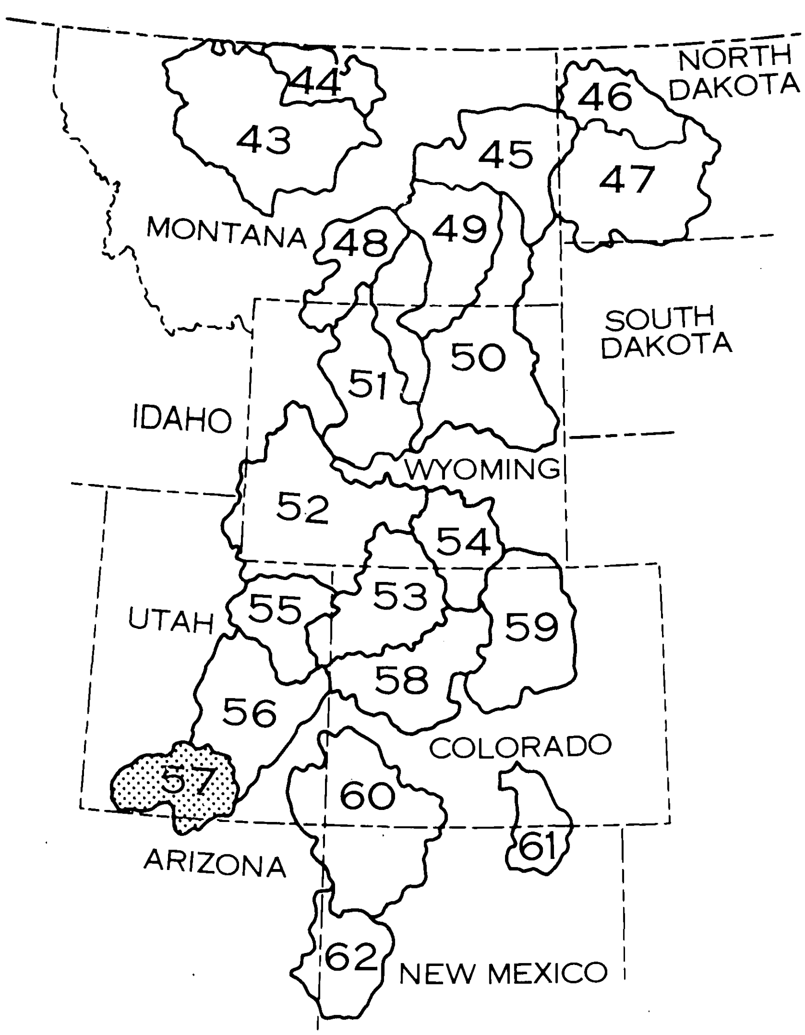
HYDROLOGY OF AREA 57, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, UTAH AND ARIZONA



- ESCALANTE RIVER
- EAST FORK SEVIER RIVER
- PARIA RIVER
- SEVIER RIVER
- NORTH FORK VIRGIN RIVER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 84-068

HYDROLOGY OF AREA 57, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, UTAH AND ARIZONA

BY
DON PRICE AND OTHERS

U.S. GEOLOGICAL SURVEY

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OPEN-FILE REPORT 84-068

SALT LAKE CITY, UTAH
JANUARY 1987

UNITED STATES DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, *SECRETARY*

GEOLOGICAL SURVEY
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1016 Administration Building
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Salt Lake City, Utah 84104

CONTENTS

Page

CONVERSION FACTORS AND RELATED INFORMATION

For the convenience of readers who may want to use the International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
acre	0.4047	square hectometer (hm^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
acre-foot per square mile (acre-ft/mi^2)	0.0004760	cubic hectometer per square kilometer (hm^3/km^2)
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]
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
ton (short, 2,000 pounds)	0.9072	megagram (metric ton) (Mg)

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = (°C \times 9/5) + 32$$
$$°C = (°F - 32) \times 5/9$$

Chemical concentration is given in milligrams per liter or micrograms per liter. Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in the inch-pound unit, parts per million.

The Geological Survey commonly classifies water as fresh to briny according to its total dissolved-solids concentration as shown in the following table adapted from Robinove and others (1958, p. 3).

Class	Total dissolved solids (milligrams per liter)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Briny	More than 35,000

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.

HYDROLOGY OF AREA 57, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, UTAH AND ARIZONA

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Abstract

Area 57 includes about 9,000 square miles in south-central Utah and north-central Arizona. About 75 percent of the area is in the Colorado River Basin, and the remaining 25 percent is in the Great Basin. All of the area's coal is in Utah, mostly in the Kolob, Alton, and Kaiparowits Plateau coal fields.

The area is characterized by a series of benches, terraces, and plateaus that have been dissected by deep, narrow canyons. Altitudes in the area vary from less than 3,000 to more than 11,000 feet, and local relief is more than 1,000 feet. Rocks ranging in age from Permian to Quaternary are exposed in the canyon walls and elsewhere throughout the area. The principal coal-bearing formations are the Dakota and Straight Cliffs Sandstones and Tropic Shale, all of Cretaceous age.

Normal annual precipitation in the area ranges from about 6 to 40 inches. Estimated mean annual runoff varies from less than 1 to about 15 inches. Dissolved-solids concentrations of streamflow generally are less than 500 milligrams per liter in the higher altitudes but locally increase to more than 2,000 milligrams per liter in the lower altitudes. Estimated annual sediment yields vary from less than 0.1 to more than 3.0 acre-feet per square mile, and suspended-sediment loads locally exceed 100,000 milligrams per liter during flood runoff.

Potential yields of individual wells generally are less than 50 gallons per minute in most of the area, but locally they exceed 1,000 gallons per minute. The largest well yields are from unconsolidated deposits of Quaternary age in Cedar and Parowan Valleys and from the Navajo Sandstone of Jurassic and Triassic age. Dissolved-solids concentrations of ground water vary from less than 500 to nearly 10,000 milligrams per liter.

Some coal in Area 57 can be surface mined, but most is recoverable only by underground mining. Very little of the coal has been mined as of 1983. This report describes some of the hydrologic impacts that could result from mining of the coal. Of particular concern are impacts on existing water rights and on water quality (including fluvial sediment and salinity in the Colorado River).

Hydrology of Area 57 Described

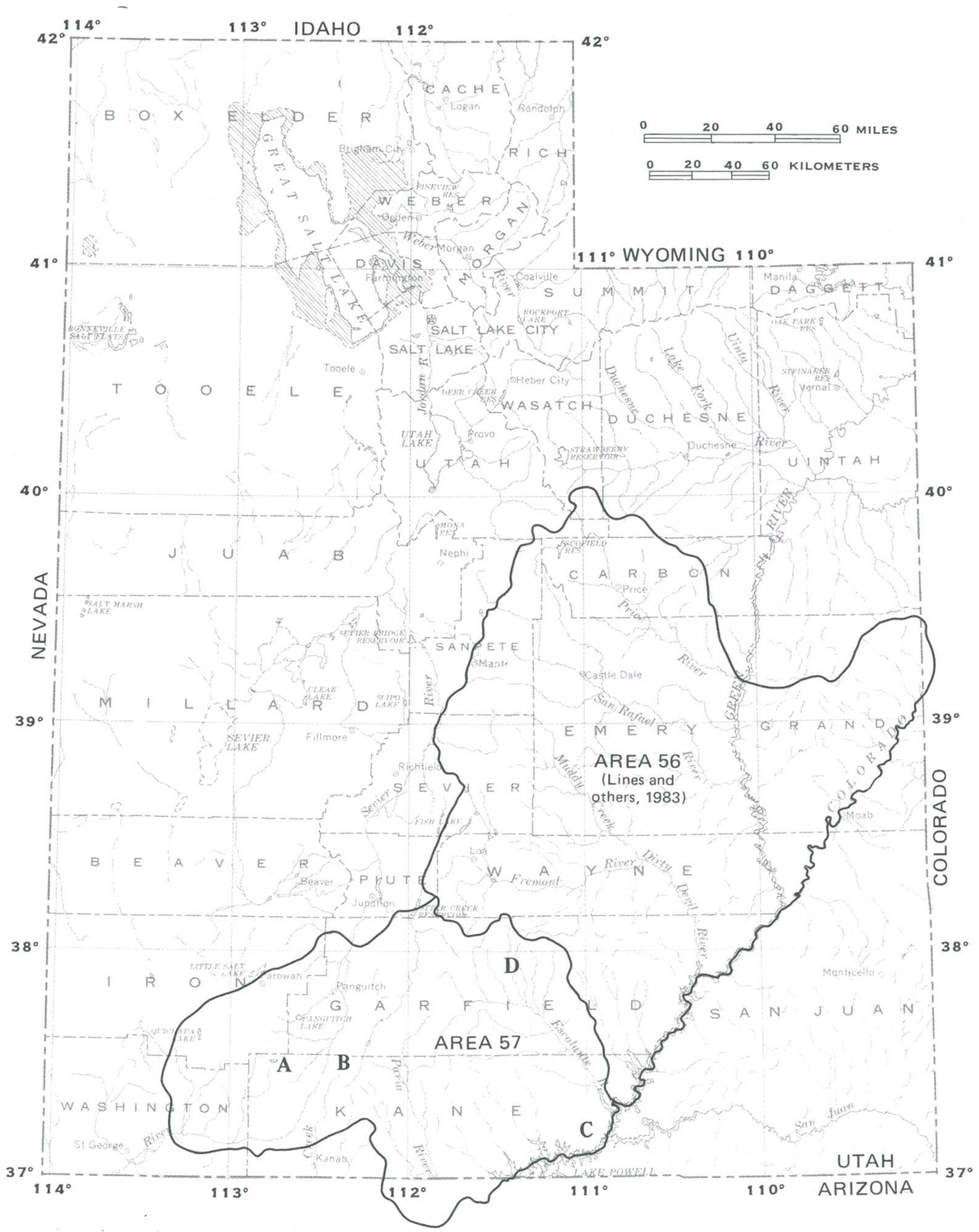
Hydrologic conditions are described, and sources of additional hydrologic information are identified.

Hydrologic information is needed by Federal agencies in order to lease and manage Federally-owned coal. The information is needed by mine-permit applicants in order to describe the hydrology of the "general area" of proposed mines. Also, the Surface Mining Control and Reclamation Act of 1977 requires that an appropriate regulatory authority issue mining permits based on review of mine-permit applications, which in part assess hydrologic impacts of the proposed mining.

This report partly fulfills the need for hydrologic information for Area 57 in Utah and Arizona (figures 1.1-1 and 1.1-2). Area 57 is one of 20 hydrologic areas in the Northern Great Plains and Rocky Mountain Coal Provinces. The report is one of a series that describes the hydrology of coal provinces nationwide.

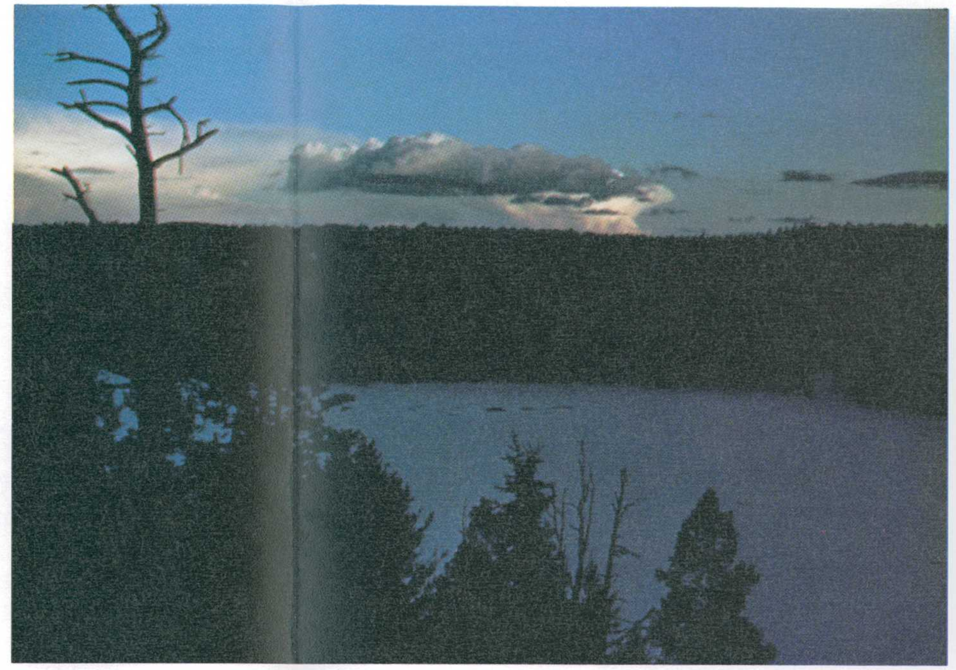
The hydrology is described by means of a brief text and accompanying maps, graphs, photographs, and tables for each of a series of water-resources related topics. Sources of additional hydrologic information also are identified in the report.

In order to define the hydrologic conditions in the vicinity of a proposed mine and to assess the hydrologic impacts of the proposed mining, information in this report will be supplemented by site-specific data provided by mine-permit applicants. The site-specific data also will be needed by the regulatory authority in order to evaluate the adequacy of the mine-permit applications.

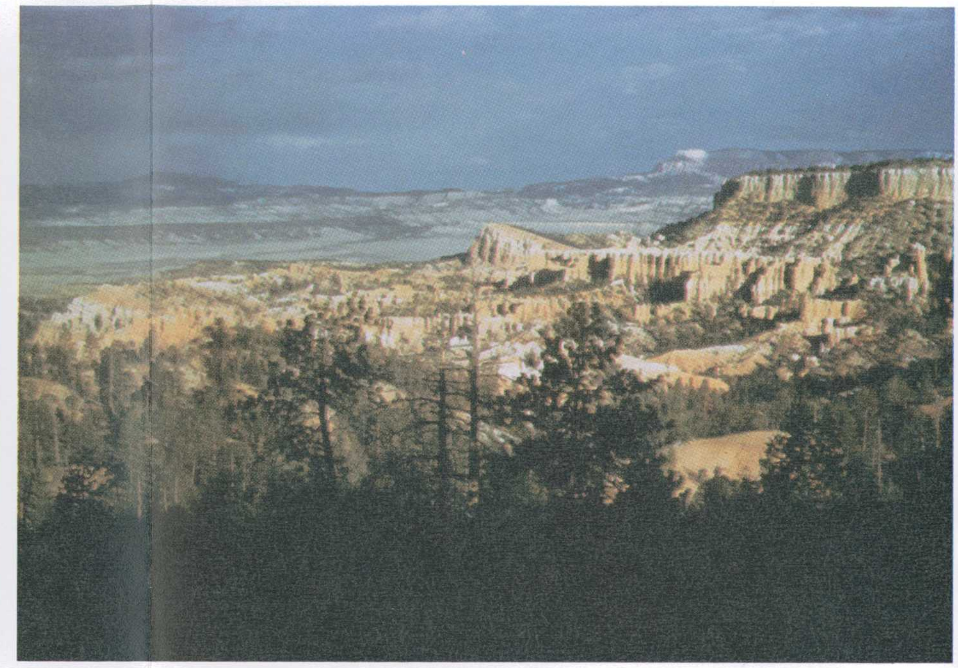


Base from U.S. Geological Survey
United States base map, 1980
1:2,500,000

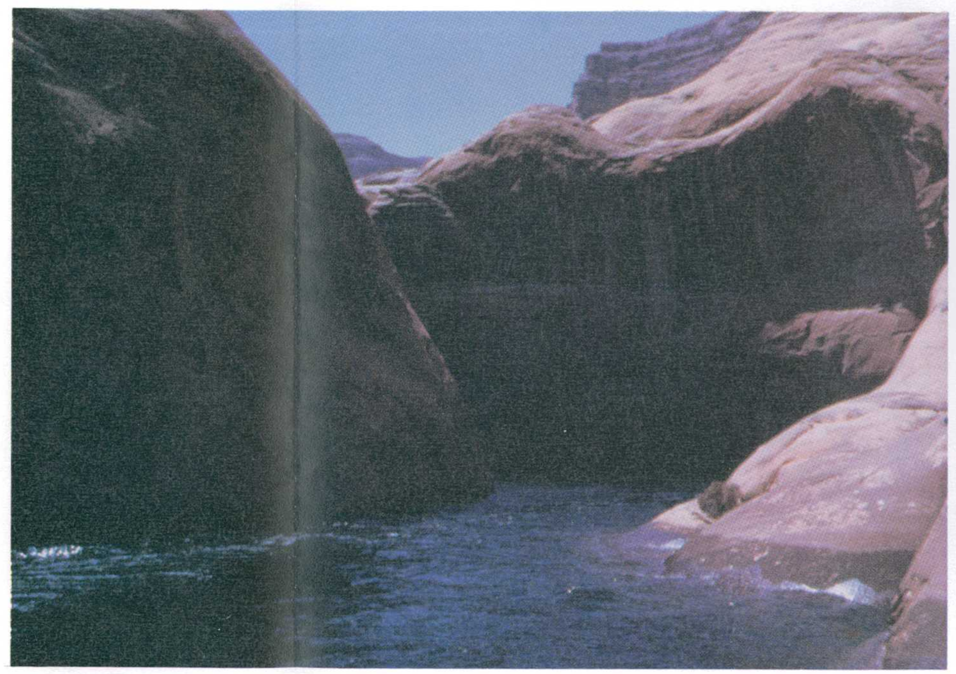
Figure 1.1-1 Location of Area 57 in Utah and Arizona.



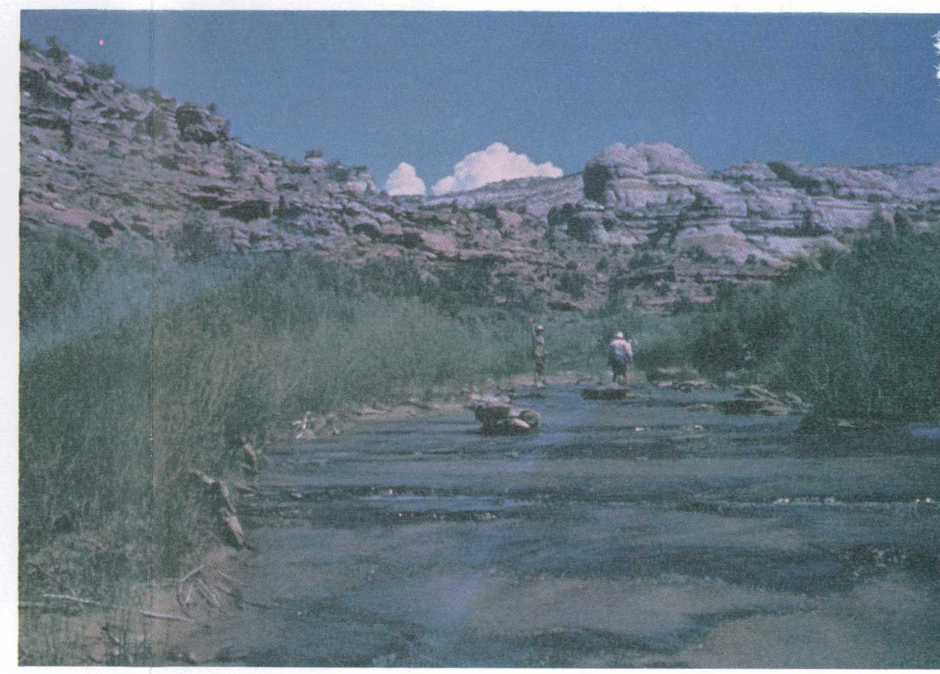
A. Navajo Lake in the Kolob coal field.



B. Bryce Canyon National Park overlooking the Alton coal field.



C. Arm of Lake Powell adjacent to the Kaiparowits Plateau coal field.



D. Calf Creek near the boundary of Area 56, which is described by Lines and others 1983.

Figure 1.1-2 Selected scenes in Area 57 (location of photographs are shown on figure 1.1-1). (Photograph D by G. W. Sandberg, U. S. Geological Survey.)

About 82 Percent of Area is Federally Owned

The area includes two National Parks and other recreational land, as well as large coal reserves.

Area 57 includes about 9,000 square miles, and about 82 percent of that land is owned by the Federal Government. The U.S. Bureau of Land Management administers the largest part of the area (figures 1.2–1 and 1.2–2) and is responsible for most of the coal-leasing activities. The U.S. Forest Service administered land (Dixie National Forest) includes headwaters of the Virgin, Sevier, and Escalante Rivers. Areas administered by the National Park Service include Bryce Canyon and Zion National Parks; Cedar Breaks National Monument; and Glen Canyon National Recreation Area. These areas are noted for their scenic beauty and natural rock sculpture (figure 1.2–3) and are popular tourist attractions in Utah.

Most of the Federal- and State-owned land is used for grazing and recreation. Much of the privately-owned land is used for agriculture, however, some of the privately-owned land also contains coal and other mineral resources.

In most instances, mineral ownership is the same as land ownership--that is, the owner of the land surface also owns the minerals on or beneath the surface. There are, however, some exceptions. For example, the Federal Government owns some of the minerals beneath privately-owned lands, and the States may own some of the minerals beneath Federally-owned lands.

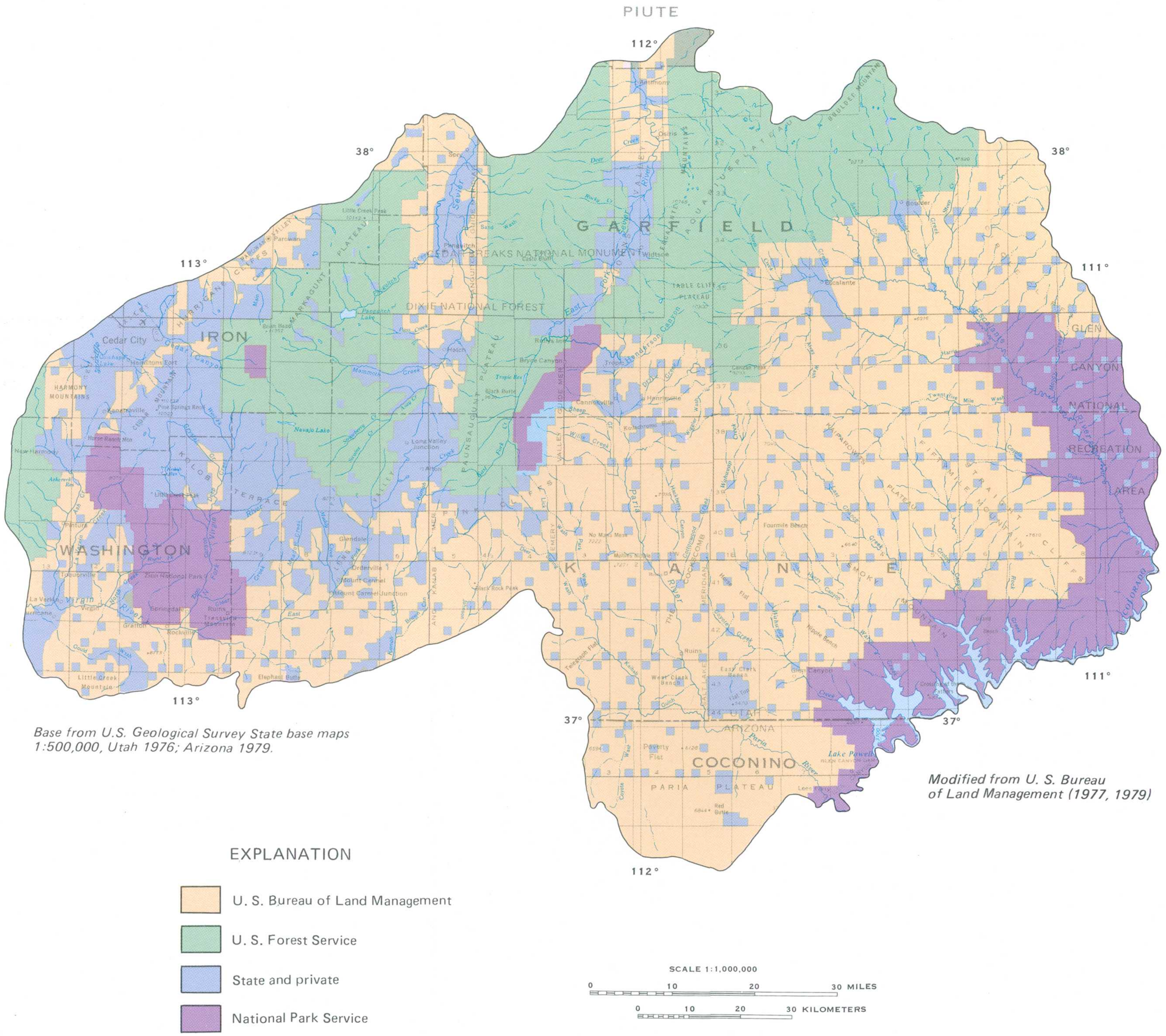


Figure 1.2-1 General land ownership and administration.

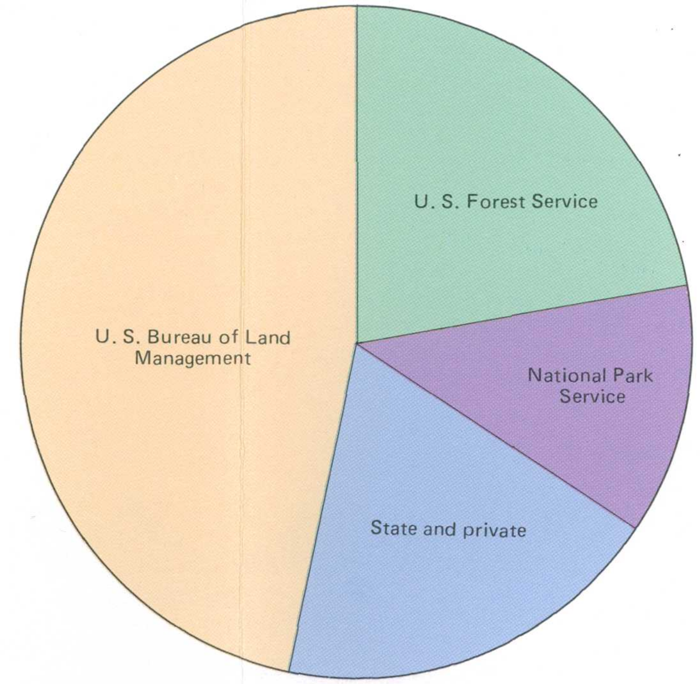


Figure 1.2-2 Comparison of land ownership and administration in Area 57 (determined for figure 1.2-1).

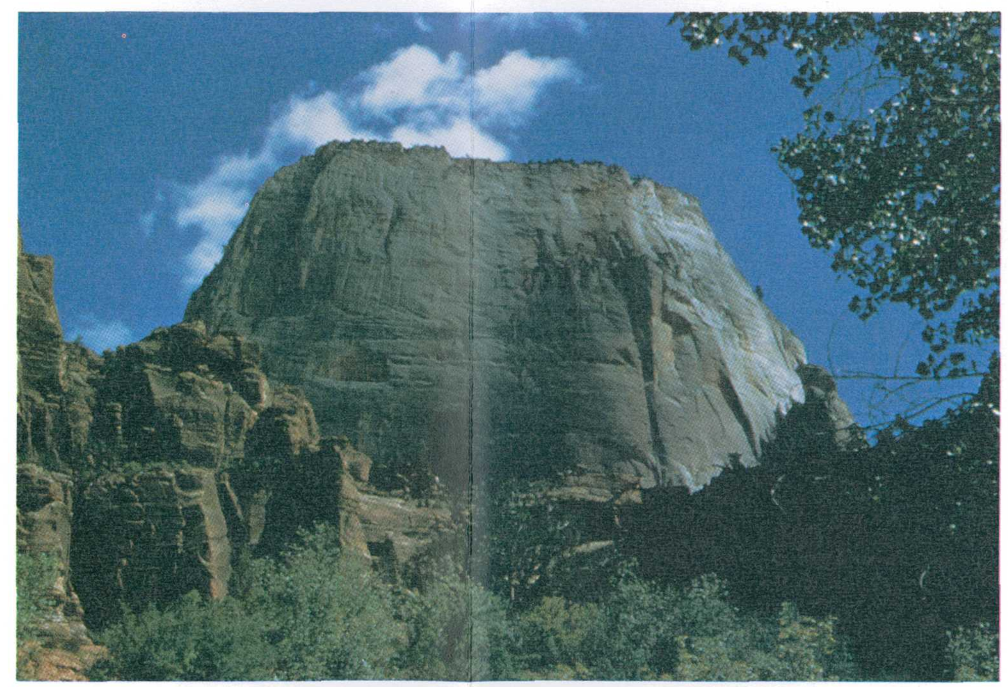


Figure 1.2-3 Great White Throne in Zion National Park.

A Variety of Topographic Maps is Available

The U.S. Geological Survey has compiled topographic maps for virtually the entire area and at several different scales; these maps are available at the Survey's Public Inquiries Offices.

An index of available U.S. Geological Survey 7½- and 15-minute topographic maps is shown in figure 1.3–1. The scales of these maps are 1:24,000 (about 2.6 inches to the mile) or 1:62,500 (about 1 inch to the mile). Contour intervals generally range from 5 to 80 feet.

The report area also is included in the U.S. Geological Survey's 1° × 2° map series:

Name	Compilation date	Revision date
Cedar City, Utah	1953	1971
Escalante, Utah; Arizona	1956	1962
Richfield, Utah	1953	1962
Salina, Utah	1956	1970
Grand Canyon, Arizona	1953	1970
Marble Canyon, Arizona; Utah	1956	1963

These maps have scales of 1:250,000 (about 0.25 inch to the mile) and contour intervals of 200 feet (with some supplementary contours at 100 feet). The 1° × 2° maps are being recompiled in 30 × 60-minute quadrangles at a scale of 1:100,000 with contours shown in meters.

