UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GROUND-WATER CONDITIONS IN THE UPPER VIRGIN RIVER AND KANAB CREEK BASINS AREA, UTAH, WITH EMPHASIS ON THE NAVAJO SANDSTONE

Open-File Report 80-524-W

Prepared in cooperation with the
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Salt Lake City, Utah

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CONVERSION FACTORS

Most values in this report are given in inch-pound units followed by metric units. The conversion factors are shown to four significant figures. In the test, however, the metric equivalents are shown only to the number of significant figures consistent with the accuracy of the value in inch-pound units.

Inch-pound Unit (Multiply)	Abbreviation	(by)	Metric Unit (to obtain)	Abbreviation
Acre		0.4047	Square hectometer	hm^2
		.004047	Square kilometer	km^2
Acre-foot	acre-ft	.001233	Cubic hectometer	hm^3
		1233	Cubic meter	m^3
Cubic foot per second	ft^3/s	.02832	Cubic meter per second	m^3/s
Cubic foot per day per foot	$(ft^3/d)/ft$	.0929	Cubic meter per day per meter	$(m^3/d)/m$
Foot	ft	.3048	Meter	m
Foot per mile	ft/mi	.1894	Meter per kilometer	m/km
Gallon per minute	gal/min	.06309	Liter per second	L/s
Gallon per minute per foot	(gal/min)/ft	.2070	Liter per second per meter	(L/s)/m
Inch	in.	25.40	Millimeter	mm
		2.540	Centimeter	cm
Mile	mi	1.609	Kilometer	km
Pound-force per square inch	lbf/in^2	6.895	Kilopascal	kPa
Square foot	ft^2	.0929	Square meter	m^2
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L). For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in the English unit, parts per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit by the following equation: $°F=1.8\ (°C)+32$.

GROUND-WATER CONDITIONS IN THE UPPER VIRGIN RIVER
AND KANAB CREEK BASINS AREA, UTAH, WITH
EMPHASIS ON THE NAVAJO SANDSTONE

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R. M. Cordova

ABSTRACT

The upper Virgin River and Kanab Creek basins area occupies parts of Iron, Kane, and Washington Counties in south-central Utah. It includes about 1,300 square miles (3,370 square kilometers) in the upper Virgin River basin and about 650 square miles (1,680 square kilometers) in the upper Kanab Creek basin. The area is sparsely populated with Kanab (population about 1,400 in 1975) being the largest community. Although the area is largely agricultural, it is known to contain large coal reserves with potential for development.

Geologic units exposed in the area range in age from Permian to Holocene. The exposed rocks consist mostly of sandstone with progressively lesser amounts of unconsolidated rocks, siltstone, mudstone, shale, limestone, igneous rocks, conglomerate, and coal. The strata dip generally less than 5° to the north and are cut by a number of northeasterly and northwesterly trending faults, the largest being the Hurricane, Sevier, and Paunsaugunt Faults.

Ground water occurs in both the unconsolidated and consolidated rocks. Principal aquifers in the unconsolidated rocks include older stream-channel deposits in the lower reaches of Johnson Canyon and Kanab Creeks, lower parts of alluvial fans along the bases of higher terraces, and stream-valley alluvium along the alluvial plains of the Virgin River, Short Creek, Gould Wash, and upper reaches of Johnson Canyon and Kanab Creeks.

The most important consolidated-rock aquifer is the Navajo Sandstone of Triassic(?) and Jurassic age. This formation contains an estimated 200 million acre-feet (250,000 hm^3 [cubic hectometers]) of recoverable water and has been tapped by a number of large-yield wells in the upper Kanab Creek basin. Other consolidated-rock aquifers of note include the Shinarump Member of the Chinle Formation of Triassic age, sandstone strata of Cretaceous age, and the Wasatch Formation of Tertiary age.

Ground-water recharge in the area is estimated to average about 80,000 acre-feet (100 hm^3) per year. The water enters the aquifers by direct infiltration of precipitation or seepage from streams chiefly in the headwaters of the Virgin River and Kanab Creek; it moves generally southward to areas of natural discharge chiefly in the lower reaches of the Virgin River, Kanab Creek, and their larger tributaries. Discharge in 1977 was at least 71,000 acre-feet (90 hm^3), broken down as follows: seepage to streams, 50,000 acre-feet (62 hm^3); evapotranspiration, 10,000 acre-feet (12 hm^3); springflow, 2,740 acre-feet (3.4 hm^3); subsurface outflow, 5,000 acre-feet (6.2 hm^3); and withdrawal from wells, 3,260 acre-feet (4.0 hm^3). The difference in the estimates of recharge and discharge results from inherent inaccuracies in the methods used to arrive at the two figures. It does not represent an imbalance between ground-water recharge and discharge.

Chemical quality of the ground water varies considerably both areally and by geologic source. The water is generally fresh, containing less than 500 milligrams per liter of dissolved solids in the recharge areas. Water in the Navajo Sandstone is also generally fresh. Dissolved-solids concentrations of 41 water samples collected from the Navajo ranged from 74 to 905 milligrams per liter and averaged about 270 milligrams per liter. The most saline waters, generally containing 1,000 to 3,000 milligrams per liter, were found in the Carmel Formation of Jurassic age and the Chinle and Moenkopi Formations of Triassic age.

Several field aquifer tests made in the area, chiefly involving the Navajo Sandstone, indicated that increased ground-water withdrawals in the area could result in increased interference between wells, a reduction of streamflow, and possible changes in water quality. It might also cause a shift of the ground-water drainage divide, whereby some ground water would be diverted into the area from adjacent drainage basins.

INTRODUCTION

Purpose and scope of the study

This report presents the results of a 2-year study by the U.S. Geological Survey in cooperation with the Utah Division of Water Rights to evaluate ground-water conditions in the upper Virgin River and Kanab Creek basins area of Utah. Fieldwork for the study was started in July 1976 and was completed in August 1978.

The purpose of the study was to obtain information needed about the ground-water system in the area to (1) help resolve existing water-right problems and (2) determine hydrologic effects of possible large increases in ground-water withdrawals for the development of the area's large coal reserves. Emphasis of study was on the Navajo Sandstone aquifer, which has been tapped by a number of large-yield wells in the area and which is a possible source of water for coal development.

The study was of a reconnaissance nature in the upper Virgin River basin where there was relatively little development of ground water by wells; it was more detailed in the Kanab Creek drainage basin where hydrologic data were most abundant. The study included some local geologic mapping, but consisted chiefly of collection and evaluation of hydrologic data including well and spring inventories, aquifer tests, seepage studies, and laboratory analyses of rock and water samples.

Previous investigations and acknowledgments

Previous hydrologic investigations in the area of this report include those by Goode (1964, 1966), Sandberg (1979), and Price (1980). In addition, the hydrology of part of the area is described in energy-related environmental assessments (U.S. Department of the Interior, 1975, 1979a). The geology of the area has been mapped by a number of workers. Principal sources of geologic information used in this report are Stokes (1964), Cook (1960), and Gregory (1950, 1951).

Personnel of various Federal, State, and local governmental agencies and private organizations provided information which facilitated the progress of this investigation. Their assistance is gratefully acknowledged as is the cooperation of landowners in the area who allowed access to their property to collect hydrologic data.

Data-site-numbering system

The system of numbering wells, springs, and other hydrologic-data sites in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the data site, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast-northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--

generally 10 acres (4 hm^2);[1] the letters a, b, c, and d indicate, respectively,

[1]Although the basic land unit, the section, is theoretically 1 mi^2 (2.6 km^2), many sections are irregular. Such sections are subdivided into 10-acre (4-hm^2) tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

the northeast, northwest, and southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of wells or springs within the 10-acre (4-hm^2) tract (the letter "S" preceding the serial number denotes a spring). Other hydrologic-data sites in this report, such as streamflow-gaging sites, do not have serial numbers. If a data site cannot be located within a 10-acre (4-hm^2) tract, one or two location letters are used and the serial number is omitted, even if a well or spring. For example, the number (C-42-5)27aaa-1 designates the first well constructed or visited in the NE¼NE¼NE¼ sec. 27, T. 42 S., R. 5 W., and (C-41-13)25c-S designates a spring known only to be in the SW¼ sec. 25. The numbering system is illustrated in figure 1.

LOCATION AND GENERAL FEATURES OF THE STUDY AREA

Physiography and drainage

The area of this report includes parts of Iron, Kane, and Washington Counties in south-central Utah (fig. 2). It includes about 1,300 mi^2 (3,370 km^2) in that part of the Virgin River basin east of the Hurricane Cliffs and about 650 mi^2 (1,680 km^2) in the upper Kanab Creek basin including the area drained by Johnson Canyon creek.

The area is characterized by broad plateaus and mesas that have been deeply dissected by the Virgin River, Kanab Creek, and their larger tributaries. Local relief in the area commonly exceeds 1,000 ft (300 m); total relief is nearly 7,000 ft (2,130 m) with altitudes ranging from about 3,100 ft (940 m)

Figure 1.--Data-site-numbering system used in Utah.

Figure 2.--Location of the upper Virgin River and Kanab Creek basins area.

where the Virgin River flows through the Hurricane Cliffs to more than 10,000 ft (3,000 m) in the headwaters of North Fork Virgin River.

The area is drained entirely by the Virgin River and Kanab Creek, which are directly tributary to the Colorado River. Both streams are perennial within the study area as are their tributaries that head at altitudes of more than 7,000 ft (2,130 m). Most of the tributaries that head at altitudes of less than 7,000 ft (2,130 m) are intermittent or ephemeral.

Irrigation practices during about the past 120 years have accelerated erosion along several streams in the area. Diversion dams built by the pioneers on Kanab Creek near Kanab and Johnson Canyon creek near the mouth of Johnson Canyon have collapsed several times under the stress of stored water. The resulting floods scoured out large volumes of the stream-valley alluvium leaving the channels of the two streams (and some of their tributaries) much deeper than could be expected under natural conditions. Some of the deepening is also attributed to natural flooding, including a major flood in the early 1950's.

Measurements in 1967 by M. E. Cooley (U.S. Geological Survey, written commun., 1979) showed that the channel of Kanab Creek has been deepened as much as 105 ft (32 m) about 2 mi (3.2 km) upstream from Kanab. Hand leveling by the writer during this study indicated that the channel of Johnson Canyon creek has been deepened as much as 40 ft (12 m) near the Arizona-Utah State line. Both streams are locally flowing on consolidated rock (where stream-valley alluvium has been eroded away) and receive influent seepage of water directly from those rocks.

Climate

The climate of the study area ranges from semiarid in the lower southern part to subhumid in the higher northern part. Normal annual precipitation ranges from less than 12 in. (305 mm) in the vicinity of Kanab to about 40 in. (1,016 mm) in the headwaters of North Fork Virgin River (figs. 3 and 4). It should be noted, however, that the amount of precipitation varies considerably from year to year and over the long term as shown by the cumulative-departure graphs in figure 5.

Most of the seasonal precipitation occurs during midwinter and late summer months (table 1). Winter precipitation generally results from frontal-type storms and occurs as snow which accumulates on the highest plateaus until the late spring-early summer snowmelt-runoff period. Summer precipitation generally results from local convection-type storms and occurs as torrential rain which runs off rapidly, commonly as flash floods.

Air temperatures vary widely throughout the area. Mean daily temperatures in January range from about 40°F (4.5°C) at the lower altitudes to -28°F (-2.0°C) at the higher altitudes; mean daily July temperatures range from near 84°F (29.0°C) at the lower altitudes to near 66°F (19.0°C) at the higher altitudes (see table 1). Daily extreme temperatures commonly exceed 100°F (38.0°C) at the lower altitudes during the summer and commonly drop below 0°F (-18.0°C) at the higher altitudes during the winter.

Annual evaporation rates in the area are high. According to Kohler and others (1959, pl. 2), average annual pan-evaporation rates range from about 75-85 in. (1,905-2,159 mm). Those values were determined largely from low-altitude stations and therefore may be high when applied to the higher altitudes of the Virgin River basin. Nevertheless, evaporation rates throughout the area are sufficient to significantly reduce the availability of water for runoff and ground-water recharge and to significantly affect the consumptive use of both surface and ground water.

Figure 3.--Selected geohydrologic information in the upper Virgin River basin.

Figure 4.--Selected geohydrologic information in the upper Kanab Creek basin.

Figure 5.--Cumulative departure from average annual precipitation for the respective periods of record at climatologic stations in and near the study area.

Table 1.--Precipitation and temperature data for climatologic stations in the study area

[P, precipitation, in inches; T, temperature, in degrees Fahrenheit]

Station (see figs. 3 and 4)	1941-70 averages					
	Alton		Kanab		Zion National Park	
Altitude	7,040 feet		4,985 feet		4,050 feet	
	P	T	P	T	P	T
January	1.90	27.1	1.47	35.2	1.55	40.2
February	1.49	29.7	1.10	39.3	1.58	44.6
March	1.48	33.2	1.21	43.9	1.69	49.3
April	1.25	42.2	.89	52.1	1.27	58.0
May	.78	50.5	.60	60.6	.69	67.5
June	.64	58.4	.44	69.1	.62	76.7
July	1.43	66.2	.88	76.4	.84	84.2
August	1.94	64.5	1.55	74.4	1.57	81.8
September	1.23	58.0	.75	68.0	.80	75.7
October	1.19	48.2	.95	57.3	1.04	64.0
November	1.26	36.9	.96	45.1	1.16	50.4
December	1.79	29.5	1.41	36.9	1.55	41.6
Average annual	16.38	45.4	12.21	54.9	14.36	61.2
	1975-77 total annuals					
1975	14.45		13.02		13.58	
1976	12.24		9.63		8.66	
1977	11.53		7.30		12.23	

Culture and economy

The area was settled by the Mormon pioneers in the late 1850's. It is sparsely populated with widely scattered ranches and community centers, mostly along the perennial streams. Kanab, with a population of about 1,400 in 1975, is the largest community in the area. Agriculture, including irrigation and livestock grazing, provides the economic base. Irrigation is mainly by diversion from the Virgin River and Kanab and Johnson Canyon Creeks. The area is known for its scenic beauty and attractive setting for filming movies. These are also important to the local economy as are the area's large coal reserves.

GEOLOGIC SETTING

General characteristics of the rocks

Geologic units exposed in the upper Virgin River and Kanab Creek basins area are shown in figure 6 and described briefly in table 2. They range in age from Permian to Holocene and consist of consolidated and unconsolidated rocks. Sandstone is the dominant exposed rock type with progressively lesser amounts of unconsolidated rocks, siltstone, mudstone, shale, limestone, igneous rocks, conglomerate, and coal. Many of those rocks have been noted in drillers' logs of wells (table 20). Most of the sandstone units are loosely to moderately cemented and contain impurities such as weathered feldspar, as well as quartz sand grains. The Navajo Sandstone of Triassic(?) and Jurassic age is the most extensive sandstone formation in the area.

According to geologists who have worked in the area, the Navajo Sandstone ~~of Jurassic and Triassic(?) age~~ intertongues with the Kayenta Formation of Triassic age; two such tongues have been recognized. (See Averett and others, 1955.) The Lamb Point Tongue of the Navajo Sandstone, which directly overlies the Kayenta, is about 400 ft (120 m) thick in Kanab Creek canyon. It thickens easterly to about 520 ft (160 m) in Johnson Canyon and thins westerly to where it pinches out about 12 mi (20 km) southwest of Kanab. The Tenny Canyon Tongue, which is part of the Kayenta Formation (but considered as part of the Navajo Sandstone aquifer in this report), overlies the Lamb Point Tongue. It is about 120 ft (37 m) thick in Kanab Creek canyon and thins easterly to where it pinches out east of the study area. The main body of the Navajo overlies the Tenny Canyon Tongue where it consists of a lower red member and an upper white member. In the study area, the maximum thickness of the red member is 800 ft (240 m) and that of the white member about 1,000 ft (300 m).

Figure 6.--General geology of the upper Virgin River and Kanab Creek basins area.

Table 2.--Generalized geology, yields of ground-water sources, and chemical quality of ground water

Unit: See figure 6.

Approximate maximum thickness: Based partly on Gregory (1950 and 1951), partly on Hintze (1976), and partly on determinations made by the writer for this study.

Numbers rounded to one or two significant figures.

Type of material: Based partly on Gregory (1950 and 1951) and partly on field observations by the writer during this investigation.

Yields of wells and springs: Small 10 gal/min or less; moderate 10 to 100 gal/min; large 100 to 1,000 gal/min.

Water quality: Freshwater has a dissolved-solids concentration of less than 1,000 mg/L; slightly saline water 1,000 to 3,000 mg/L; moderately saline water 3,000 to 10,000 mg/L.

