UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGIC RECONNAISSANCE OF THE KOLOB, ALTON, AND KAIPAROWITS PLATEAU COAL FIELDS, SOUTH-CENTRAL UTAH

Open-File Report 84-071

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By Gerald G. Plantz

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

Purpose and Scope

The study area in south-central Utah (fig. 1) is noted for its large coal reserves in the Alton, Kolob, and Kaiparowits Plateau coal fields. The area also is noted for its scenic beauty and general scarcity of water. Although there has been very little development of the coal resources through 1983, there is a potential for large-scale development with both surface- and underground-mining methods. Mining of coal could have significant effects on the quantity and quality of the water resources. The purpose of this atlas is to define the surface- and ground-water resources of the area and to identify the potential effects on these resources by coal mining.

This atlas is based mainly on a reconnaissance conducted from October 1980 to September 1983 by the U.S. Geological Survey in cooperation with the U.S Bureau of Land Management. Hydrologic data collected during the study include measurements of streamflow, well and spring inventories, and chemical analyses of surface and ground water. The hydrologic data, along with some data collected during earlier studies, are included in a separate report (Plantz, 1983).

Previous Hydrologic Studies

A number of hydrologic studies have included all or parts of the Kolob, Alton, and Kaiparowits Plateau coal fields. Reports from several of the studies were used to prepare this atlas, and they should be useful references to readers dealing with water-related problems in the area. All reports cited in this atlas are listed on sheet 2. Marine (1963) described the ground-water resources of Bryce Canyon National Park, which borders on the Alton coal field. Goode (1964, 1966, and 1969) described ground-water conditions in western Kane County and in the Escalante area. The hydrology of the Navajo Lake area was studied by Wilson and Thomas (1964). Feltis (1966) compiled data on ground water in bedrock in the Colorado Plateau in Utah, which includes most of the study area. Carpenter and others (1967) described ground-water conditions in the upper part of the Sevier River basin, and Hahl and Mundorff (1968) studied quality of surface water in the Sevier River basin. Several large springs on the Markagunt Plateau are included in Mundorff's (1971) compilation of nonthermal springs in Utah. Bjorklund and others (1978) described ground-water conditions in Cedar and Parowan Valleys, and Cordova (1981) described ground-water conditions in the upper Virgin River and Kanab Creek basins.

A series of maps that show the general availability and chemical quality of surface and ground water in the Kaiparowits Plateau coal field were prepared by Price (1977a, 1977b, 1978, and 1979). A similar series of maps were prepared by Price (1980, 1981, 1982a, and 1982b) for the Alton and Kolob coal fields. Sandberg (1979) studied the hydrology of a part of the Alton coal field.

GEOGRAPHIC SETTING

The study area includes about 4,500 mi^2 in parts of Garfield, Iron, Kane, and Washington Counties, Utah. The largest communities and their approximate populations during 1980 (in parentheses) are Cedar City (10,947), Parowan (1,840), Escalante (654), Tropic (335), and Henrieville (167). Panguitch (1,343) is in the Sevier River valley about 6 mi north of the study area, and Kanab (2,132) is in the Kanab Creek valley about 10 mi south of the area (U.S. Department of Commerce, 1980, p. 5 and 6).

Most of the land in the area is Federally owned and administered by the Bureau of Land Management, the Forest Service, and the National Park Service. Nearly all of the coal is Federally owned. Several of Utah's most popular tourist attractions are wholly or partly in the study area. They include Bryce Canyon and Zion National Parks, Cedar Breaks National Monument, Lake Powell, Glen Canyon National Recreation Area, and Dixie National Forest.

The study area is characterized by broad plateaus, terraces, and benches that are dissected by deep, narrow stream canyons. Principal physiographic features include the Kolob Terrace; the Markagunt, Paunsaugunt, and Kaiparowits Plateaus; the cliffs that border the plateaus; and the deep, narrow stream canyons. Altitudes range from less than 4,000 ft above sea level in the area inundated by Lake Powell to about 11,000 ft on the Markagunt Plateau.

About 75 percent of the study area is in the Colorado River Basin and is drained mainly by the Escalante, Paria, and Virgin Rivers, and by Kanab, Wahweap, Warm, and Deep Creeks. The remainder of the area is in the Great Basin and is drained mainly by the Sevier River, and by Coal, Summit, Center, and Parowan Creeks (fig. 1).

CLIMATE

Climate in the study area ranges from arid in the lower altitudes to subhumid on the highest plateaus. Normal annual precipitation varies from less than 6 in. near Lake Powell to more than 40 in. on the Markagunt Plateau (fig. 1). Winter precipitation commonly occurs as snow, which accumulates to depths of more than 10 ft at the highest altitudes. Summer precipitation commonly occurs during localized thunderstorms, which can produce more than an inch of rain in less than an hour.

Total annual precipitation varies markedly from year to year. At Cedar City, for example, it has ranged from 4.95 in. during 1959 to 18.76 in. during 1941. At Bryce Canyon National Park, it has ranged from 7.25 in. during 1950 to 24.11 in. during 1941. (See U.S. Department of Commerce, 1957, p. 4 and 5; 1965, p. 5).

Evaporation rates in the area are large. The annual rate of evaporation exceeds the annual rate of precipitation, even in the highest plateau areas. May-October pan evaporation ranges from about 40 in. on the Markagunt Plateau to about 65 in. in the lower altitudes near Lake Powell. (See figure 1.) The relatively large evaporation rates significantly decrease the quantity of water that otherwise would runoff in streams or be recharged to the ground-water system.

SURFACE WATER

The U.S. Geological Survey has measured streamflows in the area for many years. The location of continuous-record gaging stations is shown in figure 2, and a summary of streamflow records at each station is listed in table 1. In addition to the gaging stations, streamflow was measured and water sampled for chemical analyses at many other sites during the course of this study; the location of these sites also is shown in figure 2.

General Variations in Streamflow

There are large variations in streamflow throughout the study area. Average runoff at gaging stations varies from less than 1 in. per year in the lower altitudes to about 10 in. per year in the higher altitudes (table 1). Generally, the flow of streams that originate in the higher altitudes increases downstream. However, when streams flow through low-altitude areas, additional inflow may be less than evapotranspiration or diversions. Thus, flow can decrease downstream.

Streamflow fluctuates in response to snowmelt and rain. Most runoff from drainages at altitudes greater than 8,000 ft results from snowmelt during April-July. Rain during thunderstorms produces much of streamflow in the lower altitudes, particularly in streams that are intermittent. The distribution of flow during water year 1980 at site G, Summit Creek near Summit is shown in figure 3; the hydrograph shows the typical distribution of flow from high-altitude drainages. The typical distribution of flow at a low-altitude site is shown in figure 4 for site N, Henrieville Creek near Henrieville.