All the topographic maps may be purchased from U.S. Geological Survey Public Inquiries Offices (figure 1.3–2). Mailing addresses of offices in Denver, Colorado, and Salt Lake City, Utah, are as follows:

U.S. Geological Survey
1012 Federal Building
1961 Stout Street
Denver, Colorado 80294
Phone: (303) 837-4169

U.S. Geological Survey
8105 Federal Building
125 South State Street
Salt Lake City, Utah 84138
Phone: (801) 524-5652

In addition, many of the maps may be examined at public libraries in Utah or purchased from private businesses specializing in surveying, outdoor sports, or recreation.

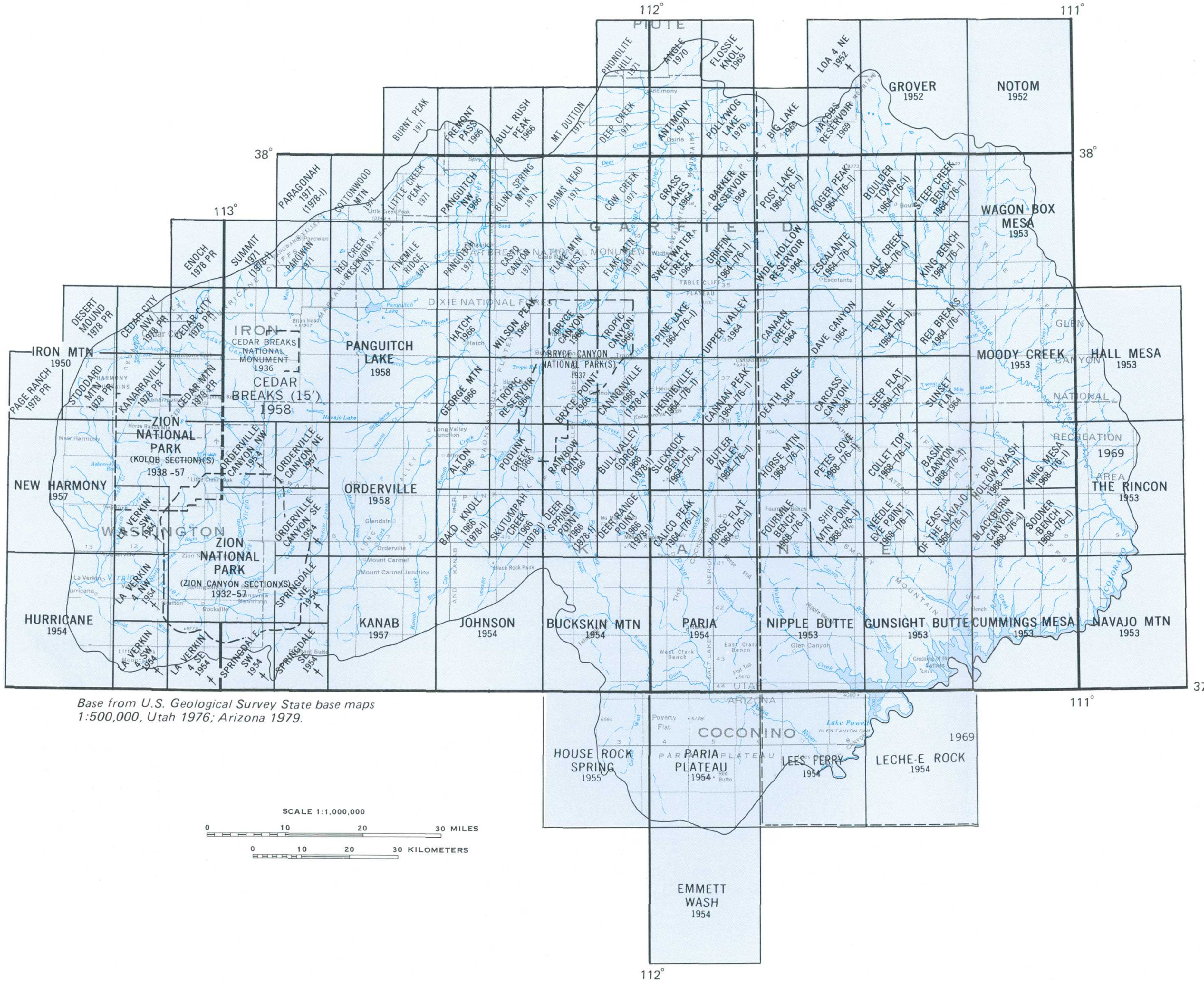
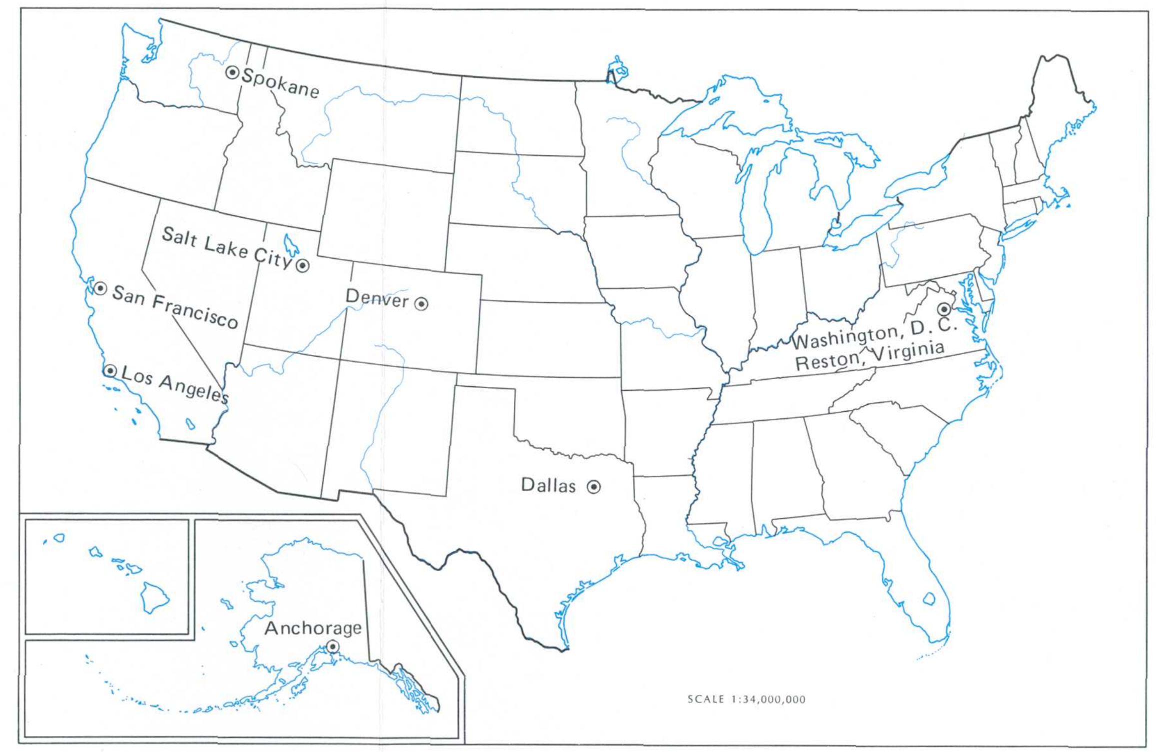


Figure 1.3-1 Index of available U. S. Geological Survey 7½- and 15-minute topographic maps.



Figures 1.3-2 Location of U. S. Geological Survey Public Inquiries Offices. (from U. S. Department of the Interior, Geological Survey, 1978)

2.0 GENERAL FEATURES OF THE AREA

2.1 Physiography

Most of Area 57 is in the Colorado Plateaus Physiographic Province

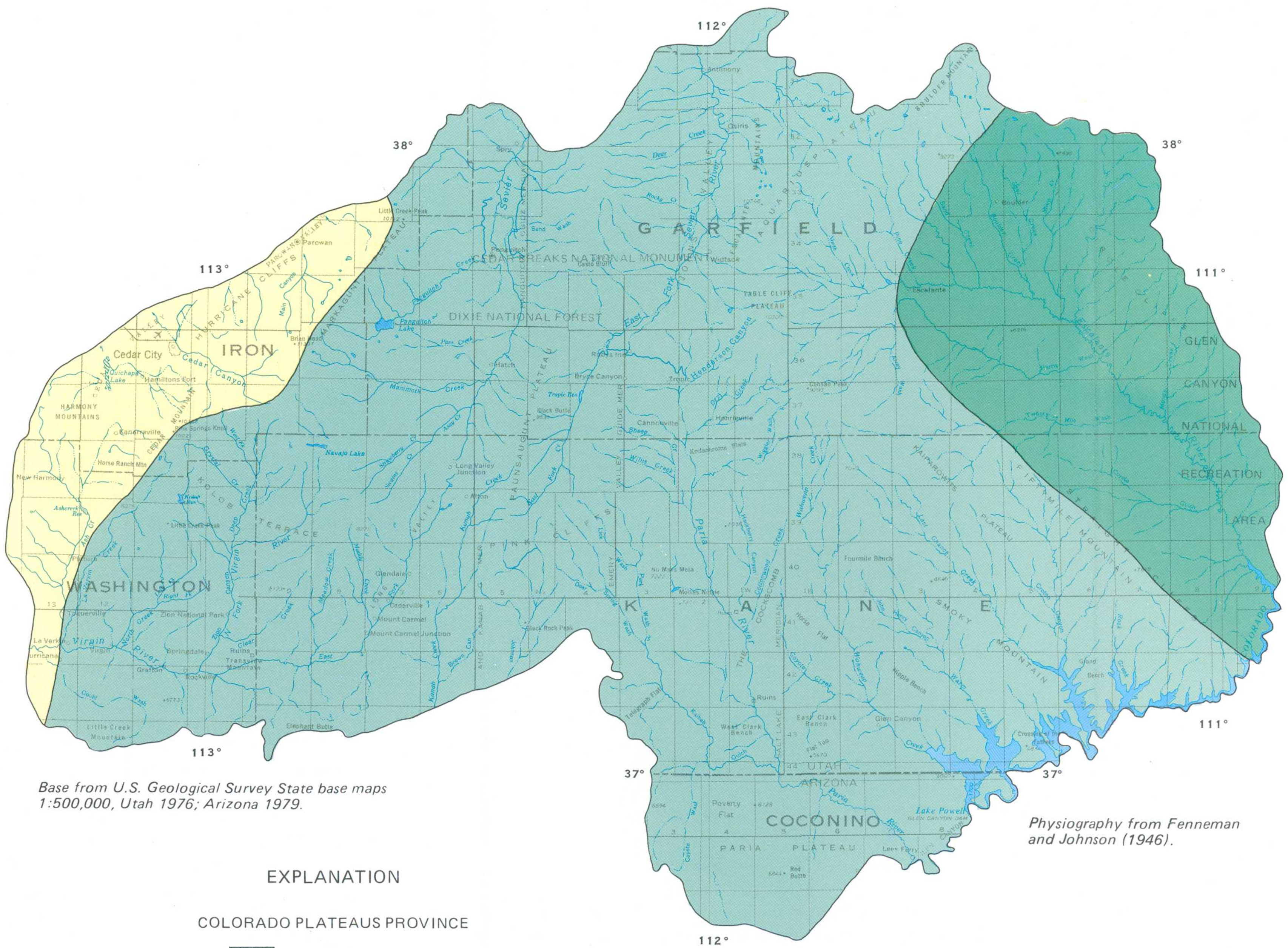
The area is composed largely of benches, mesas, terraces, and plateaus that are dissected by deep, narrow canyons; land-surface altitudes range from less than 3,000 to more than 11,000 feet, and local relief commonly exceeds 1,000 feet.

The area is in parts of the Colorado Plateaus and the Basin and Range physiographic provinces of Fenneman and Johnson (1946). About 92 percent of the area is in the High Plateaus of Utah and Canyon Lands sections of the Colorado Plateaus province, and the remaining 8 percent is in the Great Basin section of the Basin and Range province. (See figure 2.1–1).

That part of the area in the High Plateaus of Utah section is mainly a series of benches, mesas, terraces, and plateaus that are dissected by deep, narrow canyons. Dominant physiographic features in the section include the Kolob Terrace; the Markagunt, Paunsaugunt, Aquarius, Kaiparowits, and Paria Plateaus; and the Hurricane, Pink, and Straight Cliffs. (See U.S. Geological Survey, 1976). Land-surface altitudes range from less than 4,000 feet near the Colorado River to 11,307 feet on the Markagunt Plateau. Locally the cliffs that mark the edges of some of the benches and terraces are more than 1,000 feet high. Views of the Kolob Terrace and Kaiparowits Plateau are shown in figure 2.1–2.

The eastern part of the area is in the Canyon Lands section of the Colorado Plateaus province. The section includes the lower Escalante River drainage basin, which is overlooked by the lofty Aquarius and Kaiparowits Plateaus and Boulder Mountain. Included in the section are alluvium-filled valleys along the Escalante River and its tributaries and in Glen Canyon. Land-surface altitudes range from less than 4,000 feet in Glen Canyon to about 10,000 feet on the Aquarius Plateau and Boulder Mountain.

The western part of the area is in the Great Basin section of the Basin and Range province. Included in this section are Cedar and Parowan Valleys, the central part of the Virgin River basin, and adjacent parts of the Pine Valley Mountains. Cedar and Parowan Valleys are down-faulted valleys that have been filled (to depths of more than 1,000 feet) with unconsolidated erosional material from the adjacent uplands. Land-surface altitudes in this section range from about 2,900 feet where the Virgin River leaves the area west of the community of Hurricane to about 10,000 feet in the mountains east of Cedar Valley. The reader is referred to U.S. Geological Survey (1976) for a perspective of the physiography of the region and the above-mentioned physiographic features.



EXPLANATION

COLORADO PLATEAUS PROVINCE

High Plateaus of Utah section

Canyon Lands section

BASIN AND RANGE PROVINCE

Great Basin section

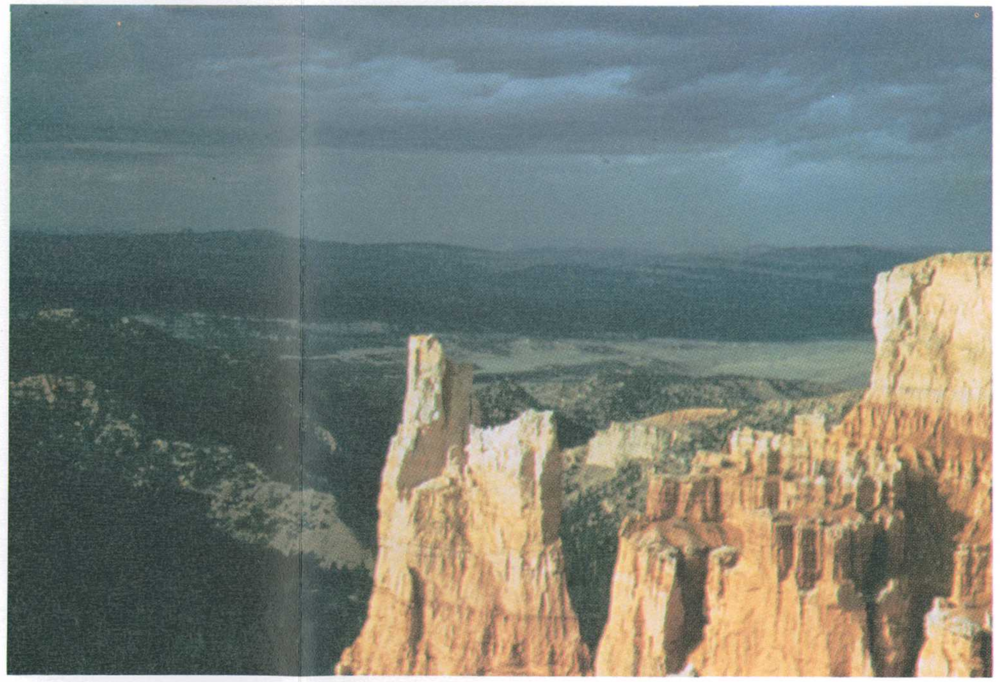
SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 2.1-1 Principal physiographic divisions.

A. View looking southwest across the Kolob Terrace from a point near Navajo Lake.



B. View looking southeast toward the Kaiparowits Plateau from Bryce Canyon National Park.

Figure 2.1-2 Selected scenes in Area 57.

Rocks Range in Age From Permian to Quaternary

Coal occurs in several geologic units; the most important are the Dakota and the Straight Cliffs Sandstones and the Tropic Shale.

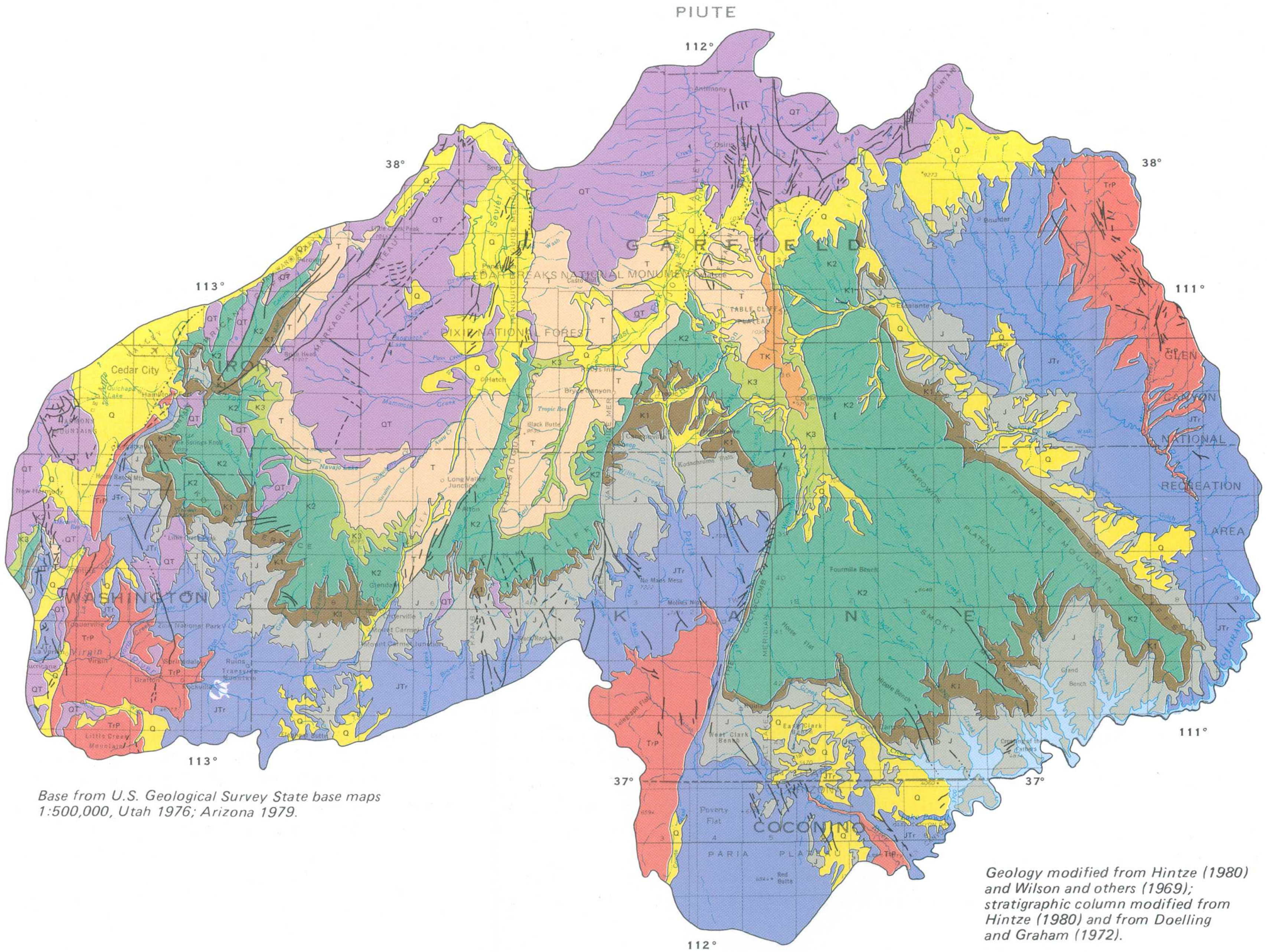
Geologic units exposed in the area range in age from Permian to Quaternary. They consist mainly of consolidated sedimentary rocks of continental origin that are capped locally by extrusive igneous rocks of Tertiary and Quaternary age and unconsolidated deposits of Quaternary age (figure 2.2–1). The widely exposed consolidated sedimentary rocks consist mainly of sandstone, siltstone, and shale with lesser quantities of limestone and conglomerate; they have a maximum aggregate thickness of more than 10,000 feet. Differential erosion of those varicolored rocks has resulted in the spectacular scenery for which Zion and Bryce Canyon National Parks and other parts of the area are noted.

The extrusive igneous rocks are most widely exposed on the Markagunt and Aquarius Plateaus. They consist mainly of basalt and andesite lava flows and have a maximum aggregate thickness of about 500 feet. Those exposed on the Markagunt Plateau in the vicinity of Navajo Lake appear to have been extruded very recently in geologic time—perhaps only a few thousand years ago.

Unconsolidated deposits consisting of clay, silt, sand, gravel, and boulders cover the igneous and consolidated sedimentary rocks at many places throughout the area. They include alluvium, talus, glacial outwash, and dune sand. Most of these deposits are less than 100 feet thick, but the alluvium along some reaches of the Sevier, Virgin, and Escalante Rivers is more than 100 feet thick. The alluvium in Cedar and Parowan Valleys is more than 1,000 feet thick.

The geologic units in the 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 east 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. 5–11, 83–88, 266–267). In most places the rocks dip only a few degrees, but locally near faults and in some folds they dip more than 10°.

The principal coal-bearing units in the area are the Dakota and Straight Cliffs Sandstones and the Tropic Shale. (See section 3.1.) Cores from test holes indicate significant lateral variations in the thickness of the coal, but there is very little information regarding the effects of faulting on the continuity of individual coal seams.



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

Geology modified from Hintze (1980) and Wilson and others (1969); stratigraphic column modified from Hintze (1980) and from Doelling and Graham (1972).

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 2.2-1 Generalized geologic map and stratigraphic column.

EXPLANATION

AGE	MAP SYMBOL	GENERAL LITHOLOGY	NAME	Thickness (feet) in specified coal field KOLOB	ALTON	KAIPAROWITS PLATEAU
Quaternary	Q		Unconsolidated deposits	0-1000	0-500	0-100
Quaternary and Tertiary	QT		Igneous rocks	0-500	0	0
Tertiary	T		Wasatch Formation	0-1350	1000-1300	0-2000
Tertiary and Cretaceous	TK		Pine Hollow Formations and Canaan Peak	0	0	0-900
Cretaceous	K3		Kaiparowits Formation	0-1200	265-700	2000-2500
	K2		Wahweap Sandstone	0-1590	500-1300	700-1350
			Straight Cliffs Sandstone		80-500	690-1835
	K1		Tropic and Mancos Shale	0-1350	700-1000	500-1000
			Dakota Sandstone		150-450	0-250
Jurassic	J		Morrison Formation	?	?	0-565
			Summerville Formation and Cow Springs Sandstone	?	?	0-350
			Entrada Sandstone	0-300	0-300	200-900
			Carmel Formation	120-350	0-300	80-520
Jurassic and Triassic(?)	JTr		Navajo Sandstone	1000-2000	1000-2000	1200-1800
Triassic and Permian	TrP		Chinle and Moenkopi Formations and Kaibab Limestone	600-1400	600-1400	?

Conglomerate — Unconsolidated deposits — Sandstone — Shale, siltstone, or mudstone — Limestone — Igneous

Coal — Gypsum — Fault: *Approximately located, dashed where uncertain, dotted where concealed* — Contact: *Approximately located*

Area Has Hot, Dry Summers and Cold, Relatively Moist Winters

Normal annual precipitation varies with altitude from about 6 to 40 inches and totals about 6 million acre-feet.

The climate of the area may be classified as arid in the lower altitudes and subhumid in the higher altitudes. Normal annual precipitation varies from about 6 inches in the vicinity of Lake Powell to about 40 inches on the Markagunt Plateau (figure 2.3–1). Based on figure 2.3–1, the total annual precipitation is estimated to average about 6 million acre-feet. The annual precipitation does, however, vary considerably from year to year as indicated by figure 2.3–2.

Most of the annual precipitation falls during October–April. It is produced chiefly by frontal-type storms that pass over the area from west to east. Those storms are regional in extent and of several hours to several days duration. The precipitation generally occurs as snow, which can accumulate to depths of more than 10 feet in the higher altitudes; snowmelt is the principal source of the late spring and early summer runoff in the area.

Most of the May–September precipitation is produced by thunderstorms that move into the area from the south. These storms are local in extent and rarely last more than a few hours. They are, however, capable of producing local flooding.

Air temperatures vary considerably both daily and annually in the area. Midsummer daytime temperatures in the lower altitudes usually exceed 100°F, and midwinter nighttime temperatures in the higher altitudes usually are less than 0°F. Average monthly temperatures at Cedar City range from about 29°F in January to about 73°F in July. In the higher altitudes the normal monthly temperatures are several degrees cooler.

The warm summer temperatures in both the low and high altitudes result in large evaporation rates. Average May–October class A pan evaporation ranges from about 40 to 80 inches (Farnsworth and others, 1982, map 1). During 1974, total evaporation from Lake Powell at Wahweap Bay was about 68 inches (figure 2.3–3).

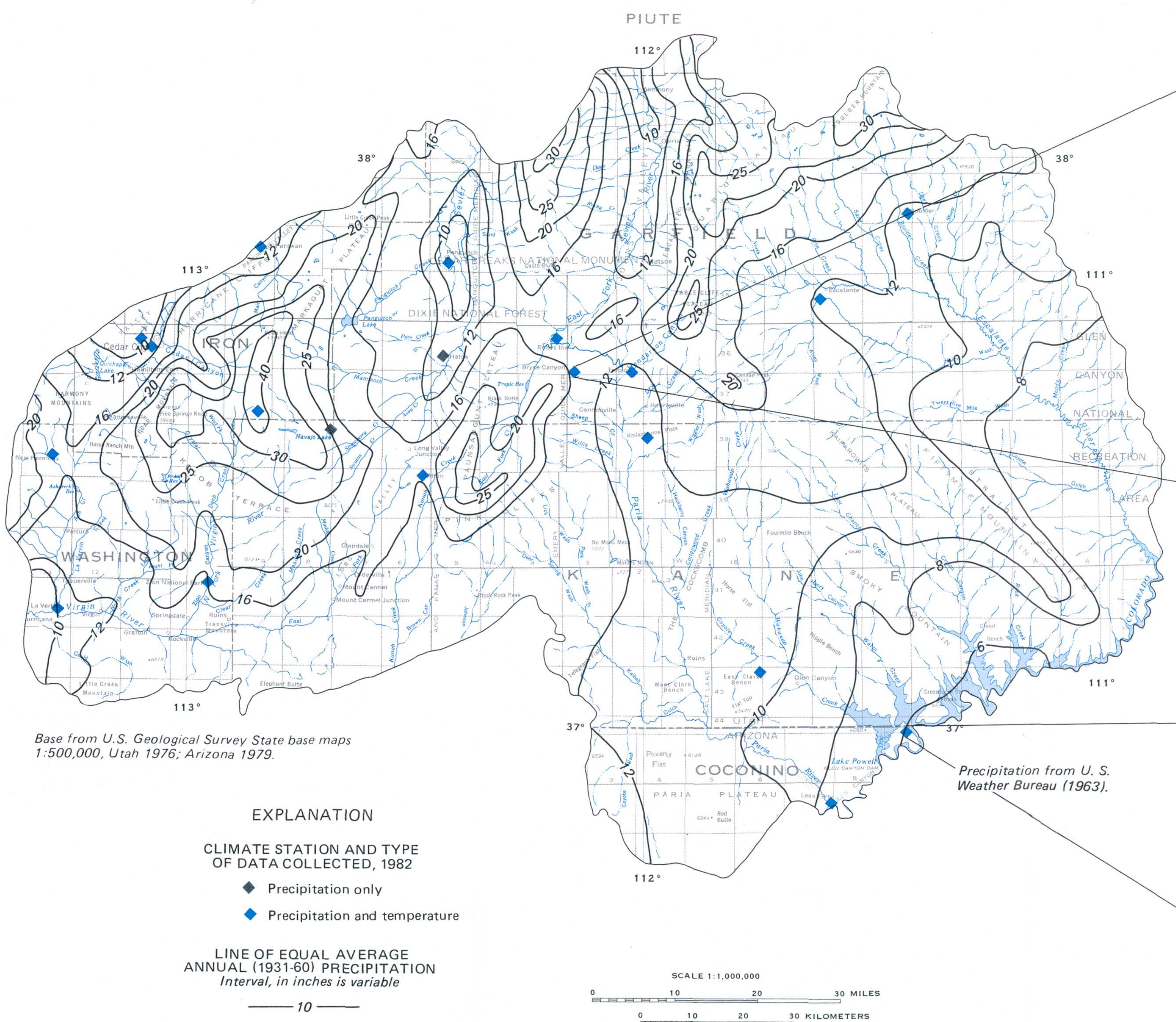


Figure 2.3-1 Average annual (1931-60) precipitation and location of climate stations.

