground-water and surface-water quality in the Grissom Creek and Barton Fork basins.

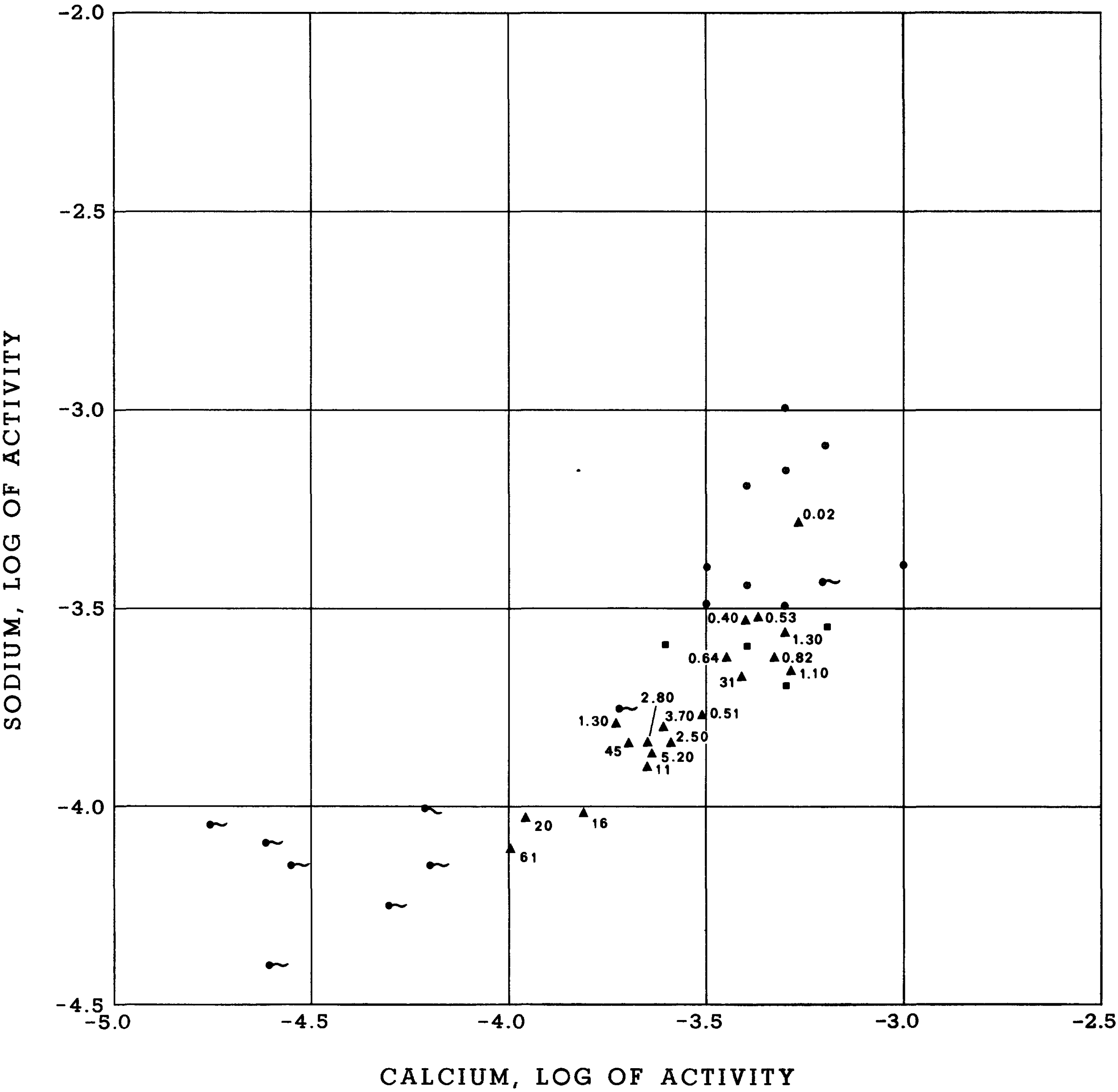
5.2 Relation between Quality of Ground and Surface Water

WATER QUALITY OF GRISSOM CREEK CHANGES WITH CHANGES IN SOURCE OF GROUND WATER

In Grissom Creek, quality of stream water at very low flow indicates the primary source of stream-water is ground-water outflow from bedrock. At higher flows, water quality indicates the primary source of stream water is ground-water outflow from weathered overburden. At even higher flows, the water quality indicates the primary source of stream water is overland runoff.