Geologic age	Unit	Approximate maximum thickness (feet)	Type of material	Yields of wells and springs	Water quality	Remarks
Quaternary	Basalt	500	Flow rock, pyroclastics, and black (some gray) cindercones	Small to large	Fresh to slightly saline	
	Valley fill	300	Unconsolidated sedimentary materials ranging from clay to boulders	do.	Fresh to moderately saline	Many irrigation and some public-supply wells are in this unit.
Tertiary	Wasatch Formation	1,300	Limestone and calcareous sandstone, conglomeratic at base; generally light colored	Small	Fresh	A major source of base flow.
Cretaceous	Kaiparowits Formation	750	Arkosic sandstone and sandy shale	Small to large	do.	Do.
	Wahweap Sandstone Straight Cliffs Sandstone	1,600	Buff, gray, or yellow sandstone (massive); minor shale	do.	Fresh to slightly saline	Do.
	Tropic Shale	1,500	Black shale, sandstone, and coal	Small to moderate	do.	
	Dakota Sandstone	100	Yellow and white sandstone; coal bearing	Unknown	do.	
Jurassic	Undivided; excludes Carmel Formation	1,400	Banded red and white sandstone, limestone, and gypsum	Small to moderate	do.	
	Carmel Formation	300	Limestone, sandstone, shale, and some gypsum	do.	Slightly saline	
Jurassic and Triassic(?)	Navajo Sandstone	2,000	Mainly quartzite but some arkosic reddish-brown and gray sandstone (massive-bedded, mainly fine grained, generally loosely cemented)	Small to large	Fresh	Many irrigation and most public-supply wells are in this unit. Dissolved-solids concentration of water produced generally less than 250 mg/L.
Triassic(?)	Kayenta Formation (exclusive of Tenney Canyon Tongue)	200	Siltstone, very fine to fine-grained sandstone, reddish-brown shale (minor)	Small to moderate	do.	
	Moenave Formation	400	Very fine to coarse-grained sandstone, siltstone, minor limestone, and light-reddish-brown, gray, and green conglomerate	do.	do.	
Triassic	Chinle Formation	1,200	Siltstone, shale, dark-red and purple sandstone	do.	Fresh to slightly saline	
	Shinarump Member of the Chinle Formation	130	Medium- to coarse-grained sandstone, white, gray, and yellow conglomerate (contains woody plant remains; generally loosely cemented)	Small to large	Fresh to moderately saline	Some irrigation and public-supply sources are in this unit.
	Moenkopi Formation	1,800	Siltstone, very fine grained sandstone, shale, gypsum, red, green, and purple limestone (minor)	Small to moderate	do.	
Permian	Kaibab Limestone	850	Limestone (massive), dolomite, gypsum locally, dark-gray chert locally	Small to large	do.	
	Undivided sequence in which the Coconino Sandstone is the thickest unit	1,800	White to gray sandstone (cross-bedded); some limestone	Unknown	Unknown	

Table 2

Petrographic analyses of selected rock samples (table 3) show that the Navajo Sandstone includes subarkoses (sandstone with significant feldspar) and orthoquartzite (sandstone with small amounts of feldspar and other minerals). Almost all the Navajo samples were poorly cemented, indicating generally poor cementation in much of the formation. This, along with local fracturing and jointing, contribute to the relatively high overall porosity and permeability of the Navajo compared to the other consolidated-rock units. However, well-cemented, poorly permeable horizons exist locally in the Navajo Sandstone aquifer (including the Lamb Point and Tenny Canyon Tongues) that impede vertical movement of ground water. This is indicated by springs that emerge from above those horizons.

General geologic structure

Geologic formations in the study area generally dip to the north, northeast, or northwest at angles of less than 5° (commonly about 3°) and from 5° to 10° adjacent to faults. The dips probably have some local control on the movement of ground water.

Faults, which also have some control on the movement of ground water, are common throughout the study area. Most are normal faults and strike northeasterly and northwesterly. They include the Hurricane, Sevier, and Paunsaugunt faults (fig. 6), which are of major scale in both length and vertical displacement. The Kanab Creek and Johnson Creek faults (fig. 6) were mapped by the writer during this study. Vertical displacement of the Kanab Creek fault probably does not exceed 100 ft (30 m) and that of the Johnson Creek fault probably does not exceed 200 ft (60 m).

Joints are common in the study area, and open joints are especially common in the sandstone formations like the Navajo Sandstone and the Shinarump Member of the Chinle Formation. However, jointing is not consistently well developed throughout the study area. Jointing seems to be more highly developed in the upper Virgin River basin than in the upper Kanab Creek basin. This is especially true of the Navajo which is highly jointed in Zion National Park.

Table 3.--Summary of petrographic analyses of selected rock samples

[Analyses by Core Laboratories, Inc., Dallas, Tex.]

Location: See data-site-numbering system.

Location	Rock unit	Rock type	Mineral content	Remarks
(C-41-5)13bcc	White member of the Navajo Sandstone	Siliceous submature subarkose	Mainly quartz; lesser amounts of feldspar, chert, calcite	Poorly cemented by authigenic quartz overgrowths, calcite and chert.
(C-41-8)25daa	do.	Supermature orthoquartzite	Mainly quartz; minor chert and feldspar	Poorly cemented by quartz overgrowths and authigenic chert
(C-42-5)2cdc	Red member of the Navajo Sandstone	do.	Mainly quartz; minor feldspar and rock fragments	Do.
23bbb	do.	Bimodal mature subarkose	Mainly quartz; minor feldspar and chert	Do.
26ccc	Lamb Point Tongue of the Navajo Sandstone	Submature subarkose	Quartz mainly, feldspar common, some chert	Poorly cemented by authigenic chert and minor secondary quartz and hematite
(C-42-6)30abb	Red member of the Navajo Sandstone	do.	Quartz and feldspar	Poorly cemented by authigenic quartz
31dac	Lamb Point Tongue of the Navajo Sandstone	Clayey bimodal submature subarkose	Mainly quartz; feldspar and authigenic clay common; some chert	Tightly packed grains with clay matrix
(C-42-7)10bdd	Red member of the Navajo Sandstone	Hematitic submature subarkose	Mainly quartz; feldspar and rock fragments common	Poorly cemented by specular hematite and dolomite, and secondary quartz overgrowths
(C-43-5)24abd	Moenave Formation	do	Mainly quartz and feldspar; some chert and rock fragments	Poorly cemented by specular hematite, secondary quartz overgrowths and a carbonate
(C-43-6)16bcd	do.	do.	Mainly quartz; feldspar common; some chert	Poorly cemented by specular hematite carbonate and secondary quartz overgrowths
(C-44-5)2aca	Shinarump Member of the Chinle Formation	Calcitic submature quartzarenite	Mainly quartz; some chert and feldspar	Partially cemented by authigenic quartz overgrowths and calcite

WATER RESOURCES

Precipitation

Based on a map showing 1931-60 normal annual precipitation in Utah (U.S. Weather Bureau, no date), the average annual volume of precipitation in the study area is about 2 million acre-ft (2,470 hm^3)--about 1,375,000 acre-ft (1,700 hm^3) in the upper Virgin River basin and 625,000 acre-ft (770 hm^3) in the upper Kanab Creek basin. Most of this precipitation is consumed by evapotranspiration and sublimation at or near the place of fall, some reaches streams as overland runoff, and some seeps deeply into the rocks where it enters the ground-water system.

Surface water

Runoff

As noted above, the study area is drained entirely by the Virgin River and Kanab Creek. Both streams receive most of their flow as snowmelt runoff from the high headwaters areas, but also receive significant flow from torential summer rains and influent ground-water seepage (base flow).

The U.S. Geological Survey operates a gaging station (09408150) on the Virgin River about 6.2 mi (10 km) west of Hurricane (and downstream from a number of irrigation diversions). Average annual gaged runoff at that station for 11 years of record between 1967 and 1978 was 302 ft^3/s (8.5 m^3/s). The peak recorded discharge was 17,300 ft^3/s (490 m^3/s), which occurred March 5, 1979 (U.S. Geological Survey, 1978, p. 230).

Runoff from the upper Kanab Creek basin also occurs mainly during the spring snowmelt period as indicated by the hydrographs in figure 7. However, instantaneous peak discharges of several hundred to more than 1,000 ft^3/s (30 m^3/s) have been recorded in the basin (table 4), commonly the result of summer cloudburst activity. Based on stream-channel-geometry measurements (Moore, 1968) in Kanab and Johnson Canyon Creeks near the Arizona-Utah State line, total mean annual runoff from the upper Kanab Creek basin into Arizona is on the order of 50,000 acre-ft (62 hm^3).

Figure 7.--Streamflow hydrographs of Mill, Skutumpah, and Thompson Creeks, 1976 and 1977 water years.

Table 4.--Maximum discharges at three partial-record (crest-gage) stations in the upper Kanab Creek basin, 1959-74

(Measurements by U.S. Geological Survey)

Date of maximum discharge	Discharge (ft^3/s)	Date of maximum discharge	Discharge (ft^3/s)
Kanab Creek at site (C-40-6)3a			
(Drainage area, approximately 72 square miles.)			
Mar. 1960	120	July 11, 1968	2,080
Sept. 8, 1961	1,300	Aug. 12, 1969	630
Feb. 12, 1962	780	Aug. 18, 1970	1,700
Sept. 18, 1963	1,600	July 30, 1971	1,370
Aug. 12, 1964	500	April 9, 1972	530
April 10, 1965	250	Oct. 11, 1973	1,140
July 30, 1966	290	1974	29
Dec. 6, 1966	1,240		
Johnson Canyon at site (C-43-4½)30c prior to 1960 and at site (C-43-4½)24d after 1960			
(Drainage area, 237 square miles.)			
Sept. 17, 1961	1,300[1]	Aug. 13, 1968	960
Sept. 28, 1962	1,200	Aug. 12, 1969	1,950
Aug. 19, 1963	1,540	Aug. 18, 1970	2,750
Oct. 18, 1963	1,100	July 20, 1971	2,100
April 9, 1965	65	Aug. 12, 1972	240
July 23, 1966	1,500	April 30, 1973	520
Sept. 25, 1967	2,000	1974	950

[1]Estimated.

Table 4.--Continued

Date of maximum discharge	Discharge (ft^3/s)	Date of maximum discharge	Discharge (ft^3/s)
Kanab Creek at site (C-43-6)5c			
(Drainage area, 198 square miles.)			
Aug. 3, 1959	160	Aug. 12, 1964	600
Sept. 6, 1960	2,100	Mar. 13, 1965	640
Sept. 8, 1961	3,030	Dec. 6, 1966	1,230
Feb. 12, 1962	1,400	July 7, 1968	1,300
Aug. 31, 1963	1,310		

Ground-water seepage to streams generally is the main source of flow (base flow) of perennial streams during dry summer months and periods of drought. As part of this study, measurements were made of the ground-water component of streamflow in the upper Virgin River and Kanab Creek basins (table 22). These measurements not only indicate low flows in perennial streams but are also useful in estimating ground-water recharge and discharge. Measurements during September-November are best for this purpose because (1) overland runoff is at a minimum, (2) consumptive use of ground water is at a minimum, and (3) ice has not yet formed in streams to affect measurements.

Figure 8 shows average monthly low flow in North Fork Virgin River at site (C-41-10)22bc as estimated from streamflow measurement made at U.S. Geological Survey gaging station 09405500 at site (C-41-10)22bc. According to those estimates, ground water contributes as much as 43 percent of the average annual flow of the stream at that site.

Chemical quality

Dissolved-solids concentrations of surface water in most parts of the study area are generally less than 1,000 mg/L (milligrams per liter) during both high and low flow periods. (See Price, 1980.) The dissolved-solids concentrations in the headwaters of both the Virgin River and Kanab Creek are generally less than 250 mg/L, but increase to more than 500 mg/L in the lower stream reaches during low flow periods. Principal sources of the dissolved solids are shale and siltstone strata of Triassic and Cretaceous age over which the streams flow, and influent seepage of ground water from those strata.

Dissolved-solids concentrations in the reach of the Virgin River that cuts through the Hurricane Cliffs commonly exceed 1,000 mg/L. This is due chiefly to inflows from La Verkin Hot Springs (table 21) which contain more than 9,000 mg/L of dissolved solids. The reach of Kanab Creek downstream

Figure 8.--Average monthly log flow (1937-76) of the North Fork Virgin River at site (C-41-10)22bc.

from Kanab also commonly contains more than 1,000 mg/L of dissolved solids owing largely to return flows and influent seepage from the Chinle and Moenkopi Formations. Selected chemical analyses of base flow at several sites in the project area are given in table 23.

Ground water

General conditions of occurrence

Water occurs in both the consolidated and unconsolidated rocks that underlie the upper Virgin River and Kanab Creek basins. In most of the consolidated rocks, the water occupies open joints and fractures. In the unconsolidated rocks and some of the poorly cemented consolidated rocks, such as parts of the Navajo Sandstone and Shinarump Member of the Chinle Formation, the water occupies intergranular spaces.

The regional water table in the study area is generally at or near the base level of the most deeply incised perennial streams. The rocks that extend beneath the regional water table are in the main zone of saturation--that is, all available pore space in those rocks contain water and comprise the main ground-water reservoir in the area. The rocks that extend above the regional water table contain only local perched ground-water bodies. In the unconsolidated rocks the perched ground water accumulates above poorly permeable clay strata or consolidated rock on which the unconsolidated rocks lie. In the consolidated rock the perched water accumulates generally in fractured or poorly cemented sandstone above shale or other poorly permeable rock strata. There are numerous perched ground-water bodies throughout the study area, but because of their limited extent and limited recharge most are not capable of sustaining large withdrawals from wells or the flow of large springs.

Unconsolidated-rock aquifers

Unconsolidated rocks contain important aquifers in several areas (table 5). Most of these aquifers are in stream deposits, including alluvial fans and older stream-channel deposits. Alluvial fans attain significant proportions when formed at the base of high escarpments such as the Vermillion Cliffs. However, the potential for development of ground water in the alluvial fans is not significant because the upper parts of those fans are generally above the regional water table and generally unsaturated. Also, their lower parts, where saturated, yield water slowly to wells. For example, several wells in the higher part of the Vermillion Terrace (in sec. 30, T. 43 S., R. 4 W.) penetrated at least 50 ft of dry alluvial-fan deposits before encountering water in the underlying consolidated rock. The wells that tap the saturated fan deposits at lower altitudes generally have small yields.

Older stream-channel deposits occur beneath fine-grained surficial deposits in several parts of the study area (table 5). Aquifers in those deposits probably have greater potential for development by wells than do the alluvial fans, because in most cases the older stream-channel deposits extend beneath the regional water table and are fully saturated.

Two aquifers in older stream-channel deposits exist in the lowland between the Vermillion Cliffs and the Shinarump Cliffs. They are in the channels of Kanab Creek near Kanab and Johnson Canyon creek near Crescent Butte (fig. 4). The aquifer near Crescent Butte is in about 150 ft (46 m) of alluvium consisting largely of sand and gravel. This aquifer would not have been known without drilling of wells, because it is concealed beneath a mantle of fine-grained alluvial-fan and aeolian deposits. The deposits that form this aquifer were apparently laid down by an ancestral stream in Johnson Canyon that was much larger than the present stream. This ancestral stream apparently meandered over a large area, because the deposits are known to underly an area of several square miles. Those deposits yield as much as 250 gal/min (16 L/s) of water to individual wells.

Table 5.--Generalized descriptions of the principal unconsolidated-rock aquifers

Remarks: *Freshwater has a dissolved-solids concentration* of less than 1,000 mg/L, slightly saline water 1,000 to 3,000 mg/L, and moderately saline water 3,000 to 10,000 mg/L.

General location (See figs. 5 and 6)	Approximate maximum depth to water (feet)	Approximate maximum saturated thickness (feet)	Yields of wells (gal/min)	Remarks
Upper Johnson Canyon drainage	40	100	Reportedly several hundred	Deposit formed by alluviation at the confluence of Thompson, Skutumpah, and Red Wash Creeks. Water is fresh.
Lower Johnson Canyon	100	100	Inferred to be less than 100	Deposit formed by alluviation in a modern stream valley. Water is fresh.
Vermillion Cliffs - Shinarump Cliffs area	50	100	As much as 400 reported near the mouth of Johnson Canyon	Some deposits formed in buried channels of ancient perennial streams and some in alluvial fans. Water is fresh to moderately saline.
Valleys of the Virgin River and its main forks	60	70	Measured maximum 240	Deposit formed by alluviation in a modern stream valley. Water is fresh to slightly saline.
Hildale area	30	70	Reportedly about 200	Deposit formed by alluviation in a modern stream valley. Water is probably fresh.
Little Plains area of Gould Wash	150	200	Ranges from less than 100 to more than 600	Deposit formed in buried channel of ancient perennial stream. Water is probably fresh to slightly saline.