Low Flow

Streamflow is sustained primarily by ground-water discharge during periods of little or no precipitation. Many streams in the area receive little ground-water discharge, and they are intermittent or ephemeral. Most of the streams that drain the Kaiparowits Plateau are intermittent as shown in figure 2. The intermittent streams commonly convey storm runoff or water issuing from a single spring; consequently they have no flow along extensive reaches during parts of most years.

Seven-day low-flow frequency curves for gaging stations with 5 or more complete years of record are shown in figure 5. The curves show the annual minimum mean flow for 7 consecutive days for selected recurrence intervals. The recurrence interval is the average time, in years, between flow that will average less than the indicated rate. The relatively flat curves, such as for site I on Coal Creek, indicate large quantities of ground-water discharge along streams. Conversely, the relatively steep curve for site L on Pine Creek indicates a small quantity of ground-water discharge; in fact, the stream is dry at the gaging station at times during some years.

The low-flow frequency curves can be used to determine the potential of streams for water supply and waste dilution. The curves also can be used to determine the effects of mining on streamflow because the curves will become flatter when flows are increased by mine discharge.

Peak Flow

Information on peak flows of specific recurrence intervals is needed for a variety of projects including the design of bridges, culverts, holding ponds, and embankments, and to identify flood-prone areas. Flood data are needed to decrease costs associated with over design and to eliminate disruption of services or even loss of life associated with under design. Maximum flows recorded at gaging stations commonly are two to three orders of magnitude larger than average flows (table 1).

Flood-frequency curves for selected gaging stations are shown in figure 6. The curves show the average interval, in years, between floods that equaled or exceeded a given discharge. The recurrence interval is an average value and does not mean that floods occur with any regularity. It is possible, for example, to have two floods of the 10-year recurrence-interval magnitude in successive years or even in the same year. On the average, a flood with a 10-year recurrence interval will be equaled or exceeded about 10 times in 100 years and has a 10-percent chance of being equaled or exceeded in any 1 year.

The reader is referred to a statewide study of peak flow by Thomas and Lindskov (1983) for methods of estimating peak flows from basin characteristics and for methods to transfer peak-flow values from gaged to ungaged sites on the same stream. In addition, Thomas and Lindskov (1983) describe procedures for mapping areas inundated by floods of selected recurrence intervals.

Quality

The chemical quality of surface water throughout the study area is shown by the water-quality diagrams in figure 2. Where data are available more than one diagram is shown for a site in order to define the differences in water quality with time and with stream discharge. As shown in figure 2, there were marked areal differences in water quality; however, water quality at most sites generally did not vary markedly with time or with stream discharge. The complete chemical analyses are listed by Plantz (1983, table 7).

Water in the headwaters of most perennial streams contained less than 500 mg/L (milligrams per liter) of dissolved solids. The predominant cation usually was calcium, and the pH and alkalinity indicated that bicarbonate was the predominant anion. Water in intermittent streams commonly contained greater than 2,000 mg/L of dissolved solids; the predominant cation in most water was sodium, and the predominant anion was sulfate.

Ground water in the area generally is more saline than direct runoff. As ground water moves from recharge areas toward natural discharge areas along streams, it dissolves minerals from the rock through which it moves. The discharge of ground water, especially from Cretaceous rocks, contributes significantly to the salinity of surface water during base flow. The salinity of surface water also is increased by irrigation-return flows, especially return of water used to irrigate soils on the Tropic Shale. The outcrops of geologic units and quality of ground water are discussed on sheet 2.

Annual sediment yields vary from less than 0.1 to more than 3.0 acre-ft/mi^2 (U.S. Department of Agriculture, 1973). The higher well-vegetated plateaus generally have the smallest sediment yields. The largest sediment yields are from sparsely-vegetated areas underlain by easily erodible shale and mudstone.

GEOLOGIC SETTING

Rocks exposed in the area range in age from Triassic to Quaternary (fig. 7). Sedimentary rocks are mainly of continental origin and include interbedded shale, siltstone, mudstone, sandstone, limestone, and conglomerate. Igneous rocks of Quaternary and Tertiary age cap the sedimentary rocks on some of the high plateaus, and unconsolidated deposits of Quaternary age locally overlie both the igneous and sedimentary rocks. The unconsolidated deposits include alluvial deposits (basin fill in Cedar and Parowan Valleys and alluvium along streams), windblown deposits, and landslide material. The principal coal-bearing units are the Dakota Sandstone and Tropic Shale in the Kolob coal field, the Dakota Sandstone in the Alton field, and the Straight Cliffs Sandstone in the Kaiparowits Plateau field. The lithology and thickness of geologic units is summarized in table 2, and outcrop areas are shown in figure 7.

Geologic units in the study area have undergone relatively little structural deformation; however, rocks in the western one-half of the area are cut by several major north-northeast-trending faults (including those that created Cedar and Parowan Valleys). Rocks in the eastern one-half have been folded into a broad structural basin (the Kaiparowits structural basin) with a number of minor folds and faults (Doelling and Graham, 1972, p. 83-88). In most places the rocks dip only a few degrees, but locally near faults and in some folds they dip more than 10°.

GROUND WATER

Occurrence

Most geologic units in the area contain water, although none are saturated everywhere. The water occurs in the intergranular spaces of both unconsolidated and consolidated units. Fractures, solution openings, and vesicular openings in consolidated rocks also may contain water. General water-bearing properties of geologic units are described in table 2.

Depth to the regional water table varies markedly from place to place depending largely on topography. The regional water table is virtually at land surface in the lower parts of Cedar and Parowan Valleys and along most perennial stream reaches. The regional water table is several hundred to more than 1,000 ft below the surface of the highest plateaus, however, perched ground water (overlying relatively impermeable unsaturated rock) commonly exists at relatively shallow depths. Perched ground water sustains the flow of many of the springs that discharge from canyon walls. In most places, the coal is unsaturated where it crops out in canyon walls. Underground from the canyon walls, however, the coal commonly is beneath the water table, and mining of the coal would require mine dewatering.

Recharge and Discharge

Precipitation and snowmelt are the main sources of ground-water recharge. Cordova (1981, p. 27 and 28) and Price and Arnow (1974, p. C69) estimate that recharge in the area averages about 4 percent of normal annual precipitation. Applying this same percentage to estimated normal annual precipitation (fig. 1, sheet 1), annual ground-water recharge in the study area averages about 150,000 acre-ft. It is likely that a larger percentage of precipitation is recharged in the higher altitudes than in lower altitudes of the area and that recharge is affected by other factors such as rock type and slope, but 4 percent probably is a fairly accurate estimate for the area as a whole.