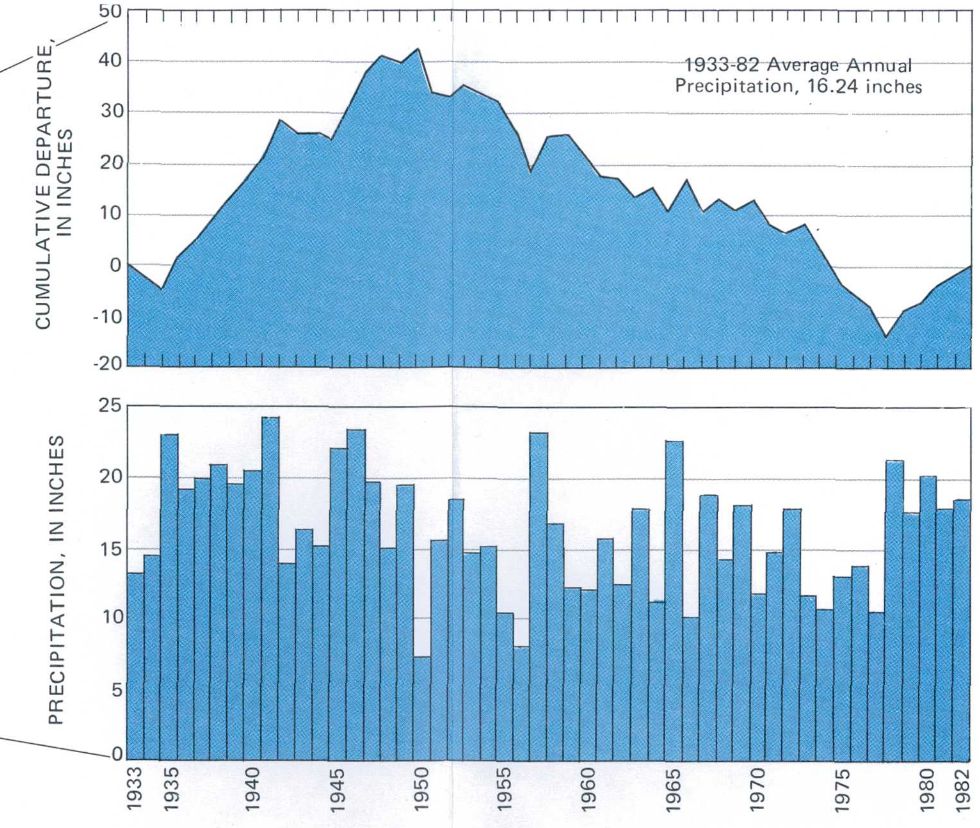


Figure 2.3-2 Annual precipitation and cumulative departure from the average annual precipitation at Bryce Canyon National Park headquarters, 1933-82.

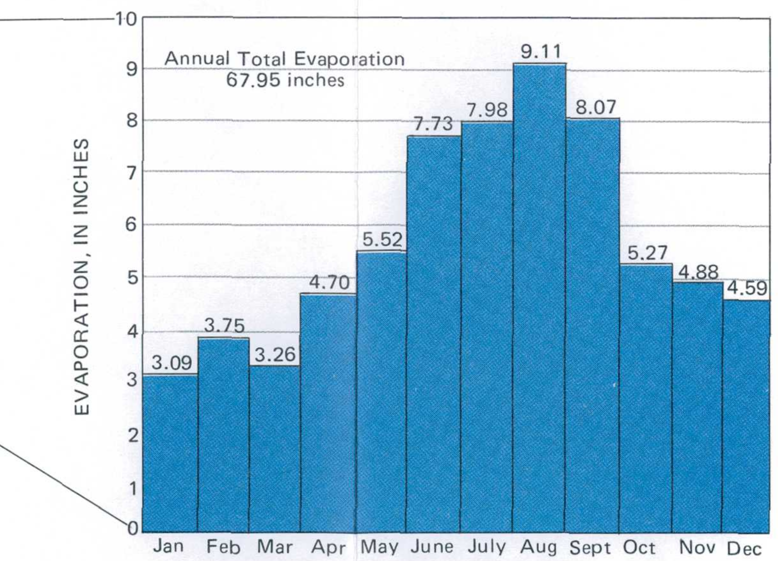


Figure 2.3-3 Monthly evaporation from Lake Powell at Wahweap Bay during 1974 (from Jacoby and others, 1977, figure 8).

Three Coal Fields Delineated

Estimated coal reserves exceed 19 billion tons, but there was virtually no mining during 1983.

Coal in Area 57 occurs in the Kolob, Alton, and Kaiparowits Plateau coal fields (figure 3.1–1). Total estimated reserves are given in the following table (Doelling and Graham, 1972, p. 15, 102, 278); estimated reserves in the Kolob field also include a small quantity of coal in the Harmony field west of Area 57:

Coal Field	Estimated Reserves (billion short tons)
Kolob	2.0
Alton	2.1
Kaiparowits Plateau	15.2
Total	**19.3**

The principal economic reserves in the Kolob coal field are near the contact between the Dakota Sandstone and the Tropic Shale; the two formations have not been divided in the Kolob field. Coal in the Alton field is in two zones near the base and near the top of the Dakota Sandstone. There are four major coal zones in the Kaiparowits Plateau coal field, all in the John Henry Member of the Straight Cliffs Sandstone. Individual coal seams in all three fields vary in thickness from less than 1 to locally more than 10 feet. The coal generally has a small sulfur content in the Alton and Kaiparowits Plateau fields, but the sulfur content is considered to be moderate to large in the Kolob field (Doelling and Graham, 1972, p. 271). Nearly all of the mineable reserves in Area 57 are beneath at least 1,000 feet of overburden and, therefore, are suited only for underground mining. Some of the coal in the Alton field (figures 3.1–2 and 3.1–3) is shallow enough to be mined by surface-mining methods.

There were no large coal mines in Area 57 during 1983. Mining, which began in the Kolob coal field during the mid-1800's, has been limited to a number of small mines and prospects, many of which have been abandoned. Maximum annual production in the Kolob coal field was about 54,000 tons (1964); in the Alton coal field it was about 3,100 tons (1948); and in the Kaiparowits Plateau coal field it probably was less than 2,000 tons. (See Doelling and Graham, 1972, p. 15, 71, 258.) There was virtually no production from any of the fields from 1978 to 1983.

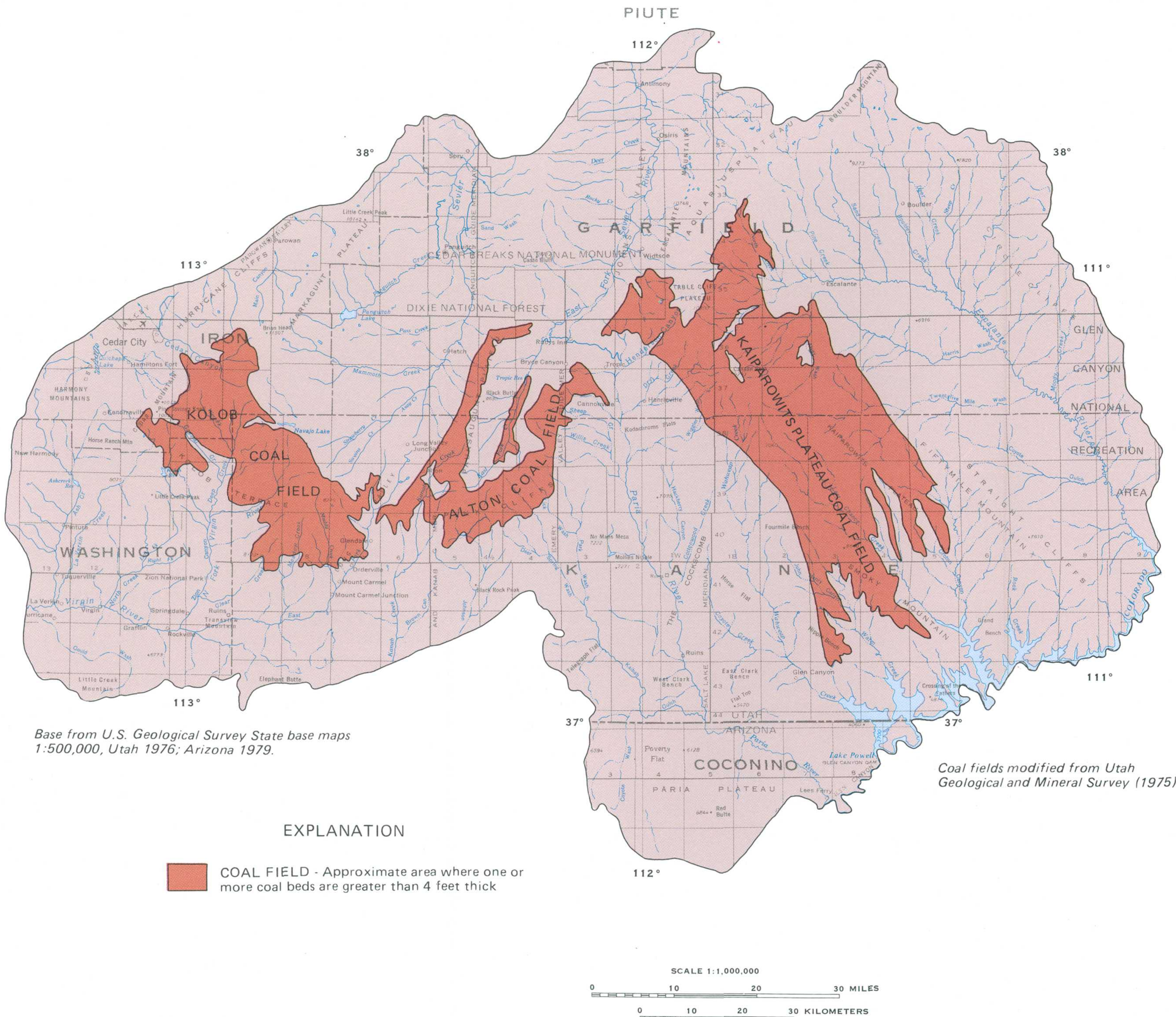


Figure 3.1-1 Location of the Kolob, Alton and Kaiparowits coal fields.

Figure 3.1-2 View looking north across part of the Alton coal field. Coal is shallow enough in this area to be recovered by surface-mining methods. (Photograph by G. W. Sandberg, U. S. Geological Survey.)

Figure 3.1-3 Exposed near-surface coal beds in the Alton coal field. (Photograph by G. W. Sandberg, U. S. Geological Survey.)

Most Mines Will Require Dewatering

Dewatering of underground coal mines can affect both ground and surface waters.

Large quantities of water could flow into coal mines in the area. The largest quantities of water probably will be encountered where the mines intercept faults or fractured rock; some water also will be produced at the working faces in mines. Some mines probably will discharge water continuously and others intermittently. Mines that encounter no ground water probably will have extended only a short distance underground from the edges of deeply incised canyons where the coal-bearing rocks are drained naturally.

Dewatering of coal mines changes the flow pattern through coal-bearing aquifers, and storage in the aquifers is reduced. The approximate change in ground-water flow that would occur in a uniformly permeable aquifer near a dewatered underground mine is shown in the sections of figure 3.2–1. As depicted in section A, flow through the aquifer is uniform prior to mining. During mining, as shown in section B, flow through the aquifer is directed toward the dewatered mine, and much of the aquifer above the older mined area is dewatered. The pattern of ground-water flow around each dewatered underground mine will be unique due to the unique configuration of each mine and because coal-bearing aquifers are not uniformly permeable; however, the pattern of flow will be similar to that depicted in section B. As shown in figure 3.2–2, mine dewatering could induce flow of saline water into aquifers containing fresh water.

Other possible effects due to mine dewatering are the degradation of surface-water quality downstream from points of mine discharge and decreases in flows of springs. Water discharged from mines probably will be more mineralized during most parts of the year than surface water upstream from points of mine discharge. It is not known, however, how much of the mine water would naturally have been discharged by springs and what would have been its quality.

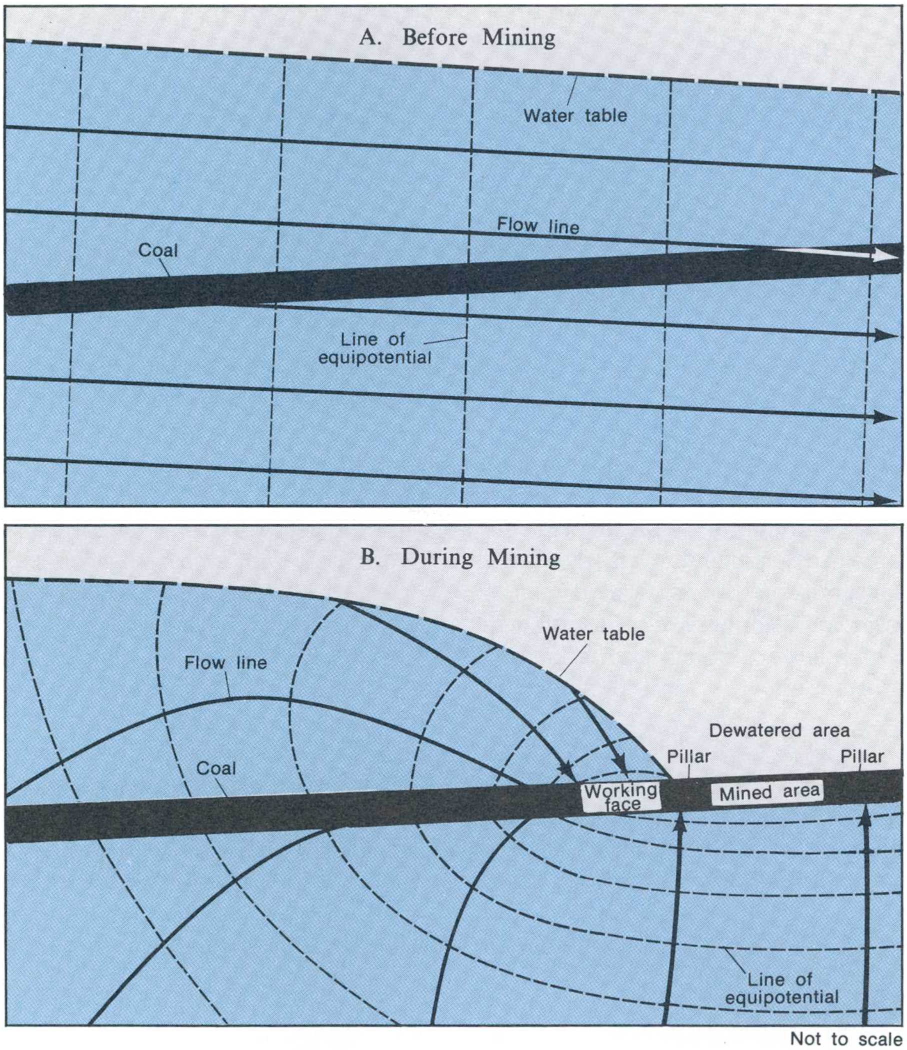


Figure 3.2-1 Cross-sections showing changes in flow through a uniformly permeable coal-bearing aquifer near an underground mine (From Lines and others, 1983, figure 3.2-2).

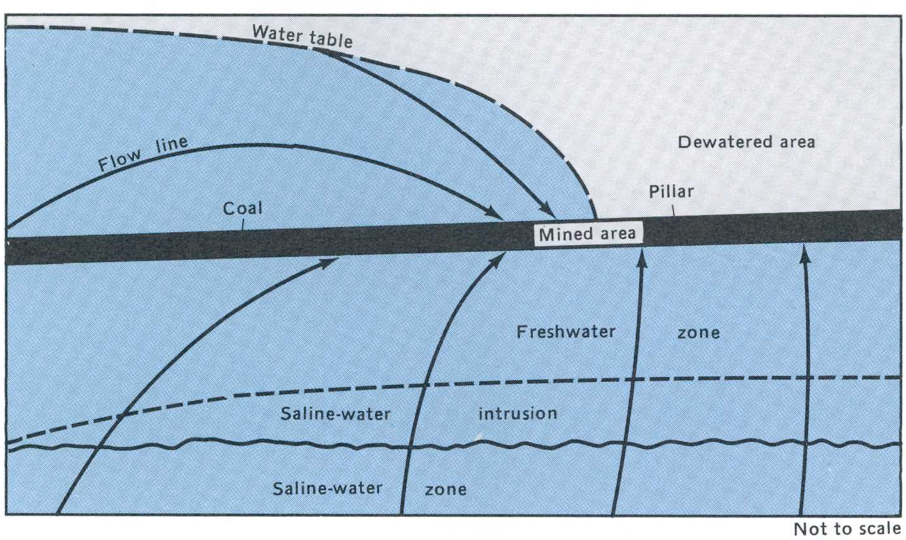


Figure 3.2-2 Cross-section showing how changes in ground-water flow due to mine dewatering (figure 3.2-1) can induce flow of saline water into freshwater zone.

Water Resources May Be Affected by Subsidence

The flow of both surface and ground waters can be altered by land subsidence and associated fracturing above underground coal mines.

Land subsidence and associated rock fracturing above underground mines can cause changes in the natural pattern of ground-water flow, can change the flow of springs, and locally can alter surface runoff. The degree of land subsidence above underground mines and the configuration of associated fractures are dependent on the thickness and strength of overburden, the configuration and rate of mining, and the thickness of coal removed. The general pattern of subsidence and rock fracturing that can occur above a mine is shown in figure 3.3–1.

There is no evidence of land subsidence due to coal mining in Area 57; this probably is because of the limited mining activity in the area to date (1983). Underground mining in any of the three coal fields of the area could, however, result in land subsidence and rock fracturing similar to that in other areas of underground mines. One such area is near Sunnyside (Lines and others, 1983), about 140 miles northeast of Escalante, where subsidence fractures have developed at the land surface about 900 feet above an underground mine. (See figures 3.3–2 and 3.3–3.) According to Dunrud (1976, p. 9), the larger fractures emit air from the mine workings, and "...these cracks divert all surface- and ground-water flow in this area to lower strata or to the mine workings."

Compression features, such as the small anticline shown in figure 3.3–4, also formed at the land surface above the mine near Sunnyside. The anticline formed when stresses along the compression arch (figure 3.3–1) reached the land surface. Measurements of the compression fractures indicate that the land surface was shortened locally by as much as 3 feet. The vertical displacement of the land surface in this area is unknown, but it probably was several feet.

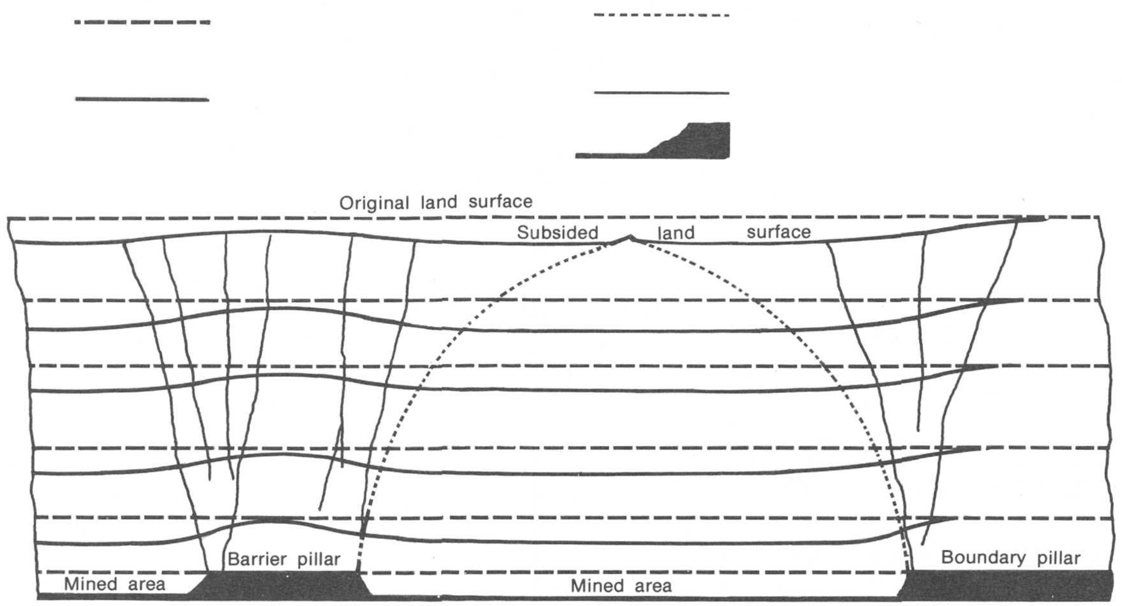


Figure 3.3-1 Generalized cross-section showing subsidence and fracturing that occurs above an underground coal mine (modified from Dunrud, 1976, figures 4 and 8).

Figure 3.3-2 Fractures at the land surface above a barrier pillar resulting from subsidence in an underground mine about 900 feet below (Dunrud, 1976, figure 9).

Figure 3.3-3 Fracture as much as 3 feet wide resulting from subsidence over an underground coal mine (Dunrud, 1976, figure 9).

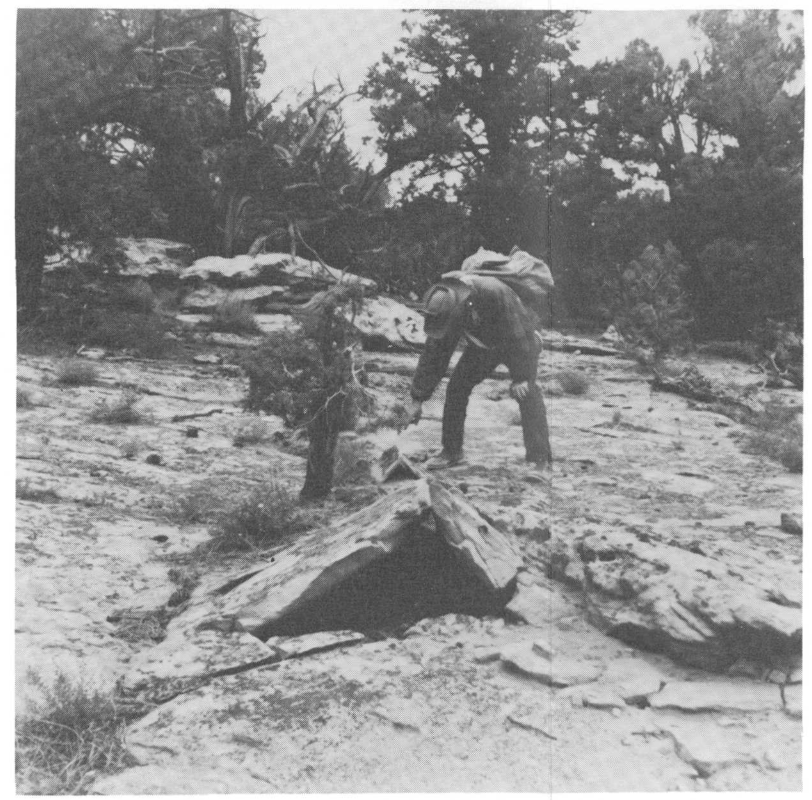


Figure 3.3-4 Compression anticline formed above an underground mine when compression arch reached the land surface (Dunrud, 1976, figure 9).

4.0 WATER USE

Irrigation is the Largest Use of Water

About 96 percent of the estimated annual use of water is for irrigation; principal sources of the irrigation water are the Sevier, Escalante, and Virgin Rivers; Coal Creek; and wells in Cedar and Parowan Valleys.

Estimated use of water in the area during 1982 was about 250,000 acre-feet. The estimate does not include instream uses, such as recreation and fish and wildlife management, or consumptive use by livestock and wildlife. The largest consumptive use of water is for irrigation—chiefly in the irrigated areas shown in figure 4.0–1. As shown in the following table and figure 4.0–2, irrigation accounted for 96 percent of the estimated use of water during 1982:

Use	Acre-feet
Irrigation	240,000
Public supply	8,100
Industry	1,200
Domestic	100
Total (rounded)	**250,000**

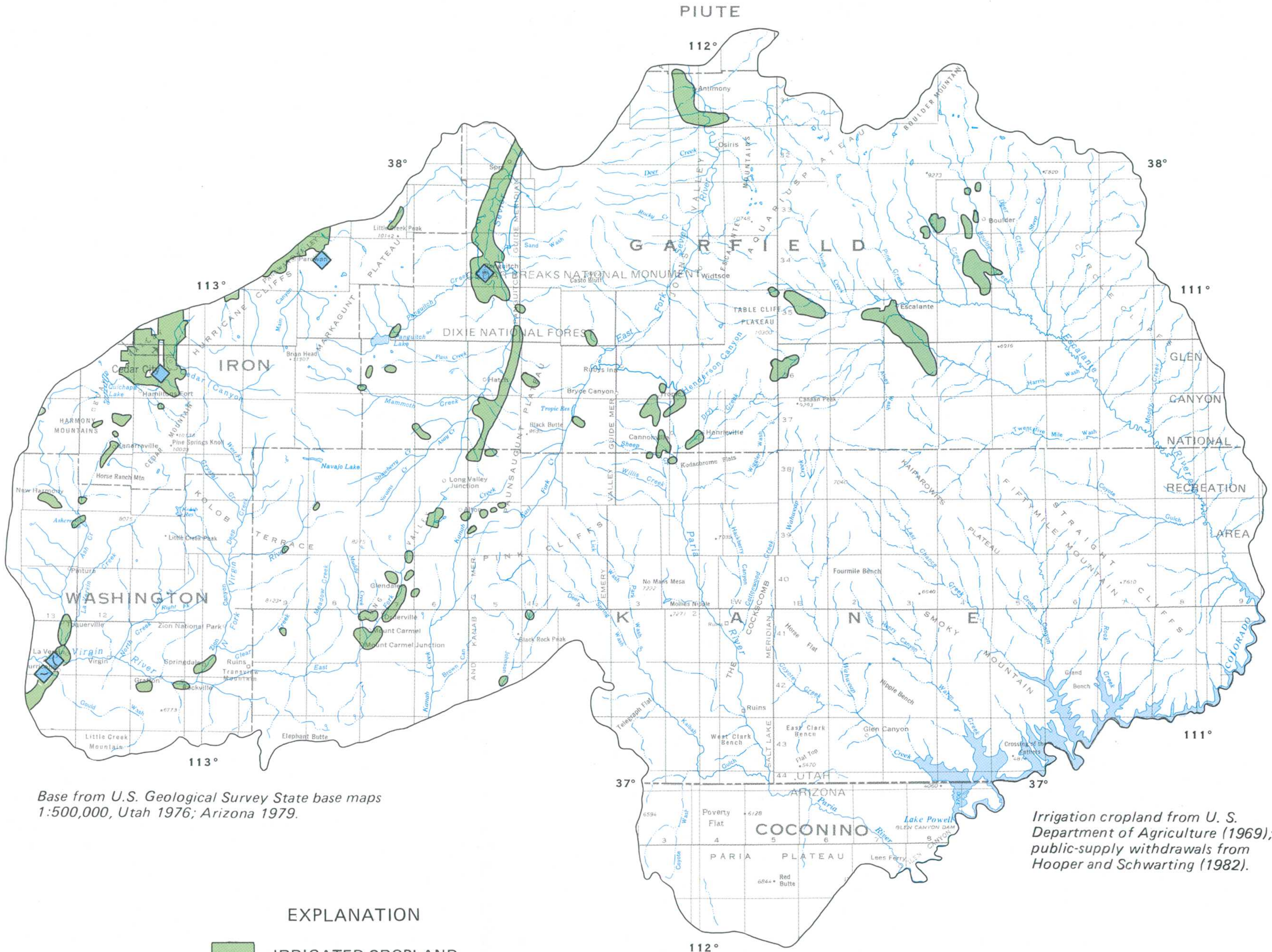
According to the Utah Department of Agriculture (1981, p. 11), there are about 122,000 acres of irrigated land in Garfield, Iron, Kane, and Washington Counties. It is estimated that about 65 percent (79,000 acres) of that land is in Area 57. The water use for irrigation was estimated assuming an average annual crop requirement of 3 feet of water.

Most of the irrigation water is diverted from the Sevier, Escalante, and Virgin Rivers and from Coal Creek. Water also was pumped from wells in Cedar and Parowan Valleys for irrigation (figure 4.0–3).

The withdrawal for public supply was estimated from data compiled by Hooper and Schwarting (1982). The large withdrawals (greater than 300 acre-feet) for public supply were in the Cedar City, Parowan, Panguitch, Hurricane, and La Verkin areas. With the exception of a local supply at Ruby's Inn near Bryce Canyon National Park, all public-water supplies in Area 57 were derived from wells and springs; the Ruby's Inn supply comes from a surface-water source in the Sevier River basin.

There are no major water-consuming industries in the area. Coal Creek water has been used at a small coal-fired electric powerplant at Cedar City. That plant, however, was not used in 1982. Estimated use of water for industry during 1982, therefore, was only about 1,200 acre-feet. Most was used in Cedar and Parowan Valleys, and the principal sources of the water were wells.

Because of the small, widely scattered rural population in Area 57, use of water for domestic supply during 1982 probably was only about 100 acre-feet. Virtually all of that water was withdrawn from wells and springs.



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

Irrigation cropland from U. S. Department of Agriculture (1969); public-supply withdrawals from Hooper and Schwarting (1982).