The older stream-channel deposits in Kanab Creek near Kanab apparently were laid down under similar conditions as those in Johnson Canyon near Crescent Butte. The deposits in Kanab Creek also consist largely of sand and gravel but are only on the order of 100 ft (30 m) thick. Although several wells tap these deposits, additional study will be required to ascertain the extent and development potential of the aquifer therein. Well (C-43-6)27dbd-1 (table 18) which taps the aquifer and the underlying Chinle Formation had a measured yield of 50 gal/min (1.4 L/s), but it is not known what percentage of that yield was from the older stream-channel deposits.

There are other unconsolidated deposits throughout the study area that may contain potentially productive aquifers. Such deposits underlie the upper Skutumpah Creek drainage area, the alluvial plains of the Virgin River, Short Creek near Hildale, Gould Wash, and Johnson Canyon upstream from the deposits near Crescent Butte.

The deposits that underlie the upper Skutumpah Creek drainage (in secs. 29-32, T. 40 S., R. 4½ W., and secs. 5 and 6, T. 41 S., R. 4½ W.) are basinlike but have fingerlike extensions into Thompson and Skutumpah Creeks which have wide flat alluvial plains. The deposits underlie 2-3 mi^2 (5-8 km^2) as determined from field reconnaissance. Their total thickness, based on data from only a few wells, is on the order of 100 ft (30 m) and may be greater locally. Depths to water in the deposits are less than 40 ft (12 m), but data from wells in the area indicate that the water is perched--that is, underlain by unsaturated rock.

The alluvial plain of East Fork Virgin River is generally less than 0.25 mi (0.4 km) wide from Long Valley Junction to near Rockville, although there are a few wider but short reaches where farming communities have become established. The alluvial plain of North Fork Virgin River is less than 0.20 mi (0.3 km) wide upstream from the confluence of Pine Creek but is generally wider downstream near Rockville. From Rockville to near Virgin, the alluvial plain of the main stem of the Virgin River is generally between 0.25 and 0.40 mi (0.4-0.6 km) wide. Below Virgin there is a narrow, steep-walled canyon containing little alluvial material.

The thickness of alluvium in the valleys of the Virgin River and its main forks is not uniform, differing considerably in short distances, but the general range is 30-100 ft (9-30 m). There does not seem to be any direct relation between thickness and distance downstream. For example, along East Fork Virgin River a well north of Alton Junction penetrated 105 ft (32 m) of alluvium, and one at Mount Carmel Junction penetrated 200 ft (61 m), but in the main stem at Grafton a well penetrated only 55 ft (17 m) of alluvium. The few available well-drillers' reports also indicate that there is no increase or decrease of coarse materials in a downstream direction. However, lateral differences in grain size probably exist because in alluvial deposits sequences of coarse materials commonly abut against sequences of fine materials in the stream-meander belt.

Short Creek valley near Hildale is underlain by an alluvial deposit, which according to a few available well logs, is less than 100 ft (30 m) thick and contains mainly sand. The reported relatively high yields of existing wells (table 18) indicate that this deposit probably has a more promising potential for additional development than does the underlying consolidated rocks which probably contain saline water.

Big and Little Plains in the valley of Gould Wash are underlain by unconsolidated materials of significant thickness. Drillers' logs of several wells indicate that their thickness increases from generally less than 100 ft (30 m) near the drainage divide (in secs. 9, 10, 16-18, T. 43 S., R. 11 W.) downvalley to nearly 300 ft (91 m) in sec. 19, T. 42 S., R. 11 W. Further downvalley from sec. 19 the thickness apparently decreases to less than 200 ft (61 m) in sec. 23, T. 42 S., R. 13 W. These changes in thickness are probably a result of faulting which has downdropped the Shinarump Member of the Chinle Formation on the southwest side of the valley or to erosion by ancestral streams which cut their channels more deeply in some places than in others.

The unconsolidated deposits that underlie Johnson Wash upstream from Crescent Butte are apparently less than 150 ft (46 m) thick. Only a few wells have been drilled into these deposits, and these are only in T. 42 S., R. 5 W. There is no apparent reason why these deposits should not extend downstream from the reach where wells have already been drilled and connect with the above-mentioned older stream-channel deposits in the Crescent Butte area. It is possible that faulting has been responsible for localizing thick deposits in the canyon, and perhaps test drilling or geophysical exploration could determine their location. The maximum well yield is not known but perhaps is measurable in hundreds of gallons per minute as in the Crescent Butte area.

Consolidated-rock aquifers

There are a number of consolidated-rock aquifers in the upper Virgin River and Kanab Creek basins that have potential for development. Of these, the Navajo Sandstone is by far the most important. This formation is the thickest, has the largest area of outcrop, and is tapped by more large-yield wells than any other consolidated-rock formation. Its maximum thickness is on the order of 2,000 ft (610 m). Its area of outcrop in the upper Kanab Creek basin is about 280 mi^2 (725 km^2) and in the upper Virgin River basin about 297 mi^2 (770 km^2).

The other consolidated-rock aquifers, although developed by relatively few wells, contribute to the flow of many springs and the base flow of perennial streams. They include chiefly the Wasatch Formation, sandstone strata in the Kaiparowits Formation, the Wahweap and Straight Cliffs Sandstones, the Shinarump Member of the Chinle Formation and, locally, basalt and the Kaibab Limestone.

The rate of discharge from wells and springs in the consolidated-rock aquifers differs considerably from area to area. The large range in discharge results mainly from the movement of water in open fracture systems. These fracture systems differ widely in the size and number of individual fractures in a given section of rock and in the degree of interconnection of these fractures. Hard, brittle rocks, such as basalt and quartzitic sandstone, generally tend to have larger and more extensive fracture systems than do softer, less brittle rocks, such as shale. Also, some rocks, such as the Navajo Sandstone, locally contain a significant amount of intergranular openings through which water moves between fractures.

Hydrologic properties of aquifers

Hydrologic properties, such as porosity, permeability, transmissivity, and storage coefficient of aquifers determine the ability of those aquifers to receive, store, and transmit water. They also help to predict the effect of discharging wells on water levels in other wells, and on springs and streams. These properties are defined as follows:

Porosity (n). The property of containing interstices or voids, generally expressed as the percent of a unit volume of rock or aquifer occupied by voids. Effective porosity refers to the amount of interconnected voids through which fluids can be transported and is expressed as a percent of a unit volume of rock or aquifer occupied by interconnected voids.

Permeability (hydraulic conductivity, K) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient. The units for K are cubic feet per day per square foot $[(ft^3/d)/ft^2]$, which reduces to ft/d. The term hydraulic conductivity replaces the term field coefficient of permeability, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per square foot. To convert to value for field coefficient of permeability to the equivalent value of hydraulic conductivity, divide by 7.48; to convert from hydraulic conductivity to coefficient of permeability, multiply by 7.48.

Transmissivity (T) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units for T are cubic feet per day per foot [$(ft^3/d)/ft$], which reduces to ft^2/d. The term transmissivity replaces the term coefficient of transmissibility, which was formerly used by the U.S. Geological Survey and which was reported in units of gallons per day per foot. To convert a value for coefficient of transmissibility to the equivalent value of transmissivity, divide by 7.48; to convert from transmissivity to coefficient of transmissibility, multiply by 7.48.

Storage coefficient (S) of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in head. S is a dimensionless number. Under confined conditions, S is typically small, generally between 0.00001 and 0.001. Under unconfined conditions, S is much larger, typically from 0.05 to 0.30.

Tables 6-8 include values for selected aquifer properties of rocks (mostly consolidated) that comprise aquifers in the study area as determined from laboratory analyses of formation samples, geophysical logs, and field aquifer tests.

Porosity of an aquifer is an important determinant of the permeability, transmissivity, and storage capacity of the aquifers. An important determinant of the porosity of a sandstone such as the Navajo is the degree of sorting of the individual sand grains, especially where poorly cemented. The more uniform the sorting, the greater the porosity, and in turn, the greater the permeability, transmissivity, and storage capacity--depending, of course, on the degree of cementation. As shown in figure 9, the sand grains of the Navajo where sampled are well-sorted, indicating that the formation where poorly cemented has a high porosity. According to the laboratory analyses given in table 6 and the electrical logs of wells (table 7), the median value for porosity of the Navajo is about 30 percent.

Figure 9.--Particle-size distribution of selected rock samples.

Table 6.--Porosity and permeability of selected surficial rock samples determined by laboratory analysis

(Analyses by Core Laboratories, Inc., Dallas, Tex.)

Location: See data-site-numbering system.
Porosity: Total porosity determined for an overburden pressure of 500 lbf/in^2.
Permeability: H, horizontal; V, vertical.

Location	Rock unit	Porosity (percent)	Permeability (K) (ft/d)	
			Horizontal	Vertical
(C-41-5)13bcc	White member of the Navajo Sandstone	25.2	3.42	1.99
(C-41-8)25daa	do.	24.4	1.85	5.00
(C-42-5)23bbb	Red member of the Navajo Sandstone	27.8	4.25	2.21
26ccc	Lamb Point Tongue of the Navajo Sandstone	30.1	--	--
(C-42-6)30abb	Red member of the Navajo Sandstone	27.2	4.47	4.59
31dac	Lamb Point Tongue of the Navajo Sandstone	15.0	.0018	.0053
(C-42-7)10bdd	Red member of the Navajo Sandstone	30.5	6.1	4.54
Median (rounded)		30.0	3.8	3.40
(C-43-5)24abd	Moenave Formation	23.7	.68	.26
(C-43-6)15bcd	do.	21.1	.068	.12
Median (rounded)		20.0	--	--
(C-44-5)2aca	Shinarump Member of Chinle Formation	22.4	--	--

Table 7.--Estimated total formation porosity at selected wells as determined from electrical logs

Location: See data-site-numbering system.

Location	Rock unit	Porosity (percent)
(C-40-5)16cdc-1	Navajo Sandstone	20
	Tenny Canyon Tongue of the Kayenta Formation[1]	24
	Lamb Point Tongue of the Navajo Sandstone	28
(C-42-6)19baa-1	Red member of the Navajo Sandstone	40
Median (rounded)		30
(C-43-5)36cab-1	Shinarump Member of the Chinle Formation	20
	Moenkopi Formation	15
(C-43-5)36ccc-1	Chinle Formation	8

[1]For purposes of this investigation, it is considered to be hydraulically a part of the Navajo Sandstone.

Table 8.--Results of aquifer tests in the upper Kanab Creek basin

Location: See data-site-numbering system.

Location	Use of well during test	Aquifer tested	Average discharge of pumped well (gal/min)	Length of test (hrs)	Maximum drawdown (ft)	Transmissivity (ft^2/d)	Storage coefficient (nondimensional)
([illegible]-5)11bdb-1	Pumped	Navajo Sandstone	600	100	28.2	5,900	--
26ccc-2	Observation	do.	530	307	2.55	7,400	1.2×10^{-2}
26cda-2	Pumped	do.	450	46	73.18	14,000	--
27aaa-1	do.	do.	370	49	40.10	13,000	--
27add-2	Observation	do.	90	53	3.74	2,500	1.2×10^{-3}
(C-42-6)19bdc-1	do.	do.	370	119	4.2	5,300	2.4×10^{-3}
19bdc-2	Pumped	do.	370	119	61.65	4,200	--
30dca-2	do.	do.	520	110	37.69	5,200	--
(C-43-4½)32aad-1	do.	Mainly Shinarump Member of the Chinle Formation	300	8	171	1,000	--
(C-43-5)36cab-1	do.	Shinarump Member of the Chinle Formation	270	24	85.51	900	--
(C-44-5)2aba-1	do.	do.	90	24	18.2	6,800	--
2bad-2	Observation	do.	30	119	.54	2,800	8×10^{-3}

Generally porosity of a formation decreases with depth, owing largely to a greater degree of compaction of the rock with depth. As figure 10 shows, the porosity of the Moenkopi Formation where tapped by well (C-43-5)36cab-1 decreases significantly with depth. This probably is due to increased compaction of the shaly layers in this formation with depth but could also be due to facies changes in the formation. The apparent small increase in porosity of the Navajo Sandstone with depth at well (C-40-5)16cdc-1 shown in figure 10 cannot easily be explained. It possibly could be due to local breakdown in cementation with depth in the formation.

Laboratory determinations of permeability (table 6) can be used to estimate transmissivity of aquifers in areas where aquifer-test data are not available, but where the aquifer thickness is known. This may be done by multiplying the aquifer thickness by the average of the horizontal and vertical permeabilities.

Figure 11 shows the relation between horizontal permeability and the 10-percentile particle-size diameter of selected rock samples. The straight-line relation shown for the Navajo Sandstone samples can be used to estimate horizontal permeability of the Navajo, using any mechanical analyses of unweathered samples from the formation. This seems viable because of the relative uniformity in particle size (fig. 9) and high permeability of the Navajo compared to most other formations.

Figure 10.--Relation between porosity and depth for two aquifers in the upper Kanab Creek basin.

Figure 11.--Relation of horizontal permeability to the 10-percentile particle-size diameter of selected rock samples.

Results of the 12 aquifer tests conducted during this study are summarized in table 8. As shown, most of the tests involved the Navajo Sandstone and exceeded 24-hours duration. Those tests indicate that transmissivity of the Navajo ranges from 2,500 to 14,000 ft^2/d (230 to 1,300 m^2/d). The higher values probably reflect the thick saturated thickness (up to 2,000 ft, or 610 m) of the Navajo in the test areas. Storage coefficients for the Navajo ranged from 1.2×10^{-3} to 1.2×10^{-2}. Rounded median values of transmissivity and storage coefficients of the Navajo are 6,000 ft^2/d (600 m^2/d) and 2×10^{-2}. These values were used to determine possible effects of increased ground-water development as discussed in a later section of this report.

Transmissivities of the Shinarump Member of the Chinle Formation as determined from four aquifer tests ranged from 900 to 6,800 ft^2/d (80 to 630 m^2/d). The only value for storage coefficient determined for that aquifer was 8×10^{-3}.

The specific capacity of a well is an important indicator of the ability of an aquifer to yield its water. However, it can only be used in a general way because the construction of a well and the development of the aquifer have a significant influence on the accuracy of the value determined. Theoretically, specific capacity of a well is directly related to the transmissivity of the aquifer. The specific capacities of selected wells in the study area are compiled in table 9. The values have different accuracies, but the range of values and the order of magnitude are revealing and pertinent. Where several values are available for an aquifer, the range is large. For example, the range for the Navajo Sandstone is 0.03 to 23 (gal/min)/ft [0.006 to 4.8 (L/s)/m]; the range for the Shinarump Member is 0.3 to 10.5 (gal/min)/ft [0.06 to 2.2 (L/s)/m]; the range for the unconsolidated rocks is 0.04 to 12 (gal/min)ft [0.008 to 2.5 (L/s)/m]. The large range indicates that the water-yielding ability of the aquifer also is considerably different from place to place.

Table 9.--Specific capacities of selected wells

Location: See data-site-numbering system.
Specific capacity: p, determined for a 24-hour pumping period; other values determined for shorter pumping periods.
Scurce of data: D, driller; G, Geological Survey; O, owner.