Calcium and sodium in water from wells and springs in the Grissom Creek basin are plotted in figure 5.2-1. Data from wells finished in bedrock, dug wells finished in weathered overburden, and springs draining from fractures near the ridgetop, plot in separate groups showing that water from each source has a slightly different chemical character resulting from a different history of movement through weathered material and rock. Water-quality analyses from Grissom Creek at differing flows also are plotted on the figure and indicate a relation between discharge and sources of ground water.

Activities of calcium and sodium in a very low stream discharge (0.02 ft^3/s) plot similarly with those from drilled wells, indicating that the main source of water at very low flows is water that drains bedrock aquifers tapped by these wells. Calcium and sodium activities from somewhat higher flows (between about 0.1 ft^3/s and 1.0 ft^3/s) generally plot similarly with those from dug wells, indicating that stream water at this discharge has as its primary source the weathered overburden tapped by these wells; these flows occur during storm recessions. Activities of calcium and sodium from even higher discharge (above 12 ft^3/s) plot near those from the dilute waters found in springs. This indicates that the primary source of stream water at high discharge is probably overland runoff, which would also be very low in calcium and sodium.



EXPLANATION

▲ Surface-water data

0.53 Discharge, in cubic feet per second

• Drilled well

▪ Dug well

•~ Spring

Figure 5.2-1 -- Comparison of calcium and sodium activities for well, spring, and stream water in Grissom Creek basin.

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6.0 HYDROLOGIC EFFECTS OF MINING

6.0 HYDROLOGIC EFFECTS OF MINING

• 6.1 *Effects of Mining on Surface Water*

6.1.1 *Flow duration*

FLOW DURATION FOR RUSSELL FORK AT HAYSI INDICATE SURFACE MINING INCREASES BASE FLOW

Flow duration curves are developed for the Russell Fork at Haysi and Clinch River at Cleveland covering pre-surface mining and surface-mining periods. The Russell Fork shows a significant increase in base flow since surface mining started, while the Clinch River, which has little mining activity in its basin, shows very little change.

Flow duration curves for the Russell Fork at Haysi for the two periods: 1927 to 1950 (prior to any significant surface mining in the drainage basin), and 1951 to 1980 (during and after substantial surface mining within the basin), are compared in figure 6.1.1-1 along with curves for approximately the same periods for the Clinch River at Cleveland. The Clinch River basin lies immediately to the east of the Russell Fork basin and has similar climatic conditions. Many areas in the Russell Fork basin have been disturbed by mining activities but few areas within the Clinch River basin above Cleveland have been affected. Data from the Clinch River site were analyzed to assess the possibility that observed changes in flow characteristics of the Russell Fork are due to changes in climatic conditions between the two periods. The figure shows little difference between the flow duration curves for the Clinch River in the pre-mining and post-mining periods in the basin.