Some water may enter the study area as subsurface flow from adjacent areas. However, the lack of potentiometric-surface data does not allow directions and rates of subsurface flow to be determined. Since 1963 when Glen Canyon Dam was completed, water from Lake Powell has recharged the Navajo Sandstone (Price and Arnow, 1974, p. C11).

Most ground water is discharged close to original recharge areas by springs and by leakage to streams. More than 750 springs have been mapped or inventoried in the study area. Records of springs are listed by Carpenter and others (1967), Goode (1964, 1966, 1969), Mundorff (1971), Bjorklund and others (1977), Cordova (1981), and Plantz (1983).

Most springs issue from formations that overlie the coal-bearing units, including the Wasatch Formation and igneous rocks. Many springs also issue from the Navajo Sandstone and related sandstone strata that underlie the coal-bearing units. The springs issue where the regional or perched water tables intersect the land surface--mainly along stream valleys and canyon walls. The springs usually issue from open fractures or from bedding planes at contacts between peremeable and less permeable rock. Their discharges fluctuate with time as shown in figure 8, and many springs cease to flow during dry seasons or prolonged drought.

Virtually all of the springs in the area have some beneficial use. Many springs are used for irrigation, either by direct diversion or diversion of streams sustained by the springs. Most of the communities and individual dwellings depend on springs for their water supplies, as do some recreational and tourist facilities. Even the most remote springs are sources of water for livestock and wildlife.

Streamflow is sustained by ground-water discharge. Most streams in the area are perennial; they receive significant quantities of ground-water discharge and flow continually. However, many streams in the Kaiparowits Plateau and some tributaries to Kanab Creek and the Paria River receive little or no ground-water discharge. Consequently, the streams have no flow along extensive reaches during parts of some years and, in some cases, for several years in succession.

Aquifer Characteristics

Unconsolidated alluvial deposits have the largest permeability and readily transmit water to wells and springs (table 2). Permeability of consolidated rocks depends, in part, on the degree of fracturing. The more brittle igneous rocks, sandstones, and limestones commonly are fractured and readily transmit water. Openings along fractures in limestones commonly are enlarged by solution. Shale, siltstone, and mudstone are common in coal-bearing Cretaceous units, and they transmit water very slowly except where fractured.

Laboratory determinations of porosity and horizontal and vertical hydraulic conductivity of several core samples from the coal-bearing Straight Cliffs Sandstone are listed in table 3. The hydraulic conductivities listed in table 3 are representative of permeabilities of unfractured rock. In the sandstone cores, horizontal hydraulic conductivities were larger than vertical hydraulic conductivities, but the differences were usually less than twofold. Hydraulic conductivities of the siltstones generally were 1 to 2 orders of magnitude less than the sandstones. Similar data also are available for the Navajo Sandstone (Cordova, 1981, table 6).

Transmissivity is the product of hydraulic conductivity and saturated thickness of an aquifer, and is a measure of the ability of the aquifer to transmit water. The larger the hydraulic conductivity and saturated thickness, the greater will be the transmissivity and ability of the aquifer to transmit water. Transmissivity of aquifers in the study area are listed in table 4. It should be noted that the transmissivity of 0.3 ft^2/d shown for the coal-bearing Dakota Sandstone probably is representative of the 20 ft of aquifer open to the test well. Where the Dakota is fully saturated in the Alton coal field, transmissivity probably is at least 2 ft^2/d.

Water is unconfined in the upper few tens of feet of coal-bearing aquifers in Tropic Shale and Dakota and Straight Cliff Sandstones. With greater depth, water probably is confined. Water is released from storage in unconfined aquifers mainly by gravity drainage, and the storage coefficient is virtually equal to specific yield. No tests were conducted that allowed for accurate estimates of storage coefficients. However, other studies (Johnson, 1967) have found that specific yield varies from about 0.01 in shale to about 0.1 in sandstone that are similar to those in the coal-bearing aquifers. Where confined, the water is released from storage mainly by compression of the aquifer and the less permeable confining beds as pressure in the aquifer decreases. The quantity of water that can be released from storage is dependent on the storage coefficient, which averages about 1×10^{-6} per foot of thickness for most confined aquifers (Lohman, 1972, p. 8).

Chemical Quality

Ground water in the study area ranges from fresh to very saline (table 2). Regardless of geologic source, ground water in the higher plateaus generally contains less than 500 mg/L of dissolved solids. The predominant cation usually is calcium, and the pH and alkalinity indicated that bicarbonate is the predominant anion (fig. 7).

In the lower altitudes, dissolved-solids concentrations generally exceed 500 mg/L, and sodium and sulfate commonly are the predominant ions. Exceptions are the Navajo Sandstone, basin fill, and some alluvium along streams that contain ground water similar in quality to high-plateau areas. As noted in table 2, the most saline water occurs in the coal-bearing Tropic Shale and in geologic units, such as the Carmel Formation, that underlie coal-bearing units. The Tropic and Carmel contain easily dissolved minerals, such as gypsum, that contribute significantly to the dissolved-solids concentration of water passing through them.

General ranges of dissolved-solids concentrations in ground water were delineated by Price (1977a, 1980) for most of the area. Chemical analyses of ground water are listed by Goode (1964, tables 6 and 7), Cordova (1981, table 23), and Plantz (1983, table 6).

POTENTIAL EFFECTS OF COAL MINING

The coal-bearing Dakota and Straight Cliffs Sandstones and Tropic Shale contain water that is discharged naturally by springs and by leakage along streams. Future underground and surface mines would intercept some of this water, which would be removed with mine-dewatering systems. Mine dewatering could decrease the flow of some springs. Also, because much of the mine water would be derived from a decrease in ground-water storage, streamflow could increase in mined basins if the mine water is discharged to streams. The quality of water in streams that receive mine water could deteriorate during some periods because ground water generally is more saline than direct runoff. Also water in coal mines is commonly exposed to oil, grease, and other contaminants used in the mining operations. Contaminated mine waters also could seep through mine floors to underlying water-bearing zones.

Another potential effect on surface-water quality is an increase in fluvial sediment. According to Kilpatrick (1979, p. 34), sediment yields can increase tenfold from areas that are actively being surface mined.

Subsidence and associated rock fracturing occurs above all underground coal mines. The degree of subsidence and fracturing are dependent on the thickness and strength of overburden, the configuration and rate of mining, and the thickness of the coal removed. Underground mining in any of the three coal fields in the area could result in subsidence similar to that near Sunnyside, about 140 mi northeast of Escalante. Near Sunnyside in the Wasatch Plateau coal field, subsidence fractures have developed at the land surface about 900 ft above an underground mine. According to Dunrud (1976, p. 9), these fractures emit air from the mine workings and "...divert all surface- and ground-water flow in this area to lower strata or to the mine workings."