EXPLANATION

IRRIGATED CROPLAND

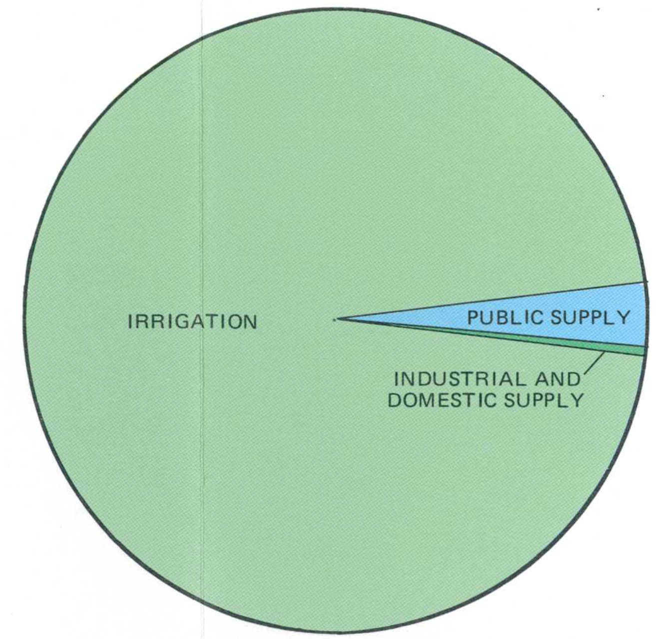
AREA IN WHICH 1980 WITHDRAWALS FOR PUBLIC SUPPLY EXCEEDED 300 ACRE-FEET

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 4.0-1 Principal water-use areas.



TOTAL USE, 250,000 ACRE-FEET

Figure 4.0-2 Distribution of water use, 1980.

Figure 4.0-3 Irrigation well in Cedar Valley.

5.0 HYDROLOGIC STUDIES

Other Hydrologic Reports Available

The U.S. Geological Survey has conducted many hydrologic studies involving a variety of subjects in the area.

Many hydrologic studies have been conducted in Area 57 by the U.S. Geological Survey; results of these studies have been published in a number of reports of the Geological Survey and cooperating agencies. The reports (table 5.0–1) should be useful references for those people involved with hydrologic problems associated with coal mining. The reports describe many components of the hydrologic system, such as the magnitude and frequency of floods, availability of ground water, and water quality. Most of the reports are interpretive in nature, but some contain only hydrologic data. The hydrologic studies were conducted and reports prepared, for the most part, by personnel of the Geological Survey's Utah District. Most of the studies were conducted in cooperation with other Federal, State, and local agencies.

Publications of the Geological Survey that are still in print may be purchased from:

Superintendent of Documents,
U.S. Government Printing Office,
Washington, D.C. 20420.

Reports that are out of print and unavailable for purchase may be examined at:

U.S. Geological Survey,
Public Inquiries Office,
8102 Federal Building,
125 South State Street,
Salt Lake City, Utah.

Open-file reports, for the most part are available for inspection at:

U.S. Geological Survey,
Water Resources Division,
Room 1016,
Administration Building,
1745 West 1700 South,
Salt Lake City, Utah.

Copies of some open-file reports may be purchased from:

U.S. Geological Survey,
Open-File Services Section,
Western Distribution Branch,
Box 25425,
Federal Center,
Denver, Colorado 80225.

The reader is referred to section 11.0 of this report for complete bibliographic information. Some of the reports are summarized in an annotated bibliography by Lines (1981).

Table 5.0-1.—Reports from hydrologic studies in Area 57 conducted by the U.S. Geological Survey through 1983

(See section 11.0, References Cited, for complete bibliographic listing.)

Principal subject of report	Author(s) and year of publication
Ground-water conditions	Appel and others, 1983
Floods	Berwick, 1962
Hydrologic data	Bjorklund and others, 1977
Ground-water resources	Bjorklund and others, 1978
Do.	Brown, 1976
Floods	Butler and Cruff, 1971
Do.	Butler and Marsell, 1972
Hydrologic data	Carpenter and others, 1964
Ground water	Carpenter and others, 1967
Water-quality data	Connor, Mitchell, and others, 1958
Spring records	Cooley, 1965
Ground water	Cordova, 1981
Do.	Davidson, 1979
Do.	Eakin and others, 1976
Floods	Eychaner, 1976
Well data	Feltis, 1966
Ground-water quality	Feth and others, 1965
Streamflow characteristics	Fields, 1975
Surface-water quality	Hahl and Cabell, 1965
Do.	Hahl and Mundorff, 1968
Hydrologic data	Iorns and others, 1964
Water-resources appraisal	Iorns and others, 1965
Ground-water quality	Kister, 1973
Ground-water resources	Marine, 1958
Sediment data	Mundorff, 1968
Spring data	Mundorff, 1971
Hydrologic data	Plantz, 1983
Ground-water quality	Price, 1977a and 1981
Ground-water availability	Price, 1977b and 1982a
Surface-water quantity	Price, 1978 and 1982b
Surface-water quality	Price, 1979 and 1980
Ground-water resources	Price and Arnow, 1974
Water resources	Price, Eakin, and others, 1974
Hydrologic data	Price and Waddell, 1973
Ground-water data	Sandberg, 1963
Ground-water resources	Sandberg, 1966
Water resources	Sandberg, 1979
Floods	Thomas and Lindskov, 1983
Ground-water resources	Thomas and Taylor, 1946
Navajo Lake	Wilson and Thomas, 1964

Streamflows Gaged at 75 Stations

Surface-water network includes 20 active and 34 discontinued continuous-record stations and 21 high-flow partial-record stations.

About 75 percent of the area drains to the Colorado River, chiefly by way of the Escalante, Paria, and Virgin Rivers and Last Chance, Warm, Wahweap, and Kanab Creeks. The remaining 25 percent of the area is in the Great Basin and is drained chiefly by the Sevier River and Coal Creek. The U.S. Geological Survey has collected continuous or miscellaneous streamflow measurements on these and other streams for many years. Daily streamflows (or reservoir stage and contents) are available for 54 continuous-record stations (figure 6.1–1) for the period of record listed in section 9.0. Water-quality data also are routinely collected at most of those stations, and fluvial-sediment data have been periodically collected at several of the stations. The station at site 41 is shown in figure 6.1–2. Only annual maximums are available for the partial-record stations (figure 6.1–1), which generally were operated for 10 to 15 years during 1959–74. One continuous-record station (site 62) was operated during 1949–61 to measure the transmountain diversion from the East Fork Sevier River in the Great Basin to the Paria River in the Colorado River Basin.

Most of the streamflow records at gaging stations are stored in the WATSTORE computer files of the Geological Survey and are available through NAWDEX (Edwards, 1977). The data have been reported in Geological Survey annual reports, which have been issued in various series since 1899. The current series is titled "Water Resources Data for Utah" (U.S. Geological Survey, issued annually since 1975). In addition to the streamflow records at gaging stations, many streamflow measurements have been made at other sites (such as shown in figure 6.1–3), and are available in the files of the U.S. Geological Survey, Salt Lake City, Utah.

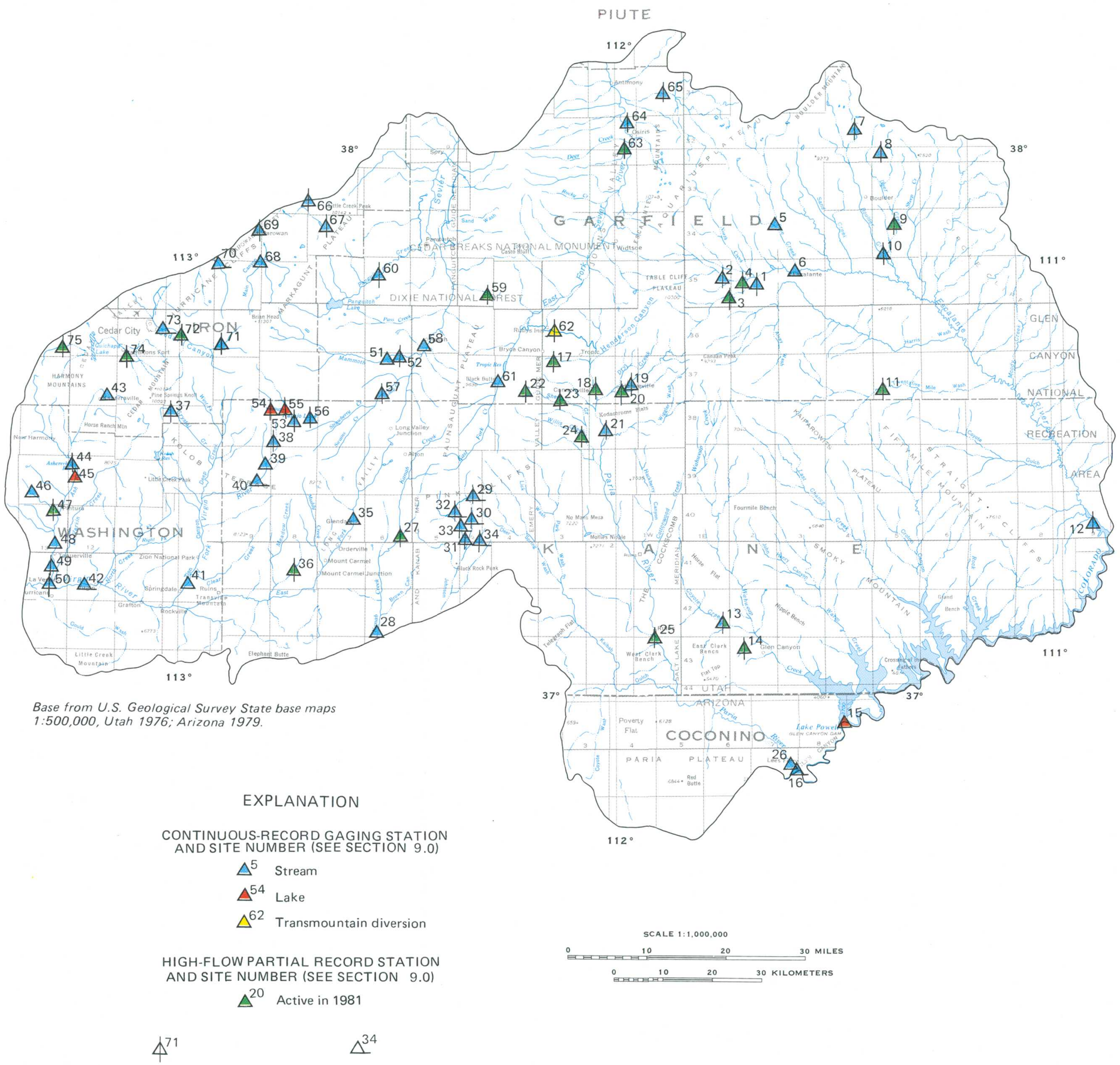


Figure 6.1-1 Surface-water network, 1982.

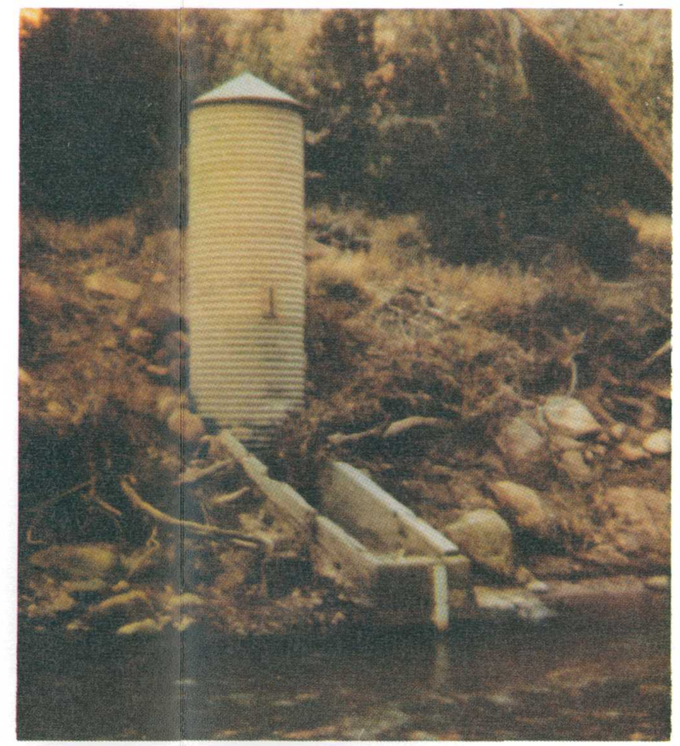


Figure 6.1-2 U. S. Geological Survey streamflow-gaging station on North Fork Virgin River at site 41 (figure 6.1-1).

Figure 6.1-3 Making a streamflow measurement on Henrieville Creek near site 19 (figure 6.1-1).

Large Variations Characterize Area 57 Streamflow

Mean daily flow fluctuates in response to precipitation and snowmelt, but long-term average flow varies with drainage area and normal annual precipitation.

Mean annual runoff from the area is estimated to range from less than 1 inch (0.07 cubic foot per second per square mile) in the lower altitudes to more than 10 inches (0.7 cubic foot per second per square mile) in the higher altitudes. The average flow of streams that originate in the higher altitudes generally increases downstream. However, when these streams flow through low-altitude areas, additional inflow may be less than infiltration, evapotranspiration, or diversions. Thus, average flow can decrease downstream. The average flow of the larger streams is shown in figure 6.2–1. The width of the bands that represent average flow generally were constructed using the data listed in table 6.2–1.

Average streamflow varies with drainage area and total precipitation. A relation of average flow to drainage area and normal annual precipitation was developed using data for 22 of the sites listed in table 6.2–1 that drain areas of less than 500 square miles and that have 5 or more years of record. The equation is:

$$Q = 0.000079\, A^{0.76}\, P^{2.91}$$

where

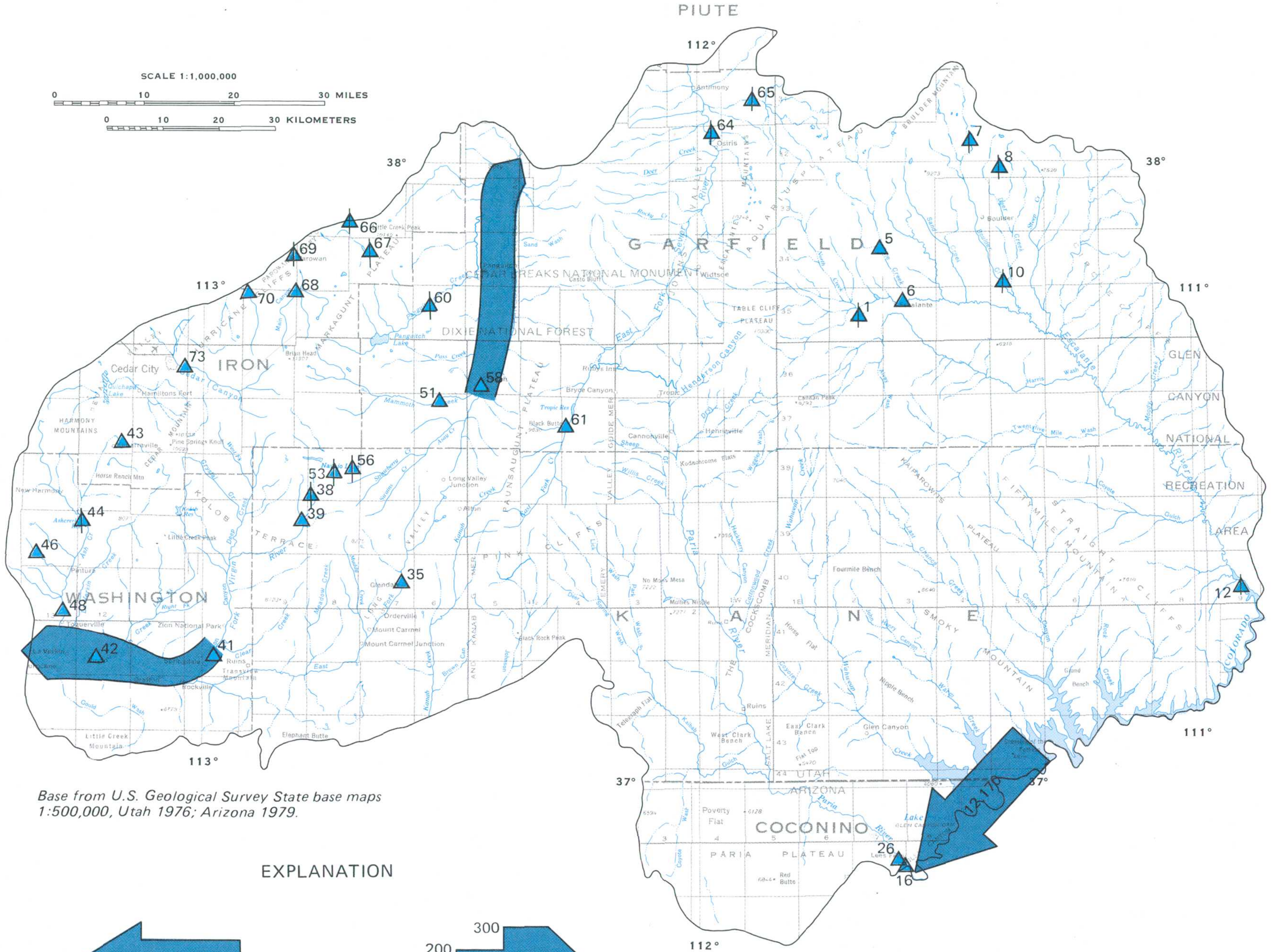
Q is the average flow, in cubic feet per second;

A is the drainage area, in square miles; and

P is the normal annual precipitation on the drainage area, in inches (computed from the U.S. Weather Bureau, 1963).

The standard error of estimate (Riggs, 1973, p. 11) is 50 percent, and the correlation coefficient is 0.91. The equation was developed using data for streams not appreciably affected by regulation, thus, its use is intended for natural flow. Sites 5, 47, 53, and 56 were not used for the analysis. These sites drain areas where volcanic rocks and limestone are common and where sink holes and springs make it difficult to accurately determine the area drained.

Streamflow fluctuates in response to thunderstorms and snowmelt. Thunderstorms produce much of the annual runoff for sites that drain the lower altitudes. The hydrograph for site 46 (figure 6.2–2) shows the typical distribution of streamflow for sites at lower altitudes. Most high-altitude (greater than 8,000 feet) runoff results from snowmelt during March–July. The hydrograph for site 70 (figure 6.2–2) shows the typical distribution of flow for high-altitude sites.



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

EXPLANATION

VALUE INSIDE OF ARROW IS AVERAGE FLOW, IN CUBIC FEET PER SECOND, FOR SITE 16 ON THE COLORADO RIVER

WIDTH OF BAND ALONG STREAM REPRESENTS AVERAGE FLOW, IN CUBIC FEET PER SECOND

CONTINUOUS-RECORD GAGING STATION AND SITE NUMBER (SEE TABLE 6.3-1 AND SECTION 9.0)

5 Active in 1982

1 Discontinued

Figure 6.2-1 Average flow of major streams and location of continuous-record gaging stations with 5 or more complete years of record.

Table 6.2-1 Average flow for continuous-record gaging stations with 5 or more complete years of record.

Site No. (see Section 9.0)	Average flow (cubic feet per second)	Drainage area (square miles)	Normal annual precipitation for drainage area (inches)
1	7.64	90	20
5	4.55	68.1	—
6	15.0	320	18
7	23.7	21.4	29
8	1.36	1.9	20
10	23.0	175	22
12	85.2	1,170	—
16	*12,170	111,800	—
26	29.9	1,410	12
35	20.7	69.2	19
38	4.39	5.65	33
39	18.5	29.6	30
41	103	344	25
42	206	934	—
43	4.15	9.85	25
44	10.6	146	21
46	6.90	11.0	25
48	23.2	190	—
51	49.0	105	24
53	.88	25.7	—
56	10.7	38.3	—
58	125	340	23
60	23.9	97	21
61	16.9	71.6	22
64	31.6	570	—
65	21.1	84.0	21
66	1.90	15.8	—
67	1.71	6.30	21
68	6.22	11.6	25
69	16.7	60	22
70	4.16	24	22
73	32.4	80.9	29

*After completion of Glen Canyon Dam.

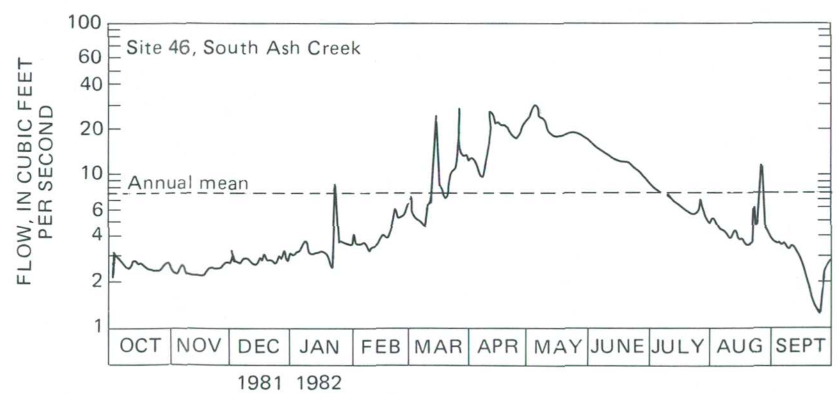


Figure 6.2-2 Typical hydrograph of daily mean flow at a low-altitude site.

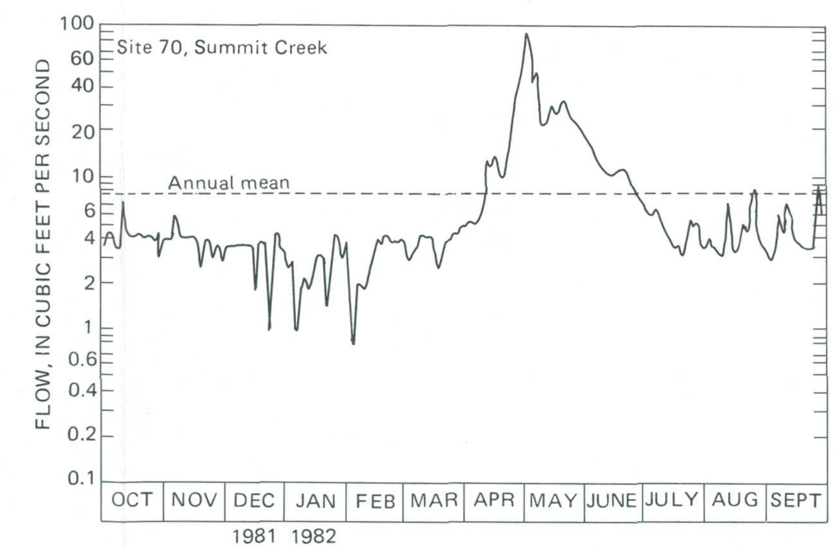


Figure 6.2-3 Typical hydrograph of daily mean flow at a high-altitude site.

Low Flows of Streams Vary Considerably

Large areal variations in precipitation and geology cause great variations in streamflow during dry periods.

Streamflow is sustained primarily by ground-water discharge during periods of little or no precipitation. Flow of the larger streams, however, generally are affected by diversions and reservoir releases. Precipitation, evapotranspiration, and geology are three of the principal factors affecting natural low flow in streams. Low-flow characteristics for 25 gaging stations (figure 6.3–1) with adequate record for frequency analysis are summarized in table 6.3–1.

An index of low flow commonly used is the 7-day 10-year low flow, which is the annual minimum mean flow for 7 consecutive days with a recurrence interval of 10 years. Another common index is the 7-day 2-year (recurrence interval of 2 years) low flow. The recurrence interval is the average time, in years, between annual minimum flows that will average less than the indicated amount for the specified number of days. For example, a 7-day 10-year low flow of 2 cubic feet per second indicates that there is a 10-percent chance that an average 7-day flow at least as low as 2 cubic feet per second will occur as an annual minimum in any given year about 10 times in 100 years. There is a 50-percent chance that the average 7-day low flow will not exceed the 7-day 2-year low flow value in any 1 year.

The 7-day 10-year low flows for gaging stations with adequate record for frequency analysis range from 0 to 0.62 cubic foot per second per square mile (table 6.3–1). Streams that drain the higher altitudes and that receive 16 or more inches of normal annual precipitation generally have 7-day 10-year low flows that exceed 0.01 cubic foot per second per square mile. The values for streams draining areas with normal annual precipitation less than 16 inches generally are less than 0.01 cubic foot per second per square mile. Exceptions are values for sites 5, 44, 53, and 58. Such exceptions are generally for sites where the surface drainage does not agree with the subsurface drainage. Flow in streams can disappear and reappear as a result of sinks and springs, especially where rocks are predominately volcanic and limestone. Most of the streams for which gages are listed in table 6.3–1 drain the higher altitudes that receive 16 or more inches of normal annual precipitation, and they are perennial. The many small drainages in areas receiving less than 16 inches of normal annual precipitation are largely ephemeral with long periods of no flow each year.

The low-flow frequency curves in figures 6.3–2 and 6.3–3 show variations in low flow for typical streams. Curves with flatter slopes and larger flow values indicate better sustained flow when compared to those with steep slopes, which show more year-to-year variation. The curves with flatter slopes are either for: (1) Streams that drain areas that receive more precipitation and generally are hydraulically connected to aquifers with good storage and permeability characteristics, (2) streams that orginate from large springs, or (3) streams that receive augmented flow from reservoirs.

The low-flow frequency curves can be used to determine the potential of streams for water supply and waste assimilation. The curves also can be used to determine the effects of mining on streamflow. When flow is increased by mine drainage, the curves become flatter.

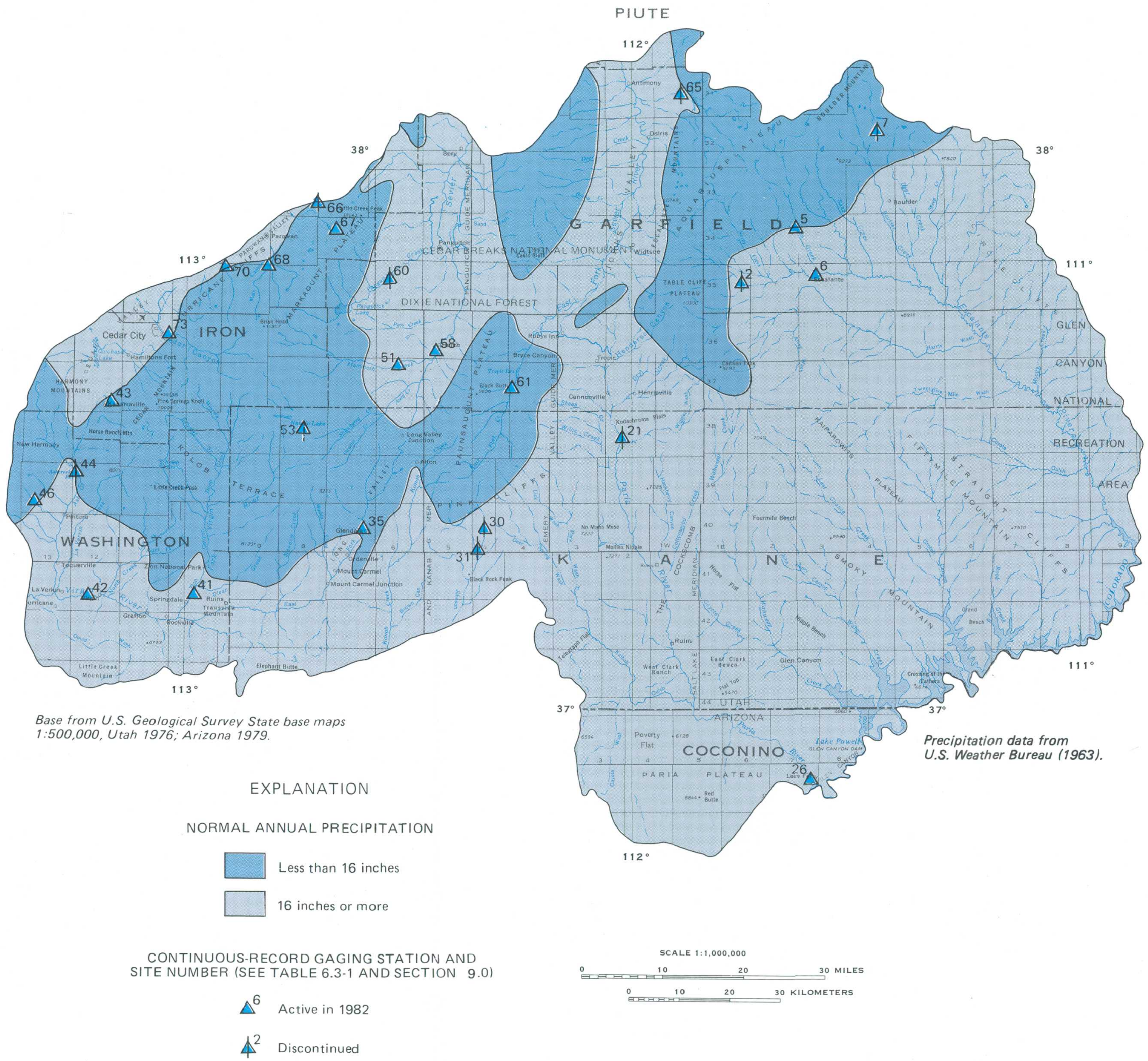


Figure 6.3-1 Location of gaging station for which low-flow statistics are summarized and areas receiving more or less than 16 inches of normal annual precipitation.

Table 6.3-1 Seven-day low-flow statistics.