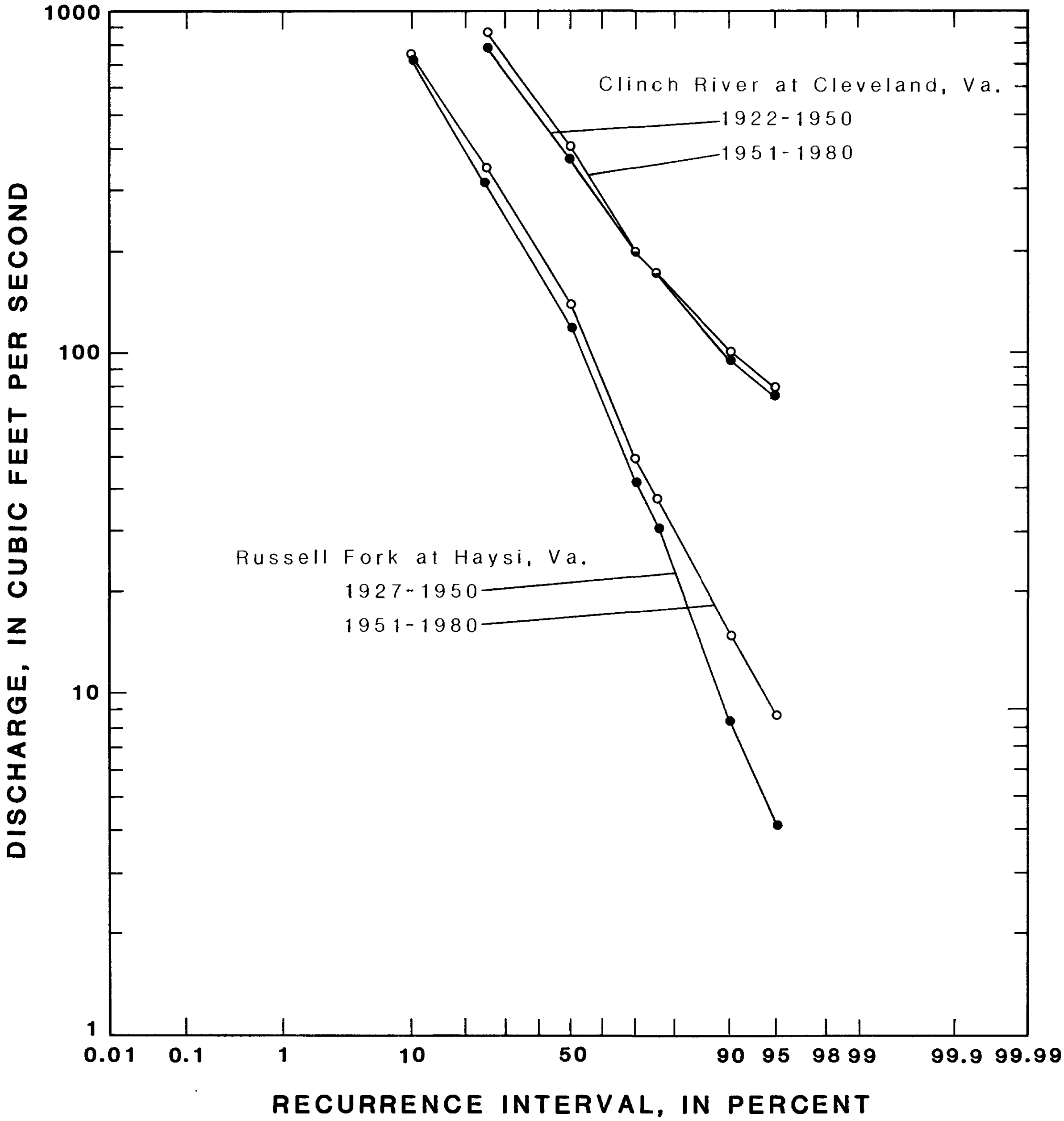

Figure 6.1.1-1 -- Flow duration curves for Russell Fork and Clinch River.

6.1.2 Streamflow recession

Base Flow Recession Curves Indicate That Increases In Surface Mining Have Increased Ground-Water Contribution To Total Runoff

A base-flow recession curve from a streamflow hydrograph is a measure of the rate of decay of ground-water storage within a basin. Composite curves from individual recessions for the Russell Fork basin show a change in the decay rate of about 34 to 59 days per log cycle of discharge for pre-1950 and post-1950 streamflows. A comparison of two individual recession periods starting with identical discharges (April 19, 1934 and March 30, 1976) illustrates the change in decay rate for the two periods of time.

Flow recession is a rate of streamflow decrease; during base-flow periods, it approximates the decay of ground-water storage in a basin. Recession curves are developed by selecting straight-line segments of stream hydrographs that show flow after storm events and transposing these segments onto a straight line through the range of discharges observed.