Location	Principal aquifer	Specific capacity [(gal/min)/ft]	Source of data
	KANAB CREEK DRAINAGE BASIN		
(C-41-5)5aaa-1	Carmel Formation	1	D
(C-42-5)11bdb-1	Navajo Sandstone	23p	G
15bdc-1	do.	9	D
23bbb-1	do.	.7	D
26ccc-1	do.	5	D
26ccc-2	do.	11	D
26cda-2	do.	6.2p	G
27aaa-1	do.	10.3p	G
34dbb-1	do.	13.3	G
(C-42-6)19bdc-1	do.	.8	G
19bdc-2	do.	5.9p	G
30cda-2	do.	16.3p	G
(C-43-4)30dba-1	Shinarump Member of the Chinle Formation	.5	D
(C-43-4½)19cbc-1	Unconsolidated rocks	12	D
32aad-1	Shinarump Member of the Chinle Formation	2	G
33abb-1	do.	7	O
(C-43-5)2bbd-1	Navajo Sandstone	1.6	D
24dca-1	Chinle Formation	5.7	O
25aaa-1	Unconsolidated rocks	2.7	O
25acd-1	do.	5.8	O
25cdb-2	do.	4	O
35aaa-1	Shinarump Member of the Chinle Formation	.08	G
36acd-1	Unconsolidated rocks	.04	G
36cab-1	Shinarump Member of the Chinle Formation and Moenkopi Formation	3.2	G
(C-43-6)9ccc-1	Moenave Formation	.2	D
27dbd-1	Unconsolidated rocks and Chinle Formation	1	D
(C-43-7)12bdb-1	Navajo Sandstone	.3	O
16bcc-1	do.	.03	G
16bdd-1	do.	1.8	G
16dba-1	do.	2.9	G

Table 9.--Specific capacities of selected wells--continued

Location	Principal aquifer	Specific capacity (gal/min)/ft	Source of data
	KANAB CREEK DRAINAGE BASIN--continued		
(C-43-8)34bbb-1	Navajo Sandstone	0.4	G
(C-44-5)2aba-1	Shinarump Member of the Chinle Formation	4.9p	G
2bad-1	do.	.3	O
2bad-2	do.	.7	G
	UPPER VIRGIN RIVER AREA		
(C-39-6)4cad-1	Wasatch Formation	3.3	D
(C-40-11)29bbd-1	Chinle Formation	.7	D
(C-41-7)4aaa-1	Unconsolidated rocks	9	D
30bba-1	Navajo Sandstone	2	D
(C-41-9)15ddb-1	do.	.5	D
(C-42-10)7acb-1	Shinarump Member of the Chinle Formation	.3	O
7bdd-1	do.	1.3	D
(C-42-11)4aaa-1	Unconsolidated rocks	.6	D
19ccc-2	Unconsolidated rocks and Moenkopi Formation	1.5	G
19ccc-3	do.	.8	D
30bad-1	do.	2	D
(C-42-12)11aac-1	Shinarump Member of the Chinle Formation	10.5	O
23daa-1	Unconsolidated rocks and volcanic rocks	5.5	G
23dab-1	Unconsolidated rocks	8.4	O
(C-43-10)23ddd-1	do.	3.8	D
34add-1	do.	4.4	D

The order of magnitude of the specific capacity of the wells tapping aquifers for which several values are available can be compared by using averages. The rounded average for the Navajo Sandstone is 6 (gal/min)/ft [1.2 (L/s)/m], for the unconsolidated rocks is 5 (gal/min)/ft [1.0 (L/s)/m], and for the Shinarump Member is 3 (gal/min)ft [0.62 (L/s)/m]. More of the specific capacities of the wells in the Navajo have a greater degree of accuracy because they were determined by controlled well-performance tests. The fact that the average is higher than the average for the unconsolidated rocks is a strong indication of the relatively high water-yielding potential of the Navajo.

Recharge

Natural recharge of ground water in the upper Virgin River and Kanab Creek basins is mainly by infiltration of precipitation and seepage losses from streams--mostly in areas where altitudes exceed 6,000 ft (1,830 m) and average annual precipitation exceeds 12 in. (305 mm). These areas include the headwaters of both the Virgin River and Kanab Creek. Here, water from rainstorms, melting snow, and streams seeps into jointed and fractured Cretaceous and Tertiary rocks and unconsolidated deposits that locally mantle those rocks. Some of this water eventually enters the older rocks including the Navajo Sandstone. Recharge also takes place locally at altitudes lower than 6,000 ft (1,830 m) where such relatively permeable formations as the Navajo, Shinarump Member of the Chinle Formation, the Kaibab Limestone and Tertiary basalt are exposed.

The average annual volume of ground-water recharge in the study area was estimated by a method in which the ratio of base flow to precipitation in selected drainage subbasins is determined and then applied to the entire area. (See Cordova and others, 1972, p. 11.) This method assumes that all recharge in each subbasin comes from precipitation in the subbasin and that all the recharge is measured as base flow in the subbasin. The base flow, determined during periods when phreatophytes are essentially dormant, is also assumed to be constant throughout the year. The ratio of base flow to precipitation in the study area was determined to be 0.04 based on the information given in table 10. Using this value, average annual ground-water recharge was estimated to be about 80,000 acre-feet (100 hm^3) broken down as follows:

Drainage basin	Average annual precipitation (acre-feet)	Average annual ground-water recharge (acre-feet)
Upper Virgin River	1,375,000	55,000
Upper Kanab Creek	625,000	25,000
Total		80,000

An unknown, but significant volume of ground water enters the study area as subsurface flow from the upper Sevier River basin (which adjoins the study area on the north). The water seeps from Navajo Lake (in the Sevier River basin) and flows through solution cavities in the Wasatch Formation to areas of discharge, such as Cascade Springs (table 21), in the upper Virgin River basin. (See Wilson and Thomas, 1964.)

Table 10.--Relation between precipitation and base flow in selected drainage basins

Area of drainage basin: Determined from topographic maps.
Average annual precipitation: Estimated from U.S. Weather Bureau (no date).

Drainage basin	Area of drainage basin (acres)	Average annual precipitation (acre-feet)	Average annual base flow (acre-feet)	Period of base flow record	Ratio of base flow to precipitation
Kanab Creek[1]	109,000	128,000	5,100[2]	1976-77	0.04
Thompson Creek[3]	6,140	10,400	220[4]	1975-77	.02
Mill Creek[5]	3,140	5,270	220[4]	1975-77	.04
Arithmetic mean weighted according to area of drainage basin					.04

[1]Measurement sites (C-42-6)32aca and (C-38-5)33bdd. Flows at these sites are summed.
[2]Average base flow estimated from measurements (table 22) to be 7 ft^3/s.
[3]Measurement site (C-40-5)13bdb.
[4]Average base flow estimated from stream-gage record to be 0.3 ft^3/s.
[5]Measurement site (C-40-4½)6add.

Movement

In the upper Virgin River and Kanab Creek basins, ground water generally moved from principal recharge areas in the northern highlands southward to areas of natural discharge along the lower reaches of the larger streams. This is shown for the upper Kanab Creek basin by the potentiometric-surface contours in figure 4 and is inferred in the upper Virgin River basin on the basis of a few water-level records, ground-water-discharge measurements, and field observations. Except for the above mentioned movement of water from Navajo Lake (in the Sevier River basin) to the upper Virgin River basin, there is no significant movement of ground water into the study area from adjacent drainage basins, nor is there any indication of interbasin movement of ground water between the upper Virgin River and Kanab Creek basins within the study area. Figure 12, which is based on relatively few data, shows that the ground-water divide between the upper Virgin River and Sevier River basins is slightly south of the topographic divide between the two basins. This suggests that there is some natural movement of ground water from the upper Virgin River basin northward to the Sevier River basin. However, more accurate topographic and water-level data probably would show that the ground-water and topographic divides actually coincide with little or no interbasin flow of ground water.

Figure 12.--Profile of the potentiometric surface at the divide between the upper Virgin River and Sevier River basins.

The general southward gradient of the potentiometric surface in the Kanab Creek basin (fig. 4) apparently continues into Arizona as indicated by higher altitudes of water levels in wells in Utah compared to water levels in wells in Arizona. For example, the water level in well (C-44-6)5cdd-1 is about 10 ft (3.0 m) higher than the water level in a well 0.7 mi (1.1 km) to the south in Arizona. In the Virgin River basin, there is a westerly component of ground-water flow toward the Hurricane Cliffs. This is evidenced by water-level contours in Gould Wash (fig. 3) that show a downvalley ground-water gradient. Also geohydrologic data in the central Virgin River basin (Cordova and others, 1972) show that ground water moves across the Hurricane Fault from the east.

Discharge

Annual discharge of ground water in the upper Virgin River and Kanab Creek basins at the 1977 level of development is estimated to be at least 71,000 acre-ft (90 hm^3) as shown in the following table:

Type of discharge	Annual rate (acre-feet)	
	Upper Virgin River basin	Upper Kanab Creek basin
Seepage to streams	42,000	8,000
Evapotranspiration	4,000	6,000
Springs	1,940	800
Withdrawal from wells	1,260	2,000
Subsurface outflow	Unknown	5,000
Totals (rounded)	49,000	22,000

The difference in the estimates of recharge and discharge results from inherent inaccuracies in the methods used to arrive at the two figures. It does not represent an imbalance between ground-water recharge and discharge.

Seepage to streams

Seepage of ground water into stream channels (base flow) is the principal means of ground-water discharge in the study area. Most of this discharge is from the main zone of saturation but some is also from perched aquifers. The above estimates were made from measurements of base flow given in table 22 and summarized in table 11.

Although the total estimate --50,000 acre-ft (62 hm^3) per year-- of seepage to streams is based only on 1 year of base-flow measurements, it probably approximates the long-term annual averages. This is because, except locally, ground-water recharge and discharge (including seepage to streams) are in equilibrium over the long term.

Evapotranspiration

Evapotranspiration of ground water takes place mainly in areas of phreatophyte growth; these are areas where ground water occurs at or within a few feet of the land surface. Such conditions prevail chiefly in and next to the alluvial plains of the perennial streams. Field reconnaissance showed that the common phreatophytes in the study area include cottonwood (*Populus* sp.), saltcedar (*Tamarix gallica*), willow (*Salix* sp.), and meadowgrass (*Festuca* sp.). Locally important are greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus* sp.), and Russian-olive (*Elaeagnus angustiofolia*). The general areas of phreatophytic growth are shown in figures 3 and 4. The extent of the areas was determined with the aid of aerial photographs taken in September 1967 and by field reconnaissance in 1977.

Table 11.--Estimated average annual seepage of ground water to streams in the upper Kanab Creek basin, 1977 (estimated from data in table 22)

Stream	Average annual seepage: Cubic feet per second (rounded)	Average annual seepage: Acre-feet (rounded)	Geologic source
Kanab Creek	5.1	3,700	Navajo Sandstone
Do.	1.7	1,230	Kayenta, Moenave, and Chinle Formations
Tiny Canyon creek	.11	80	Navajo Sandstone and Kayenta Formation
Hog Canyon creek	.22	160	Do.
Johnson Canyon creek	.64	460	Navajo Sandstone
Do.	.26	190	Kayenta, Moenave, and Chinle Formations
Do.	.25	180	Shinarump Member of Chinle Formation and Moenkopi Formation
Rush Canyon creek	.09	65	Formations of Cretaceous age
Three Lakes Canyon creek	.074	53	Navajo Sandstone
Cave Lakes Canyon creek	.25	180	Do.
Water Canyon creek	.10	72	Do.
Mill Creek	.24	170	Formations of Cretaceous age
Thompson Creek	.23	168	Do.
Kanab Creek main fork	1.8	1,300	Do.
Totals (rounded)	11	8,000 1/	

1/ About 60 percent of the seepage is from the Navajo Sandstone; about 70 percent is from the main zone of saturation.

Saltcedar is a phreatophyte of special interest because it uses large amounts of ground water and spreads rapidly. This plant, according to reports of local residents, has been in the Kanab Creek basin for at least 50 years. Today, it is still in all the major stream valleys of the study area. Russian-olive was introduced into the Kanab Creek basin for windbreaks in the 1940's. Today, single trees or small stands are seen throughout the area. Estimated evapotranspiration of ground water by these and other plants in various parts of the study area are given in table 12.

Springs

Numerous individual springs and seeps occur throughout the study area, especially in those areas where altitudes exceed 8,000 ft (2,440 m). Most of the springs issue from the main zone of saturation and are dependable perennial sources of water; some issue from perched aquifers and may dry up in late summer or during periods of drought.

Most of the spring discharge is directly into stream channels; the annual amount is included in the foregoing estimate of seepage to streams (as base flow). Some of the spring discharge is also included in the foregoing estimates of evapotranspiration. Spring discharge not included in the estimates of seepage to streams or evapotranspiration totals nearly 3,000 acre-ft (3.2 hm^3) per year. This estimate was made by multiplying the estimated total number of individual springs in the area (determined from field reconnaissance, topographic maps, and records of the Utah State Engineer) by the mean discharge (about 2 gal/min or 0.13 L/s) of the representative springs listed in table 21. The flow of those springs is used chiefly for public supply (table 13), livestock, wildlife, and recreation.

Table 12.--Estimated evapotranspiration of ground water

Locality (see figs. 3 and 4)	Area (acres) Total	Area (acres) Adjusted to 100-percent density	Principal phreatophyte	Annual evapotranspiration Feet	Annual evapotranspiration Acre-feet (rounded)
		Upper Virgin River basin			
Virgin River including North and East Forks	2,300	800	Trees[1], meadowgrass	4	3,200
Lydias and Stout Canyons	300	300	Meadowgrass, trees	2	600
Gould Wash	40	20	Trees	4	80
Hildale area	20	5	Trees	4	20
Totals (rounded)	2,700	1,100	-	-	4,000
		Upper Kanab Creek basin			
Sink Valley	1,600	1,200	Meadowgrass	1.5	1,800
Johnson Canyon	300	300	Meadowgrass, trees	4	1,200
Hamblin area	350	260	Greasewood	4	1,000
Kanab Creek, Kanab area	440	200	Meadowgrass, saltcedar	4	800
Kanab Creek near Alton	480	360	Meadowgrass, rabbitbrush	2	700
Johnson Lakes and Flood Canyons	20	20	Meadowgrass, saltcedar	4	80
Cottonwood Canyon	50	10	Cottonwood	4	40
Tenny Canyon	40	40	Meadowgrass	1.5	60
Three Lakes Canyon	20	20	Meadowgrass	1.5	30
Totals (rounded)	3,300	2,400	-	-	6,000

1/Include cottonwood, willow, and Russian-olive.

Table 13.--Springflow used for public supply, 1977

Community	Average daily flow (cubic feet per second)	Yearly total (acre-feet, rounded)	Geologic source
	Upper Virgin River basin		
Orderville	0.13[1/]	95	Sandstone of Cretaceous age
Rockville	.008[1/]	6	Shinarump Member of the Chinle Formation
Springdale	.13[1/]	95	Navajo Sandstone
Virgin	.016[1/]	12	Moenkopi Formation
Zion National Park	.5[1/]	360	Navajo Sandstone
Hildale, Utah, and Colorado City, Ariz.[2/]	.044[3/]	32	Navajo Sandstone and Kayenta Formation
Totals (rounded)	0.83	600	
	Upper Kanab Creek basin		
Alton	0.022[1/]	16	Wasatch Formation
Fredonia, Ariz.	.31[4/]	220	Navajo Sandstone
Kanab	.13[4/]	95	Do.
Totals (rounded)	0.46	330	

1/Reported by local or government official.
2/Directly across State line from Hildale.
3/Based on one measurement during this investigation.
4/Based on several measurements during this investigation.

Wells

The largest withdrawals of ground water from wells are for public supply and irrigation. At least 1,100 acre-ft (1.4 hm^3) per year of water was pumped for public supply during 1977 as shown in the following table:

Community	Withdrawal (acre-feet)	
	1976	1977
Upper Virgin River basin		
Glendale	72	51
Mount Carmel	4	4
Orderville	68	55
Rockville	7	7
Springdale	4	4
Subtotals	155	121
Upper Kanab Creek basin		
Kanab	970	860
Fredonia, Ariz.	64	78
State Park	10	10
Subtotals	1,074	948
Totals (rounded)	1,200	1,100

At least 75 percent of this amount was for the city of Kanab (from wells that tap the Navajo Sandstone). Approximately 1,500 acre-ft (1.8 hm^3) of water was withdrawn by irrigation wells in the study area during 1977. This included about 1,000 acre-ft (1.2 hm^3) in the upper Kanab Creek basin (table 14) and at least 470 acre-ft (0.6 hm^3) from the upper Virgin River basin (chiefly along Gould Wash and Short Creek). The estimate for the upper Kanab Creek basin is based on a pumping inventory. Most of the wells inventoried are in Johnson Canyon and tap either the Navajo or unconsolidated rocks. These two geologic units produce 26 and 27 percent, respectively, of the 1977 withdrawal for irrigation. The estimate for the upper Virgin River basin is based only on reconnaissance and probably is conservative.

Withdrawals of ground water by domestic, stock, commercial, and other wells are estimated to total not more than 700 acre-ft (0.9 hm^3) in 1977. The amount was roughly estimated by multiplying the number of such wells known to have existed in the area during 1977 by 25 percent of the average measured pumping rates of those that were inventoried (table 18). This was done under the assumption that all the wells were pumped about 25 percent of the time during the year.

Table 14.--Estimated discharge from irrigation wells in the upper Kanab Creek basin, 1976-77

Well No.	Discharge, acre-feet 1976	Discharge, acre-feet 1977	Geologic source
(C-40-4½)31bda-1	0	50	Unconsolidated rocks
32bad-1	140	140	Do.
(C-41-4½)6aad-1	60	0	Do.
(C-42-5)11bdb-1	140	140	Unconsolidated rocks and Navajo Sandstone
26ccc-2	54	0	Navajo Sandstone
26cda-2	69	113	Do.
27aaa-1	61	44	Do.
27add-1	26	25	Do.
35bbb-1	0	163	Do.
(C-43-4½)31ddd-1	10	10	Shinarump Member of the Chinle Formation
32aad-1	2	16	Do.
32cdb-1	.04	.02	Do.
33abb-1	7	9	Do.
33cac-1	16	.5	Shinarump Member of the Chinle Formation and Moenkopi Formation
(C-43-5)2bbd-1	45	73	Navajo Sandstone
25bda-1	0	39	Unconsolidated rocks
25cda-1	0	1.7	Do.
25cdb-1 and 2, 25cac-1	0	43	Do.
36cab-1	100	113	Shinarump Member of the Chinle Formation and Moenkopi Formation
(C-43-6)27dbd-1	1	.3	Unconsolidated rocks and Chinle Formation
(C-44-5)2aba-1	0	13	Shinarump Member of the Chinle Formation
2bad-1	0	9.5	Do.
Totals (rounded)	730	1,000	

Subsurface outflow

Some ground water probably discharges from the upper Virgin River basin as subsurface flow westward beneath the Hurricane Cliffs as indicated by Cordova and others (1972, p. 73). There are insufficient data from which to determine the annual rate, but based on geologic and geophysical data it probably is small.