Site No. (See Section 10.0)	Recurrence interval, in years: 2 — Cubic feet per second	2 — Cubic feet per second per square mile	10 — Cubic feet per second	10 — Cubic feet per second per square mile
2	0	0	0	0
5	.48	.007	0	0
6	1.27	.004	.51	.002
7	15.6	.73	13.3	.62
21	0	0	0	0
26	2.83	.002	1.86	.001
30	0	0	0	0
31	0	0	0	0
35	9.81	.14	7.33	.11
41	37.5	.11	28.6	.083
42	61.6	.066	38.4	.041
43	1.59	.16	1.23	.12
44	0	0	0	0
46	1.45	.13	.65	.059
51	8.28	.079	3.98	.038
53	0	0	0	0
58	51.5	.15	35.3	.10
60	2.40	.025	.93	.010
61	3.70	.052	2.65	.037
65	14.4	.17	13.0	.15
66	.45	.028	.11	.007
67	.82	.13	.53	.084
68	3.42	.29	2.62	.23
70	.89	.037	.48	.020
73	7.18	.089	5.26	.065

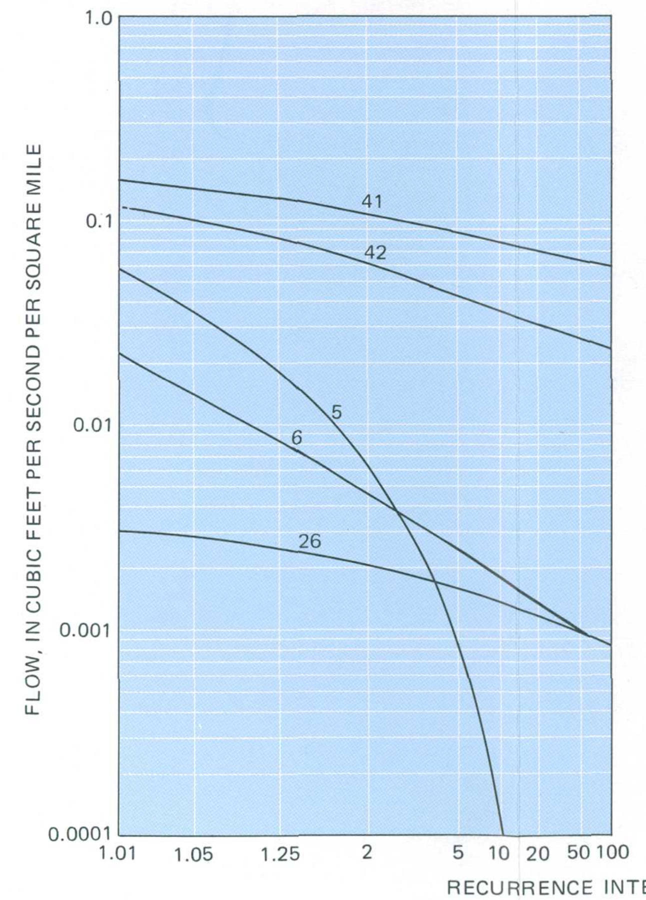


Figure 6.3-2 Frequency curves for 7-day low flow at selected stations on streams in the Colorado River basin.

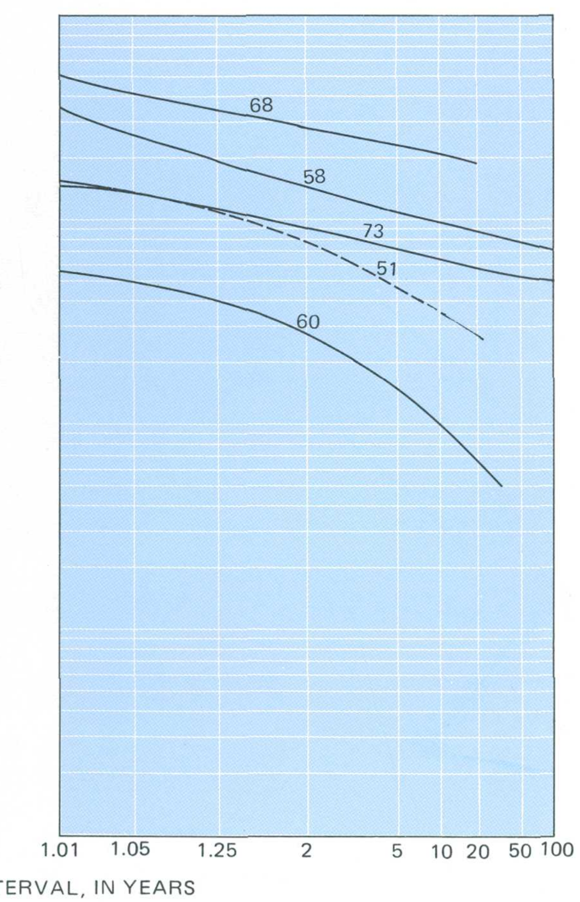


Figure 6.3-3 Frequency curves for 7-day low flow at selected stations on streams in the Great Basin.

Large Day-to-Day Fluctuations in Flow Occur

Daily-duration hydrographs indicate odds of streamflow being high or low during specific seasons.

The percentage of time that daily streamflows are equaled or exceeded is shown in figure 6.4–1 for four streams having different types of flow. The daily-duration hydrographs in A represent high-altitude stream-flow with snowmelt during March to June and relatively large base flow throughout the year. Hydrographs in B represent lower-altitude streamflow with a minimum of snowmelt during February and March, large increases during the July to October thunderstorm season, and fairly large base flow throughout the year. Hydrographs in C represent streamflow produced by a combination of snowmelt and thunderstorms. Hydrographs in D represent streamflow affected by reservoir regulation. However, there are no sites on ephemeral streams with sufficient record to define daily-duration hydrographs. Ephemeral streams are common at the low altitudes and flow only a few days each year in response to thunderstorms.

The daily-duration hydrographs for each station were developed by arraying, in ascending order, all daily mean flows for the entire period of record for a particular day of the year and calculating the percentage of days that the flow on that day was equaled or exceeded. For example, the hydrograph for 90 percent gives the daily mean flow that was equaled or exceeded 90 percent of the time for any given day of the year.

Daily flows of the high-altitude streams are more predictable and generally peak during May and June in response to snowmelt. Low-altitude streamflow is not as predictable, and smaller streams in these areas commonly are dry during most times of the year. Large flows in low-altitude streams are possible any time of the year but are more common during the July–September thunderstorm season. Daily flows of streams that are regulated by reservoirs can be augmented by reservoir releases or completely depleted by reservoir storage.

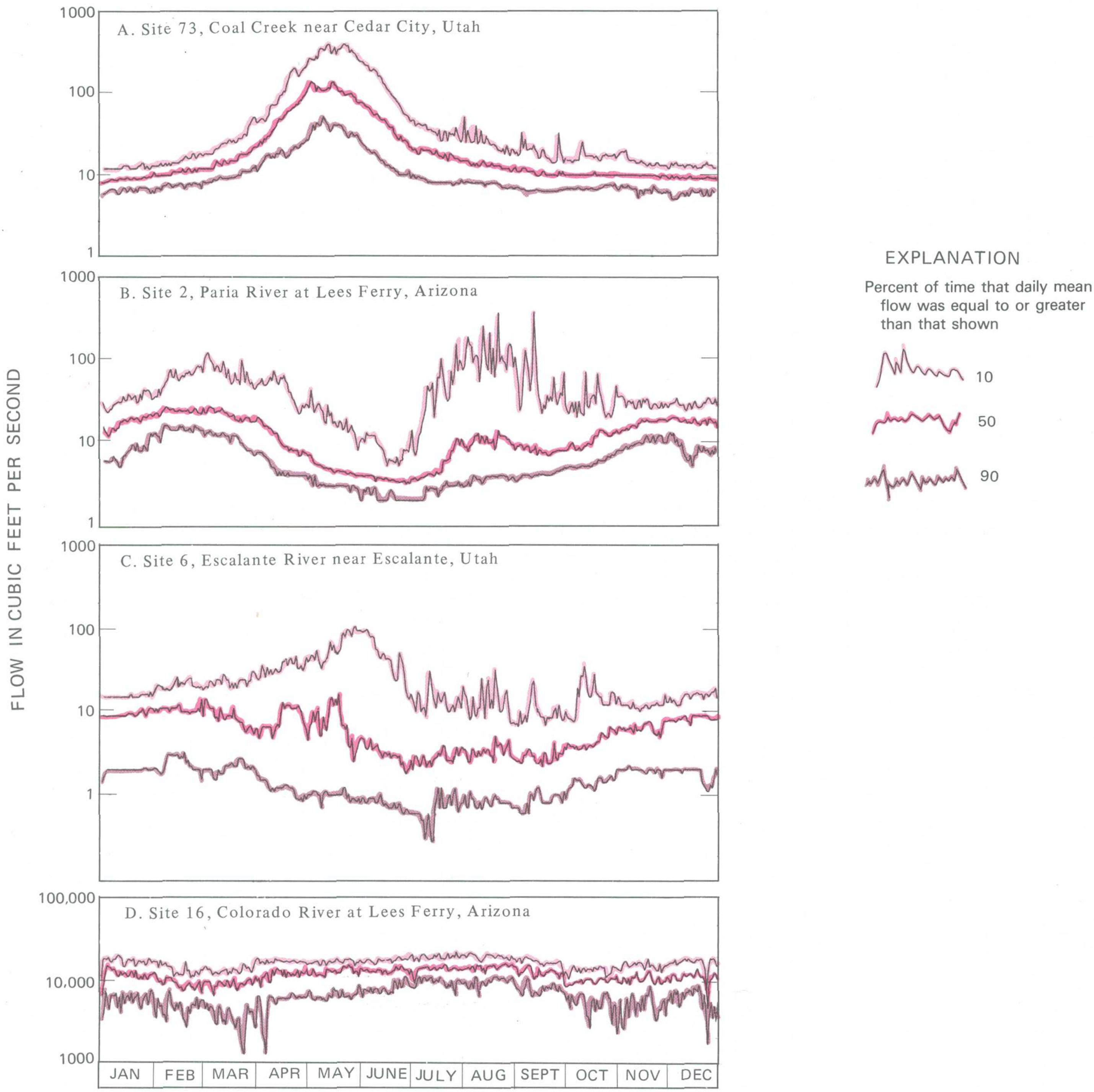


Figure 6.4-1 Daily-duration hyrdograph for four sites.

Floods Produced Mainly by Thunderstorms

Magnitudes of peak flow are determined using gaging-station records and are related to basin characteristics.

Information on peak flow is needed for a variety of projects such as identifying flood-prone areas and designing bridges, culverts, dams, holding ponds, and embankments. The data are needed to reduce costs associated with over design and to eliminate disruption of services or even loss of life associated with under design.

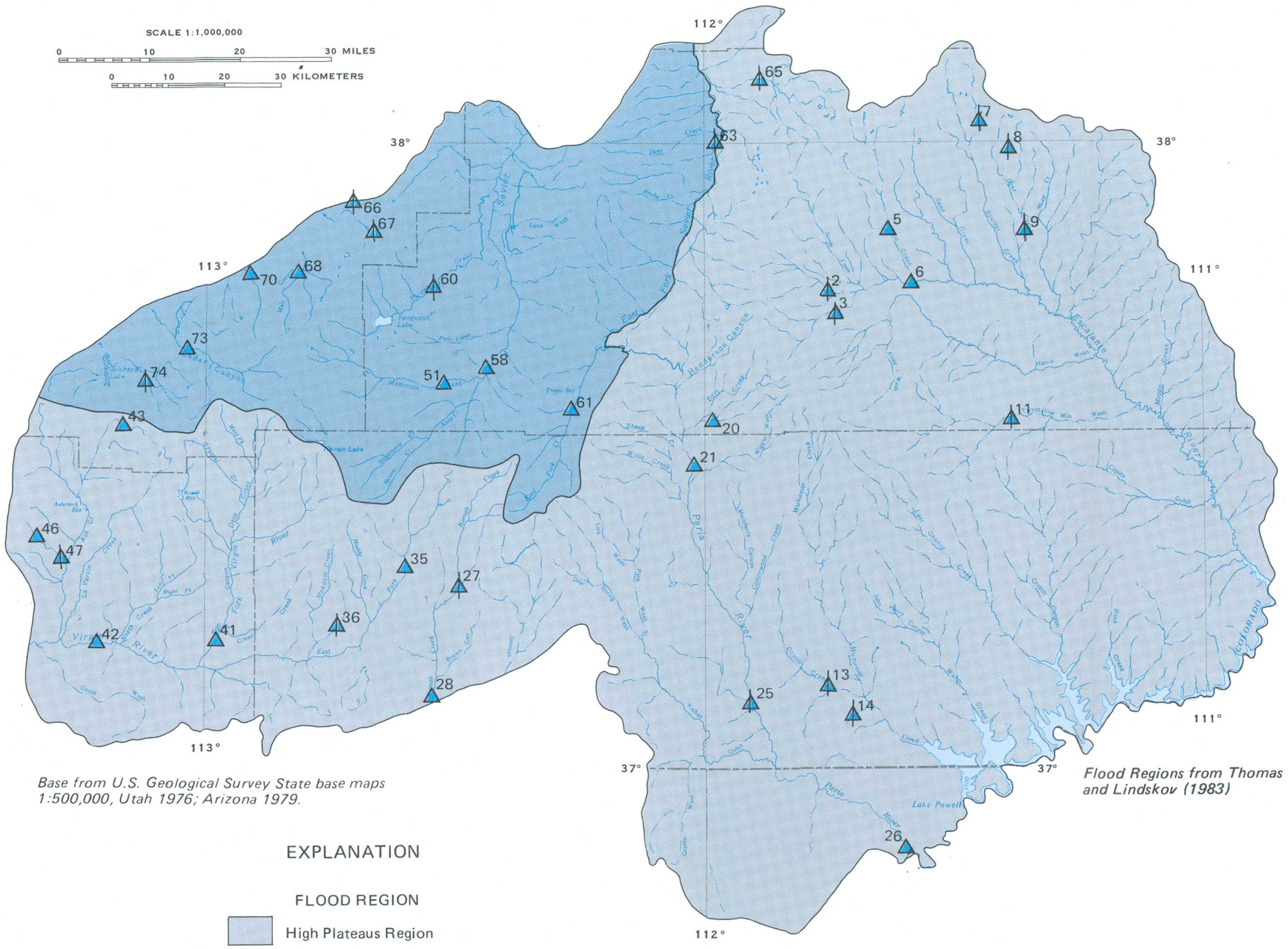
A typical flood-frequency curve for site 5 is shown in figure 6.5–1. The frequency curve shows the average interval, in years, between floods that equaled or exceeded a given peak flow. This does not mean that floods occur with any regularity; the recurrence intervals are average values only. It is possible to have two floods of the 10-year recurrence-interval magnitude in successive years or even in the same year. A 10-year peak flow would 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.

Peak-flow data for 35 sites in the area are listed in table 6.5–1. Peak-flow values usually are needed for sites where streamflow records are not available. Thus, it is common to transfer peak-flow values from gaged to ungaged sites. Many times the information needed can be obtained by interpolating between values for two gage sites listed in table 6.5–1. See Thomas and Lindskov (1983, p. 10) for procedures for transferring peak-flow values to sites near gaged sites on the same stream. In addition, it is common to transfer peak-flow values from gaged to ungaged sites by relating to basin and climatic characteristics (Benson and Carter, 1973).

The report area covers parts of two regions (A and B in fig. 6.5–2) of a study by Thomas and Lindksov (1983). Three sets of equations developed by Thomas and Lindskov apply to Area 57 and are given in table 6.5–2. Equations for the High Plateaus Region apply to area A in figure 6.5–2, and equations for the Great Basin High Elevation Subregion apply to area B. Equations for the Low Plateaus Region apply to both areas A and B. The equations for the High Plateaus Region or the Great Basin High Elevation Subregion are applicable for sites with mean basin elevations greater than 8,000 feet and with an elevation at the study site greater than 7,000 feet. If the mean basin elevation is less than 8,000 feet and the elevation at the study site is less than 7,000 feet, the equations for the Low Plateaus Region are applicable. A more detailed description of the regions and the procedures to be used for sites that are near region boundaries appears in Thomas and Lindskov (1983, p. 15–33). In addition, Thomas and Lindskov describe procedures for mapping areas inundated by floods.

The high-elevation areas are mixed-population flood areas with floods resulting from snowmelt and thunderstorms. The infrequent thunderstorms will produce larger floods than snowmelt, especially for sites that drain small areas. Summer thunderstorms produce most of the floods for sites draining the low elevations where snowmelt floods are rare and usually small.

The equations in table 6.5–2 need to be used with judgment for small basins underlain by very permeable rock because estimates from the equations will be larger than actual values. Geology is important in determining peak-flow differences from one location to another, and a good geologic index could improve the equations, however, it is difficult to quantify the effects of geology.



EXPLANATION

FLOOD REGION

High Plateaus Region

Great Basin High Elevation Subregion

CONTINUOUS-RECORD GAGING STATION AND SITE NUMBER (SEE SECTION 9.0)

6 Active in 1982

14 Discontinued

Figure 6.5-2 Location of flood regions and gaging stations with 10 or more years of record.

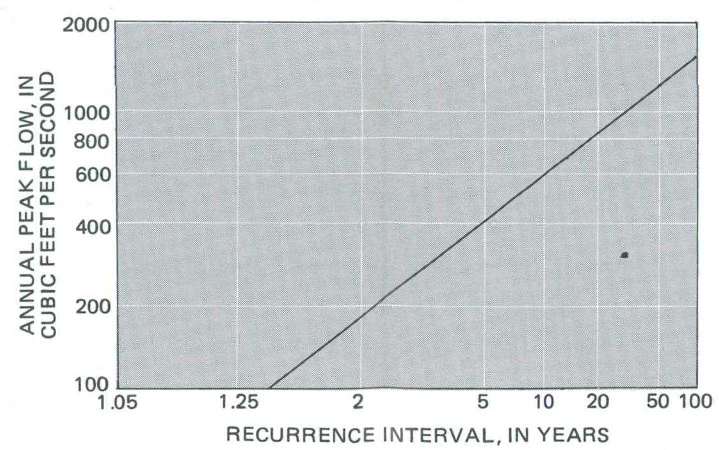


Figure 6.5-1 Flood-frequency curve for site 5, Pine Creek near Escalante, Utah.

Table 6.5-1 Basin characteristics and peak-flow frequency for gaging stations with 10 or more complete years of record.

Site No. (See Section 9.0)	Drainage area (square miles)	Mean drainage basin elevation (feet)	Peak flow (cubic feet per second) for indicated recurrence interval (years) 2	10	100
2	36	8,080	434	1,740	–
3	53	7,620	721	2,440	–
5	68.1	8,890	173	655	1,740
6	320	8,030	771	2,670	6,910
7	21.4	10,500	200	374	599
8	1.9	9,290	20	122	594
9	63	7,680	327	2,430	–
11	140	6,170	1,660	4,080	–
13	89	5,110	1,400	3,880	–
14	5.25	5,030	10	215	–
20	34	7,120	866	3,330	–
21	220	6,890	2,780	6,590	14,100
25	668	6,390	2,480	7,960	–
26	1,410	6,150	4,140	10,300	19,800
27	72	7,250	621	2,150	–
28	198	6,670	1,030	2,390	4,570
35	69.2	7,300	152	585	1,780
36	7.6	6,110	239	2,160	–
41	344	7,350	1,820	4,560	9,630
42	834	8,400	3,810	10,300	23,800
43	9.85	7,950	148	614	–
46	11.0	7,210	238	1,050	3,200
47	14.0	6,720	194	739	2,140
51	105	9,000	404	681	974
58	340	8,480	608	1,090	1,710
60	97	8,890	143	361	866
61	71.6	8,640	119	275	568
63	28	9,471	26	139	–
65	84.0	9,560	229	551	985
66	15.8	7,470	36	245	1,280
67	6.3	9,050	14	33	–
68	11.6	8,450	63	261	910
70	24.0	8,230	73	498	2,730
73	80.9	8,640	773	2,580	6,420
74	12.8	8,032	269	684	–

Table 6.5-2 Summary of regression equations.

Recurrence intervals (years) T	Regression constant a	Exponent x	Exponent z	Average standard error of estimate (percent)
A High Plateaus Region $Q_T = aA^xE^z$				
2	10.8	0.800	–	66
10	680	.706	–1.30	53
100	347,000	.631	–3.68	68
B Great Basin High Elevation Subregion $Q_T = aA^xE^z$				
2	.004	.786	3.51	83
10	24.2	.665	–	61
100	68.1	.630	–	65
A and B Low Plateaus Region $Q_T = aA^xE^z$				
2	3,980	.535	–2.21	87
10	23,700	.433	–2.23	67
100	83,100	.356	–2.17	66

Q is peak flow, in cubic feet per second;
A is drainage area, in square miles;
E is mean basin elevation, in feet divided by 1,000.

Dissolved Solids in Streams Related to Geology

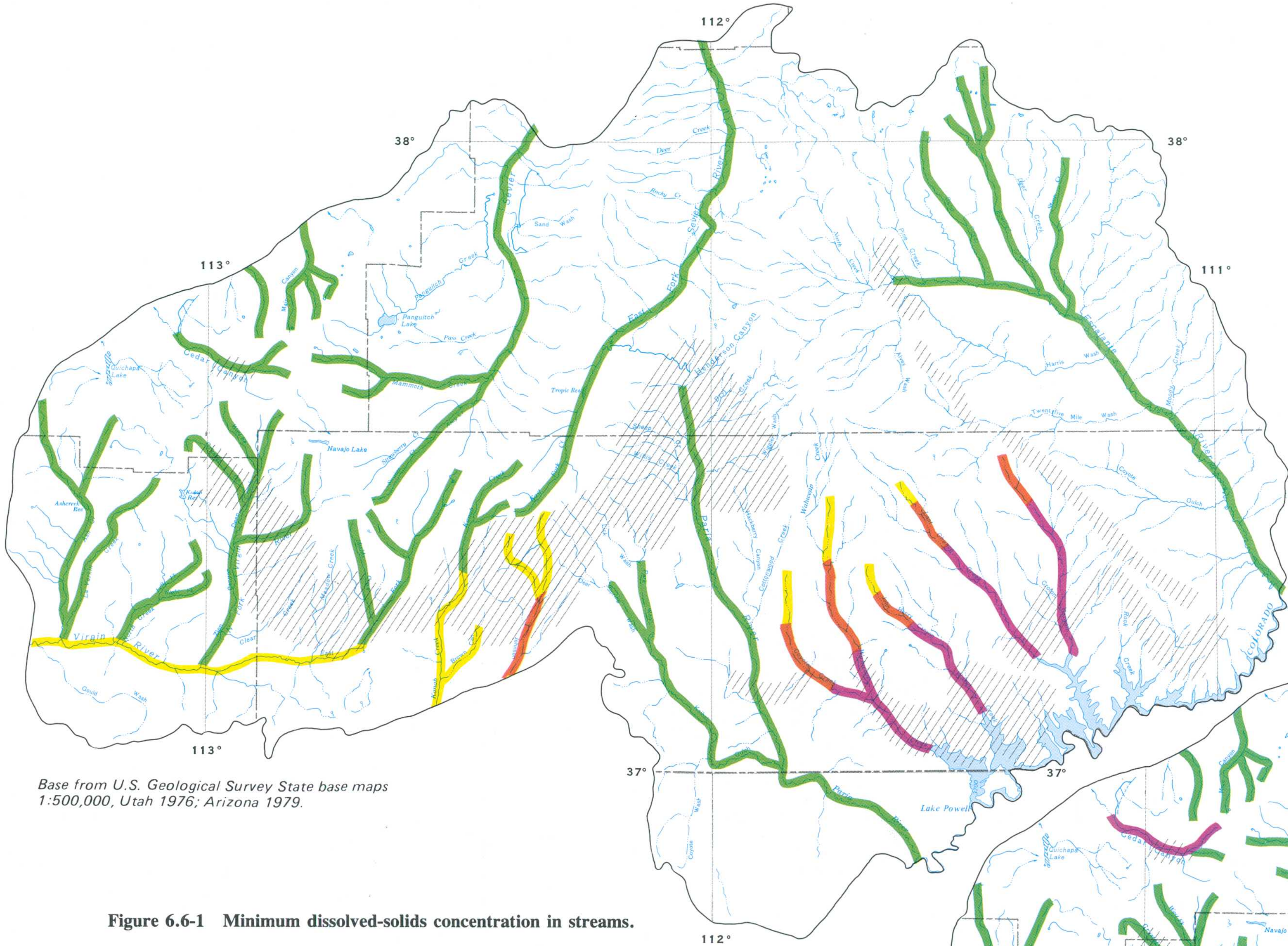
The concentration of dissolved solids in streams varies from less than 300 to more than 3,000 milligrams per liter.

Dissolved-solids concentrations in surface water at the higher altitudes generally are less than 300 milligrams per liter. They increase markedly as the streams emerge from the higher plateaus and cross outcrops of the Tropic Shale and Carmel Formation in the lower altitudes—especially during periods of low flow. These geologic formations and soils developed on them typically contain large quantities of easily dissolved minerals including gypsum ($CaSO_4 \bullet 2H_2O$) and mirabilite ($NaSO_4 \bullet 10H_2O$). The minerals are readily dissolved and transported to streams by both overland runoff and irrigation-return flows.

In the lower altitudes, the dissolved-solids concentrations in streams vary from less than 300 to more than 3,000 milligrams per liter depending on the rate of runoff. During most years, the minimum dissolved-solids concentrations (figure 6.6–1) occur during high flows resulting from snowmelt. The maximum concentrations (figure 6.6–2) generally occur during the late summer, fall, and winter when streamflows are maintained primarily by ground-water discharge. The smallest seasonal changes occur at high altitudes and the largest seasonal changes occur where the streams flow over the Tropic Shale and Carmel Formation in the lower altitudes. The dominant dissolved ions in the higher altitudes are calcium, magnesium, and bicarbonate during low and high flow. In the lower altitudes the dominant ions generally are calcium, magnesium, and bicarbonate during high flow and sodium, calcium, and sulfate during low flow.

Less than 500
500-1000
1000-2000
More than 2000

OUTCROP AREAS OF THE TROPIC SHALE AND CARMEL FORMATION



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

Figure 6.6-1 Minimum dissolved-solids concentration in streams.