Figure 6.1.2-1 shows recession curves for two time periods for the Russell Fork gage at Haysi. Winter recession curves are used to minimize the effects of losses due to evapotranspiration. The figure shows a significant flattening of the curve during the post-1950 period and a time of 59 days per log cycle of discharge compared to 34 days per log cycle of discharge during the pre-1950 period. This increase in decay time is attributed to greater storage in surface-mine spoil banks.

A technique requiring fewer data to determine the recession rate uses individual recession periods. Two nearly identical peak flows and their subsequent recessions (April 19 to June 3, 1934 and March 30 to May 19, 1976) are shown in figure 6.1.2-2. The hydrographs are overlain, and a straight line is drawn through one log cycle along straight line segments of each. The time change per log cycle of discharge for the 1934 period is 36 days and for the 1976 period, 57 days. These values compare very closely to rate changes of 34 days and 59 days using long-term composite curves.

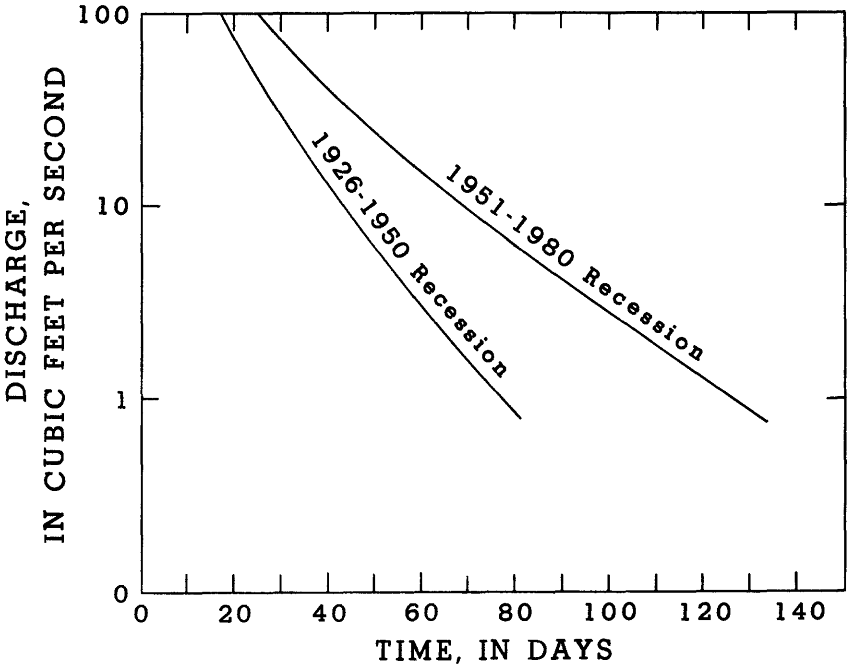

Figure 6.1.2-1 -- Composite winter recessions before and after 1950 for Russell Fork at Haysi, Va.