It is not possible to quantify the potential impacts without mining and reclamation plans and site-specific hydrologic data. As mining plans are filed, site-specific data should allow impacts to be mitigated.

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Conversion Factors

For readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per square mile (acre-ft/mi^2)	0.004761	cubic hectometer per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09294	meter squared per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Table 1.--Summary of streamflow records at gaging stations

[mi2, square miles; ft, feet; in.,inch; ft3/s, cubic feet per second; acre-ft/yr, acre-feet per year; in/yr, inches per year.]

Site identi-fication	Downstream number	Station name	Drainage area (mi^2)	Period of record (water year)	Altitude of gage (ft)	Mean annual precipitation (in.)	Average discharge			Extremes for period of record			
							ft^3/s	acre-ft/yr	in/yr	Maximum (ft^3/s)	Date	Minimum (ft^3/s)	Date
						GREAT BASIN							
A	10173450	Mammoth Creek above West Hatch Ditch, near Hatch	105	1964-82	7,300	24	([1]) 49.0	35,500	6.34	652	June 6, 1979	0.06	Dec. 25, 1977
B	10173900	Duck Creek near Hatch	—	1953-59	8,530	—	—	—	—	226	June 6, 1958	.04	During winter months for most years
C	10174000	Assay Creek above West Fork, near Hatch	—	1954-59	—	—	—	—	—	419	May 11, 1958	13.0	Jan. 22 to Mar. 30, 1956
D	10174450	Sevier River near Hatch	340	1911-28, 1939-82	6,870	23	([1])125	90,560	5.00	1,490	May 26, 1922	20.0	Aug. 30, 31; Sept. 1, 7-9, 1977
E	10183900	East Fork Sevier River near Ruby's Inn	71.6	1961-82	7,860	22	16.9	12,240	3.20	448	May 23, 1980	0	Feb. 26 to Mar. 10, 1964
F	10241470	Center Creek above Parowan Creek, near Parowan	11.6	1964-82	6,900	22	6.22	4,510	7.29	353	Aug. 10, 1965	1.4	July 16, 1972; Jan. 24, 1979
G	10241600	Summit Creek near Summit	24.0	1964-82	6,310	22	4.16	3,010	2.36	858	Aug. 6, 1971	.05	Feb. 5-7, 1971
H	10241800	Ash Down Creek near Cedar City	13.1	1957-61	7,540	—	—	—	—	1,000	Aug. 3 1959	1.7	Nov. 23, 1958
I	10242000	Coal Creek near Cedar City	80.9	1917-19, 1936-82	6,000	29	([1]) 32.4	23,470	5.44	4,620	July 23, 1969	.30	Nov. 5, 14, 17, 26, 1959; Feb. 17, 1960; Feb. 24, 1961

Table 1.—Summary of streamflow records at gaging stations—Continued

Downstream number	Station name	Drainage area (mi^2)	Period of record (water year)	Altitude of gage (ft)	Mean annual precipitation (in.)	Average discharge			Extremes for period of record			
						ft^3/s	acre-ft/yr	in/yr	Maximum (ft^3/s)	Date	Minimum (ft^3/s)	Date
					COLORADO RIVER BASIN							
09335500	North Creek near Escalante	90	1950-55	6,100	20	7.64	5,530	1.15	3,610	Aug. 21, 1952	0	Aug. 6, 1956; Nov. 25-27, 1952; Dec. 1, 1953
09336500	Birch Creek near Escalante	36	1950-51	6,090	—	([1])	—	—	1,010	July 12, 1954	.01	July 13, 14, 1955
09337000	Pine Creek near Escalante	68.1	1950-55, 1957-82	6,400	23	4.55	3,300	.91	1,010	Aug. 2, 1967	0	No flow at times in some years
09337500	Escalante River near Escalante	320	1909-13, 1942-55, 1971-82	5,670	18	([1]) 15.0	10,870	.64	3,450	Aug. 1953	.07	Dec. 24, 1978
09381000	Henrieville Creek near Henrieville	29	1950-55	6,100	—	—	—	—	3,360	July 31, 1953	0	Nov. 22, Dec. 22 1952
09381500	Paria River near Cannonville	220	1950-55	5,440	—	([1])	—	—	5,160	Aug. 16, 1955	0	No flow for many days each year
09403620	Mill Creek near Glendale	4.81	1975-77	6,820	—	—	—	—	147	Aug. 17, 1977	.06	Jan. 26, 1977
09403630	Skutumpah Creek near Glendale	14.8	1975-77	—	—	—	—	—	314	Aug. 17, 1977	0	No flow during most winter months
09403640	Intermediate Drainage near Glendale	2.49	1975-77	6,120	—	—	—	—	42	Sept. 26, 1976	0	No flow most days
09403650	Thompson Creek (upper station) near Glendale	9.8	1975-77	6,420	—	—	—	—	700	Aug. 18, 1977	.09	Aug. 28-30, 1977
09403660	Thompson Creek (lower station) near Glendale	16.6	1975-77	6,300	—	—	—	—	700	Aug. 18, 1977	.06	Aug. 31, Sept. 1, 1977
09403670	Thompson Creek near Glendale	19.2	1980-81	6,050	—	—	—	—	1,030	Aug. 14, 1981	.23	July 31 to Aug. 9, 1981
09404450	East Fork Virgin River near Glendale	69.2	1966-82	5,900	33	20.7	15,000	4.06	640	July 27, 1976	6.3	June 18, 1977
09405300	Crystal Creek near Cedar City	10.2	1956-60	8,320	—	7.23	5,230	9.63	1,300	Aug. 19, 1959	.10	July 6-9, 1957
09405420	North Fork Virgin River below Bullock Canyon near Glendale	29.6	1974-82	6,420	30	18.5	13,400	8.49	225	Oct. 2, 1977	2.6	Aug. 3, 1977
09405450	North Fork Virgin River above Zion Narrows, near Glendale	45.5	1978-82	6,000	—	—	—	—	242	Aug. 23, 1982	2.2	Aug. 12, 1981

Diversions upstream from station.