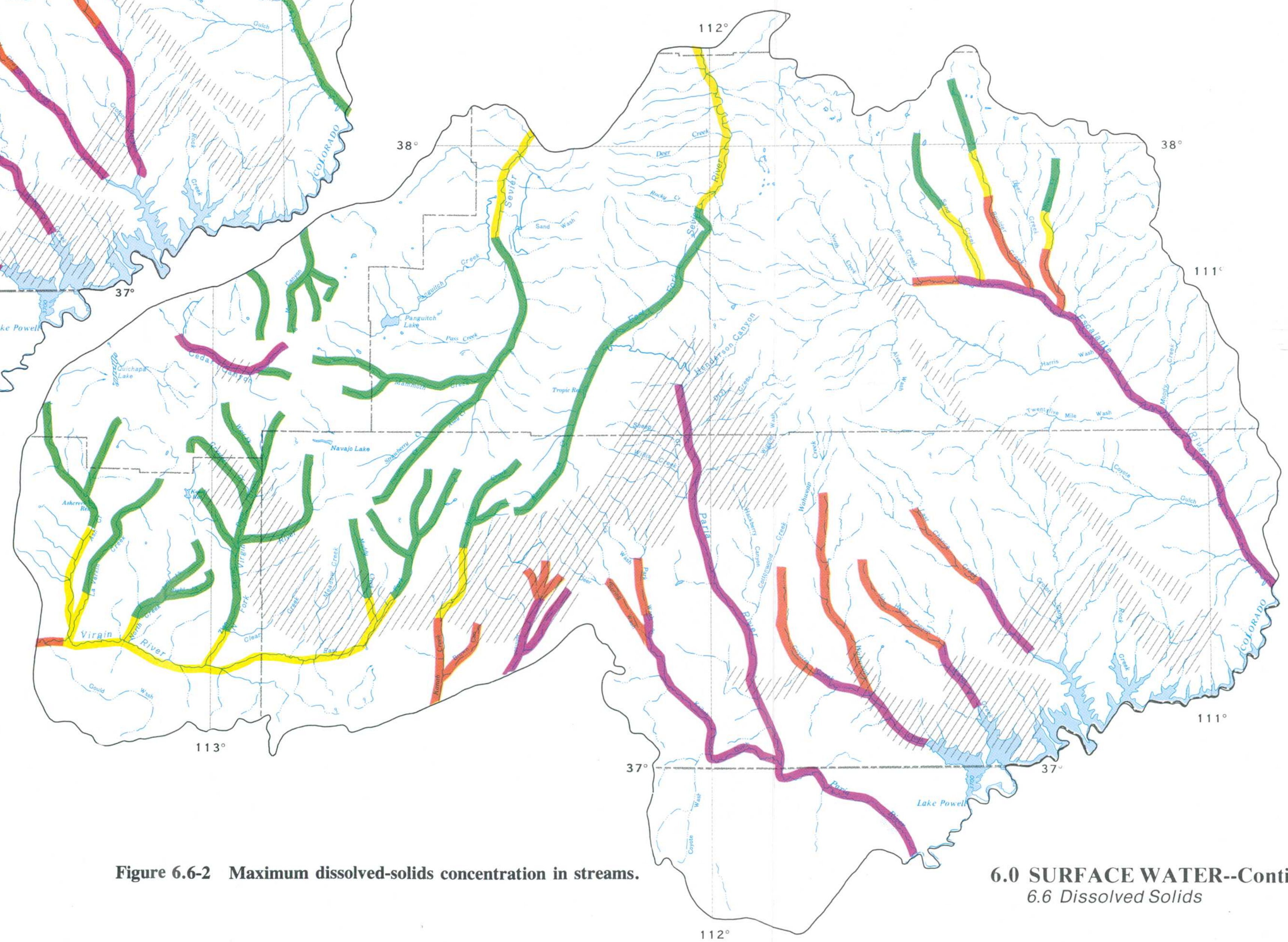


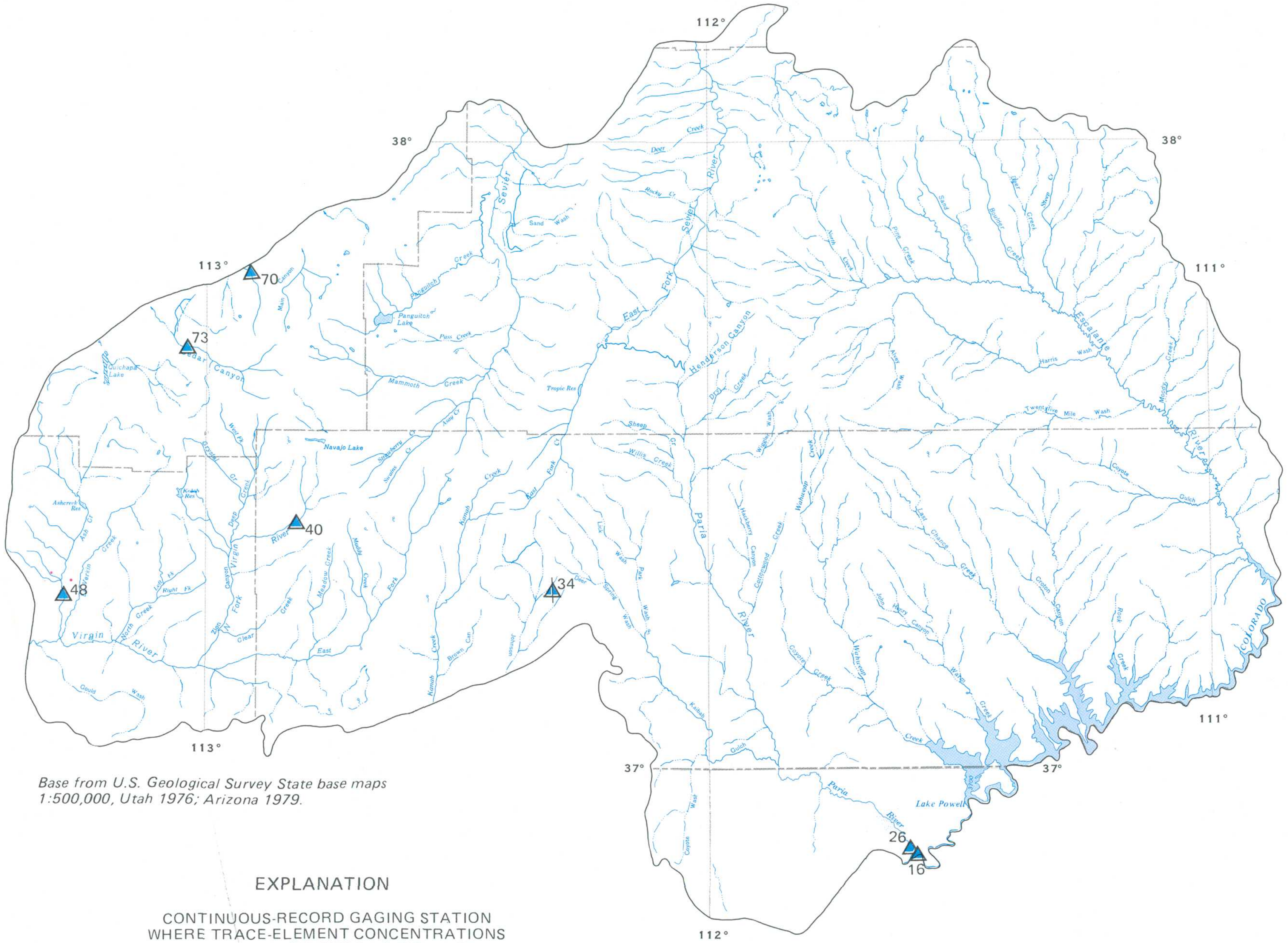
Figure 6.6-2 Maximum dissolved-solids concentration in streams.

Trace-Element Concentrations in Streams are Small

Concentrations of dissolved trace elements in streams generally do not exceed maximum limits for public supply.

The concentrations of selected dissolved trace elements were determined in samples collected at seven surface-water sites (figure 6.7–1). The minimum and maximum values of eight select trace elements and the mandatory maximum limits for public supply (U.S. Environmental Protection Agency, 1976, p. 5) are shown in table 6.7–1. The concentrations did not exceed the limits, except for iron at site 16.

No limits for public supply have been established for the concentrations of boron, lithium, and strontium. Boron, lithium, and strontium generally increase in concentration downstream porportional to the increase in dissolved-solids concentration in the streamflow. The greatest increases occur after the water draining from the higher altitudes is diverted for irrigation of lowland areas; thus, streams in the lowland areas generally contain the largest concentrations of boron, lithium, and strontium.



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

EXPLANATION

CONTINUOUS-RECORD GAGING STATION WHERE TRACE-ELEMENT CONCENTRATIONS IN STREAMFLOW WERE DETERMINED (SEE TABLE 6.7-1 AND SECTION 9.0)

40 Active

34 Discontinued

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 6.7-1 Location of gaging stations where surface water was sampled for trace-element analysis.

Table 6.7-1 Concentrations of trace elements in water from selected surface-water sites. (Constituents are dissolved and values are reported in micrograms per liter.)

Site No. (see figure 6.7-1)		Arsenic (As)	Boron (B)	Chromium (Cr)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Selenium (Se)	Strontium (Sr)
16	Number of samples	37	579	37	243	37	3	37	3
	Minimum-Maximum	1-19	0-960	1-<20	0-1,000	<1-50	39-42	<1- 5	850-910
26	Number of samples	27	43	5	35	23	0	27	0
	Minimum-Maximum	0-4	0-620	1-<20	0-110	0-14	–	<1-10	–
34	Number of samples	3	8	3	8	3	2	3	2
	Minimum-Maximum	1-2	90-250	0-10	<10-30	2-5	100-110	1	1,000-1,400
40	Number of samples	0	6	0	2	0	0	0	0
	Minimum-Maximum	–	10-20	–	<10-40	–	–	–	–
48	Number of samples	1	3	1	1	1	1	1	0
	Minimum-Maximum	4	50-60	<10	<3	<1	10	1	–
70	Number of samples	0	1	0	2	0	0	0	0
	Minimum-Maximum	–	20	–	<10	–	–	–	–
73	Number of samples	2	0	0	0	0	1	2	0
	Minimum-Maximum	1	–	–	–	–	20	1	–
Mandatory or recommended maximum concentration for public water supply		50	–	50	300	50	–	10	–

* Exceeds mandatory maximum concentration for public supply

Sediment Yields Related to Geology

Annual sediment yields vary from less than 0.1 to more than 3 acre-feet per square mile.

The estimated sediment yields shown in figure 6.8–1 are based largely on the geology of the area. The sediment yields vary from less than 0.1 to more than 3 acre-feet per square mile per year. The smaller yields generally are from the higher, well-vegetated plateaus that are underlain mainly by extrusive igneous rock, sandstone, and limestone. The larger yields generally are from lower, less vegetated plateaus that are underlain mainly by shale and siltstone. However, the easily eroded rocks in Bryce Canyon National Park (figure 6.8–2) also contribute significantly to the fluvial-sediment loads of the Virgin and Paria Rivers and Kanab Creek.

Suspended-sediment concentrations in streams fluctuate considerably depending largely on streamflow. The concentrations generally increase with increased streamflow. The largest concentrations generally occur during rapid snowmelt and cloudburst runoff; the smallest concentrations commonly occur during periods of low flow. This is in contrast to dissolved-solids concentrations (section 6.6), which generally decrease as flow increases. The large variation in suspended-sediment concentrations and loads is illustrated in table 6.8–1.

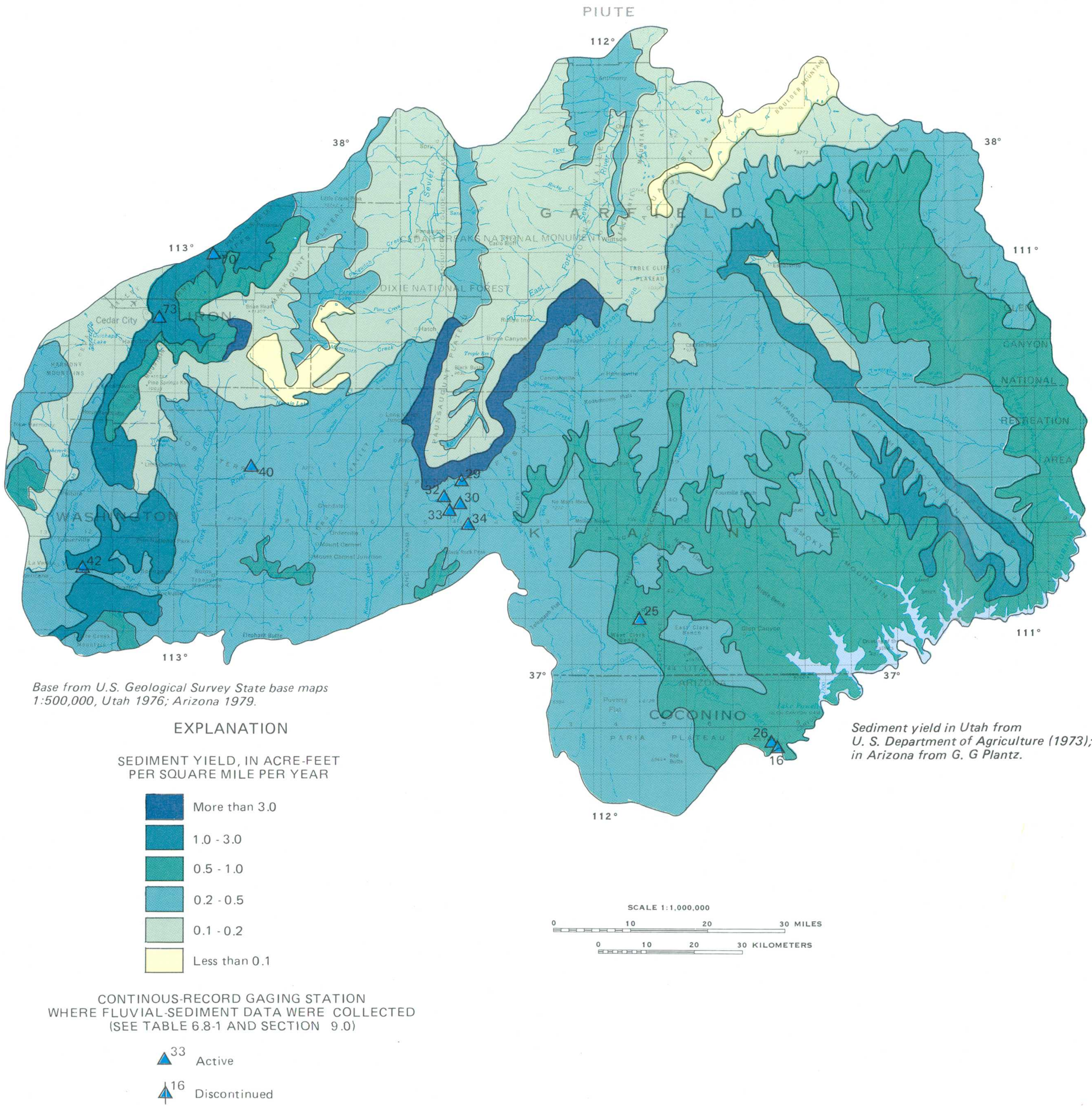


Figure 6.8-1 Estimated natural sediment yields.

Figure 6.8-2 Bryce Canyon National Park, a major source of fluvial sediment.

Table 6.8-1 Suspended-sediment yields at selected sites.

Site No. (see section 9.0)	Drainage area (square miles)	Period of record	Number of samples	Suspended sediment: Daily load (tons) Maximum	Daily load (tons) Minimum	Concentration (milligrams per liter) Maximum measured	Concentration Minimum measured
16	111,800	1895 1982	555	1,980,000	17	38,700	1
26	1,410	1923-82	106	7,630,000	.11	1,130,000	9
29	4.81	1975-77	518	1,500	0	206,000	1
30	14.8	1975-77	459	3,000	0	176,000	1
32	9.80	1975-77	518	1,600	.03	243,000	141
33	16.6	1975-77	518	11,000	.01	372,000	30
34	19.2	1980-81	7	131	.29	18,600	468
40	45.5	1978-82	2	18	1.20	248	66
42	934	1909-71 1978-82	167	4,680,000	34	408,000	61
70	24.0	1964-82	2	2.4	.09	74	14
73	80.9	1916-19 1935-82	147	1,050,000	26	921,000	143

Water Levels Measured Since the 1930's

Water levels were measured in 38 wells during 1982, most of which were in agricultural areas.

As part of the U.S. Geological Survey's statewide observation-well network, water levels were measured in 38 wells in Area 57 during 1982. In addition, water samples were collected from four of the wells for chemical analyses. The location of observation wells in the area is shown in figure 7.1–1. The aquifer tapped by each well, the period of record, and the frequency of measurements are listed in section 10.0. Hydrographs of water levels in two wells with long-term records are shown in figure 7.1–2.

Most of the observation wells were in the populated agricultural areas and were privately owned. Alluvium was tapped by 33 of the wells in the network; bedrock aquifers were tapped by 5 of the wells. Water levels were measured in most wells once or twice a year, and water-level data for several wells are available since the 1930's. During 1982, three wells were equipped with continuous water-level recording gages similar to the one shown in figure 7.1–3.

The water-level data are stored in the National Water-Data Storage and Retrieval System (WATSTORE). This computerized system is described in section 8.3. In addition to the water-level records, year-to-year changes in water levels in Cedar and Parowan Valleys and other parts of the area are described in an annual report series titled "Ground-water conditions in Utah." (See for example Appel and others, 1983.) The reports also include information about ground-water withdrawals.

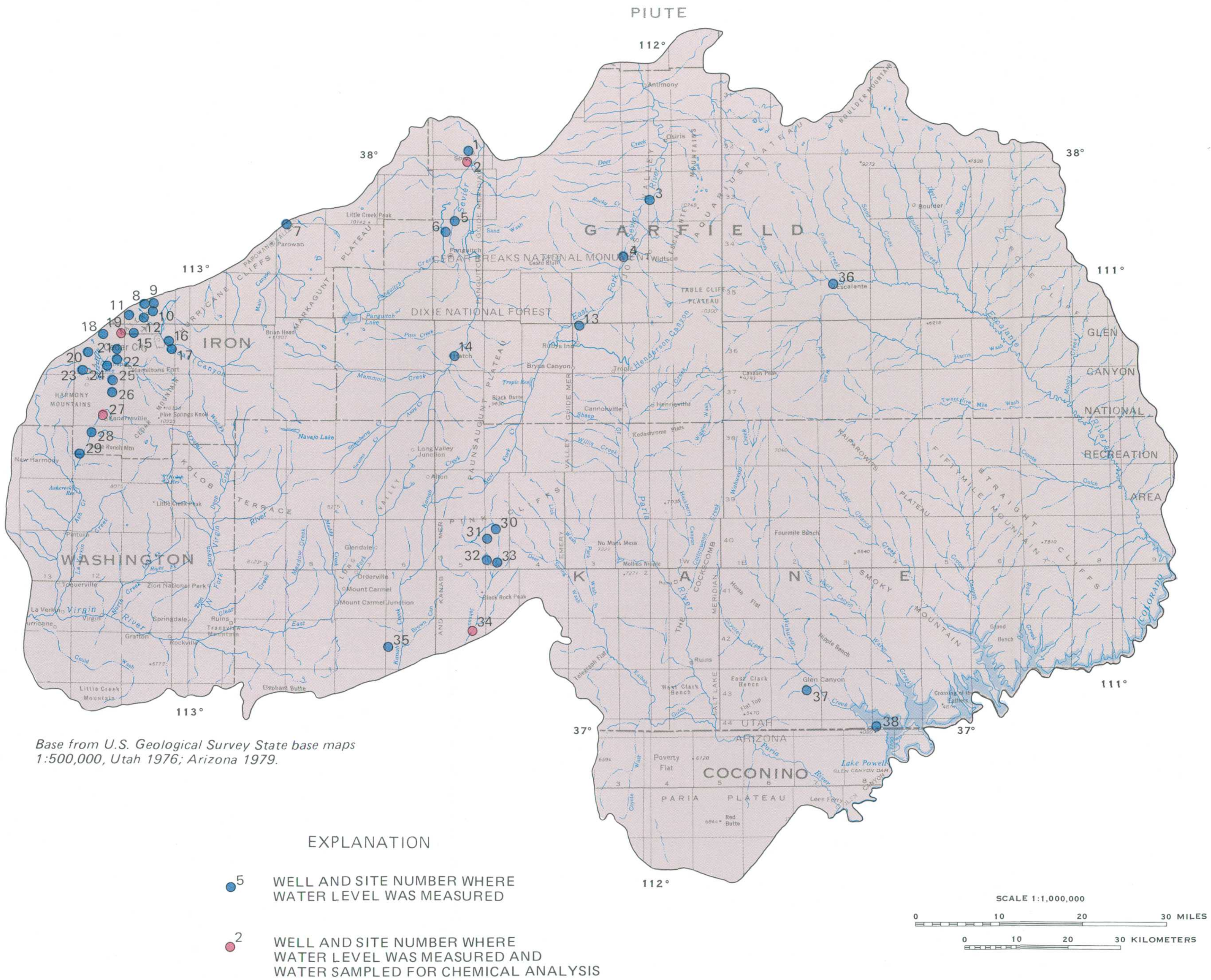


Figure 7.1-1 Observation-well network, 1982.

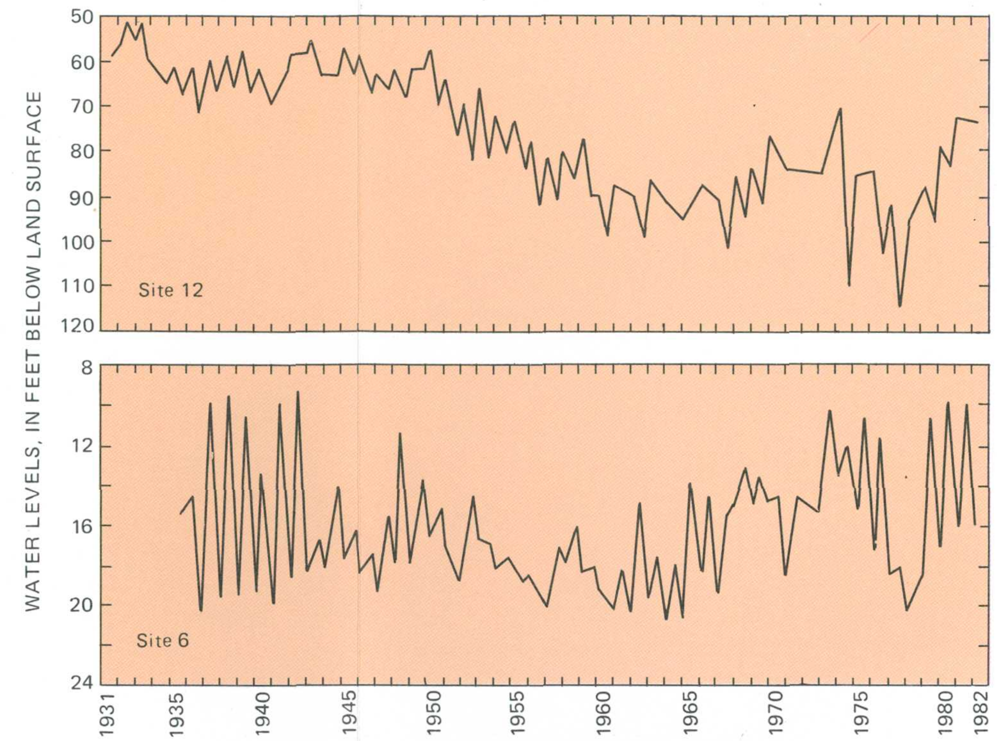


Figure 7.1-2 Water levels in two observation wells.

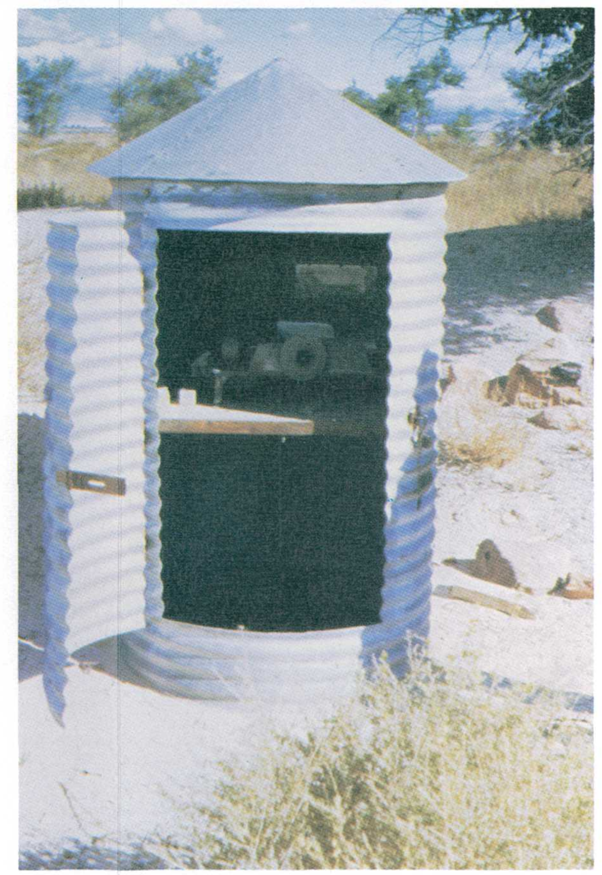


Figure 7.1-3 A water-level recording gage.

Most Geologic Units Contain Water

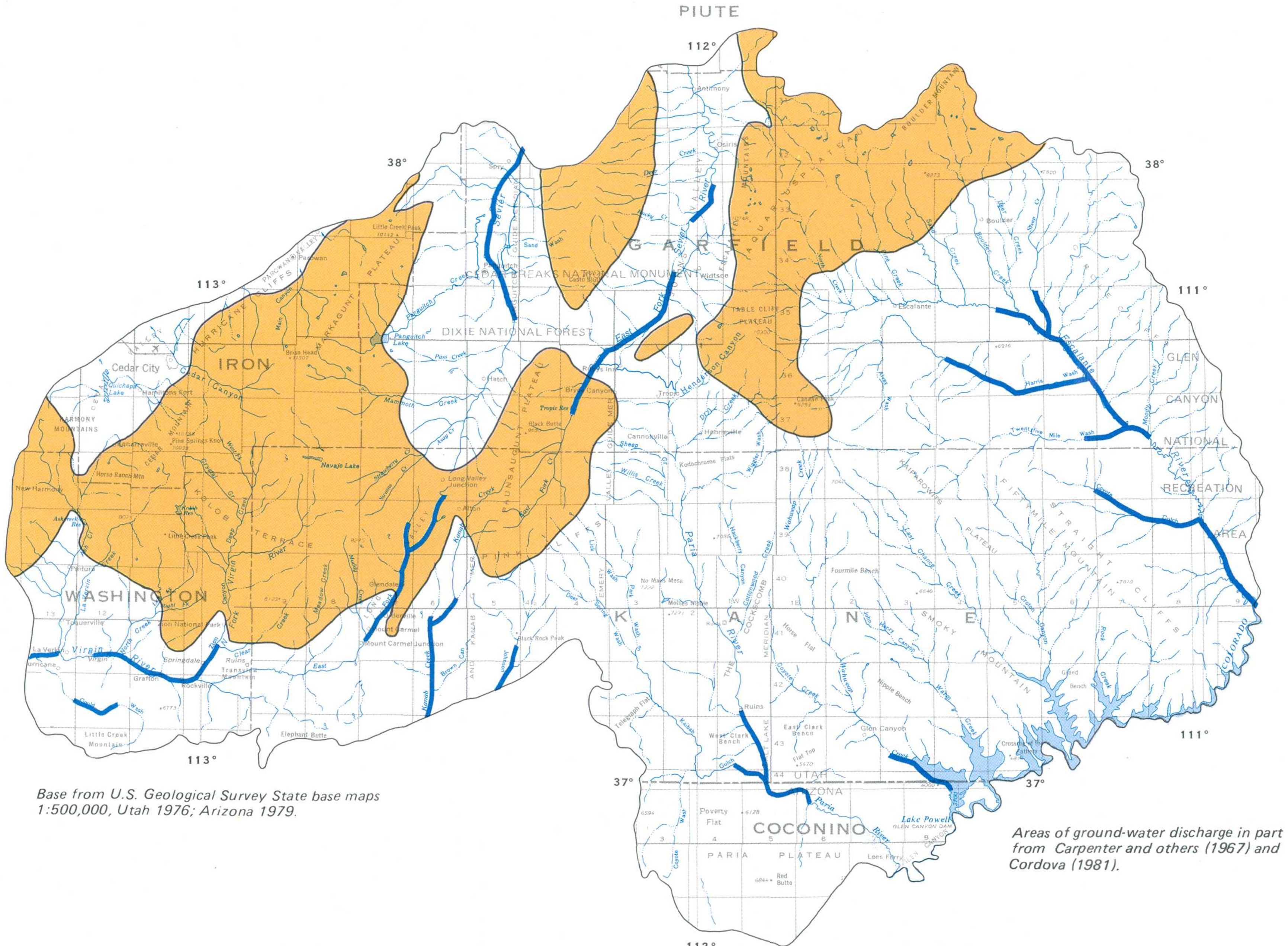
The ground-water system is recharged mainly by precipitation and snowmelt in the higher altitudes; water is discharged by springs and by leakage to streams.

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.

Depth to the regional water table (figure 7.2–1) varies considerably from place to place depending largely on topography. The regional water is virtually at land surface in the lower parts of Cedar and Parowan Valleys and along some stream reaches. The regional water table is several hundred to more than 1,000 feet below the surface of some plateaus, however, perched ground water (overlying poorly permeable unsaturated rock) commonly exists at relatively shallow depths. Perched water sustains the flow of many of the springs that discharge from canyon walls.

Most ground-water recharge occurs from infiltration of precipitation and snowmelt in the higher altitudes where normal annual precipitation exceeds 16 inches and where much of the precipitation occurs as snow (figure 7.2–2). Some recharge probably also occurs along losing reaches of streams as shown in figure 7.2–3. Some of the water is discharged by seeps and springs near original recharge areas. Some of the water also moves to areas of lower altitude where it is discharged along gaining reaches of streams (figure 7.2–3).

The relation of ground water to the coal-bearing units is shown diagrammatically in figure 7.2–1. As shown, the coal is unsaturated where it crops out in canyon walls. Back from the canyon walls, however, the coal extends beneath the water table, and mining of the coal would require mine dewatering.



EXPLANATION

PRINCIPAL AREA OF GROUND-WATER RECHARGE FROM PRECIPITATION AND SNOWMELT

KNOWN AREA OF NATURAL GROUND-WATER DISCHARGE ALONG STREAM

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 7.2-2 Principal areas of ground-water recharge and known areas of natural discharge along streams.

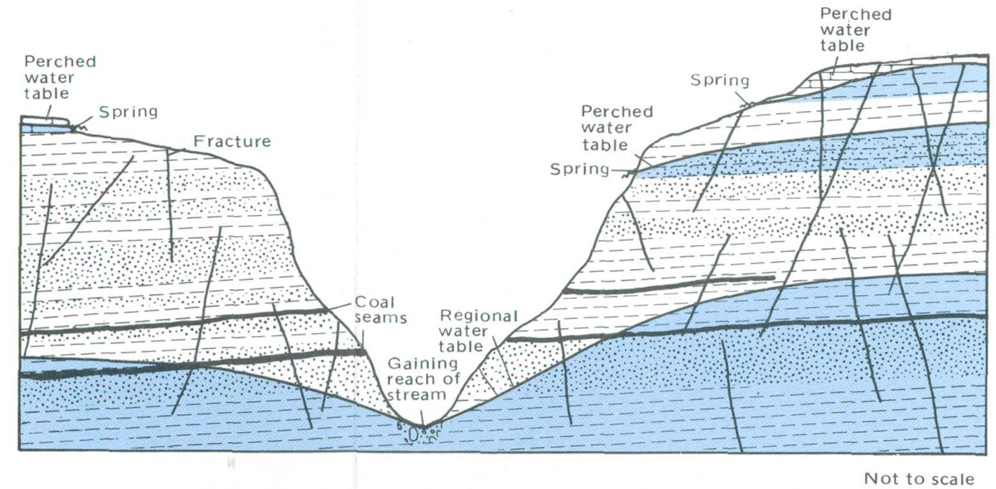


Figure 7.2-1 Diagrammatic section showing relation of ground water to coal beds. (Modified from Lines and others, 1983, Figure 7.2-1.)