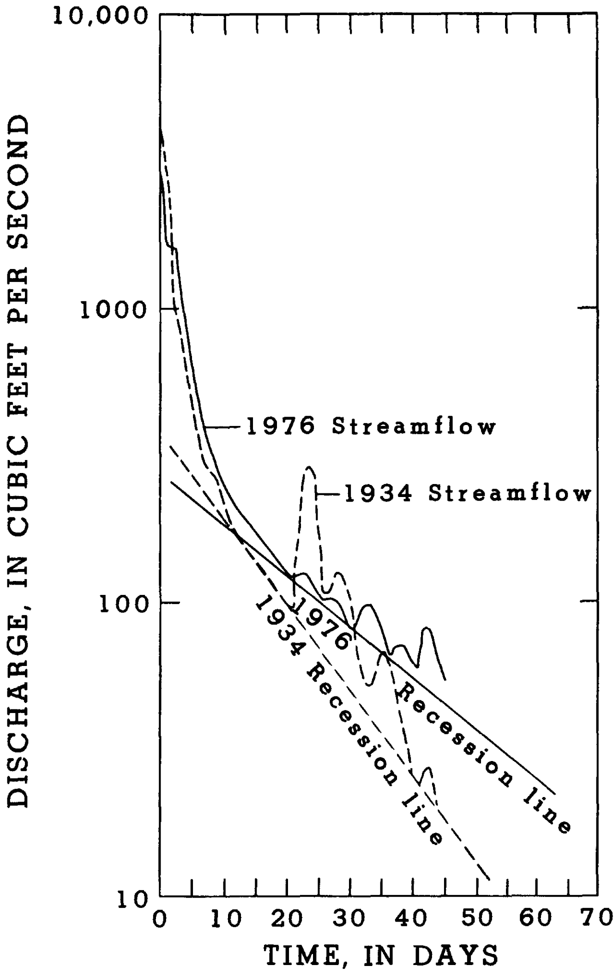

Figure 6.1.2-2 -- Streamflow recessions for Russell Fork at Haysi, Va., April 19 to June 3, 1934 and March 3 to May 19, 1976.

6.1 Effects of Mining on Surface Water

6.1.3 Diffusivity

AQUIFER DIFFUSIVITIES INDICATE A MAJOR HYDROLOGIC IMPACT OF SURFACE MINING

Aquifer diffusivities calculated for five streamflow gaging stations indicate significant changes in aquifer hydraulic properties due to surface-mining activities. Diffusivity values range from 28,500 feet squared per day (ft^2/d) for Russell Fork at Haysi (pre-1950, with no surface mining), to 10,100 ft^2/d for Barton Fork near Council (19.5 percent of drainage area surface mined).

Aquifer diffusivities (T/S) were determined from data at five gaging stations in the Russell Fork basin, using the Rorabaugh equation (see section 4.5). Recessions following single storm events and pre-1950 and post-1950 composite recessions based on several recession segments are used to determine diffusivity. Table 6.1.3-1 lists the physical characteristics used in the analysis of base-flow recessions and summarizes the calculated hydraulic characteristics. Diffusivity values for Russell Fork at Haysi declined from 27,000-28,500 ft^2/d (pre-1950) to 15,400-17,000 ft^2/d (post-1950).

Figure 6.1.3-1 is a plot of diffusivities as a function of percentage of mined area for the five gages in the Russell Fork basin during the April 1982 base-flow recession period. Five composite and individual recessions for the Russell Fork at Haysi during selected time periods were also used. The graph shows an inverse relationship between percent of basin mined and diffusivity.

The decrease in diffusivities caused by surface mining indicates an increase in ground-water storage within the spoil material on the strip benches. The relatively flat strip benches retain precipitation for percolation into the spoils creating small ground-water reservoirs. These reservoirs slowly release the ground water in storage by seepage at the base of the spoil piles, which causes higher flows during dry periods.

Table 6.1.3-1 -- Selected physical and Hydraulic characteristics of basins above five gaging stations in the Russell Fork basin.

Gaging Station	Drainage Area (mi^2)	Surface Mine Disturbance (percent)	Distance from stream to divide (ft)	Recession Period Analyzed (month/year)	Time for one log cycle change in discharge (days)	Diffusivity T/s (ft^2/day)	Time for recession rate to stabilize (days)
Grissom Creek near Council	2.82	0.0	1220	4/82	56	24,800	11
Barton Fork near Council	1.23	19.5	936	4/82	81	10,100	16
Russell Fork at Council	10.2	6.3	1180	4/82	78	16,700	16
Russell Fork at Birchleaf	86.5	3.9	1023	4/82	56	17,400	11
Russell Fork at Haysi	286	0.0	1020	3-5/34	36	27,000	7
		0.0	1020	1927-1950	34	28,500	7
		5.0	1020	3-5/76	57	17,000	11
		5.0	1020	1951-1980	59	16,500	12
		5.0	1020	4/82	63	15,400	13