Table 2.—General description of geologic units, their water-bearing properties, and chemical quality of ground water

[ft, feet; gal/min, gallons per minute; mg/L, milligrams per liter.]

ical quality of water: Fresh, less than 1,000; slightly saline, 1,000 to 3,000; moderately saline, 3,000 to 10,000; and very saline, 10,000 to 35,000 milligrams per liter of dissolved solids.

logic ge	Geologic units(s) and map symbol(s)	Approximate thickness (feet) West of Sevier fault	Between Sevier and Paunsaugunt faults	East of Paunsaugunt fault	Lithology	General water-bearing properties	Chemical quality of water
ernary	Unconsolidated deposits (Qa,Qw,Ql)	0-1,000 in Cedar Valley; 0-100 in most other places	0-500 in upper Sevier River valley; 0-100 in other places	0-100	Mainly alluvial, windblown, and landslide deposits of clay, silt, sand, and gravel; locally cobbles and boulders. Includes basin fill in Cedar Valley and alluvium along the Escalante, Sevier, Virgin, and Paria Rivers and other streams	The basin fill in Cedar Valley and the alluvium along the Sevier River are major sources of water; the deposits locally yield several hundred to more than 1,000 gal/min to individual wells (Bjorklund and others, 1977, table 1; and Carpenter and others, 1967, table 1). In other areas the unconsolidated deposits are too thin or limited in extent to support large sustained well yields.	Generally fresh to slightly saline. Dissolved-solids concentrations in basin fill and alluvium in higher altitudes are commonly less than 500 mg/L. Dissolved-solids concentrations in alluvium in the lower altitudes commonly range from 500 to 1,000 mg/L in the Kolob and Alton coal fields and exceed 1,000 mg/L in the Kaiparowits Plateau field
ernary d iary	Igneous rocks (Qb,Tb)	0-500	Unknown	220-660	Mainly basaltic lava flows with associated breccias	Yields water readily but, because of limited thickness in most places, the rocks have a relatively small storage capacity. Yields several gallons per minute to a few wells and many individual springs. Transmits several hundred to more than 1,000 gal/min to several springs (Mundorff, 1971, p. 24)	Generally fresh. Dissolved-solids concentrations are generally less than 500 mg/L; locally less than 250 mg/L
	Sevier River Formation (Ts)	0-450	0-450	0	Unconsolidated to partly consolidated deposits of gravel, sand, silt, and clay	Generally yields water slowly, but coarser-grained unconsolidated strata may yield more than 10 gal/min to wells	Probably fresh
iary	Wasatch Formation (Tw)	0-1,350	1,000-1,300	0-2,000	Mainly red, white, and gray massive limestone with interbeds of mudstone, siltstone and sandstone; base of formation consists mainly of conglomerate	Yields less than 1 to a few gallons per minute to widely scattered springs. The basal conglomerate locally transmits several hundred gallons per minute to springs. Considered to be a major source of base flow of streams (Cordova, 1981, table 2)	Generally fresh. Dissolved-solids concentrations in 14 samples averaged 240 mg/L
	Kaiparowits Formation (Kk)	0-1,200	265-700	2,000-2,500	Mainly light to dark gray, fine- to medium-grained sandstone with interbedded mudstone and some conglomerate	Generally yields less than 10 gal/min to widely scattered springs, but locally yields 10 to more than 100 gal/min. According to Cordova (1981, table 2), it is a major source of base flow of streams	Fresh to slightly saline. Dissolved-solids concentrations in 12 samples ranged from 170 to 1,780 and averaged 580 mg/L

Table 2.—General description of geologic units, their water-bearing properties, and chemical quality of ground water—Continued

eologic age	Geologic units(s) and map symbol(s)	Approximate thickness (feet): West of Sevier fault	Approximate thickness (feet): Between Sevier and Paunsaugunt faults	Approximate thickness (feet): East of Paunsaugunt fault	Lithology	General water-bearing properties	Chemical quality of water
	Wahweap Sandstone (Kw,Kws)	1,000	500-1,300	760-1,350	Mainly buff, fine- to medium-grained sandstone; some interbedded shaly sandstone and mudstone; minor deposits of coal	Generally yields water slowly; flows of individual spring that issue from the formation range from less than 1 to about 5 gal/min. A test well completed in the Wahweap and the underlying Straight Cliffs Sandstone in Bryce Canyon National Park produced 200 gal/min (Marine, 1963, p. 480)	Generally fresh in upper part; fresh to moderately saline in lower part. Dissolved-solids concentrations in 13 samples range from 170 to 3,530 and averaged 640 mg/L
etaceous	Straight Cliffs Sandstone (Ks,Kws)	600	80	80-1,500	Mainly gray and tan fine to medium-grained sandstone with interbedded siltstone and shale. The principal coal-bearing unit in the Kaiparowits Plateau field	Similar to the Wahweap Sandstone. The Drip Tank Member, a sandstone stratum as much as 140 ft thick that overlies the coal in the Kaiparowits Plateau area, is the principal water-bearing unit; it has reportedly yielded water to a number of coal-test holes and supports the flow of several springs. A test well reportedly yielded 87 gal/min by pumping with 70 ft of drawdown (Lorang and Sieh, 1975, p. 17 and 18)	Fresh to slightly saline. Dissolved-solids concentrations in 11 samples ranged from 250 to 2,320, and averaged 680 mg/L; generally exceeded 1,000 mg/L in samples from coal-test holes
	Tropic Shale (Kt,Ktd)	1,000-2,000	700-1,000	550-1,000	Gray shale with thin lenses of mudstone and sandstone; considerable salt, gypsum, and carbonaceous material. Contains coal in the Kolob field	Transmits water slowly and not considered as a source of water. Commonly is a confining bed with respect to ground-water flow	Generally very saline
	Dakota Sandstone (Kd,Ktd)	100-150	150-450	0-250	Mainly buff medium- to coarse-grained sandstone with interbedded shale; principal coal-bearing unit in the Kolob and Alton fields	Generally yields less than 1 to about 10 gal/min to springs; probably would yield similar quantities to wells	Generally fresh to slightly saline; dissolved-solids concentrations less than 1,000 mg/L in higher altitudes, but probably more than 1,000 mg/L where in close proximity to the Tropic Shale.
rassic and iassic	Morrison and Winsor Formations, Bluff Sandstone, Summerville Formation, Entrada Sandstone, Carmel Formation, Navajo Sandstone, Kayenta Formation, Moenave Formation, Wingate Sandstone, Chinle Formation, and Moenkopi Formation (JTru)	>4,000	>4,000	>4,000	Mainly sandstone, shale, and conglomerate. Sandstones in the Navajo are as such as 2,000 ft thick. The Carmel Formation is mainly limestone with salt and gypsum deposits	Navajo Sandstone is a major aquifer in the area (Goode, 1964, 1966, 1969; Price, 1977b; and Cordova, 1981). The Navajo yields several hundred to more than 1,000 gal/min to individual wells; it also supports the flow of many springs and is an important source of base flow of streams. The Shinarump Member of Chinle Formation yields more than 200 gal/min to individual wells locally. Other units generally yield water very slowly, but support the flow of a few widely scattered small springs and seeps.	Water from Navajo Sandstone is generally fresh, and dissolved-solids concentrations are commonly less than 500 mg/L. Water from other units is generally slightly to moderately saline, but locally is fresh

Table 3.—Porosity and hydraulic conductivity of core samples from three test holes in the coal-bearing Straight Cliffs Sandstone on the Kaiparowits Plateau

[Determinations by Core Laboratories, Inc., Dallas, Texas.]