According to the potentiometric-suface contours in figure 4, ground water leaves the upper Kanab Creek basin as subsurface flow southward beneath the Arizona-Utah State line. Most of this outflow occurs in the Moenkopi Formation, which has a generally low permeability. Some occurs in the relatively higher permeable Shinarump Member of the Chinle Formation and younger rocks, which have somewhat higher permeability than the Moenkopi.

The annual rate of outflow--5,000 acre-ft (6 hm^3)--was estimated using a variant of Darcy's law, $Q = TIL$. In this equation, Q is the annual rate of subsurface flow, in acre-feet; T is the transmissivity, estimated to be 160 ft^2/d (15 m^2/d) based on a hydraulic conductivity of 0.08 ft/d (0.02 m/d) (estimated from an aquifer test) and a saturated flow section 2,000 ft (610 m) thick; I is the hydraulic gradient, estimated to be 100 ft/mi (19 m/km) and based on the average of the gradients of the potentiometric surface along lines A-B and C-D in figure 4; and L is the length of section (about 40 mi or 64 km) across which flow is assumed to occur.

Storage

According to table 15, there is an estimated 200 million acre-ft (250,000 hm^3) of recoverable water in the Navajo Sandstone where it underlies the study area. This is the amount of water that can drain by gravity from the formation without additional recharge. It is essentially the maximum volume of water that can be withdrawn from the Navajo within the study area by wells if natural recharge to and discharge from the formation were to cease. Large-scale development of this supply, however, would be subject to various legal, economic, and environmental constraints.

Estimates were not made of the volume of recoverable water in other geologic units that underlie the study area. Recoverable water in the other consolidated rocks, with their large areal extent and thick saturated sections, is probably also in the millions of acre-feet. The unconsolidated rocks even though they have a higher storage capacity per unit volume probably contain only a fraction of the recoverable water in the consolidated rock. This is because of the limited extent and saturated thickness of the unconsolidated rocks.

Table 15.--Estimated amount of recoverable water in the Navajo Sandstone

Areal extent of aquifer: Determined from figure 6.
Estimated average saturated thickness: Roughly estimated for the upper Kanab Creek basin from approximated total thickness of formation and depth-to-water data at a few sites; for the upper Virgin River basin assumed to be the same as in the upper Kanab Creek basin because of sparsity of data.
Effective porosity: Values estimated from data in the central Virgin River basin (Cordova, 1978) to be 50 percent of the average total porosity of 30 percent (tables 6 and 7); values for upper Virgin River basin assumed to be the same as for the upper Kanab Creek basin.
Volume of recoverable ground water: Product of areal extent, thickness, and effective porosity.

Area	Areal extent of aquifer (thousands of acres)		Estimated average saturated thickness (feet)		Effective porosity	Volume of recoverable water in aquifer (acre-feet, rounded)		
	Outcropping	Buried	Outcropping	Buried		Where outcropping	Where buried	Total
Upper Virgin River basin	190	380	300	2,000	0.15	9×10^6	1×10^8	1×10^8
Upper Kanab Creek basin	180	240	300	2,000	.15	8×10^6	7×10^7	8×10^7
Total (rounded)	370	620	-	-	-	17×10^6	2×10^8	2×10^8

Changes in ground-water storage are reflected by fluctuations of water levels in wells (table 19 and figs. 13 and 14). Rising water levels generally indicate increases in storage whereas declining water levels generally indicate decreases in storage. The hydrographs shown in figure 13 represent the available long-term water-level records in the study area. A comparison of these hydrographs with cumulative-departure curves of precipitation (fig. 5) shows two main relations. First, water levels have generally been responding to above- and below-normal precipitation since the beginning of the water-level record. Second, the overall decline in water levels in part of the 1970's is a result of below-normal precipitation. It may, however, also be due in part to local increases in ground-water withdrawals during the same period.

Reduction of ground water in storage by pumping wells is indicated by water-level records of wells in two localities in the upper Kanab Creek basin. The large water-level declines following 1970 in wells (C-43-5)25acd-1 and 25dbb-1 reflect local decreases in stored water, resulting largely from large withdrawals at each of these wells. In these areas, recharge has not been sufficient to return the water levels to their pre-pumping altitudes. Recharge could only come from precipitation which was generally below normal during and after pumping periods. Pumping terminated in 1972 after a short period of heavy pumping so that the continued general decline of water levels in these two wells is attributed to continued below-normal precipitation.

Figure 13.--Water-level fluctuations in selected wells in the study area.

Figure 14.--Graphs showing water-level fluctuations (1976-78) in selected wells in the upper Kanab Creek basin.

Comparison of the March 16, 1962, and February 27, 1977, (pre-pumping season) water levels in well (C-42-6)19bdc-1 (table 19) shows a decline of about 30 ft (9 m). This well and a nearby newer well, (C-42-6)19bdc-2, are the most heavily pumped of all the wells used by the city of Kanab. Increased usage probably would result in greater withdrawals from storage, especially during periods of below-normal precipitation that are probably accompanied by little or no recharge.

Chemical quality

General characteristics

Chemical analyses of ground water in the upper Virgin River and Kanab Creek basins are shown in table 23. Important factors affecting the chemical quality are the availability of soluble substances in the rocks through which the water moves and the length of time the water is in contact with these soluble substances. Among consolidated-rock aquifers in the study area, limestone and shale contain the largest amounts of soluble substances; whereas, sandstone and basalt contain the smallest amounts. In the unconsolidated-rock aquifers, the amounts of soluble substances depend partly on the sources of the materials comprising the aquifers and partly on the nature of the underlying consolidated rocks.

Dissolved-solids concentration in water is related to specific conductance, which is a measure of the ability of the water to conduct an electrical current. This relation for ground water in the study area is shown in figure 15 based on selected chemical analyses in table 23. The average ratio of dissolved-solids concentration to specific conductance is 0.65. Therefore, if a field determination of specific conductance is made of a water sample, that value multiplied by 0.65 will give the approximate dissolved-solids concentration of the water.

Figure 15.--Relation of dissolved-solids concentration to specific conductance of ground water in the study area.

The dissolved-solids concentration in the ground water of the study area differs considerably according to locality and aquifer, as shown in tables 16 and 23. The areas most likely to yield water containing less than 1,000 mg/L of dissolved solids are generally north of the Vermillion Cliffs. The Wasatch Formation and the Navajo Sandstone are the aquifers most likely to yield water with a dissolved-solids concentration of less than 500 mg/L (table 16). This is also true of such sandstone strata as the Wahweap Sandstone and Kaiparowits Formation where they crop out in or near major recharge areas. Shale, such as the Tropic Shale and Carmel and Moenkopi Formations commonly yield water containing several thousand milligrams per liter of dissolved solids. A known local exception (and others probably also exist in the study area) is the Shinarump Member of the Chinle Formation. A sample from spring (C-43-4)31aad-1, which discharges from the Shinarump had only 94 mg/L of dissolved solids, compared to the average concentration of 900 mg/L in 15 samples from that formation. The small dissolved-solids concentration indicates that the spring is near a local recharge area and the water has been in the rocks only a relatively short time.

The Navajo Sandstone consisting largely of silica sand of low solubility consistently yields water low in dissolved-solids concentration. Of 41 water samples collected from the Navajo, dissolved-solids concentrations ranged from only 74 to 905 mg/L and averaged about 270 mg/L (table 16). About 80 percent of the samples had dissolved-solids concentrations of less than 300 mg/L. The highest value of 905 mg/L--in a sample collected at well (C-40-5)16cdc-1--may be attributed to mixing in the well of the Navajo water with more saline water from the overlying Carmel Formation. Some of the sampled springs that issue from the Navajo also had higher-than-expected dissolved-solids concentrations. The samples were collected from spring ponds where the water may have been concentrated by evaporation or contaminated prior to sampling.

Table 16.--Summary of dissolved-solids concentration, in milligrams per liter, in ground water by aquifer

Geologic source	Number of samples	Dissolved-solids concentration Range	Dissolved-solids concentration Average (rounded)
Unconsolidated rocks	14	31-3,150	890
Basalt	1	266	--
Wasatch Formation	2	288-308	300
Rocks of Cretaceous age, undivided	11	225-2,320	760
Rocks of Jurassic age, undivided (above the Navajo Sandstone)	7	900-3,100	2,000
Navajo Sandstone	41	74-905	270
Shinarump Member of the Chinle Formation	15	94-3,470	900
Rocks of Triassic age, undivided, below the Navajo Sandstone (excluding the Shinarump Member of the Chinle Formation)	8	266-9,490	1,740
Kaibab Limestone[1]	1	9,390	--

[1]Thermal water from the La Verkin Hot Springs and probably not typical of ground water from the formation.

Ground water can be classified into chemical types by Stiff diagrams (Stiff, 1951) as shown in figure 16. This classification is useful in determining the geologic source or sources of the water. In the study area, there are two basically dominant types of ground water. One is the bicarbonate type, in which the principal anion is bicarbonate and the principal cation is calcium, magnesium, or sodium. The other is the sulfate type, in which the principal anion is sulfate and the principal cation is calcium, magnesium, or sodium.

The Navajo Sandstone typically contains water in which calcium is the dominant cation and bicarbonate is the dominant anion. Locally, however, it has water in which sodium is the dominant cation and sulfate is the dominant anion. This probably is due to mixing with water from the overlying Carmel Formation (which commonly contains gypsum).

The Wasatch Formation and formations of Cretaceous age commonly contain water in which calcium or magnesium are the dominant cations and bicarbonate is the dominant anion. However, the shaly or coal-bearing formations of Cretaceous age like the Tropic Shale contain water in which magnesium and sulfate are the dominant ions.

The Shinarump Member of the Chinle Formation and the unconsolidated rocks may contain water high in either sulfate or bicarbonate. The unconsolidated rocks commonly contain water that is similar to the underlying consolidated rocks. For example, where the Chinle and other rock units underlie unconsolidated rocks, the latter commonly contain water in which sulfate is the dominant anion.

Figure 16.--Common chemical types of water from various aquifers in the study area. (Diagrams after Stiff, 1951, p. 15-17.)

Changes in chemical quality of ground water percolating through various rock types can be determined from chemical analyses of base flow of streams. Such changes are shown graphically in figure 17 by Stiff diagrams of chemical analyses of base-flow samples (table 23) collected at varous sites along Johnson Canyon creek. At the upstream site, the base flow was mainly from the Navajo Sandstone, and the dominant ions were calcium and bicarbonate. At the central site, the base flow was from the unconsolidated rocks and the Moenave and Chinle Formations; here the dominant ions were magnesium and bicarbonate, but sulfate had increased compared to the upstream site. At the downstream site, base flow was from the Shinarump Member of the Chinle Formation and the Moenkopi Formation; the dominant ions were sodium, magnesium, and sulfate. The downstream increase of sodium, magnesium, and sulfate is an indication of increasing amounts of these ions in water that seeps from aquifers crossed by the stream.

Figure 17.--Changes in chemical quality of base flow in Johnson Canyon creek.

(Diagrams after Stiff, 1951, p. 15-17.)

Relation to use

Public supply.--The U.S. Public Health Service (1962, p. 7) has recommended quality standards for public drinking water and water-supply systems. A partial list of these standards is as follows:

Constituent	Recommended maximum limit (milligrams per liter)
Dissolved solids	500
Sulfate	250
Chloride	250
Nitrate	45 1/

1/ The limit is 10 mg/L for total nitrogen (N).

The analyses in table 23 indicate that some of the ground water from most aquifers is likely to have dissolved-solids and sulfate concentrations that exceed the recommended maximum limits. This is particularly true for aquifers older than the Navajo Sandstone and for the unconsolidated rocks. The concentrations of chloride and nitrate are generally lower than the respective maximum recommended limits.

The maximum recommended limit for chloride was only exceeded in a few cases. Most of the ground water analyzed had chloride concentrations that were significantly less than 100 mg/L. The ground water that contained more than 100 mg/L was from the Chinle and older formations or from unconsolidated rocks overlying these formations. The highest concentrations of chloride were 3,610 mg/L in water from La Verkin Hot Springs, which rises from the Kaibab Limestone, and 1,000 mg/L in water from well (C-43-5)36ccc-1, which taps the Moenkopi Formation.

Table 23 shows concentrations of nitrite (NO_2) plus nitrate (NO_3) determined as nitrogen (N), in which case the maximum recommended limit for drinking water is 10 mg/L. As shown in table 23 that limit was exceeded in only two of the samples analyzed. Concentrations in most of the waters analyzed were less than 3 mg/L, and in many, less than 2 mg/L. Waters containing more than 3 mg/L of nitrogen may have been in contact with organic waste, such as might be found in pastures in recharge areas.

Irrigation supply.--Ground water in the study area is classified in figure 18 according to salinity and sodium hazard, using the method of the U.S. Salinity Laboratory Staff (1954, p. 69). In classifying water for irrigation by this method, it is assumed that an average quantity of water will be used under average conditions of soil texture, salt tolerance of crops, climate, drainage, and infiltration. The classification in figure 18 is based on the relation between sodium-adsorption ratio (SAR) and specific conductance of the water. The SAR is a measure of the sodium hazard, and the specific conductance is a measure of the salinity hazard. Using the diagram, water can be classified into 16 categories according to the degree that it may cause salinity problems and undesirable ion-exchange effects. The higher the salinity or sodium hazards the less suitable the water is for irrigation.

Ground water in the study area is shown in figure 18 to have a salinity hazard that ranges from low to very high. The sodium hazard of the water also ranges from low to very high but is mostly low. The reader interested in the sodium and salinity hazards of any of the water sources for which analyses are given in table 23 may determine those hazards by plotting in figure 18 the respective specific conductance and SAR values given in table 23.

Figure 18.--Classification for irrigation of selected ground-water samples from the study area (after U.S. Salinity Laboratory Staff, 1954).

High boron concentrations in irrigation water may also present a problem because of the toxicity of boron to some types of plants. Table 17 shows a classification of irrigation water based on boron content. The quantity of boron in solution in ground-water samples from the study area ranged from 0 to 5,000 μg/L, but most samples contained less than 500 μg/L (table 23). The water that contained boron in excess of 500 μg/L was mainly from the Chinle Formation and other rocks. The largest value of 5,000 μg/L was in water from La Verkin Hot Springs, which rise from the Kaibab Limestone.

Temperature

The temperature of ground water in the upper Virgin River and Kanab Creek basins (table 23) ranges from 7.0°C (45°F) to 37.5°C (100°F), but most of the ground water has a temperature in the range of 11.0°C (52°F) to 16.0°C (61°F). Figure 19 shows that in the study area, ground-water temperature is generally related to the altitude of the potentiometric surface, which is a reflection of distance from principal recharge areas. The best-fit line through the data points indicates a gradient of about 2.5°C (6°F) decrease of temperature for each 1,000 ft (305 m) of increase in altitude. Extrapolating the gradient to lower altitudes indicates that ground-water temperatures at the altitude of 3,000 ft (914 m) are most likely less than 20.0°C (68°F). The measured temperature of La Verkin Hot Springs is about 17.5°C (64°F) hotter than the expected temperature, suggesting deep circulation of the spring water in the Hurricane Fault. (See Milligan and others, 1966, p. 42.)

Table 17.--Classification of irrigation water based on the boron content

(Modified from Scofield and Wilcox, 1931, p. 9-10)

Sensitive crops: Include most deciduous fruit and nut trees.
Semitolerant crops: Include most small grains, potatoes, and some other vegetables.
Tolerant crops: Include alfalfa and most root vegetables.

(For a more complete listing of crop tolerances, see U.S. Salinity Laboratory Staff, 1954, p. 67.)

Class of water	Sensitive crops (µg/L)	Semitolerant crops (µg/L)	Tolerant crops (µg/L)
Excellent	Less than 330	Less than 670	Less than 1,000
Good	330-670	670-1,330	1,000-2,000
Permissible	670-1,000	1,330-2,000	2,000-3,000
Doubtful	1,000-1,250	2,000-2,500	3,000-3,750
Unsuitable	More than 1,250	More than 2,500	More than 3,750

Figure 19.--Relation of ground-water temperature to the altitude of the potentiometric surface.