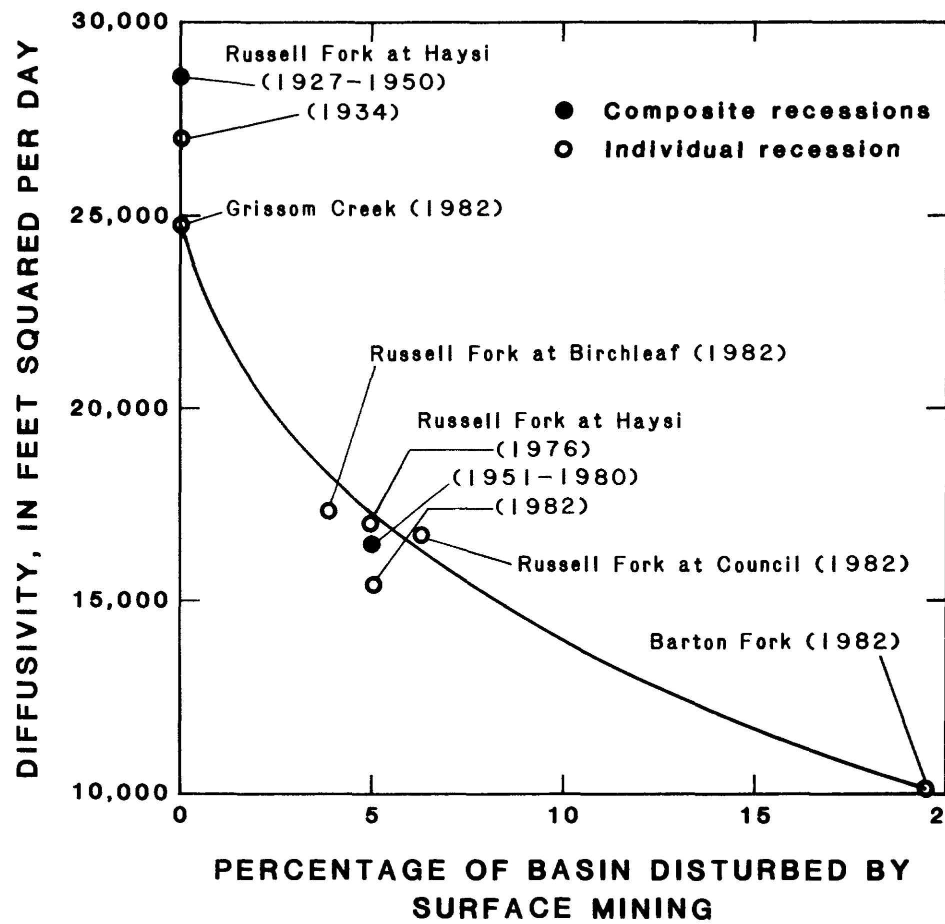

Figure 6.1.3-1 -- Relation of diffusivity to extent of surface mining in the upper Russell Fork basin.

6.2 Effects of Mining on Ground Water

SURFACE AND UNDERGROUND MINING OF COAL ALTER THE NATURAL GROUND-WATER SYSTEM

A conceptualized ground-water flow system indicates the majority of ground-water movement is within the thin veneer of soil, colluvium-alluvium, and weathered bedrock. Any surface-mine activity will intercept this shallow ground water and alter its natural movement. Underground mining intercepts the small quantities of ground water moving within fractures in the unweathered bedrock. The ground water will then flow to the surface along the mined-out areas or is stored in the void left after mining.

The effects of mining on the ground-water system have been subtle but can be seen at mines in the basin. Underground mining of coal creates a drain, where water moving through the rock materials is intercepted and flows out through the mine opening. Water may also be ponded in the void left by the coal-mining operation, which creates a subsurface storage reservoir, as shown in figure 6.2-1.

Surface-mine operations create large flat strip benches that act as catchment areas for precipitation. The precipitation percolates into the unconsolidated and weathered material created by the mining operation creating a ground-water reservoir. Seep areas found at the toe of strip benches are the discharge points for the ground water. Figure 6.2-2 illustrates the ground-water flow system in a surface-mined area.