Lithology: Very fine grained, 0.0625 to 0.125 millimeter; fine grained, 0.125 to 0.250 millimeter; medium grained, 0.250 to 0.50 millimeter.

Site identification	Depth below land surface (feet)	Porosity (percent)		Hydraulic conductivity (feet per day)		Lithology
		Horizontal	Vertical	Horizontal	Vertical	
H	590.6	12.3	—	1.3×10^{-7}	—	Siltstone, slightly indurated, very shaly
	655.2	—	31.9	—	8.9×10^{-1}	Sandstone, slightly indurated, fine to very fine grained, moderately well to well sorted
	750.5	12.9	—	1.1×10^{-4}	—	Siltstone, slightly indurated, shaly
	831.2	18.7	18.4	3.6×10^{-3}	2.1×10^{-3}	Sandstone, moderately indurated, very fine to medium grained, moderately well to well sorted, slightly calcareous, slightly silty
	846.5	28.5	28.9	12.6×10^{-1}	8.8×10^{-1}	Sandstone, slightly indurated, very fine to medium grained, moderately well to well sorted
	927.3	25.7	23.8	10.6×10^{-1}	9.1×10^{-1}	Sandstone, moderately indurated, very fine to medium grained, moderately well to well sorted, calcareous
	1,088.3	21.5	21.1	1.8×10^{-2}	9.0×10^{-3}	Sandstone, slightly indurated, very fine to medium grained, moderately well to well sorted, calcareous
I	853.4	25.2	25.7	3.7×10^{-1}	2.0×10^{-1}	Sandstone, moderately indurated, fine grained
	1,023.5	4.9	4.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Sandstone, well indurated, very fine to fine grained, calcareous, slightly laminated
	1,165.6	5.6	6.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, slightly laminated
	1,260.5	14.7	13.6	6.3×10^{-4}	3.4×10^{-4}	Sandstone, moderately indurated, medium grained, slightly calcareous
J	631.2	22.9	22.4	8.5×10^{-2}	2.7×10^{-2}	Sandstone, moderately indurated, medium grained, coal lens
	658.0	6.0	5.2	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, moderately indurated, slightly dolomitic
	720.9	19.3	19.7	3.9×10^{-3}	3.9×10^{-3}	Sandstone, moderately indurated, medium grained, slightly calcareous
	814.7	9.3	7.6	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, slightly carbonaceous, calcareous
	878.5	6.3	.77	$<3.7 \times 10^{-4}$	$<3.7 \times 10^{-4}$	Siltstone, well indurated, calcareous, slightly fractured

Table 4.—Transmissivity of selected aquifers in the study area

Subarea	Aquifer	Number of values	Range of transmissivity (feet squared per day)	Remarks
Cedar Valley	Basin fill	8	2,540 - 52,000	Aquifer tests (Bjorklund and others, 1978, table 4)
Parowan Valley	do.	15	1,400 - 677,000	Do.
Sevier River valley and Johns Valley	Alluvium	—	10 - 2,000	Aquifer tests (Carpenter and others, 1967, table 6)
Alton coal field	Dakota Sandstone	1	0.3	Aquifer test. Well open to 20 feet of the Dakota Sandstone
Kaiparowits coal field	Straight Cliffs Sandstone			
	Drip Tank Member	1	630	Aquifer test (Lorang and Sieh, 1975, p. 17 and 18)
	John Henry Member	1	66	Aquifer test (Lorang and Sieh, 1975, p. 19 and 20)
Kanab Creek basin	Navajo Sandstone	8	2,500 - 14,000	Aquifer tests (Cordova, 1981, table 8)
Escalante River basin	do.	6	500 - 11,500	Laboratory analyses of core samples
Wahweap Creek basin	do.	2	6,700 - 7,000	Aquifer tests