The temperature gradient below the potentiometric surface is an important consideration in the development of the ground-water resources by wells. Temperature-gradient data are available from several wells in the upper Kanab Creek basin and are given below:

Well No.	Temperature gradient
(C-40-5)16cdc-1	1°C/180 ft
(C-41-5)5aaa-1	1°C/110 ft
(C-42-6)19baa-1	1°C/210 ft
(C-43-5)36ccc-1	1°C/150 ft
(C-44-6)5ddd-1	1°C/230 ft

The average gradient, or increase of temperature with depth, is about 1°C per 180 ft (55 m). This gradient is relatively low. Some meteoric water probably circulates to moderate depths along some faults. This is indicated by higher temperature gradients at well (C-41-5)5aaa-1, which is adjacent to the inferred fault in Kanab Creek canyon, and at well (C-43-5)36ccc-1, which is adjacent to the inferred fault in Johnson Canyon (fig. 6).

POSSIBLE HYDROLOGIC EFFECTS OF INCREASED GROUND-WATER DEVELOPMENT

Hydrologic effects that can occur by increased ground-water development in the study area include (1) interference with existing wells, (2) a shift of the natural ground-water drainage divide, (3) reduction of spring and stream discharge, and (4) possible changes in the chemical quality of water.

Interference with existing wells

Withdrawal of ground water from a well results in a cone of depression in the water table or the potentiometric surface. This cone will continue to deepen and expand until a new balance is reached between the rate that water is recharged to or discharge from the aquifer. If withdrawal from the well is then increased, the cone of depression will again begin to deepen and expand.

When an expanding cone of depression reaches an existing well, the water level in that well will be lowered. The yield of the well might also be lowered if that drawdown is a significant part of the saturated thickness of the aquifer at the well. Interference between discharging wells has been observed in several parts of the study area, including Johnson Canyon and Kanab Creek Canyon, the Vermillion Terrace, and Gould Wash.

During aquifer tests in Johnson Canyon, all pumped wells tapped the Navajo Sandstone as did most of the observation wells. When well (C-42-5)27add-1 was pumped, 3.74 ft (1.14 m) of drawdown was measured in observation well (C-42-5)27add-2 100 ft (30 m) to the south. When well (C-42-5)35bbb-1 was pumped, 255 ft (0.78 m) of drawdown was measured in observation well (C-42-5)26ccc-2 540 ft (165 m) to the north. The effects of pumping irrigation well (C-42-5)35bbb-1 on well (C-42-5)26ccc-2 are shown in figure 14. Water levels also fluctuated in wells (C-42-5)26ccc-1 and 35bdc-3 in response to the pumping of well (C-42-5)35bbb-1 during the 1977 irrigation season.

Two aquifer tests in Johnson Canyon showed interference between deep and shallow wells in the same aquifer and between wells in superposed aquifers. For example, when well (C-42-5)11bdb-1 in the Navajo Sandstone was pumped, a drawdown of about 0.2 ft (0.06 m) was measured in observation well (C-42-5)11bab-1, which taps the overlying unconsolidated deposits 1,500 ft (460 m) to the north. This test showed that ~~interference~~ pumping effects cannot be obviated entirely by constructing wells in the Navajo where it is overlain by another aquifer because interaquifer hydraulic connection must be considered as a distinct possibility.

Furthermore, in an area of relatively shallow wells, interference cannot necessarily be obviated entirely by drilling deep wells in the same aquifer because of possible hydraulic connection between lower and upper parts of the aquifer. For example, when well (C-42-5)26cda-2 was pumped, a drawdown of about 9 ft (2.7 m) occurred in observation well (C-42-5)26cda-1 about 8 ft (2.4 m) to the south east. The observation well is only 26.5 ft (8.1 m) deep whereas the pumped well is 380 ft (116 m) deep. Pumping a deep well would, however, produce less drawdown in a well that taps the same aquifer at a shallower depth than in one that taps the aquifer at the same depth. Similarly, pumping a shallow well would produce less drawdown in deep wells than in other shallow wells that tap the same aquifer.

Well interference was also observed in several parts of Kanab Creek canyon. Pumping well (C-42-6)19bdc-2 caused a water-level decline of 4.2 ft (1.3 m) in well (C-42-6)19bdc-1 500 ft (150 m) to the east. It also produced a slight but measurable decline in well (C-42-6)19baa-1 about 2,000 ft (610 m) to the north. The overall decline of water level in well (C-42-6)19baa-1 (fig. 14) is possibly the net result of both interference and below-normal precipitation. Also the sharp fluctuations of water level are probably due to fluctuations of barometric pressure rather than interference by wells (C-42-6)19bdc-1 and 19bdc-2.

On the Vermillion Terrace, interference was shown by an aquifer test in the Shinarump Member of the Chinle Formation and by existing water-level records. Pumping well (C-44-5)2bad-2 caused the water level in well (C-44-5) 2bad-1, 360 ft (110 m) to the southwest, to decline 0.54 ft (0.16 m). Pumping of irrigation well (C-43-5)36cab-1 probably caused the approximately 1 ft (0.30 m) water-level decline in well (C-43-5)36ccc-1 (fig. 14), which is about 2,500 ft (760 m) to the southwest.

In summary, the pumping of a well anywhere in the Navajo Sandstone in the Kanab Creek basin probably would cause some decline of water levels elsewhere in the aquifer and probably also in overlying and underlying ~~in superposed~~ aquifers in the basin. Although data are not available for the upper Virgin River basin, pumping of wells in the Navajo would probably produce the same interference effects. Furthermore, pumping of wells in any aquifer in the study area can be expected to cause declines of water levels to some degree in other nearby wells in that aquifer and in overlying and underlying ~~superposed~~ aquifers. The extent of decline, however, would depend on hydraulic properties of the aquifers, distances from the pumped well, depths of the respective wells, the pumping rate, and the length of time the well is pumped.

The amount of drawdown in a well in the Navajo Sandstone in the Kanab Creek basin caused by pumping another well may be computed from the aquifer coefficients of transmissivity and storage. Drawdowns at distances of 100 ft (30 m) and greater from a pumped well may be determined using the sets of distance-drawdown curves in figure 20. The curves are based on the assumptions that the aquifer is homogeneous, isotropic, infinite in areal extent, and constant in permeability and thickness. Few, if any, aquifers satisfy these assumptions, and those in the study area are no exception. The distance-drawdown curves nevertheless do provide an insight to the order-of-magnitude interference effects under given rates of pumping.

Figure 20.--Theoretical relation between drawdown and distance from a pumping well in the Navajo Sandstone for selected pumping durations.

The upper family of curves in figure 20 were computed using the average aquifer coefficients determined for the Navajo Sandstone by aquifer testing. These curves are probably most useful in the area where the Navajo crops out, or where it is not covered by a significant thickness of younger formations. The curves show that if a well were pumped at 1,000 gal/min (63 L/s), the water level in a well 1,000 ft (300 m) away would be lowered about 11.5 (3.5 m) in 10 days. If pumping were continued for 10,000 days, the lowering would be about 28 ft (8.5 m), assuming no induced recharge or increased discharge. The greater the distance between wells, the less the water-level decline. Declines for pumping rates other than 1,000 gal/min (63 L/s) can be computed by determining the drawdown for 1,000 gal/min and then increasing or decreasing the decline by the proportionate difference between the two pumping rates. For example, if the pumping rate were 5,000 gal/min (310 L/s), the decline would be 5 x 11.5 ft or about 58 ft (18 m) after 10 days of pumping.

The Navajo Sandstone underlying the Alton and Bald Knoll areas probably has a coefficient of storage that is smaller than the average of 2×10^{-3} used to construct the upper family of curves in figure 20. The value is not known but may be on the order of 1×10^{-5}. This smaller value is probable because the aquifer is buried under a thick section of younger rocks and is therefore subjected to higher external pressures than in the area of outcrop. These higher pressures increase the rigidity of the aquifer and therefore decrease the coefficient of storage. The lower family of curves in figure 20 was computed using the average transmissivity for the Navajo but the coefficient of storage was 1×10^{-5}. A comparison of these curves with the upper family of curves shows that the smaller coefficient of storage increases the rate of expansion of the cone of depression. For example, using the upper family of curves, a well pumping 1,000 gal/min (63 L/s) in the Bald Knoll area would cause a drawdown of 18.5 ft (5.6 m) at a distance of 10,000 ft (3,050 m) after 20,000 days of pumping; by comparison, using the lower family of curves, the same pumping rate of the same well would cause a drawdown of about 32 ft (9.8 m) at the same distance and after the same period of pumping. Based on the presumed leaky nature of the aquifer system as discussed above, these rates would probably not prevail for a long pumping period and drawdowns would probably therefore by very much less. In order to be better prepared to predict the effects of pumping in the Alton and Bald Knoll areas, however, an aquifer test is needed in the Navajo to more accurately evaluate the coefficient of storage.

Figure 21 shows theoretical distance-drawdown curves computed using the aquifer coefficients determined for localities where the Shinarump Member of the Chinle Formation is the only known or the main aquifer developed by wells. The pumping rate used is probably average for large-discharge wells in the aquifer.

Figure 21.--Theoretical relation between drawdown and distance from a pumping well tapping mainly the Shinarump Member of the Chinle Formation for selected pumping durations.

Shift of the ground-water divide

Wells constructed in the Alton or Bald Knoll areas would be within 16 mi (25.7 km) of the topographic divide between Kanab Creek and the Sevier and Paria Rivers. As noted earlier, the ground-water divide is assumed to be coincident with the topographic divide in the area. Should the cone of depression of a discharging well in the Alton-Bald Knoll area expand to the ground-water divide, the result would be an increased ground-water gradient between the well and the divide. This would increase the amount of water flowing toward the well. The cone of depression could continue to expand beyond the divide and thus shift it into an adjoining drainage basin.

The amount of potential lateral shift of the ground-water divide induced by pumping is not known, but the amount of drawdown can be estimated at the divide by referring to figure 20. Assume a well tapping the Navajo Sandstone in the Bald Knoll locale pumps for 40 years (about 15,000 days) at the rate of 4,000 gal/min (250 L/s). The potentiometric surface could be lowered about 100 ft (30 m) at a ground-water divide 6 mi (9.7 km) away, assuming a nonleaky system, which is unlikely. Therefore, such a decline would be an extreme case.

The actual drawdowns in the ground-water reservoir may be greater or less than those determined from figure 20. Boundary conditions are among the most important factors controlling the magnitude of drawdown. A boundary may be the natural finite extent of the aquifer, impermeable fault zones in the aquifer, or an area of natural discharge such as a spring or gaining stream reach. Faults are fairly common in the study area and some are probably impermeable so that fault-induced image effects may be expected to occur in some localities sooner than the effects resulting from the cone of depression meeting the boundaries of the aquifer. The proximity of faults and the southern limit of the Navajo Sandstone in the areas of Johnson Canyon and Kanab Creek suggest that drawdowns could eventually be affected by these boundaries. When the cone of depression intercepts an area of natural discharge, the actual drawdown will be less than the theoretical drawdown because the water from these natural sources is diverted to the discharging well. The springs and streams in Johnson Canyon and Kanab Creek canyon are natural-discharge boundaries, which would eventually be intercepted by the expanding cones of depression of wells in these canyons.

Reduction of streamflow

Discharge from a well can affect streamflow where there is hydraulic connection between a stream and the aquifer from which a discharging well is withdrawing water. Where an aquifer is hydraulically connected to a stream channel, wells discharging water from the aquifer may divert streamflow or water that would otherwise discharge into the stream channel as springs or seeps. The percentage of water discharged by a well which is diverted from a stream can be roughly estimated from a graph prepared by Theis and Conover (1963, fig. 30).

In the study area, hydraulic connection between aquifers and streams apparently exists in (1) the valleys of Thompson and Mill Creeks, (2) the valley of Skutumpah Creek to its junction with Red Wash, (3) Johnson Canyon from sec. 22, T. 42 S., R. 5 W., to the Utah-Arizona State line, (4) Johnson Lakes Canyon in sec. 32, T. 42 S., R. 4½ W., (5) the valley of Kanab Creek in the reach above Alton and in the reach from sec. 4, T. 42 S., R. 6 W., to the State line, and (6) the valleys of the North and East Forks of the Virgin River and of the main stem of the Virgin River to the Hurricane Cliffs. For all these streams, base flow comprises a significant part of the total annual flow.

Based on available data, most of the base flow in the lower reaches of Kanab and Johnson Canyon Creeks comes from the Navajo Sandstone; consequently, increased withdrawals of water by wells in the Navajo would, in time, measurably reduce the flow of those streams. This effect has been observed locally in Johnson Canyon where well (D-43-5)25aaa-1 taps the Navajo near Johnson Canyon creek. Pumping of that well measurably decreases the flow of springs that discharge from the Navajo to the creek about 300 ft (91 m) upstream.

Effects on chemical quality of water

The present (1978) level of ground-water development has had minimal effects on the chemical quality of ground and surface water in the upper Virgin River and Kanab Creek basins. Increased withdrawals from the Navajo Sandstone could affect the chemical quality of water in that aquifer and in nearby streams.

As noted, dissolved-solids concentrations of water in the Navajo Sandstone are relatively low, averaging less than 300 mg/L where sampled. Dissolved-solids concentrations in water in both the overlying and underlying formations are generally high, commonly exceeding 1,000 mg/L. Increased withdrawals from the Navajo by wells could eventually create a large enough hydraulic gradient towards the pumped area to induce movement of the more highly mineralized water from the overlying and underlying rocks into the Navajo, thus deteriorating the chemical quality of water in the Navajo. Similar events have occurred in several of the more heavily developed valley-fill aquifers in western Utah (Handy and others, 1969), and it is possible that it could also occur in the consolidated-rock aquifers in the study area.

Increased withdrawals of water from the Navajo Sandstone also would affect the chemical quality of streamflow, especially in Johnson Canyon and Kanab Creeks. As noted above, most of the base flow in the lower reaches of those streams comes from the Navajo. Some of the more highly mineralized base flow comes from the older and younger rocks, including the Carmel, Moenkopi, and Chinle Formations. As an increasing amount of water is pumped from wells in the Navajo (and thus diverted from the streams), the ratio of fresher Navajo water and more mineralized water from the older and younger formations in those streams will decrease. This will result in a net increase in the ~~salinity~~ dissolved-solids concentration of the streams. However, it would not increase the total salt load that those streams transport to the Colorado River. Return of the pumped water as from municipal and industrial uses and irrigated land probably would be more mineralized and would therefore increase the salt load transported by Johnson Canyon and Kanab Creeks to the Colorado River. The added salt load cannot be estimated from available data, but it would probably be small compared to the average annual salt load (nearly 9 million tons) carried by the Colorado River through Grand Canyon. (See U.S. Department of the Interior, 1979b, p. 80.)

SUMMARY AND CONCLUSIONS

Both unconsolidated and consolidated rocks contain productive aquifers in the upper Virgin River and Kanab Creek basins. Aquifers in unconsolidated older stream-channel deposits in Johnson Canyon creek and Kanab Creek probably have the greatest potential for increased development by wells. The Navajo Sandstone is the most important consolidated-rock aquifer in the study area. The Navajo is the thickest, has the largest area of outcrop, and supports more large-discharge wells than any other consolidated-rock aquifer. Other principal consolidated-rock aquifers are the Wasatch Formation, the sandstone formations of Cretaceous age, and the Shinarump Member of the Chinle Formation.

The long-term average amount of ground-water recharge to the study area is estimated to be about 80,000 acre-ft (99 hm^3), broken down according to drainage basin as follows: upper Virgin River, 55,000 acre-ft (68 hm^3), and Kanab Creek, 25,000 acre-ft (31 hm^3). The direction of ground-water movement is from the major areas of recharge in the northern highlands generally southward to the major areas of discharge in the lower valleys of the larger streams. The amount of discharge in 1977 in the study area was estimated to be at least 71,000 acre-ft (88 hm^3) broken down by drainage basin as follows: upper Virgin River, 49,000 acre-ft (60 hm^3), and Kanab Creek, 22,000 acre-ft (27 hm^3).

The amount of recoverable ground water in the Navajo Sandstone is estimated to be 200 million acre-ft (250,000 hm^3). Reduction of ground water in storage is indicated by water-level records of wells in two localities in the upper Kanab Creek basin.

The dissolved-solids concentration of the ground water in the study area differs considerably according to locality and aquifer. The aquifers most likely to yield water with dissolved-solids concentrations of less than 500 mg/L are the Wasatch Formation and the Navajo Sandstone. Ground water from most other aquifers is likely to have dissolved-solids and sulfate concentrations that exceed the recommended maximum limits of the U.S. Public Health Service for public drinking water. This is particularly true for aquifers older than the Navajo and for aquifers in the unconsolidated rocks. The concentrations of chloride and nitrate are, however, significantly lower generally than the respective recommended limits.