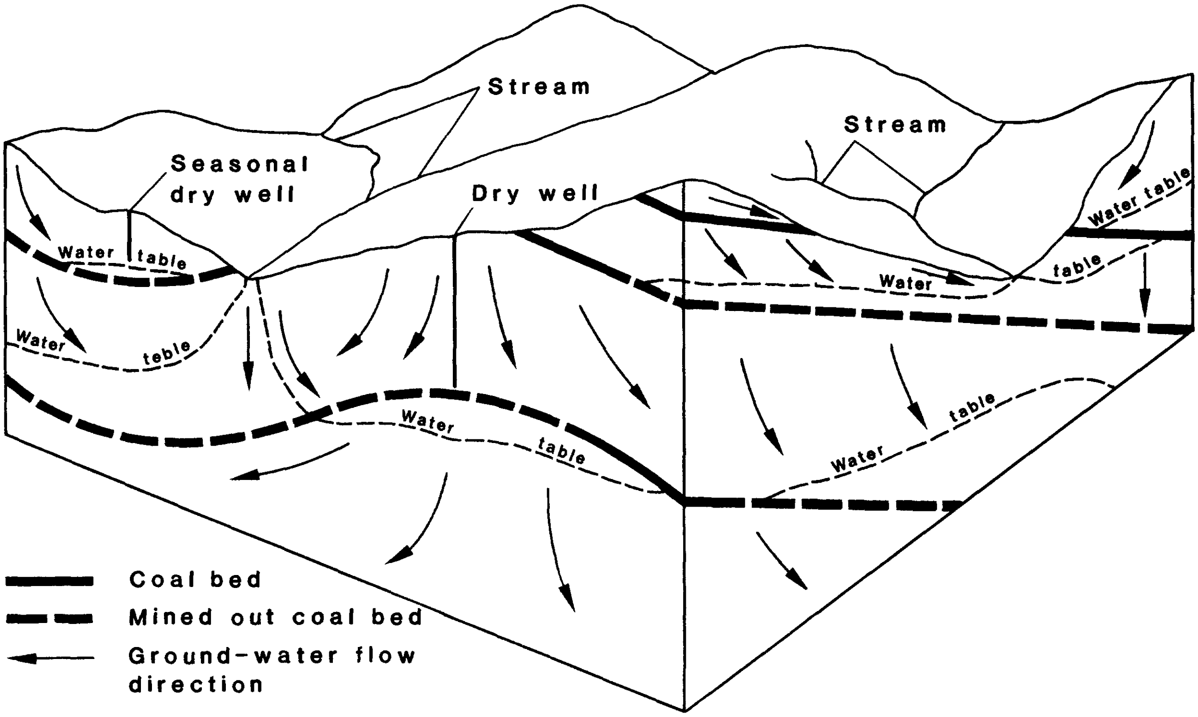

Figure 6.2-1 -- Effects of underground mining on the ground-water system.