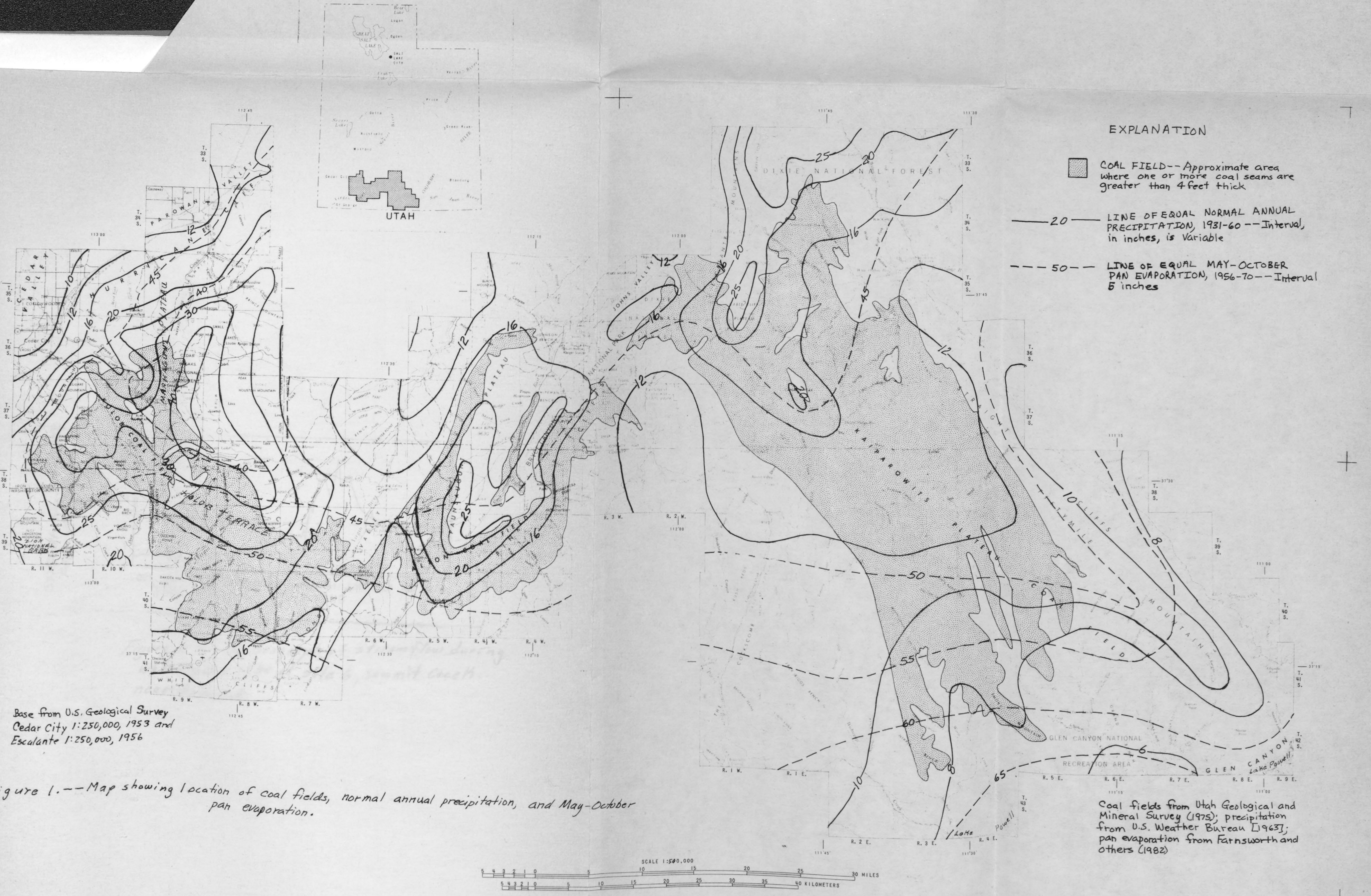

Figure 1.--Map showing location of coal fields, normal annual precipitation, and May-October pan evaporation.

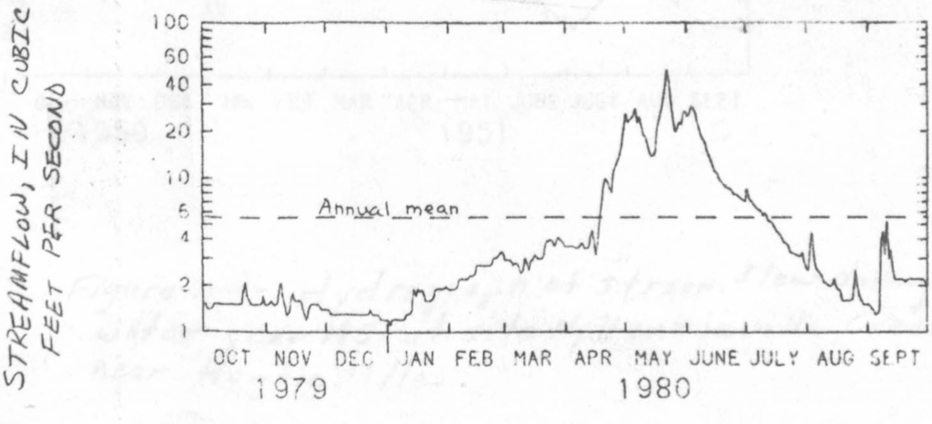

Figure 3.-- Hydrograph of streamflow during water year 1980 at site 6, Summit Creek near Summit.

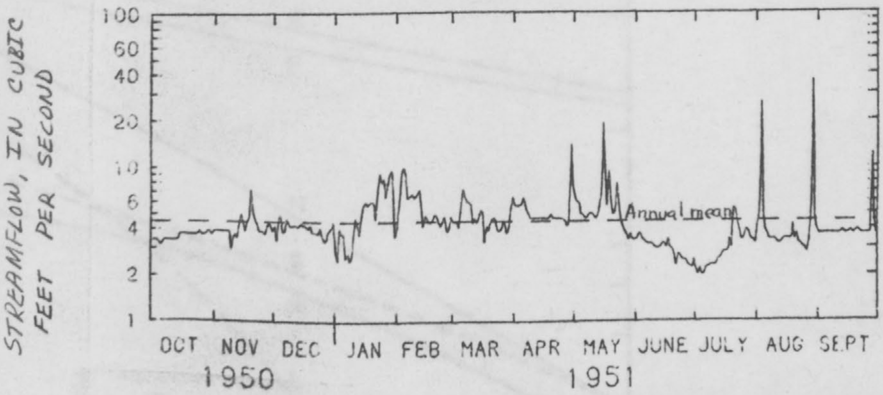

Figure 4.-- Hydrograph of streamflow during water year 1951 at site N, Henrieville Creek near Henrieville.

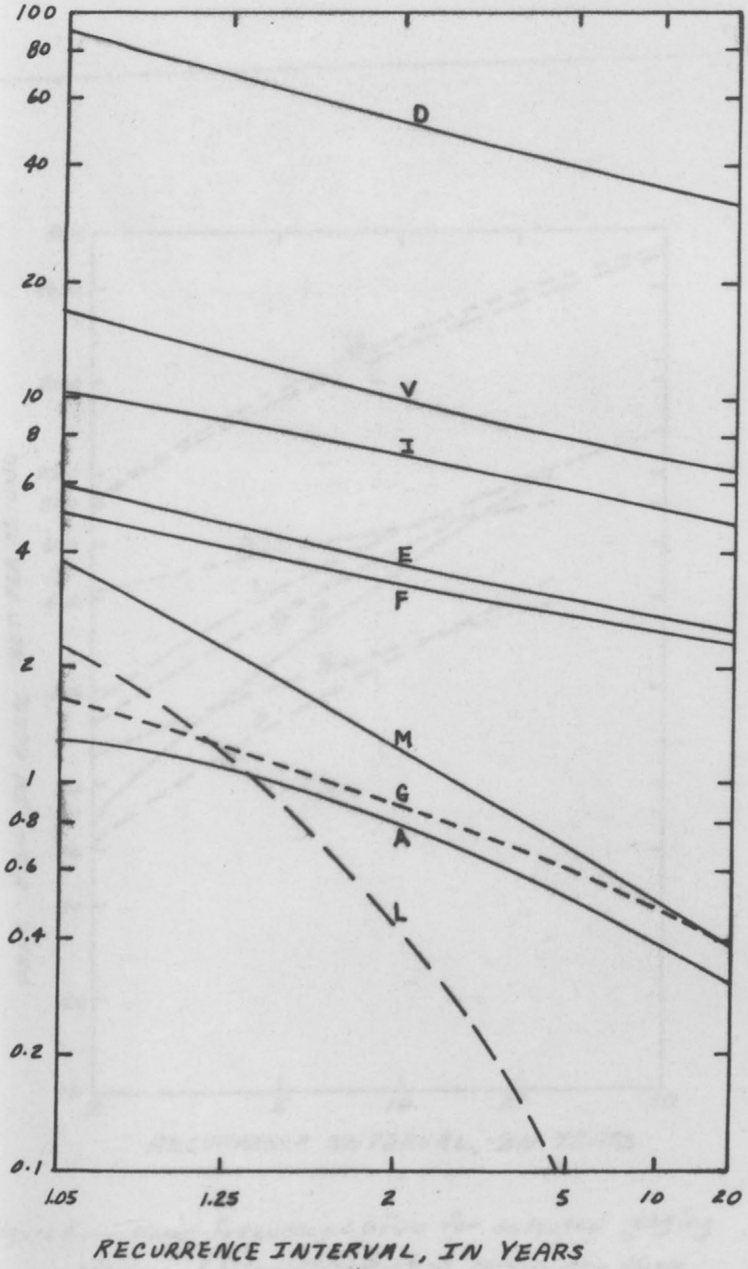

Figure 5.--Seven-day low-flow frequency curves for gaging stations with 5 or more complete years of record. (Site-identification letters are thosed used in table 1 and in figure 2.)