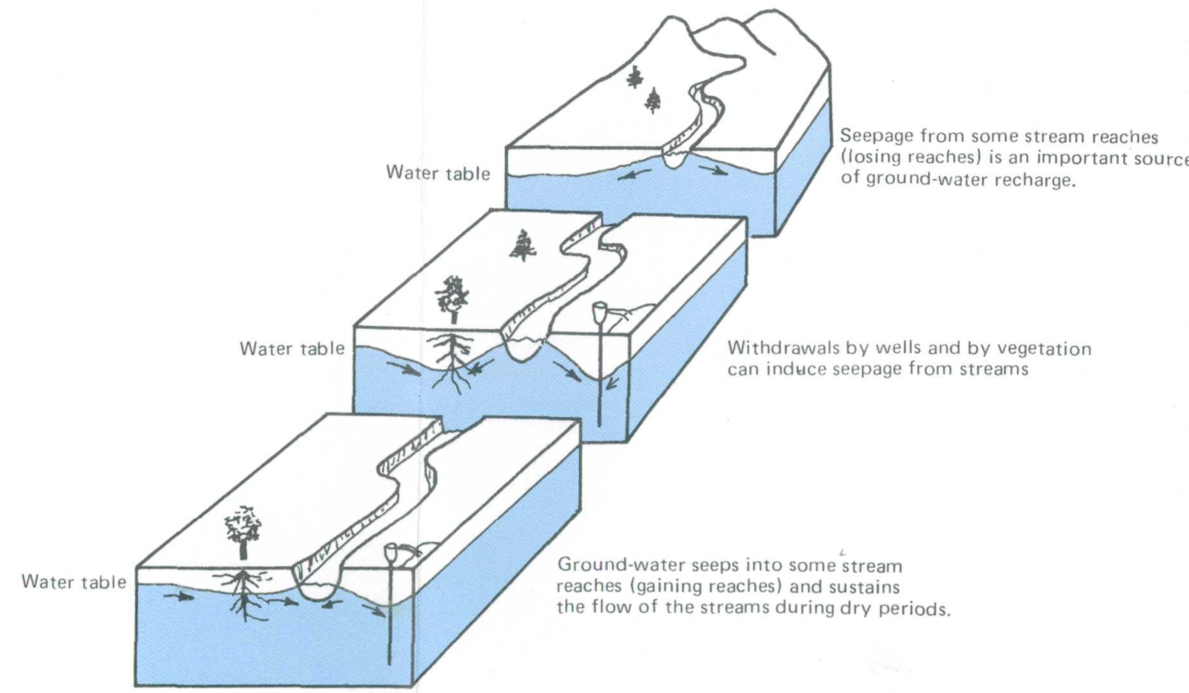


Figure 7.2-3 General relation between ground water and surface water, (arrow indicates direction of ground water movement).

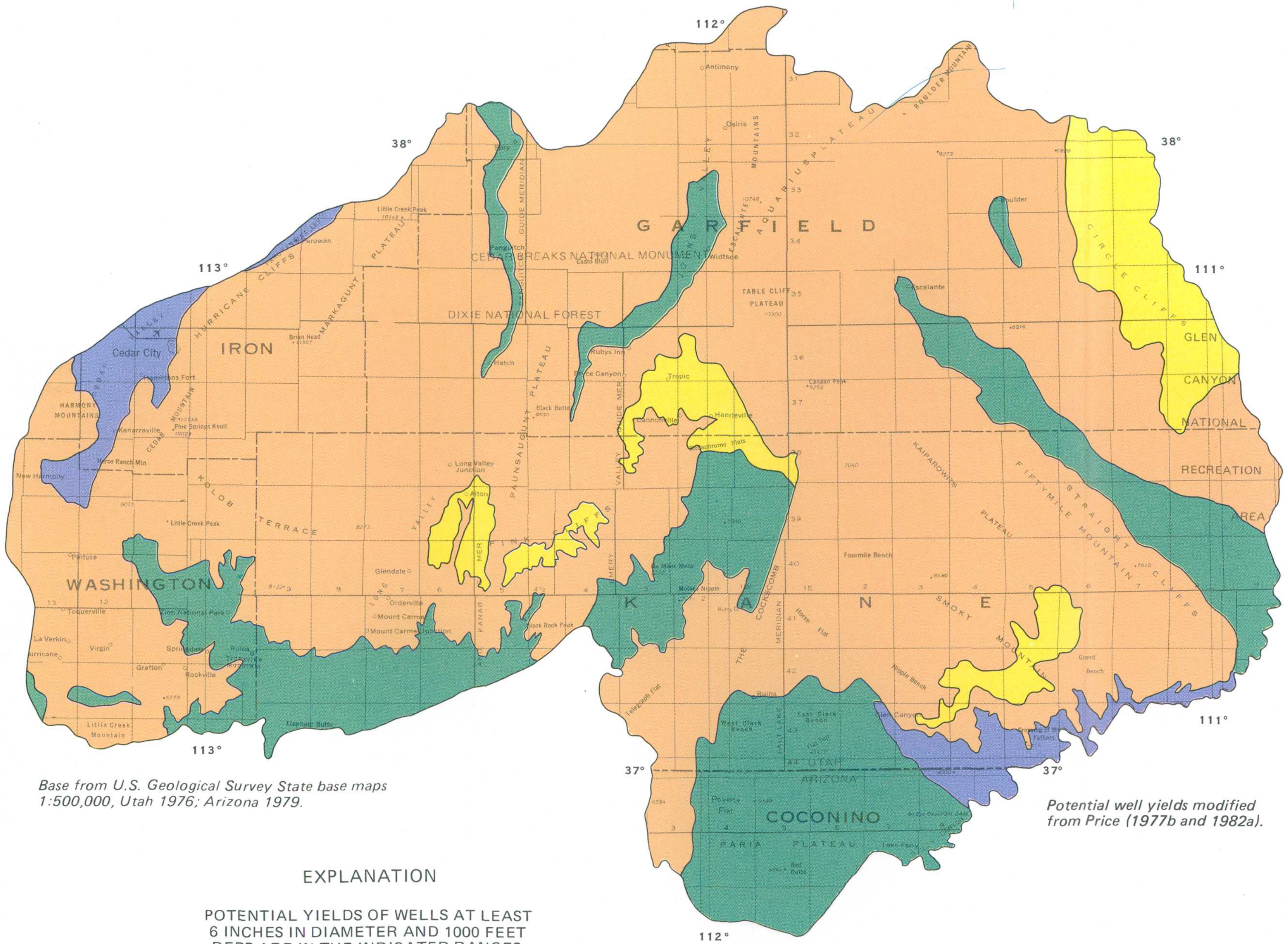
Well Yields Vary Markedly

Several wells that tap unconsolidated deposits yield more than 2,000 gallons per minute.

The range of potential yields of individual wells is shown in figure 7.3–1. Wells that tap the thick, nearly fully-saturated unconsolidated deposits in Cedar and Parowan Valleys are capable of yielding 500 to more than 1,000 gallons of water per minute. Several large-diameter irrigation wells in those valleys, such as the one shown in figure 7.3–2, yield more than 2,000 gallons per minute (Bjorklund and others, 1977, table 1). The saturated unconsolidated deposits in other parts of the area generally are thinner, and yields of wells are less than those in Cedar and Parowan Valleys. Alluvium in the valleys of the Sevier River and other large perennial streams generally yields as much as 500 gallons per minute to individual wells; the unconsolidated deposits in most other parts of the area, however, have insufficient saturated thickness to yield large quantities of water.

The consolidated rock unit most capable of yielding large quantities of water to wells is the Navajo Sandstone that underlies much of the area. The Navajo ranges in thickness from 1,000 to 2,000 feet, and it is fully saturated in many places. Where not fully saturated, as in most areas of outcrop, individual wells yield as much as 500 gallons per minute. Where the Navajo is fully saturated (chiefly where it underlies the coal-bearing formations), wells that fully penetrate the unit may yield more than 1,000 gallons per minute. For example, a test well that fully penetrated the Navajo near Bald Knoll in the Alton coal field reportedly yielded more than 1,000 gallons per minute (Lambert Jensen, U.S. Geological Survey, oral commun., 1982). Other wells that tap the Navajo in the drainage basins of the Virgin, Paria, and Escalante Rivers and Kanab and Wahweap Creeks yield several hundred to more than 1,000 gallons of water per minute (Cordova, 1981, table 18; Paul Blanchard, U.S. Geological Survey, written commun., 1983).

The coal-bearing rocks, where saturated, generally will yield yield 1 to 50 gallons per minute to individual wells. These rocks also can yield much larger rates. For example, a test well near the Bryce Canyon National Park headquarters was pumped at a rate of about 200 gallons per minute (Marine, 1963, p. 481), much of the water was from the coal-bearing Straight Cliffs Sandstone. A test well on the Kaiparowits Plateau produced 110 gallons per minute from the coal-bearing John Henry Member of the Straight Cliffs Sandstone, and another test well produced 87 gallons per minute from the Drip Tank Member of that same formation (Lorang and Sieh, 1975, p. 11).



Base from U.S. Geological Survey State base maps 1:500,000, Utah 1976; Arizona 1979.

Potential well yields modified from Price (1977b and 1982a).

EXPLANATION

POTENTIAL YIELDS OF WELLS AT LEAST 6 INCHES IN DIAMETER AND 1000 FEET DEEP ARE IN THE INDICATED RANGES (IN GALLONS PER MINUTE)

- 1-5
- 5-50 (locally 50 to more than 100)
- 50-500 (locally 500 to more than 1000)
- 500-1000 (locally 1000 to 3000)

SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 7.3-1 Potential well yields.

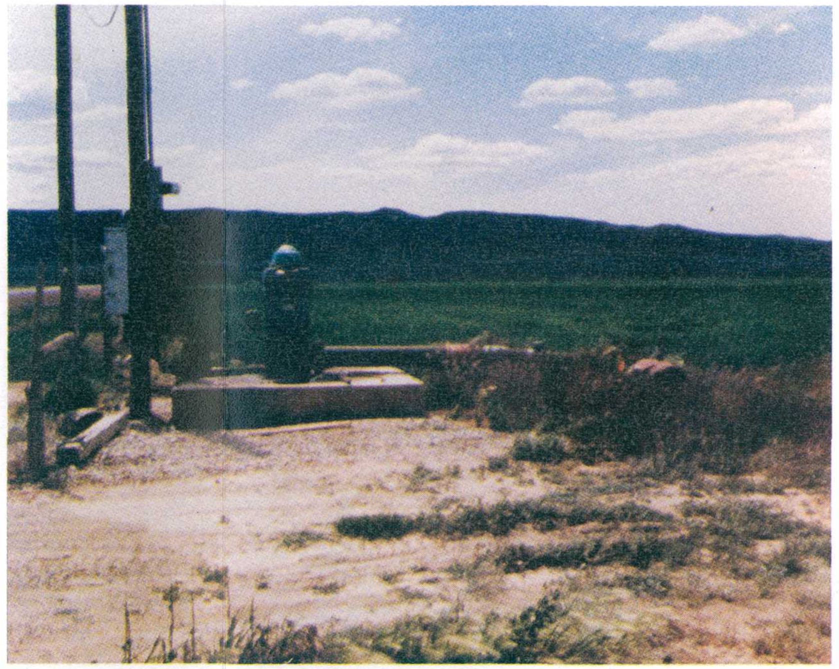


Figure 7.3-2 A large yield irrigation well in Cedar Valley.

Springs Issue from Virtually Every Geologic Unit

Although springs are found throughout the area, they are most abundant in the higher altitudes of the Kolob and Alton coal fields; the springs are important sources of water for public supply, irrigation, recreation, livestock, and wildlife.

More than 750 springs have been mapped or inventoried in the area. The springs issue from virtually every geologic unit and have yields that range from a trickle to more than 30 cubic feet per second (more than 13,000 gallons per minute). Most of the springs, including several of Utah's largest non-thermal springs are found in the higher altitudes of the Kolob and Alton coal fields. Approximate locations of springs for which records have been published are shown in figure 7.4–1. La Verkin Hot Springs in section 24, Township 41 South, Range 13 West is the only known thermal spring in the area. Records of springs are included in the following reports: Carpenter and others (1964); 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 channels and canyon walls. Most springs issue from open fractures or from bedding planes at contacts between permeable and less permeable rock strata. Their discharges fluctuate with time (figure 7.4–2), and many springs cease to flow during dry seasons or prolonged drought.

Virtually all of the springs in the area have some beneficial use. The large springs, including La Verkin Hot Springs, are used for irrigation by either direct diversion or by diversion of the streams into which they flow. Several springs are used for fish propagation. Most of the communities and many individual dwellings in the area depend on springs for their water supplies as do the recreational and tourist facilities. Even the most isolated and remote springs are sources of water for livestock and wildlife.

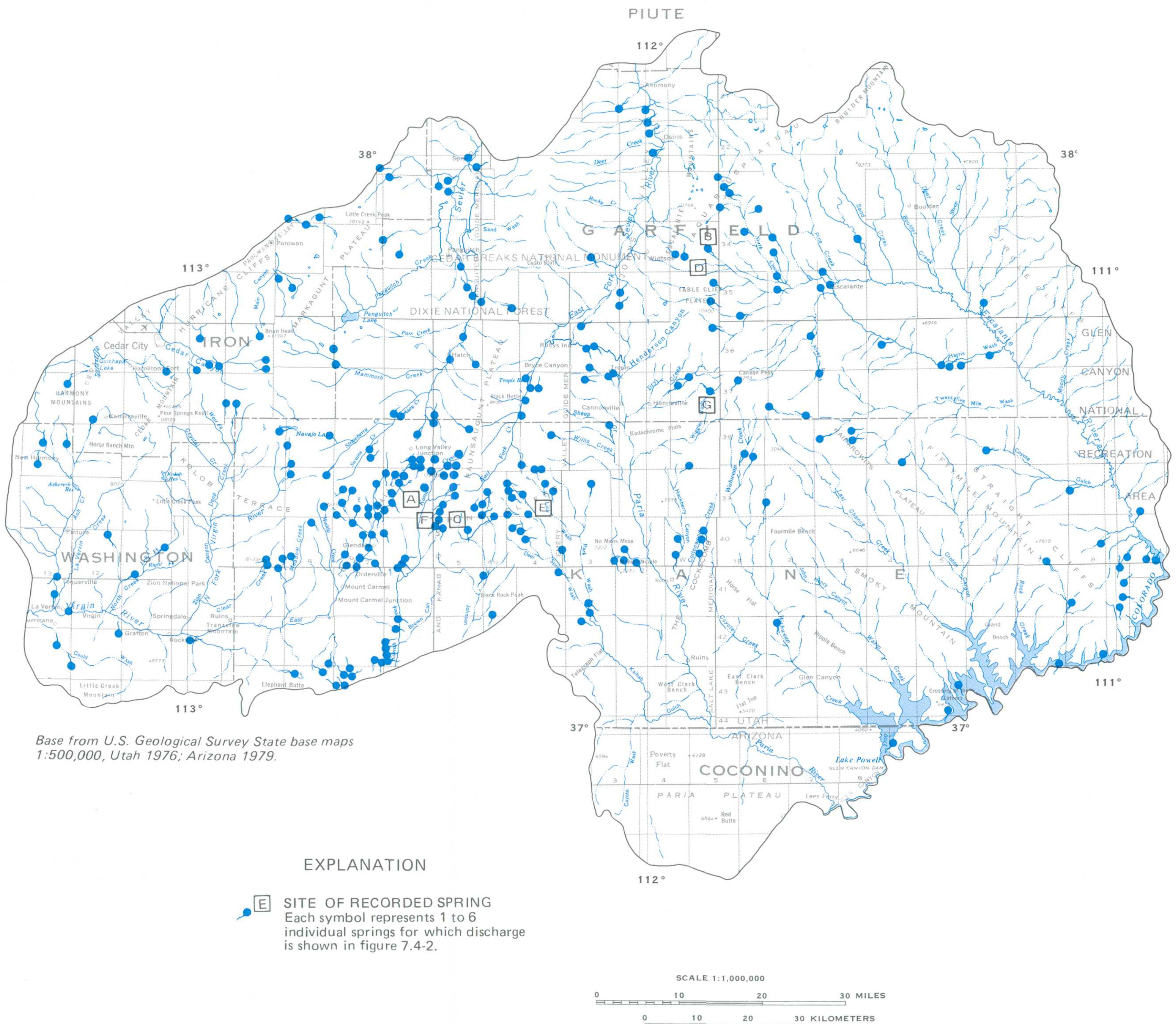


Figure 7.4-1 Approximate location of springs for which published reports are available.

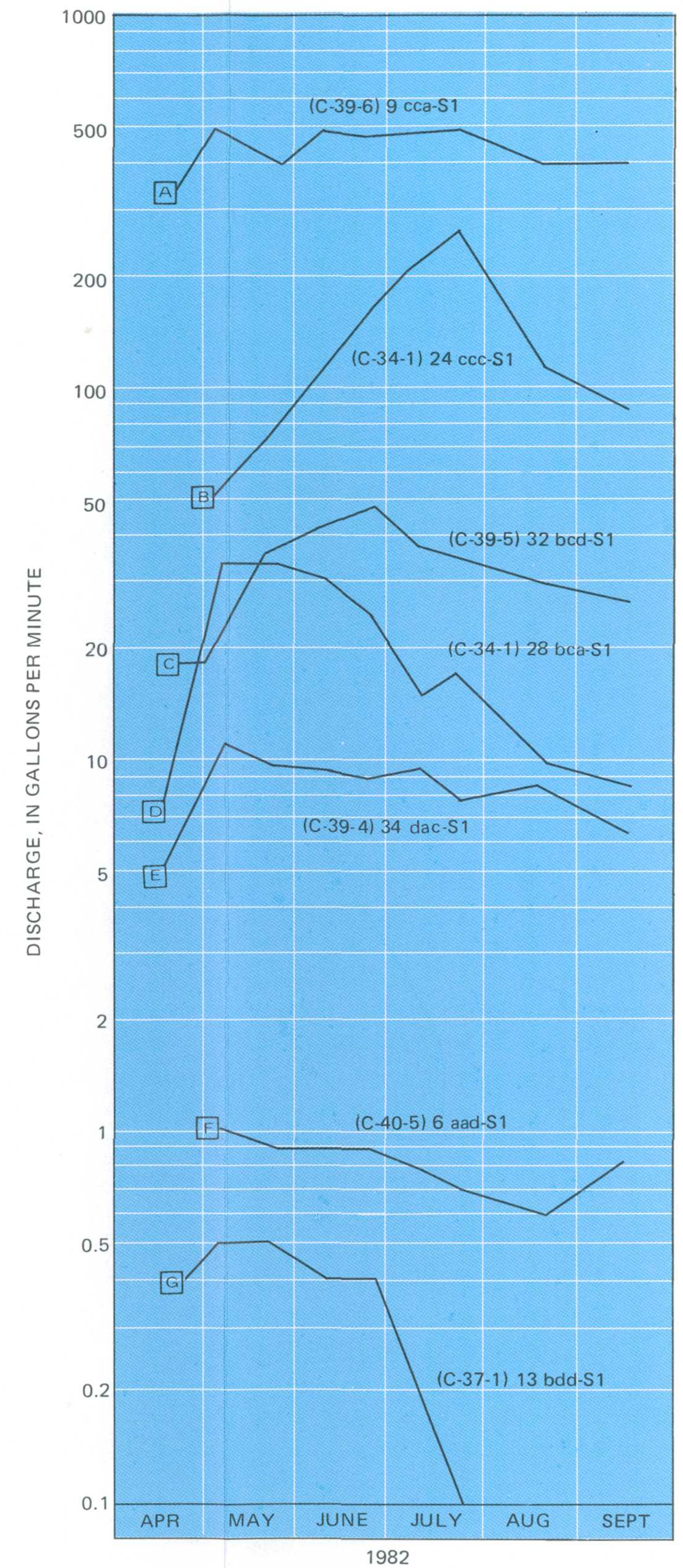


Figure 7.4-2 Discharge variations of seven springs. (Letter identifies spring shown on figure 7.4-1; local number as in Plantz, 1983.)

Ground Water is Fresh to Moderately Saline

Dissolved-solids concentrations in ground water range from less than 500 to about 3,500 milligrams per liter depending largely on geologic source.

The chemical quality of ground water reflects the solubility and kinds of rock through which the water moves and the length of time the water is in contact with the rocks. Geologic units such as the Tropic Shale and Carmel Formation, which contain large quantities of gypsum and other easily dissolved salts, contribute large quantities of dissolved solids to ground water. In the coal fields some of the most saline water is only a few feet above or below fresh water zones.

Ranges of dissolved solids most likely to be found in the ground water are shown in figure 7.5–1. The ranges were determined mainly from chemical analyses of water from a few widely scattered water wells, coal-test holes, and some of the springs shown in figure 7.4–1. Stream quality during periods of base flow and rock type also were considered.

The freshest ground water in the area is found in the Wasatch Formation, igneous rocks, and unconsolidated surficial deposits that underlie the highest parts of the Markagunt, Paunsaugunt, and Aquarius Plateaus. In these areas the ground water contains 100 to 500 milligrams per liter of dissolved solids, and the dominant ions are usually calcium and bicarbonate. Fresh water also generally is found in the Navajo Sandstone where it is exposed in the lower altitudes of the area. In the Navajo, dissolved-solids concentrations are commonly less than 1,000 milligrams per liter and calcium, magnesium, and bicarbonate usually are the dominant ions. There are some local exceptions, however, where dissolved-solids concentrations range from 500 to 1,500 milligrams per liter and sodium and sulfate are the dominant ions.

Water in the coal-bearing formations generally ranges from fresh to slightly saline. Dissolved-solids concentrations vary markedly in short distances, both vertically and laterally. For example, water from several coal-test holes in the Straight Cliffs Sandstone on the Kaiparowits Plateau had dissolved-solids concentrations ranging from less than 500 to more than 2,300 milligrams per liter. Ranges of dissolved-solids concentrations of water samples from the coal-bearing and related formations are given in table 7.5–1.

Very few ground-water samples from the report area have been analyzed for concentrations of such toxic trace elements as arsenic, mercury, or selenium. Consequently there are insufficient data from which to adequately compare trace-element concentrations with maximum allowable limits for public-water supplies (U.S. Environmental Protection Agency, 1976, p. 5). Water from several wells in the Navajo Sandstone in the Wahweap Creek area near Lake Powell contained arsenic concentrations that equaled or exceeded the allowable limit for that element. The arsenic may have its source in the Carmel Formation where leakage to the underlying Navajo has been induced by recharge from Lake Powell (Paul Blanchard, U.S. Geological Survey, written commun., 1983).

Table 7.5-1 Dissolved-solids concentration in water from selected geologic units.

Geologic unit	Number of analyses	Dissolved-solids concentration Maximum	Minimum	Average
Unconsolidated deposits	25	3,490	220	620
Wasatch Formation	14	330	160	240
Kaiparowits Formation	12	1,780	170	580
Wahweap Sandstone	13	3,530	170	640
Straight Cliffs Sandstone	11	2,320	250	680
Tropic Shale	3	1,120	720	880
Dakota Sandstone	3	620	230	420

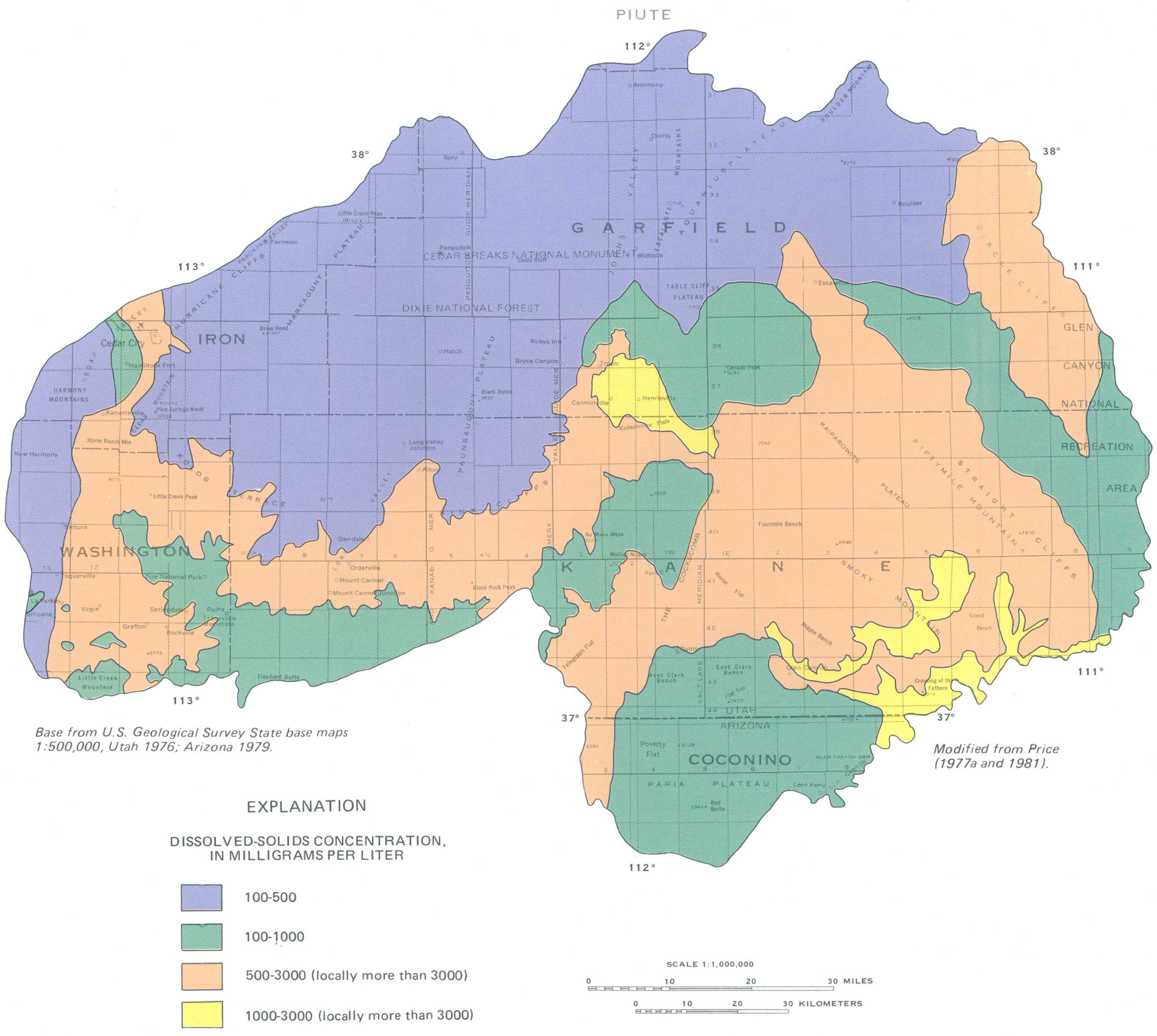


Figure 7.5-1 Dissolved-solids concentration in ground water.

NAWDEX, WATSTORE, OWDC Have Water-Data Information

Water data are collected in coal areas by a large number of organizations for a wide variety of missions and needs.

Within the U.S. Geological Survey there are three activities that help to identify and improve access to the vast amount of existing water data.

1. The National Water-Data Exchange (NAWDEX) indexes the water data available from over 400 organizations and serves as a central focal point to help those in need of water data by identifying information already available.

2. The National Water-Data Storage and Retrieval System (WATSTORE) serves as the central repository of water data collected by the U.S. Geological Survey and contains large volumes of data on the quantity and quality of both surface and ground waters.

3. The Office of Water-Data Coordination (OWDC) coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." To assist in identifying available water-data activities in coal provinces of the United States, special indexes to the Catalog are being printed and made available to the public.

A more detailed explanation of these three activities is given in sections 8.2, 8.3, and 8.4.

NAWDEX Simplifies Access to Water Data

The National Water-Data Exchange (NAWDEX) is a nationwide program managed by the U.S. Geological Survey to assist users of water data or water-related data in identifying, locating, and acquiring needed data.

NAWDEX is a national confederation of water-oriented organizations working together to make their data more readily accessible and to facilitate a more efficient exchange of water data.

Services are available through a Program Office at the U.S. Geological Survey's National Center in Reston, Va. and a nationwide network of Assistance Centers in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities. (See figure 8.2–1.) A directory, which is available on request, provides names of organizations and persons to contact and addresses, telephone numbers, and office hours for each of the organizations [Directory of Assistance Centers of the National Water-Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 79–423 (revised)].

NAWDEX can assist any organization or individual in identifying and locating needed water data and can refer the requester to the organization that retains the data required. To provide this service, NAWDEX maintains a computerized Master Water-Data Index (figure 8.2–2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A Water-Data Sources Directory (figure 8.2–3), which also is maintained, identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition, NAWDEX has direct access to large water-data bases of some of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search-assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In all cases, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and in all cases where costs are anticipated to be substantial.