Regarding suitability for irrigation, ground water in the study area has a salinity hazard that ranges from low to very high. The sodium hazard of the water also ranges from low to very high but is mostly low. Generally values of SAR that exceed 3.0 are of ground water from formations older than the Navajo. The quantity of boron in solution in sampled ground water ranged from 0 to 5,000 µg/L, but most waters sampled contained less than 500 µg/L. Waters that contained boron in excess of 500 µg/L were also mainly from formations older than the Navajo.

Most ground water has a temperature in the range of 11.0° to 16.0°C (52° to 61°F). The average gradient, or increase of temperature with depth, is about 1°C per 180 ft. This gradient is relatively low.

Possible hydrologic effects of increased ground-water development in the study area include increased interference between wells, change in the ground-water divide between the study area and the Sevier and Paria River basins, reduction of streamflow, and changes in chemical quality of the water. Two aquifer tests in Johnson Canyon showed that interference can occur between deep and shallow wells in the same aquifer and between wells in underlying and overlying aquifers. Pumping of a well that taps the Navajo Sandstone near Johnson Canyon also indicates the possible reduction of streamflow with increased ground-water withdrawal from the Navajo.

Sufficient data were not available during this study to ascertain a possible shift of the ground-water divide between the study and the Sevier or Paria River basins. Theoretically long-term, large-scale pumping from the Navajo Sandstone in the Alton area could shift the divide between the upper Virgin and Sevier River basins northward; this would divert some ground water naturally tributary to the Sevier River southward into the study area. However, the amount of ground water diverted would be only a small fraction of the water pumped. It probably would be very small compared to the total water supply in the Sevier River basin, which is estimated to exceed 1 million acre-ft (1,230 hm^3) per year (Eakin and others, 1971, table 23).

Large withdrawals of freshwater from the Navajo Sandstone probably would induce inflow into that formation of relatively more mineralized water from overlying and underlying rocks. It could also result in increased salinity of Johnson Canyon and Kanab Creeks but probably would not significantly increase the total salt load transported by those streams to the Colorado River.

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Table 19.--Water levels in selected observation wells

See data-site-numbering system in text.
Water levels are in feet below or above(+) land-surface datum.

(C-40-4½)31bda-1					
Oct. 14, 1976	16.35	Apr. 28, 1977	16.31	Nov. 9, 1977	18.13
Feb. 25, 1977	14.75	June 18	47.46	June 21, 1978	13.98
(C-40-4½)32bad-1					
Oct. 20, 1976	39.57	Apr. 28, 1977	34.93	Nov. 9, 1977	39.80
Feb. 25, 1977	35.34	June 18	46.05	June 21, 1978	37.46
(C-41-4½)6aad-1					
Oct. 20, 1976	32.28	June 18, 1977	33.02	Dec. 8, 1977	34.10
Feb. 25, 1977	32.97	Aug. 27	33.51	June 21, 1978	32.70
Apr. 28	32.86	Nov. 9	34.03		
(C-41-5)3bda-2					
June 30, 1977	56.13	Nov. 10, 1977	55.40	Dec. 8, 1977	55.24
(C-41-5)5aaa-1					
Sept. 22, 1976	64.90	Apr. 28, 1977	65.13	Aug. 23, 1977	65.12
Feb. 25, 1977	65.02	June 18	65.11	Nov. 9	65.23
(C-42-5)11bab-1					
Oct. 7, 1976	97.01	Apr. 30, 1977	94.02	Aug. 24, 1977	94.44
Feb. 24, 1977	93.78	May 13	94.11	Aug. 29	94.82
Apr. 4	93.95	June 18	94.36	Sept. 17	94.58
Apr. 28	94.02	July 2	94.25	Nov. 9	94.38
Apr. 29	93.94	July 5	94.36		
(C-42-5)11bdb-1					
Oct. 7, 1976	86.64	July 5, 1977	89.61	Nov. 9, 1977	86.70
Feb. 24, 1977	85.83	Aug. 24	a 113.68	Dec. 8	86.34
Apr. 30	88.63	Aug. 29	91.51	June 21, 1978	86.40
July 2	88.19	Sept. 17	88.30		
(C-42-5)15bdc-1					
Mar. 25, 1976	87.60	Mar. 31, 1976	87.55	Apr. 5, 1976	87.50
Mar. 29	87.61	Apr. 2	87.57		
(C-42-5)26ccc-1					
Feb. 24, 1977	20.58	May 28, 1977	21.99	June 15, 1977	22.85
May 19	21.04	May 29	22.10	June 24	22.35
May 20	21.03	May 30	22.23	Aug. 24	23.20
May 25	21.80	May 31	22.30	Nov. 8	22.28
May 26	21.85	June 3	22.53		
(C-42-5)26ccc-2					
Feb. 24, 1977	24.20	Apr. 30, 1977	25.48	May 26, 1977	28.04
Apr. 27	25.80	May 19	24.76	May 28	28.24
Apr. 28	26.40	May 20	24.66	May 29	28.45
Apr. 29	26.79	May 25	27.89	May 30	28.67

Table 19.--Water levels in selected observation wells--Continued

(C-42-5)26ccc-2 - Continued

May 31, 1977	28.67	June 24, 1977	26.56	Nov. 9, 1977	25.23
June 2	29.03	July 2	29.23	Dec. 8	28.54
June 3	29.13	Aug. 24	27.38	Apr. 17, 1978	23.97
June 15	26.80	Sept. 17	26.12	June 21	27.17
June 21	26.33				

(C-42-5)26cda-1

Oct. 14, 1976	10.67	Apr. 27, 1977	21.78	Aug. 24, 1977	15.10
Oct. 15	10.09	June 16	12.35	Nov. 9	8.34
Feb. 24, 1977	7.12	June 21	10.60	June 21, 1978	25.49

(C-42-5)26cda-2

Oct. 14, 1976	12.57	Apr. 27, 1977	a 85.03	Aug. 24, 1977	14.36
Oct. 15	a 78.60	June 16	12.68	Nov. 9	10.20
Feb. 24, 1977	8.42	June 21	11.39		

(C-42-5)27aaa-1

Oct. 1, 1976	a 50.59	May 13, 1977	3.57	Aug. 24, 1977	0.64
Feb. 24, 1977	.88	May 15	.51	Nov. 9	.89
Apr. 28	a 45.08	May 16	.28	June 21, 1978	3.27
May 12	7.22	June 16	.25		

(C-42-5)27add-2

Oct. 7, 1976	45.23	Apr. 27, 1977	48.36	June 24, 1977	46.30
Feb. 24, 1977	44.27	Apr. 28	46.90	Nov. 9	44.86

(C-42-5)34dbb-1

June 16, 1977	5.84	Sept. 17, 1977	6.54	Nov. 9, 1977	6.45
Aug. 24	6.47				

(C-42-5)35bbb-1

Apr. 27, 1977	32.50	May 20, 1977	26.32	June 21, 1977	30.60
May 19	26.29	June 15	32.70		

(C-42-5)35bdc-1

Oct. 7, 1976	1.70	June 20, 1977	2.92	July 5, 1977	3.85
Feb. 24, 1977	1.65	June 23	2.90	Aug. 24	3.90
June 16	3.13	June 25	3.10	Nov. 9	2.35
June 18	1.99	July 2	3.70		

(C-42-5)35bdc-3

Oct. 7, 1976	29.37	June 20, 1977	30.64	July 7, 1977	31.86
Feb. 24, 1977	28.70	June 23	30.53	July 15	b 32.75
Apr. 27	29.17	June 25	30.54	Aug. 24	31.74
June 3	30.97	July 2	31.37	Sept. 17	30.90
June 16	30.87	July 5	31.71	Nov. 9	29.95
June 18	30.71				

(C-42-6)19baa-1

Feb. 25, 1977	165.51	May 1, 1977	165.77	May 12, 1977	165.80
Apr. 26	165.81	May 10	165.85	May 15	165.87

Table 19.--Water levels in selected observation wells--Continued

(C-42-6)19baa-1 - Continued

May 20, 1977	165.98	June 14, 1977	165.98	Nov. 8, 1977	166.05
May 25	165.88	July 3	165.94	Dec. 8	166.15
May 27	165.82	Aug. 27	165.88	Apr. 18, 1978	166.58
May 31	166.16	Sept. 28	166.10	June 22	166.53
June 3	165.98				

(C-42-6)19bdc-1

Mar. 15, 1962	29.73	May 15, 1977	a c 171.39	July 3, 1977	a c 171.40
Dec. 18	c 42.06	May 25	51.10	Aug. 27	a c 171.40
Apr. 27, 1963	c 41.97	May 27	49.18	Sept. 28	a c 171.39
Feb. 25, 1977	59.80	June 14	53.10	Nov. 8	a 137.58
May 10	a c 171.20				

(C-42-6)19bdc-2

May 10, 1977	a 120.66	June 14, 1977	a 113.90	Sept. 28, 1977	a 141.00
May 15	a 132.28	July 3	a 114.00	Nov. 8	54.80
May 25	58.64	Aug. 27	a 133.21	Dec. 8	a 114.20
May 27	54.20				

(C-42-6)30cda-2

Feb. 26, 1977	64.56	Sept. 28, 1977	79.36	Nov. 8, 1977	72.50
July 3	a 117.04	Sept. 29	78.85	Dec. 8	67.54
Aug. 27	a 116.23				

(C-42-11)19cca-1

Nov. 15, 1977	106.67	Nov. 18, 1977	109.54	Dec. 7, 1977	105.61

(C-42-11)19ccc-1

Nov. 15, 1977	94.58	Nov. 17, 1977	94.44	Dec. 7, 1977	93.58
Nov. 16	94.50	Nov. 18	97.94		

(C-42-11)19ccc-2

Nov. 17, 1977	102.55	Dec. 7, 1977	101.02	June 20, 1978	a 123.73
Nov. 18	a 115.05				

(C-42-11)19ccc-3

Nov. 15, 1977	92.64	Nov. 17, 1977	92.59	Dec. 7, 1977	92.04
Nov. 16	92.64	Nov. 18	95.50	June 20, 1978	110.09

(C-43-4)30bdd-1

Oct. 19, 1976	121.35	June 15, 1977	120.96	Nov. 8, 1977	121.05
Feb. 24, 1977	120.72	Aug. 24	120.93	June 22, 1978	121.12
Apr. 26	120.92				

(C-43-4½)19cbc-1

Oct. 6, 1976	20.90	Apr. 26, 1977	20.35	June 15, 1977	19.85
Feb. 23, 1977	21.58				

(C-43-4½)30cca-2

Sept. 28, 1976	30.13	June 15, 1977	30.35	Nov. 8, 1977	32.82
Feb. 23, 1977	30.35	Aug. 24	30.49	June 21, 1978	31.44
Apr. 26	30.30				

(C-43-4½)32aad-1

Oct. 5, 1976	1.74	June 15, 1977	2.15	Sept. 15, 1977	d 130.14
Oct. 14	a 45.00	July 5	2.30	Nov. 8	9.04
Feb. 24, 1977	1.60	Aug. 24	+1.06	July 21, 1978	+.47
Apr. 26	2.01				

(C-43-4½)33abb-1

Oct. 27, 1976	24.68	June 15, 1977	24.09	Nov. 8, 1977	26.14
Feb. 24, 1977	23.87	July 15	23.90	June 21, 1978	24.38
Apr. 26	24.08	Aug. 24	24.10		

(C-43-5)2bbd-1

Oct. 6, 1976	7.27	Apr. 27, 1977	7.52	Aug. 24, 1977	8.70
Feb. 23, 1977	5.41	June 15	a 37.56	Nov. 9	8.42

(C-43-5)24dca-1

Oct. 6, 1976	36.57	Dec. 8, 1977	36.99	June 21, 1978	35.20
Nov. 8, 1977	37.49				

(C-43-5)24dca-2

Oct. 6, 1976	36.43	June 15, 1977	36.40	Nov. 8, 1977	36.80
Feb. 23, 1977	36.50	Aug. 24	36.77	Dec. 8	36.46
Apr. 26	36.38				

(C-43-5)25aaa-1

May 26, 1977	27.40	Aug. 23, 1977	27.87	Dec. 8, 1977	28.00
June 18	27.41	Nov. 10	28.10	June 22, 1978	26.00

(C-43-5)25bbd-1

Sept. 28, 1976	68.13	June 15, 1977	69.34	Nov. 8, 1977	68.50
Feb. 23, 1977	67.95	Aug. 24	67.94	Dec. 8	68.50
Apr. 26	67.98	Sept. 28	68.33	June 21, 1978	68.64

(C-43-5)25bda-1

Sept. 22, 1976	44.39	June 15, 1977	44.44	Sept. 28, 1977	a 88.76
Feb. 23, 1977	44.28	Aug. 24	46.50	Nov. 8	47.69
Apr. 26	44.35	Sept. 27	a 90.30	June 21, 1978	45.44

(C-43-5)25cac-1

Sept. 22, 1976	31.49	June 15, 1977	31.53	Nov. 8, 1977	38.02
Feb. 23, 1977	31.40	Aug. 24	32.34	Dec. 8	34.96
Apr. 26	31.36	Sept. 28	a 79.95	June 21, 1978	37.47

(C-43-5)25cda-1

Sept. 22, 1976	28.27	June 15, 1977	28.41	Nov. 8, 1977	31.38
Feb. 23, 1977	28.29	Aug. 24	28.88	Dec. 8	30.82
Apr. 26	28.20	Sept. 28	30.08	June 21, 1978	31.35

(C-43-5)25cdb-1

Sept. 22, 1976	29.60	June 15, 1977	29.44	Nov. 8, 1977	35.18
Feb. 23, 1977	29.48	Aug. 24	30.20	Dec. 8	32.63
Apr. 26	29.46	Sept. 28	33.06	June 21, 1978	34.46

Table 19.--Water levels in selected observation wells--Continued

(C-43-5)25cdb-2					
Apr. 26, 1977	32.38	Aug. 24, 1977	33.48	Sept. 28, 1977	a 53.73
June 15	32.49				
(C-43-5)25dbb-1					
Sept. 28, 1976	34.55	Aug. 24, 1977	35.00	Nov. 8, 1977	36.64
Apr. 26, 1977	34.44	Sept. 28	35.65	June 21, 1978	36.74
June 15	34.48				
(C-43-5)34abd-1					
Sept. 30, 1976	162.06	Apr. 26, 1977	165.12	Aug. 24, 1977	160.42
Feb. 23, 1977	a 231.59	Apr. 28	160.23	Nov. 8	162.58
Feb. 24	160.33	June 15	167.15	June 12, 1978	162.56
(C-43-5)35aaa-1					
Feb. 23, 1977	39.79	May 3	a 71.75	Aug. 25, 1977	38.28
Apr. 26	40.11	June 15	36.43	Nov. 10	38.43
(C-43-5)35dab-2					
Aug. 25, 1977	32.13	Sept. 22, 1977	32.15	Dec. 8, 1977	32.74
Sept. 21	32.18	Nov. 8	33.40	June 21, 1978	31.43
(C-43-5)36ada-1					
Apr. 26, 1977	17.42	Aug. 25, 1977	17.85	Nov. 8, 1977	18.25
June 15	17.10				
(C-43-5)36cab-1					
Sept. 30, 1976	10.60	June 15, 1977	d 29.40	Sept. 20, 1977	13.68
Feb. 23, 1977	10.68	Aug. 25	d 18.95	Nov. 8	12.93
Feb. 25	10.61	Sept. 15	13.75	Dec. 8	12.19
Apr. 26	d 20.00	Sept. 16	13.71	June 22, 1978	12.09
May 4	d 24.67	Sept. 19	13.60		
(C-43-5)36ccc-1					
Sept. 30, 1976	29.34	May 17, 1977	29.72	July 5, 1977	30.00
Oct. 5	29.61	May 20	29.78	Aug. 25	30.55
May 4, 1977	29.65	May 28	29.79	Nov. 8	31.09
May 13	29.78	June 15	29.95	June 22, 1978	31.86
(C-43-6)27dbd-1					
Oct. 14, 1976	42.87	June 16, 1977	41.36	Nov. 8, 1977	41.66
Feb. 24, 1977	41.80	Aug. 23	41.96	June 21, 1978	41.70
Apr. 27	43.20				
(C-43-7)16bcc-1					
May 11, 1977	150.61	June 17, 1977	152.49		
(C-43-7)16bdd-1					
May 11, 1977	90.54	Sept. 27, 1977	a 139.35	Nov. 11, 1977	94.92
(C-43-7)16dba-1					
May 11, 1977	56.20	Sept. 27, 1977	a 105.50	Nov. 11, 1977	63.42
June 17	a 96.60				

Table 19.--Water levels in selected observation wells--Continued

(C-44-5)2aba-1					
Apr. 30, 1977	a 54.23	May 4, 1977	36.10	Aug. 25, 1977	37.17
May 2	35.85	June 15	a 54.04	Nov. 10	40.12
(C-44-5)6cbb-1					
Sept. 30, 1976	59.59	Apr. 27, 1977	55.50	Aug. 26, 1977	55.65
Feb. 24, 1977	a 58.20	June 15	58.00	Nov. 8	a 59.10
(C-44-6)5ddd-1					
June 2, 1977	64.50	Aug. 28, 1977	63.05	Nov. 10, 1977	62.44

a Pumping.
b Reported.
c Nearby well pumping.
d Recently pumped.