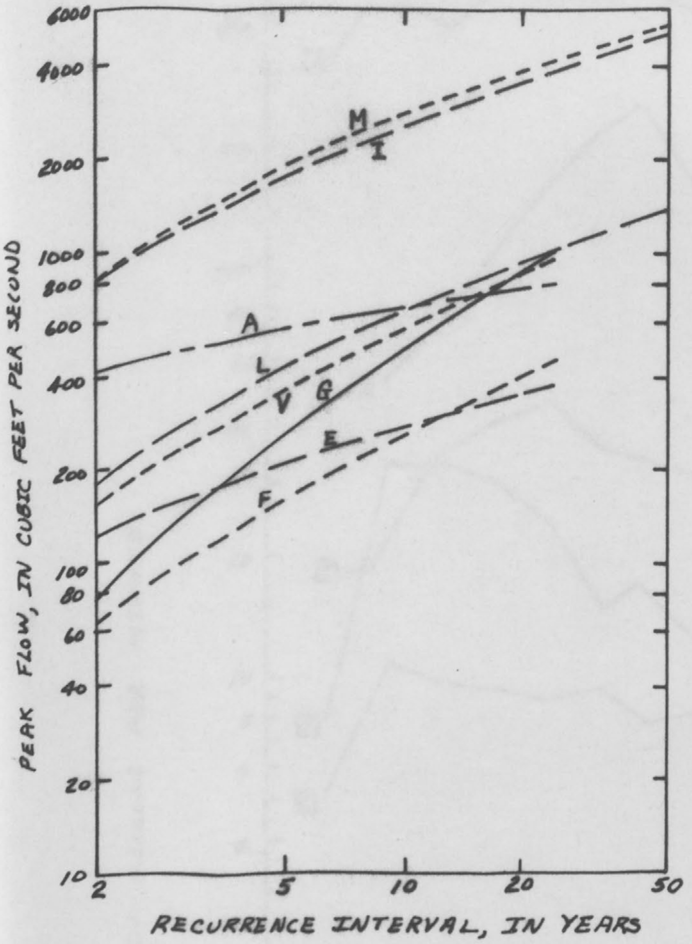

Figure 6.-- Flood-frequency curves for selected gaging stations. (Site-identification letters are those used in table 1 and in figure 2.)

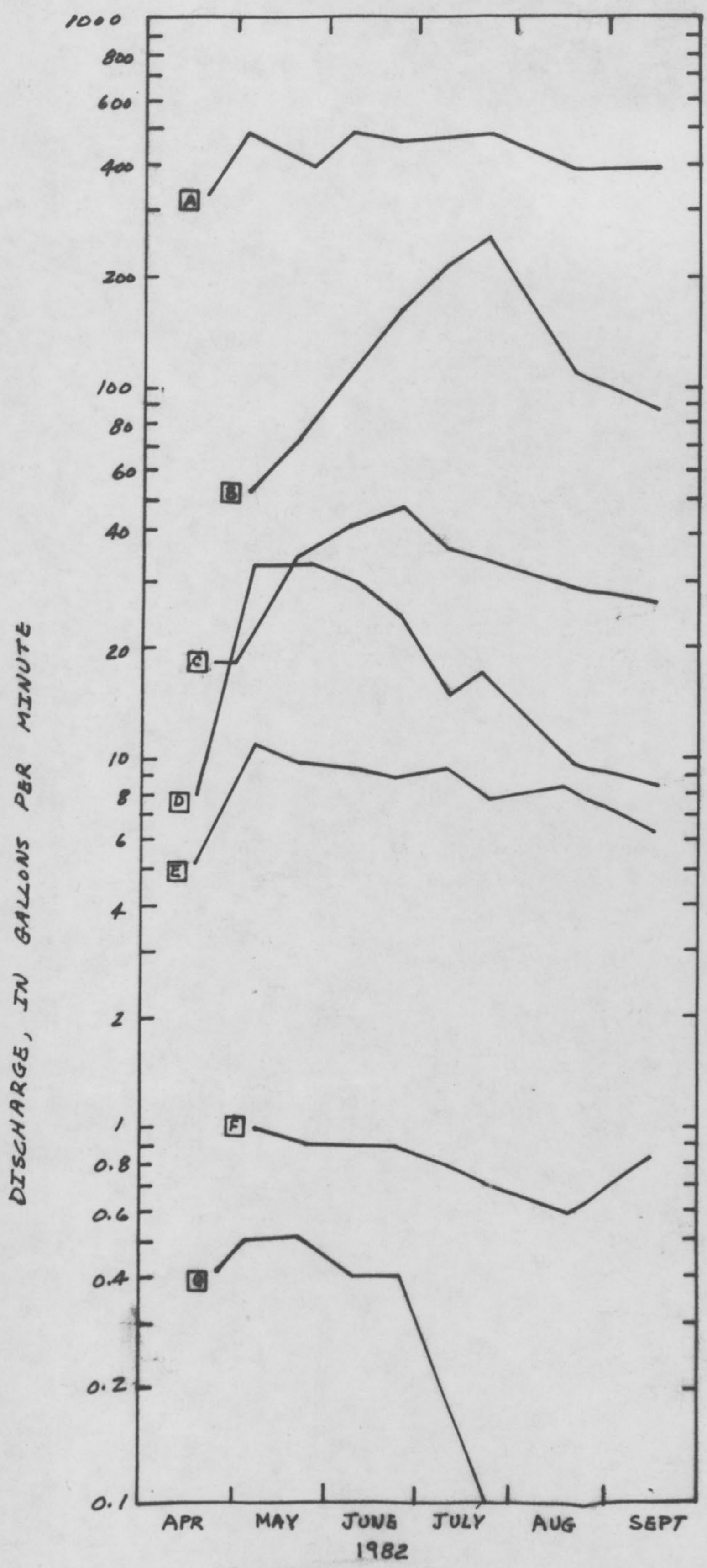

Figure 8.—Graph showing discharge of seven springs in the study area during late spring and summer 1982. (Letters identify springs shown in figure 7.)