For additional information concerning the NAWDEX program or its services contact:

Program Office
National Water-Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703)860-6031
FTS 928-6031
Hours 7:45 a.m. to 4:15 p.m. Eastern Time

NAWDEX ASSISTANCE CENTER
UTAH
Room 1016, Administration Bldg.
1745 West 1700 South
Salt Lake City, UT 84104
Telephone (801)524-5654
FTS: 588-5654
Hours: 8:00 a.m. to 4:30 p.m. Mountain Time

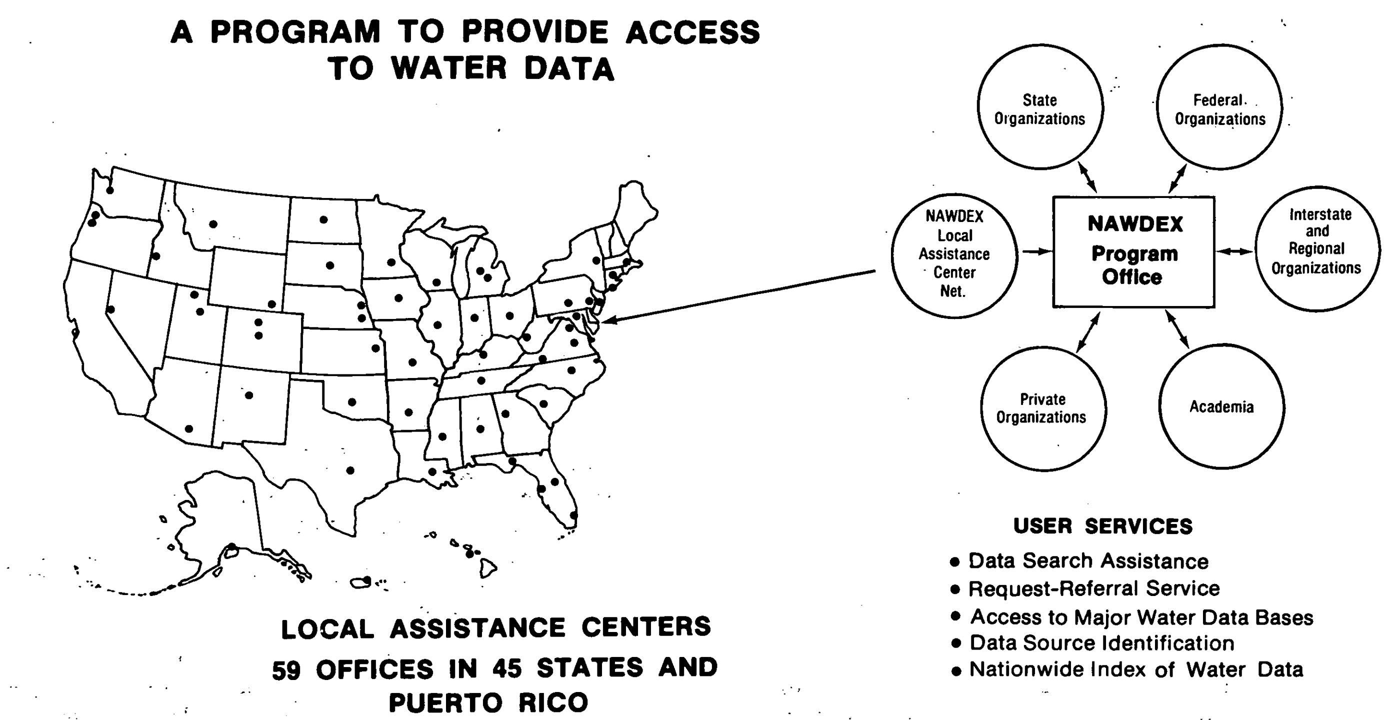


Figure 8.2-1 Access to water data.

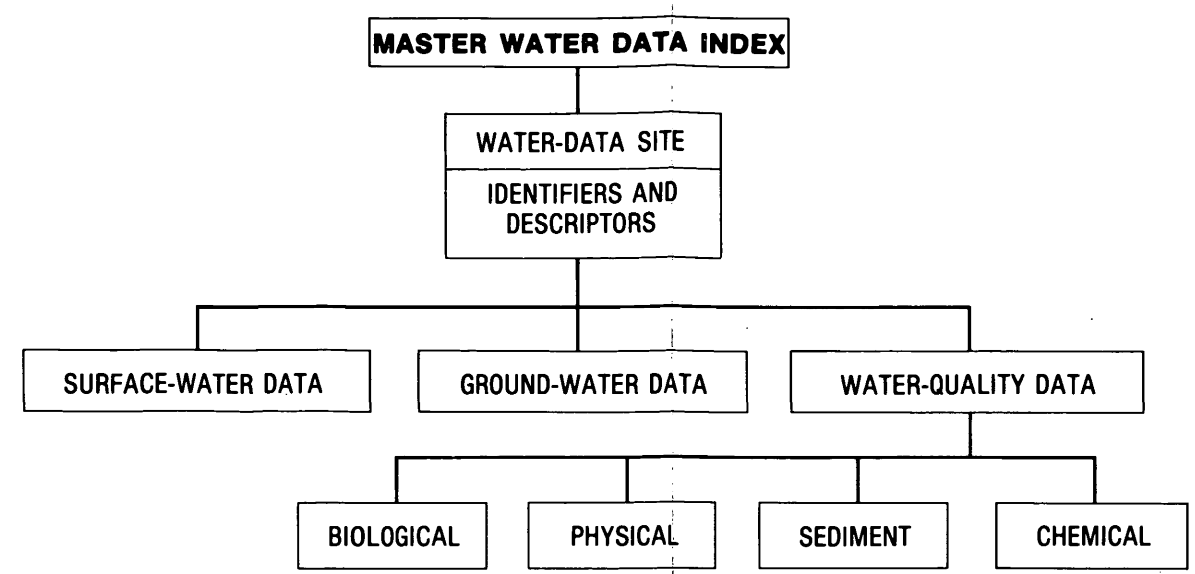


Figure 8.2-2 Master Water-Data Index.

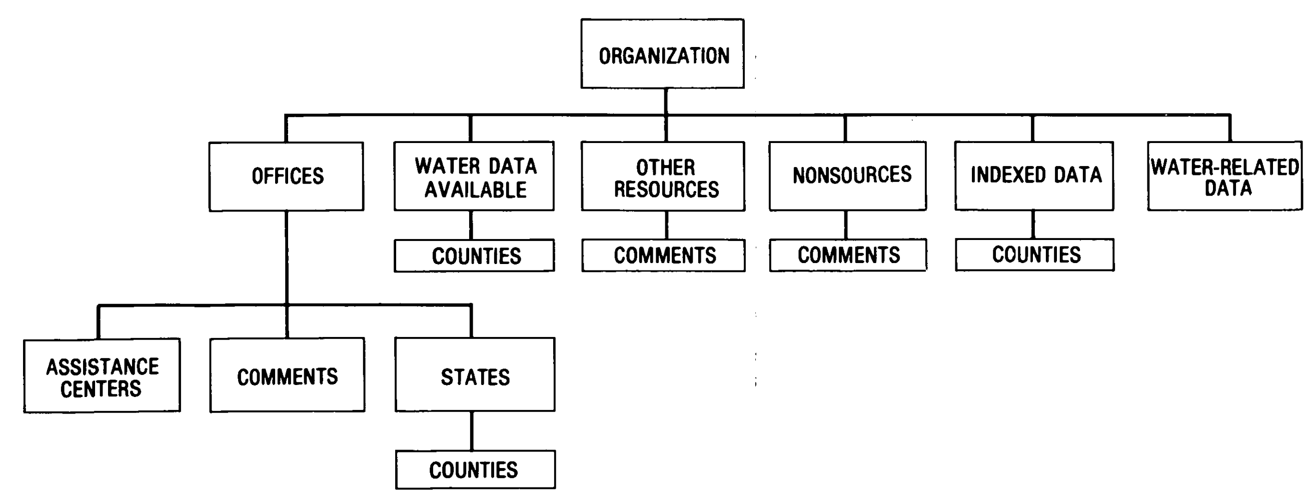


Figure 8.2-3 Water-Data Sources Directory.

WATSTORE Automated Data System

The National Water-Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey provides computerized procedures and techniques for processing water data and provides effective and efficient management of data-releasing activities.

The National Water Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Virginia. Data may be obtained from WATSTORE through the Water Resources Division's 43 district offices. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, VA 22092

U.S. Geological Survey
Water Resources Division
Room 1016, Administration Building
1745 West 1700 South
Salt Lake City, Utah 84104

U.S. Geological Survey
Water Resources Division
Federal Building, 301 W. Congress
Tucson, Arizona 85701

The Geological Survey currently (1980) collects data nationwide at approximately 16,000 stream-gaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,020 sediment stations, 30,000 water-level observation wells, and 12,500 ground-water quality wells. Each year, many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) Surface water, quality of water, and ground water measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is maintained (figure 8.3–1). A brief description of each file is as follows:

Station-Header File: Information pertinent to the identification, location, and physical description of nearly 220,000 sites are contained in this file. All sites for which data are stored in the Daily-Values, Peak-Flow, Water-Quality, and Unit-Values Files of WATSTORE are indexed in this file.

Daily-Values File: All water-data parameters measured or observed either on a daily or on a continuous basis and numerically reduced to daily values are stored in this file. Instantaneous measurements at fixed-time intervals, daily mean values, and statistics such as daily maximum and minimum values also may be stored. This file currently contains over 200 million daily values including data on streamflow, river stages, reservoir contents, water temperatures, specific conductance, sediment concentrations, sediment discharges, and ground-water levels.

Peak-Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values at surface-water sites constitute this file, which currently contains over 400,000 peak observations.

Water-Quality File: Results of more than 1.4 million analyses of water samples are contained in this file. These analyses contain data for as many as 185 different constituents and physical properties that describe the chemical, physical, biological, and radiochemical characteristics of both surface and ground waters.

Unit-Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and temperature data are examples of the types of data stored in the Unit-Values File.

Ground-Water Site-Inventory File: This file is maintained within WATSTORE independent of the files discussed above, but it is cross-referenced to the Water-Quality File and the Daily-Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 700,000 sites.

Water-Use File: This file is also an independent file maintained within WATSTORE. It contains aggregated estimates of water use by county and hydrologic unit.

All data files of the WATSTORE system are maintained and managed on the central computer facilities of the Geological Survey at its National Center. However, data may be entered into and retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunications network.

Remote Job-Entry Sites: Almost all of the Water Resources Division's district offices are equipped with high-speed computer terminals for remote access to the WATSTORE system. Using these terminals, data can be entered into or retrieved from the system within an interval of several minutes to overnight, depending upon the priority placed on the request. The number of remote job-entry sites is increased as the need arises.

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stage, conductivity, water temperature, turbidity, wind direction, and chloride concentraion. Data are recorded on 16-channel paper tape; the tape is removed from the recorder, and the data are transmitted over telephone lines to the receiver at Reston, Va. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for transmitting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data-relay stations are being operated currently by the Water Resources Division.

Central Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colo., and Atlanta, Ga., analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic substances, such as chloride, to complex organic compunds, such as pesticides. As each analysis is completed, the results are verified by laboratory personnel and transmitted via a computer terminal to the central computer facilities to be stored in the Water-Quality File of WATSTORE.

Water data are used in many ways by decision makers for the management, development, and monitoring of our water resources. In addition to its data processing, storage, and retrieval capabilities, WATSTORE can provide a variety of useful products ranging from simple tables of data to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

Computer-Printed Tables: Users most often request data from WATSTORE in the form of tables printed by the computer. These tables may contain lists of actual data or condensed indexes that indicate the availability of data stored in the files. A variety of formats is available to display the many types of data.

Computer-Printed Graphs: Computer-printed graphs for the rapid analysis or display of data are another capability of WATSTORE. Computer programs are available to produce bar graphs (histograms), line graphs, frequency-distribution curves, X-Y point plots, site-location-map plots, and other similar items by means of line printers.

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package (SAS) to provide extensive analyses of data such as regression analyses, analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also makes use of software systems that prepare data for digital plotting on peripheral of fline plotters available at the central computer site. Plots that can be obtained include hydrographs, frequency-distribution curves, X-Y point plots, contour plots, and three-dimensional plots.

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable form for use on other computers or for use as input to user-written computer programs. These data are available in the standard format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

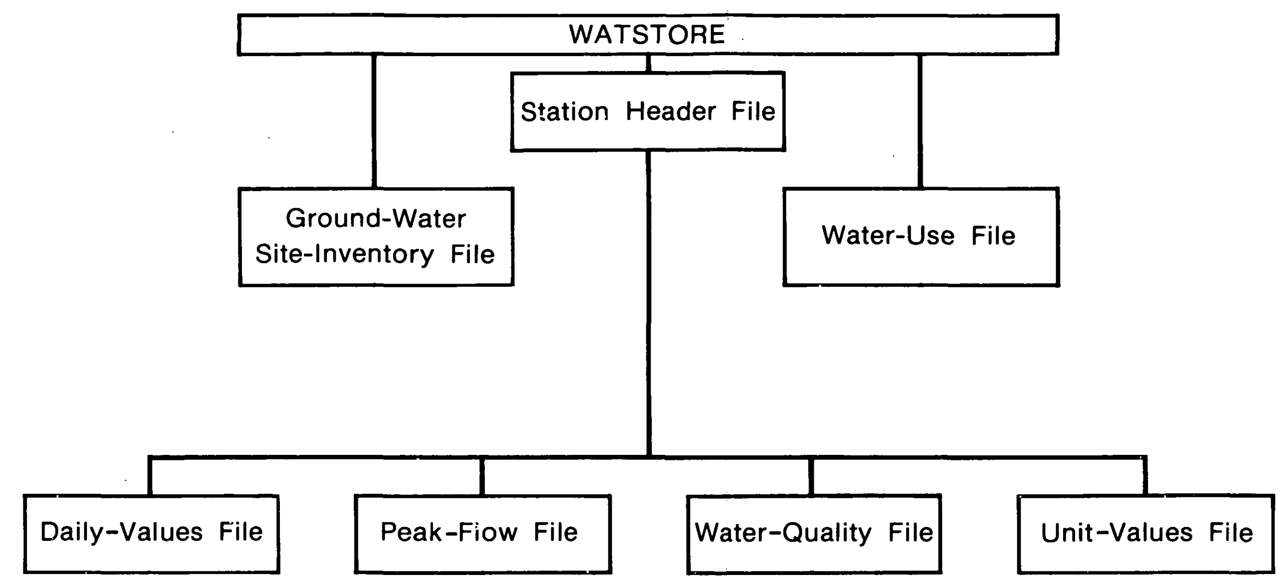


Figure 8.3-1 Index file of stored data.

Water Data Indexed for Coal Provinces

A special index, "Index to Water-Data Activities in Coal Provinces of the United States," has been published by the U.S. Geological Survey's Office of Water-Data Coordination (OWDC).

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information on the availability of water-resources data in the major coal provinces of the United States. It is derived from the "Catalog of Information on Water Data," which is a computerized information file about water-data acquisition activities in the United States and its territories and possessions, with some international activities included.

This special index consists of five volumes (figure 8.4–1): volume I, Eastern Coal Province; volume II, Interior Coal Province; volume III, Northern Great Plains and Rocky Mountain Coal Provinces; volume IV, Gulf Coast Coal Province; and volume V, Pacific Coast and Alaska Coal Provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A–C includes: (1) the identification and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are shown in a table.

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water-Data Exchange (NAWDEX). (See section 8.2.)

Further information on the index volumes and their availability may be obtained from:

U.S. Geological Survey
Water Resources Division
Room 1016 Administration Bldg.
1745 West 1700 South
Salt Lake City, UT 84104
Telephone: (801) 524-5654
FTS 588-5654

Office of Surface Mining
U.S. Department of the Interior
Brooks Towers
1020 15th Street
Denver, CO 80202
Telephone: (303)827-5511
FTS 327-5511

See my insert on p. 33 and on fig 6.6-2 explanation

Identify + add if necessary QW + sed stations?

10.0 LIST OF SURFACE-WATER STATIONS

Site No. (see figure 6.1-1)	Station number and name		Location Latitude ° ' "	Location Longitude ° ' "	Drainage area (square miles)	Period of record
1	09335500	North Creek near Escalante, Utah	37 46 00	111 41 00	90	1950-55
2	09336000	Birch Creek near Escalante, Utah	37 45 45	111 44 15	36	1950-51, [1]1959-74
3	09336400	Upper Valley Creek near Escalante, Utah	37 44 30	111 42 30	53	[1]1959-74
4	09336500	Birch Creek at mouth, near Escalante, Utah	37 46 00	111 41 00	100	1951-55
5	09337000	Pine Creek near Escalante, Utah	37 51 45	111 38 07	68.1	1950-55, 1957-82
6	09337500	Escalante River near Escalante, Utah	37 46 41	111 34 26	320	1909-13, 1942-55, 1971-82
7	09338000	East Fork Boulder Creek near Boulder, Utah	38 02 31	111 26 58	21.4	1950-55, 1957-72
8	09338500	East Fork Deer Creek near Boulder, Utah	38 00 05	111 23 20	1.9	1950-55, [1]1959-74
9	09338900	Deer Creek near Boulder, Utah	37 51 13	111 21 17	63.0	[1]1959-74
10	09339000	Boulder Creek near Boulder, Utah	37 48 00	111 23 00	175	1950-55
11	09339200	Twentymile Wash near Escalante, Utah	37 33 54	111 22 55	140	[1]1959-68
12	09339500	Escalante River at mouth, near Escalante, Utah	37 18 51	110 54 10	1,770	1950-55
13	09379800	Coyote Creek near Kanab, Utah	37 07 13	111 45 06	89.0	[1]1959-74
14	09379820	Buck Tank Draw near Kanab, Utah	37 05 10	111 42 20	5.25	[1]1959-70
15	09379900	Lake Powell at Glen Canyon Dam, Arizona	36 56 12	111 29 00	111,700	1963-82
16	09380000	Colorado River at Lees Ferry, Arizona	36 51 53	111 35 15	111,800	1895-82
17	09380380	Bryce Creek at Park Boundary, near Tropic, Utah	37 36 54	112 07 50	2.72	[1]1965-66
18	09380400	Paria River at Cannonville, Utah	37 34 05	112 03 00	96	[1]1959-62
19	09381000	Henrieville Creek near Henrieville, Utah	37 34 15	111 58 15	29.0	1950-55
20	09381100	Henrieville Creek at Henrieville, Utah	37 38 41	111 58 42	34.0	[1]1959-74
21	09381500	Paria River near Cannonville, Utah	37 28 50	112 01 15	220	1950-55, [1]1959-74
22	09381590	Sheep Creek at Park Boundary, near Cannonville, Utah	37 34 00	112 12 00	3.56	[1]1965-66
23	09381600	Sheep Creek near Cannonville, Utah	37 33 00	112 08 00	17	[1]1959-64
24	09381700	Sheep Creek Reservoir, Utah	37 29 10	112 03 50	31.1	[1]1961-68
25	09381800	Paria River near Kanab, Utah	37 06 23	111 54 13	668	[1]1959-74
26	09382000	Paria River at Lees Ferry, Arizona	36 52 20	111 35 38	1,410	1923-82
27	09403500	Kanab Creek near Glendale, Utah	37 17 30	112 29 30	72	[1]1959-74
28	09403600	Kanab Creek near Kanab, Utah	37 06 02	112 32 50	198	[1]1959-68, 1979-82
29	09403620	Mill Creek near Glendale, Utah	37 21 49	112 20 30	4.81	1975-77
30	09403630	Skutumpah Creek near Glendale, Utah	37 19 18	112 19 37	14.8	1975-77
31	09403640	Intermediate drainage near Glendale, Utah	37 18 10	112 20 46	2.49	1975-77
32	09403650	Thompson Creek (upper station) near Glendale, Utah	37 20 11	112 22 19	9.8	1975-77
33	09403660	Thompson Creek (lower station) near Glendale, Utah	37 18 10	112 20 46	16.6	1975-77
34	09403670	Thompson Creek near Glendale, Utah	37 17 45	112 21 07	19.2	1980-81
35	09404450	East Fork Virgin River near Glendale, Utah	37 20 19	112 36 13	69.2	1966-82
36	09404500	Mineral Gulch near Mt. Carmel, Utah	37 14 00	112 44 10	7.6	[1]1959-74
37	09405300	Crystal Creek near Cedar City, Utah	37 31 20	113 01 25	10.2	1956-60
38	09405400	North Fork Virgin River near Glendale, Utah	37 28 22	112 46 40	5.65	1972-78
39	09405420	North Fork Virgin River below Bulloch Canyon, near Glendale, Utah	37 25 06	112 47 59	29.6	1974-82
40	09405450	North Fork Virgin River above Zion Narrows, near Glendale, Utah	37 23 26	112 49 30	45.5	1978-82

Site No. (see figure 6.1-1)	Station number and name		Location Latitude ° ′ ″	Location Longitude ° ′ ″	Drainage area (square miles)	Period of record
41	09405500	North Fork Virgin River near Springdale, Utah	37 12 35	112 58 40	344	1925-82
42	09406000	Virgin River at Virgin, Utah	37 11 53	113 12 22	934	1909-71, 1978-82
43	09406300	Kanarra Creek at Kanarraville, Utah	37 32 17	113 10 04	9.85	1959-82
44	09406500	Ash Creek near New Harmony, Utah	37 25 00	113 12 00	130	1939-47
45	09406600	Ash Creek Reservoir near New Harmony, Utah	37 24 38	113 14 05	133	1972-82
46	09406700	South Ash Creek below Mill Creek, near Pintura, Utah	37 21 50	113 20 01	11.0	1966-82
47	09406800	South Ash Creek near Pintura, Utah	37 19 53	113 16 55	14.0	[1]1959-74
48	09407200	Ash Creek below West Field Ditch, at Toquerville, Utah	37 15 38	113 16 30	190	1972-82
49	09407600	Ash Creek near Toquerville, Utah	37 13 57	113 17 00	213	1956-58
50	09407800	Ash Creek near La Verkin, Utah	37 12 20	113 17 10	215	1956-58
51	10173450	Mammoth Creek above West Hatch Ditch, near Hatch, Utah	37 37 19	112 31 07	105	1964-82
52	10173500	Mammoth Creek near Hatch, Utah	37 37 00	112 28 00	151	1912-14, 1915-19
53	10173600	Midway Creek near Hatch, Utah	37 31 10	112 43 35	25.7	1957-62
54	10173700	Navajo Lake west of dike, near Hatch, Utah	37 31 00	112 46 00	—	1953-59
55	10173800	Navajo Lake east of dike, near Hatch, Utah	37 31 00	112 46 00	—	1953-59
56	10173900	Duck Creek near Hatch, Utah	37 31 00	112 42 00	38.3	1953-59
57	10174000	Asay Creek above West Fork, near Hatch, Utah	37 33 00	112 31 00	—	1954-59
58	10174500	Sevier River at Hatch, Utah	37 39 04	112 25 46	340	1911-28, 1939-82
59	10174800	Red Canyon tributary near Bryce Canyon, Utah	37 44 00	112 17 00	2.2	[1]1959-74
60	10176300	Panguitch Creek near Panguitch, Utah	37 46 18	112 32 12	97.0	1961-80
61	10183900	East Fork Sevier River near Rubys Inn, Utah	37 34 33	112 15 54	71.6	1961-82
62	10184000	Tropic and East Fork Canal near Tropic, Utah (Transmountain Diversion)	37 40 07	112 08 31	—	1949-61
63	10184400	Deer Creek near Osiris, Utah	38 00 00	111 58 00	28	[1]1959-68
64	10184450	East Fork Sevier River near Antimony, Utah	38 03 00	111 58 40	570	1961-66
65	10185000	Antimony Creek near Antimony, Utah	38 05 57	111 53 21	84.0	1946-48, 1957-76
66	10241400	Little Creek near Paragonah, Utah	37 54 20	112 42 30	15.8	1959-80
67	10241430	Red Creek near Paragonah, Utah	37 51 25	112 40 30	6.3	1965-73
68	10241470	Center Creek above Parowan Creek, near Parowan, Utah	37 47 35	112 48 55	11.6	1964-82
69	10241500	Center Creek near Parowan, Utah	37 50 00	112 49 00	60	1942-50
70	10241600	Summit Creek near Summit, Utah	37 47 13	112 54 56	24.0	1964-82
71	10241800	Ashdown Creek near Cedar City, Utah	37 38 15	112 54 15	13.1	1957-61
72	10241900	Coal Creek above Right Hand Creek, near Cedar City, Utah	37 39 00	112 59 00	54.2	[1]1959-68
73	10242000	Coal Creek near Cedar City, Utah	37 40 20	113 02 02	80.9	1916-19, 1935-82
74	10242100	Shirts (Shurtz) Creek near Cedar City, Utah	37 37 00	113 07 00	12.8	[1]1959-74
75	10242200	Duncan Creek near Cedar City, Utah	37 38 00	113 16 00	11.9	[1]1959-68

[1] Annual maximums only.

10.0 LIST OF OBSERVATION WELLS

Aquifer: 110ALVM, Alluvium; 210DKOT, Dakota Sandstone; 220NVJO, Navajo Sandstone.
Frequency of water-level measurements: A, annual; S, semiannual; C, continuous.

Site No. (figure 7.1-1)	Site-identification No.	Local No.	Aquifer	Period of record	Frequency of water-level measurements
1	380005112225001	(C-32-5)26aca-1	110ALVM	1951-82	S
2	375927112232401	(C-32-5)35bab-1	110ALVM	1962-82	S
3	375634111592301	(C-33-2)22aab-1	110ALVM	1962-82	S
4	374845112031001	(C-34-2)30ccc-1	110ALVM	1962-82	S
5	375235112245501	(C-34-5)4ddd-1	110ALVM	1951-54, 56-82	S
6	375210112261501	(C-34-5)8adb-2	110ALVM	1935-82	S
7	375241112471001	(C-34-8)5bca-1	110ALVM	1935-82	C
8	374423113053401	(C-35-11)21dbd-2	110ALVM	1951-82	A
9	374346113043801	(C-35-11)27acc-1	110ALVM	1931-72, 74-82	S
10	374423113053301	(C-35-11)27bbc-1	110ALVM	1938-39, 51-82	A
11	374251113074102	(C-35-11)31acd-2	110ALVM	1951, 56-58, 66-82	A
12	374304113052901	(C-35-11)33aac-1	110ALVM	1930-82	S
13	374205112091501	(C-36-3)6dba-1	110ALVM	1946-82	S
14	373908112253801	(C-36-5)28bdc-1	110ALVM	1962-82	S
15	374132113063601	(C-36-11)8aab-1	110ALVM	1935-43, 45-73, 78-82	C
16	374021113021101	(C-36-11)13adc-3	110ALVM	1981-82	A
17	374012113021301	(C-36-11)13dba-1	110ALVM	1982	A
18	374151113104601	(C-36-12)10dda-1	110ALVM	1959-82	A
19	374104113084801	(C-36-12)12dba-1	110ALVM	1936-82	S
20	373855113130501	(C-36-12)20ddc-1	110ALVM	1940-82	S
21	373855113093801	(C-36-12)24ccc-1	110ALVM	1977-82	A
22	373830113090801	(C-36-12)25bdd-1	110ALVM	1957-72, 74-82	A
23	373710113132701	(C-36-12)32dcc-1	110ALVM	1977-82	A
24	373742113100801	(C-36-12)35aac-1	110ALVM	1977-79, 81-82	A
25	373606113094701	(C-37-12)11aaa-1	110ALVM	1953-79, 81-82	A
26	373509113101101	(C-37-12)14abc-1	110ALVM	1959-61, 63-82	A
27	373236113111401	(C-37-12)34abb-1	110ALVM	1934-82	A
28	373040113122501	(C-38-12)9aab-1	110ALVM	1972-80, 82	A
29	372815113134801	(C-38-12)20cca-1	110ALVM	1970-82	S
30	372035112194801	(C-40-4½)8dca-1	210DKOT	1978-82	A
31	372002112212301	(C-40-4½)18bcd-1	110ALVM	1978-82	A
32	371740112210601	(C-40-4½)31bad-1	110ALVM	1978-79, 81-82	S
33	371739112200201	(C-40-4½)32bad-1	110ALVM	1978-82	A
34	371034112230401	(C-42-5)11bdb-1	220NVJO	1978-82	S
35	370901112335001	(C-42-6)19baa-1	220NVJO	1977-82	C
36	374709111391201	(D-35-3)8dba-1	110ALVM	1979-82	S
37	370438111395001	(D-43-2)14bab-1	220NVJO	1963-82	S
38	370010111302501	(D-44-4)7aab-1	220NVJO	1964-82	S

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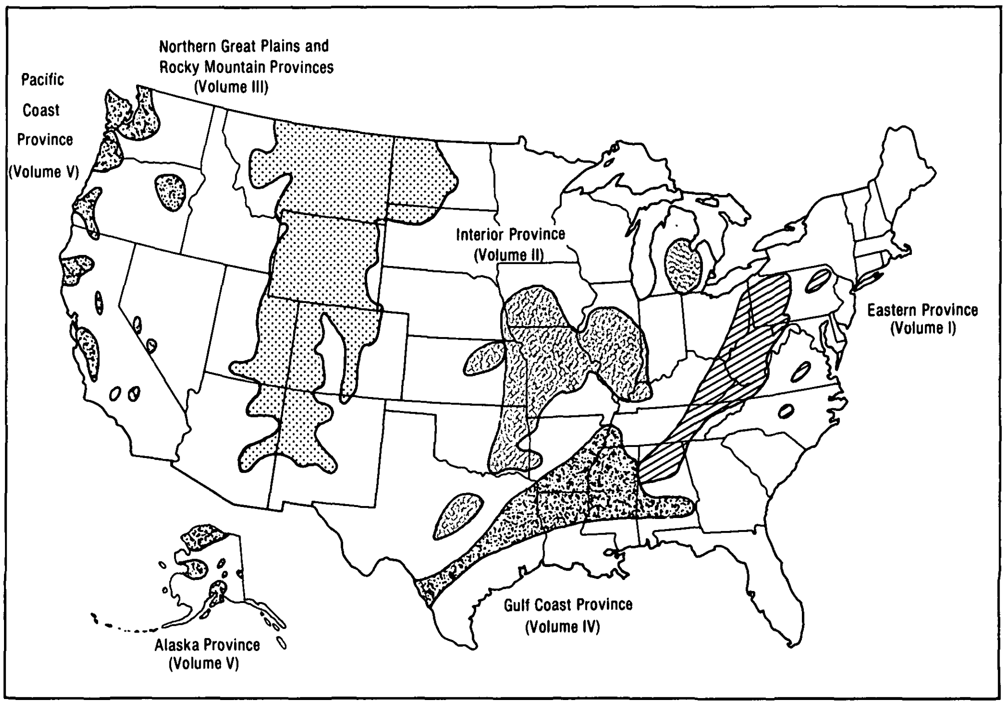

Figure 8.4-1 Index volumes and related provinces.