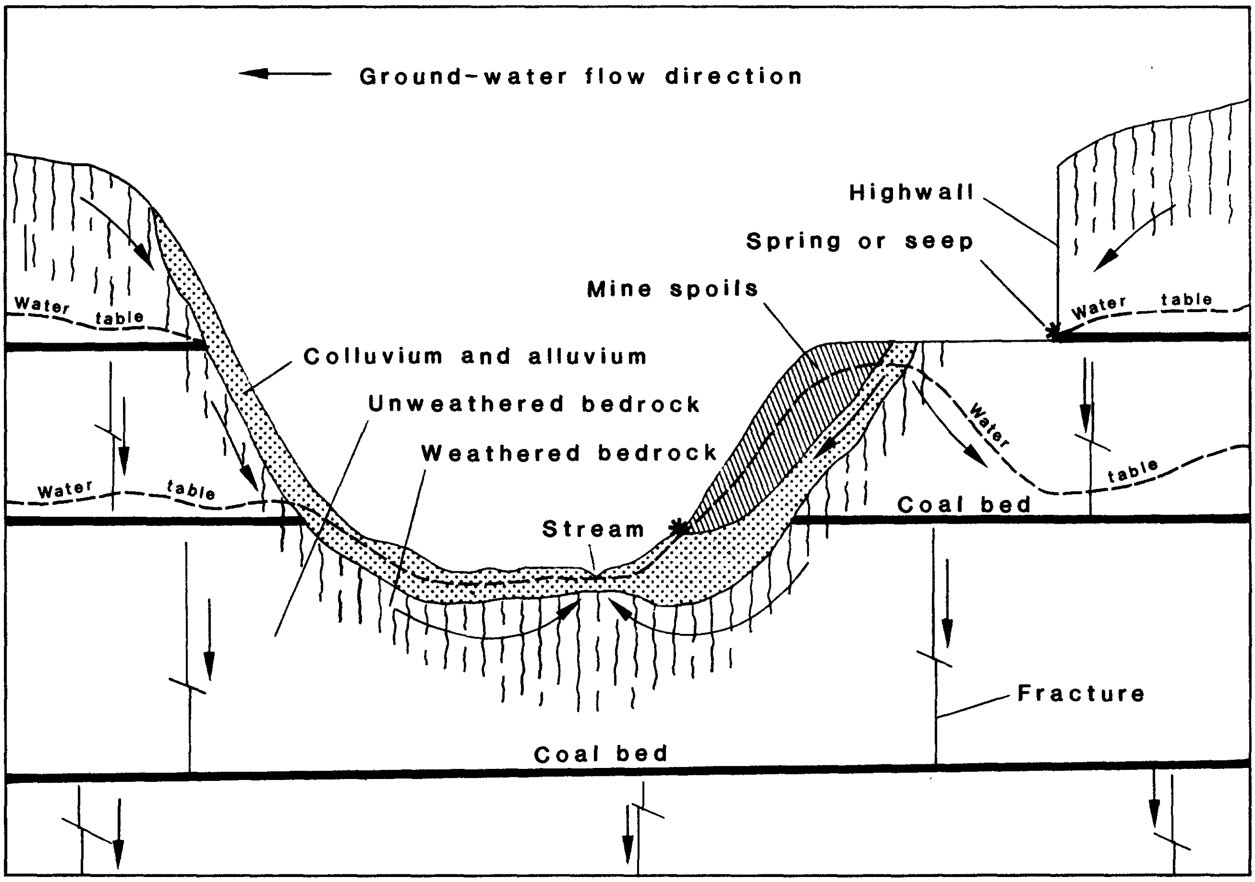

Figure 6.2-2 -- Effects of surface mining on the ground-water system.

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7.0 SUMMARY AND CONCLUSIONS

7.0 SUMMARY AND CONCLUSIONS

Study Of Upper Russell Fork Basin Indicates Presence Of A Shallow Ground-Water Aquifer System And Significant Changes In The Hydrologic Cycle With Mining

Results from aquifer tests conducted in the upper Russell Fork basin indicate that transmissivity decreases with depth. Saturated materials in the valley bottoms constitute the major aquifer system with estimated transmissivities of about 270 ft^2/d in alluvium, 120-140 ft^2/d in the weathered bedrock zone and about 0.15 ft^2/d in unweathered bedrock below the valleys. Aquifer tests using ridgetop wells indicate transmissivities of about 0.3 ft^2/d near land surface and less than 0.01 ft^2/d at a depth of 500 feet. The data suggest that most ground water moves through a shallow aquifer system, and that little water moves at depth.

Flow-duration analysis of gaging-station data indicate that base flows of streams have increased since the start of surface mining. At the 95-percent flow duration, flows have increased from 4.0 ft^3/s (1928-50) to 8.9 ft^3/s (1951-80). Changes in flow duration indicate infiltration and storage of precipitation have increased and that this water drains more gradually during base-flow periods.

Analysis of a composite base-flow recession curve for the Russell Fork at Haysi gage indicates that the time required for the stream to decline in flow through one log cycle of discharge increased from 34 days (pre-1950) to 59 days (post-1950). The slope of recession was used to calculate diffusivity. The pre-1950 diffusivity value is 28,500 ft^2/d, and the post-1950 diffusivity is 16,500 ft^2/d.

Individual recession periods were analyzed at five gaging stations in the basin. Diffusivities obtained varied from 27,000 ft^2/d for Russell Fork at Haysi before major surface-mining activities started, to 10,100 ft^2/d for Barton Fork near Council, which has 19.5 percent of its area disturbed by surface mining.

Coal mining affects ground-water and surface-water quality. Sulfate concentrations are higher in mined basins than in unmined basins. The sulfate concentrations in surface water within a mined area are greater at high flow when water is most dilute than in an unmined basin at low flow when concentrations of constituents are highest.

8.0 SELECTED REFERENCES

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