Table 20.--Selected drillers' logs of wells

Altitudes are in feet above mean sea level for land surface at well; interpolated from U.S. Geological Survey topographic maps.
Thickness in feet.
Depth in feet below land surface.
Geologic designations and simplification of logs by R. M. Cordova.

Material	Thickness	Depth
UPPER KANAB CREEK BASIN		
(C-39-5)18bcd-1. Log from 0 to 703 ft by Phelps Pump and Equip. Co. and from 703 to 1,600 ft by R. Moss Co. Alt. 6,900.		
Unconsolidated terrace deposits:		
Clay and silt	52	52
Tropic Shale:		
Coal	19	71
Shale with minor sandstone	49	120
Limestone with minor shale	25	145
Sandstone and limestone	110	255
Shale with minor sandstone	75	330
Coal	4	334
Shale with sand streaks	44	378
Undifferentiated Cretaceous and Jurassic rocks:		
Sandstone with shale streaks	38	416
Shale with sand streaks	12	428
Sandstone with shale streaks	69	497
Shale, arenaceous, gray	23	520
Sandstone with minor shale	115	635
Shale, arenaceous, green and red	68	703
Shale, gravelly, red and gray, with minor limestone	522	1,225
Carmel Formation:		
Limestone and shale	180	1,405
Limestone	25	1,430
Navajo Sandstone	170	1,600
(C-39-5)30bdc-1. Log by Oil Inc. Alt. 6,850.		
Tropic Shale:		
Shale	10	10
Coal	14	24
Sandstone and shale	126	150
Coal, sandstone, and shale	30	180
Shale and sandstone	30	210

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-39-5)30bdc-1. - Continued		
Dakota Sandstone:		
Sandstone, conglomeratic	30	240
Jurassic rocks, undivided:		
Sandstone and shale	390	630
Sandstone	300	930
Siltstone and shale	30	960
Carmel Formation:		
Limestone, shale, and gypsum	240	1,200
Navajo Sandstone:		
Sandstone	249	1,449
(C-40-4½)31bda-1. Log by K. Bentley. Alt. 6,050.		
Valley fill:		
Clay, sand, and gravel	41	41
Gravel	19	60
Clay and sand	34	94
Gravel	18	112
Jurassic rocks:		
Shale	38	150
(C-40-4½)32baa-2. Log by T. Ballard. Alt. 6,080.		
Valley fill:		
Soil	5	5
Gravel	40	45
Silt and sand	10	55
Gravel	11	66
Clay	6	72
Gravel	8	80
Clay and sand	55	135
(C-40-4½)32bad-1. Log by T. Ballard. Alt. 6,065.		
Valley fill:		
Silt	35	35
Gravel	55	90
Jurassic rocks, undivided:		
Shale	45	135

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-40-4½)33cba-2. Log by J. Moore. Alt. 6,060.		
Valley fill:		
Silt.	10	10
Jurassic rocks, undivided:		
Sandstone, limestone, and siltstone	58	68
Limestone, gypsum, and siltstone.	51	119
Gypsum, siltstone, and limestone.	9	128
Shale, minor limestone, and gypsum.	10	138
Carmel Formation:		
Limestone, siltstone, shale, sandstone, and gypsum.	90	228
Navajo Sandstone:		
Sandstone, white, tan, and some red-brown shale	657	885
(C-40-5)16cdc-1. Log from 0-1,148 ft by Rudy Johnson Drilling Co., from 1,148 to 2,694 by Gunnison Drilling Co. Alt. 6,645.		
Valley fill:		
Silt, clayey, and silty clay.	55	55
Jurassic rocks, undivided:		
Sandstone, light-gray to white, very fine and fine-grained, minor shale, and siltstone. .	199	254
Siltstone, tan, some sandstone and mudstone; water at 370 ft	321	575
Shale, gray and brown, and gypsum	57	632
Sandstone, fine-grained, light-brown to tan, gypsum, minor shale, and mudstone	118	750
Carmel Formation:		
Limestone, some gypsum, siltstone, shale, and sandstone	210	960
Navajo Sandstone:		
Sandstone, medium- and fine-grained, gray to white, frosted	514	1,474
Sandstone, fine- to medium-grained, white to light-red, frosted	395	1,869
Sandstone, fine- to medium-grained, light-red, frosted.	505	2,374
Tenny Canyon Member of Kayenta Formation:		
Siltstone and sandstone	60	2,434
Lamb Point Tongue of Navajo Sandstone:		
Sandstone, tan to light-pink, grains frosted.	260	2,694

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-41-4½)6aad-1. Log by T. Ballard. Alt. 5,970.		
Valley fill:		
Clay and sand	35	35
Sand	5	40
Sand and gravel	20	60
Clay, sand, and gravel	10	70
Sand and gravel	30	100
(C-41-5)5aaa-1. Log by Rudy Johnson Drilling Co. Alt. 6,275.		
Unconsolidated deposits:		
Silt, clayey, and silty sand	30	30
Carmel Formation:		
Limestone, siltstone, shale, and gypsum; water	190	220
Navajo Sandstone:		
Sandstone, very fine to medium-grained, light-gray to white, frosted	160	380
Sandstone, fine- to medium-grained, frosted, white, tan, and light-red; moisture near bottom	577	957
(C-42-5)11bdb-1. Log by F. Hastings. Alt. 5,540.		
Valley fill:		
Clay	30	30
Sand	20	50
Clay and sand	42	92
Gravel	1	93
Hardpan	5	98
Navajo Sandstone:		
Sandstone, red	102	200
Shale, red	36	236
Sandstone, white	9	245

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-42-5)15bdc-1. Log by T. Ballard. Alt. 5,460.		
Valley fill:		
Clay and sand	2	2
Sand	13	15
Clay	56	71
Sand	57	128
Navajo Sandstone:		
Sandstone	56	184
Shale, sandy	16	200
(C-42-5)23bbb-1. Log by P. Measfelder. Alt. 5,600.		
Valley fill	101	101
Navajo Sandstone	94	195
(C-42-5)34dbb-1. Log by W. Cox. Alt. 5,400.		
Valley fill:		
Sand	55	55
Gravel	10	65
Navajo Sandstone	215	280
(C-42-6)19bdc-1. Log by H. Maroney. Alt. 5,500.		
Valley fill	18	18
Navajo Sandstone:		
Sandstone, red	87	105
Sandstone, white	31	136
Sandstone, red	62	198
Tenney Canyon Member of Kayenta Formation:		
Shale, red, and sandstone	42	240
Shale, red	31	271
(C-43-4)30bdd-1. Log by T. Ballard. Alt. 5,315.		
Valley fill:		
Clay and sand, blue	50	50
Chinle Formation:		
Shale, blue and brown	107	157
Shinarump Member of Chinle Formation	38	195

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-43-$4\frac{1}{2}$)19cbc-2. Log by T. Ballard. Alt. 5,145.		
Valley fill:		
Sand, silty and clayey	86	86
Gravel, coarse, and sand	27	112
Chinle Formation:		
Shale.	1	113
(C-43-$4\frac{1}{2}$)30cca-1. Log by F. Quinn. Alt. 5,120.		
Valley fill:		
Sand, clay, and rock	22	22
Sand, clayey, hard	10	32
Clay, brown.	23	55
Sand, quick.	25	80
Sand, clayey	15	95
Clay and gravel.	4	99
Gravel, coarse	2	101
Gravel and clay.	29	130
Chinle Formation:		
Shale, gray, brown, and blue	217	347
(C-43-$4\frac{1}{2}$)31ddd-1. Log by P. Bradshaw. Alt. 5,110.		
Valley fill:		
Clay, red and gray	37	37
Sand and gravel.	2	39
Chinle Formation:		
Shale, gray, blue, and red	178	217
Shinarump Member of Chinle Formation:		
Sandstone, conglomeratic	38	255
Moenkopi Formation:		
Shale, sandy, gray and red	14	269
(C-43-$4\frac{1}{2}$)32aad-1. Log by W. Cox. Alt. 5,180.		
Valley fill:		
Sand and clay.	55	55
Sand and fine gravel	5	60
Chinle Formation:		
Shale, blue.	180	240
Shinarump Member of Chinle Formation:		
Sandstone, conglomeratic	60	300
Moenkopi Formation:		
Shale, red	5	305

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-43-5)24dca-1. Log by T. Ballard. Alt. 5,120.		
Valley fill:		
Clay and sand	28	28
Clay	15	43
Chinle Formation:		
Shale, red	7	50
Not reported	195	245
(C-43-5)25aaa-1. Log by T. Ballard. Alt. 5,120.		
Valley fill:		
Clay and sand	30	30
Sand and gravel	135	165
Chinle Formation:		
Shale, red	10	175
(C-43-5)25bbd-1. Log by T. Ballard. Alt. 5,160.		
Valley fill:		
Sand	56	56
Gravel	2	58
Sand	42	100
Gravel	22	122
Chinle Formation:		
Shale, blue	3	125
(C-43-5)25cac-1. Log by T. Ballard. Alt. 5,120.		
Valley fill:		
Sand, red	75	75
Sand and gravel	28	103
Chinle Formation:		
Shale, blue	7	110
(C-43-5)25dcb-1. Log by W. Cox. Alt. 5,100.		
Valley fill:		
Clay and sand	55	55
Sand and gravel	27	82
Clay, brown	8	90
Chinle Formation:		
Shale, purple	4	94

Material	Thickness	Depth
UPPER KANAB CREEK BASIN - Continued		
(C-43-5)35aaa-1. Log by D. White. Alt. 5,110.		
Valley fill:		
Sand	12	12
Chinle Formation:		
Shale	183	195
Shinarump Member of Chinle Formation:		
Sandstone, conglomeratic	35	230
Moenkopi Formation	8	238
(C-43-5)36cab-1. Log by Grimshaw Drilling Co. Alt. 5,080.		
Valley fill:		
Sand and gravel	21	21
Clay	7	28
Shinarump Member of Chinle Formation:		
Sandstone, conglomeratic	92	120
Moenkopi Formation:		
Shale, blue	330	450
Limestone, green	330	780
Sandstone, red	100	880
Not reported	297	1,177
(C-43-6)27dbd-1. Log by W. Cox. Alt. 5,000.		
Valley fill:		
Sand	35	35
Gravel	60	95
Chinle Formation:		
Shale, red and blue	130	225
(C-44-6)5ddd-1. Log by T. Ballard. Alt. 4,840.		
Unconsolidated terrace deposits:		
Sand, gravel, and boulders	10	10
Clay, sand, and gravel	40	50
Gravel	10	60
Chinle Formation:		
Shale, blue and gray	82	142
Shale, sandy, red	18	160
Shale, red and gray	182	342
Sandstone, white	23	365
Shale, reddish-brown	10	375

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER VIRGIN RIVER BASIN		
(C-39-6)4cad-1. Log by T. Ballard. Alt. 7,080.		
Valley fill:		
Clay and gravel	10	10
Clay, red	40	50
Clay, sandy, white and yellow	25	75
Clay, red	30	105
Wasatch Formation:		
Shale, pink	65	170
(C-39-11)12ddb-1. Log by L. Glazier. Alt. 7,910.		
Soil	5	5
Lava	115	120
Lava, porous, red	48	168
(C-40-7)14bad-1. Log by W. Cox. Alt. 5,880.		
Valley fill:		
Clay, sand, and boulders	30	30
Clay, sand, and gravel	40	70
Wahweap Sandstone:		
Sandstone, conglomerate, and shale; coal	29	99
Sandstone, fractured	21	120
(C-40-11)8dcd-1. Log by P. Bradshaw. Alt. 5,900.		
Valley fill:		
Sand	50	50
Volcanic flow rock and cinders	214	264
Clay and sand	36	300
Navajo Sandstone:		
Sandstone and some shale	456	756
Kayenta Formation:		
Shale, red and gray	67	823
(C-41-7)4aaa-1. Log by T. Ballard. Alt. 5,480.		
Valley fill:		
Sand	18	18
Sand, partly cemented	22	40
Sand and gravel	35	75

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER VIRGIN RIVER BASIN - Continued		
(C-41-7)19cdc-2. Log by P. Bradshaw. Alt. 5,200.		
Valley fill:		
Clay, sand, and gravel	46	46
Carmel Formation:		
Limestone and shale	39	85
Navajo Sandstone	210	295
(C-41-7)30bba-1. Log by T. Ballard. Alt. 5,190.		
Valley fill:		
Sand	20	20
Sand and gravel	50	70
Sand	80	150
Clay	10	160
Sand	40	200
Navajo Sandstone	110	310
(C-41-9)15dcd-1. Log by P. Bradshaw. Alt. 5,970.		
Valley fill:		
Loam, sandy	30	30
Clay and gravel	50	80
Clay	20	100
Clay and gravel	8	108
Gravel and rocks	9	117
Navajo Sandstone:		
Sandstone, yellow	98	215
Sandstone, red and white	30	245
(C-41-10)28bdb-1. Log by B. Bradshaw. Alt. 3,930.		
Valley fill:		
Sand and gravel	38	38
Gravel	30	68
Clay and gravel	2	70
Gravel	14	84
Chinle Formation:		
Shale	16	100

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER VIRGIN RIVER BASIN - Continued		
(C-42-11)1dcb-1. Log by F. Hastings. Alt. 3,700.		
Valley fill:		
Clay	31	31
Clay and gravel	7	38
Gravel	10	48
Clay and gravel	13	61
Clay	9	70
Moenkopi Formation:		
Shale, red	22	92
(C-42-11)3aad-1. Log by F. Hastings. Alt. 3,750.		
Terrace deposits:		
Gravel, cemented	30	30
Moenkopi Formation:		
Shale, red and white	124	154
(C-42-11)19ccc-1. Log by B. Bradshaw. Alt. 4,700.		
Valley fill:		
Clay and sand	50	50
Sand and gravel	40	90
Clay and sand	50	140
Sand and gravel	2	142
Clay and sand	68	210
Gravel	32	242
Moenkopi Formation:		
Shale	43	285
(C-42-11)32ada-1. Log by B. Bradshaw. Alt. 4,845.		
Valley fill:		
Clay and sand	60	60
Clay, sand, and gravel	30	90
Chinle Formation:		
Shale, purple and gray	106	196
Shinarump Member of Chinle Formation:		
Sandstone, conglomeratic, gray and white	54	249
Moenkopi Formation:		
Shale	1	250

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER VIRGIN RIVER BASIN - Continued		
(C-42-11)34bbb-1. Log by T. Ballard. Alt. 4,960.		
Valley fill:		
Clay and sand.	5	5
Gravel and boulders.	10	15
Sand and gravel.	85	100
Chinle Formation:		
Shale, gray, blue, and brown	325	425
Shinarump Member of Chinle Formation:		
Sandstone, white	30	455
(C-42-12)11adb-1. Log by P. Bradshaw. Alt. 5,080.		
Soil, clay	15	15
Shinarump Member of Chinle Formation:		
Sandstone, white, yellow, and gray	155	170
(C-42-12)18ccd-1. Log by T. Ballard. Alt. 4,240.		
Terrace deposits:		
Sand and clay.	5	5
Clay	40	45
Sand and gravel.	5	50
Moenkopi Formation:		
Shale.	25	75
(C-42-12)23daa-2. Log by B. Bradshaw. Alt. 4,640.		
Valley fill:		
Clay and sand.	10	10
Sand and gravel.	15	25
Clay and sand.	20	45
Gravel	1	46
Clay and sand.	106	152
Clay	11	163
Volcanic rocks:		
Cinders and clay	15	178
Lava, solid.	9	187
Cinders and clay	28	215
Lava, solid.	8	223
Cinders and clay	22	245

Table 20.--Selected drillers' logs of wells - Continued

Material	Thickness	Depth
UPPER VIRGIN RIVER BASIN - Continued		
(C-43-10)34add-1. Log by J. Jessop. Alt. 5,050.		
Valley fill:		
Sand with minor clay	38	38
Sand	7	45
Clay	4	49
Sand	21	70
Clay and sand	20	90
Chinle Formation at bottom		
(C-43-11)15ccb-1. Log by J. Jessop. Alt. 4,840.		
Chinle Formation:		
Shale, red	36	36
Shinarump Member of Chinle Formation:		
Sandstone, yellow, red, and brown	129	165
Moenkopi Formation:		
Shale, red	2	167