# GEOHYDROLOGY OF THE NAVAJO SANDSTONE IN WESTERN KANE, SOUTHWESTERN GARFIELD, AND SOUTHEASTERN IRON COUNTIES, UTAH

By Geoffrey W. Freethey

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4040

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UTAH DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL, GAS, AND MINING

Salt Lake City, Utah
1988

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

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[Plates are in pocket]



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## CONVERSION FACTORS

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

| Multiply inch-pound units | By | To obtain metric units |
|---|---|---|
| acre | 0.4047 | hectare |
| | 0.004047 | square kilometer |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer |
| acre-foot per year (acre-ft/yr) | 0.001233 | cubic hectometer per year |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot per mile (ft/mi) | 0.18939 | meter per kilometer |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day |
| gallon per minute (gal/min) | 0.06308 | liter per second |
| gallon per minute per foot [(gal/min/ft)] | 0.20696 | liter per second per meter |
| inch (in) | 25.4 | millimeter |
| inch per year (in/yr) | 25.4 | millimeter per year |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |

Chemical concentration and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume of water. For concentrations less than 7,000 mg/L the numerical value is about the same as for concentrations in parts per million. A concentration of 1,000 µg/L is equivalent to 1 mg/L.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter (meq/L), a term which is numerically equal to the inch-pound unit equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ (°C) + 32.$$

Specific conductance is reported in microsiemens per centimeter at 25 °C (µS/cm).

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929".

# GEOHYDROLOGY OF THE NAVAJO SANDSTONE IN WESTERN KANE, SOUTHWESTERN GARFIELD, AND SOUTHEASTERN IRON COUNTIES, UTAH

by Geoffrey W. Freethey

## ABSTRACT

The upper Navajo and Lamb Point aquifers in the Navajo Sandstone are the principal source of water for the city of Kanab, irrigation, stock, and for rural homes in the study area. Well logs and outcrop descriptions indicate the Navajo Sandstone consists of the Lamb Point Tongue and an unnamed upper member that are separated by the Tenney Canyon Tongue of the Kayenta Formation. The main Kayenta Formation underlies the Lamb Point Tongue. The Lamb Point Tongue and the upper member of the Navajo Sandstone are saturated and hydraulically connected through the Tenney Canyon Tongue. Available data indicate that precipitation percolates to the ground-water reservoir where the Navajo Sandstone crops out. Estimates of the rate of recharge at the outcrop range from 0.1 to as much as 2.8 inches per year. Water-level data indicate that water moves from the upper member of the Navajo Sandstone, through the Tenney Canyon Tongue, and into the Lamb Point Tongue. Lateral flow is generally from the outcrop areas towards the incised canyons formed by tributaries of Kanab Creek and Johnson Wash. Direction and rate of ground-water movement and the location and character of the natural hydrologic boundaries in the northern part of the area where the Navajo Sandstone is buried cannot be determined conclusively without additional water-level data.

## INTRODUCTION

Because of impending development of the coal resources and a related need for water in western Kane, southwestern Garfield, and southeastern Iron Counties, ground water has become a natural resource of significant interest in this moderately dry region of southwestern Utah (fig. 1). Before issuing a permit to develop ground water, the Utah Division of Water Rights requires reasonable assurance that the rights of current holders of water-use permits will not be violated. In addition, the Utah Division of Oil, Gas, and Mining needs to assess the possible impacts of the mining project on the environment of the surrounding area. This includes assessing the effects of lowering the potentiometric surface of the upper Navajo and Lamb Point aquifers because of pumping or other disturbances.

Plans for mining the coal resources of the area include developing a well field to pump water from the Navajo Sandstone. The proposed location of the well field is near Alton, Utah. The well field will provide water for mining operations and slurrying the coal for transportation to a power plant 25 mi northeast of Las Vegas, Nevada, and about 150 mi southwest of Alton. The quantity of water required depends on the quantity of coal to be transported, which in turn depends on the electrical output of the power plant. Because of changes in the projected output of the power plant, water requirements have decreased from estimates of 8,000 gal/min in 1979 to 2,500 gal/min in 1987.

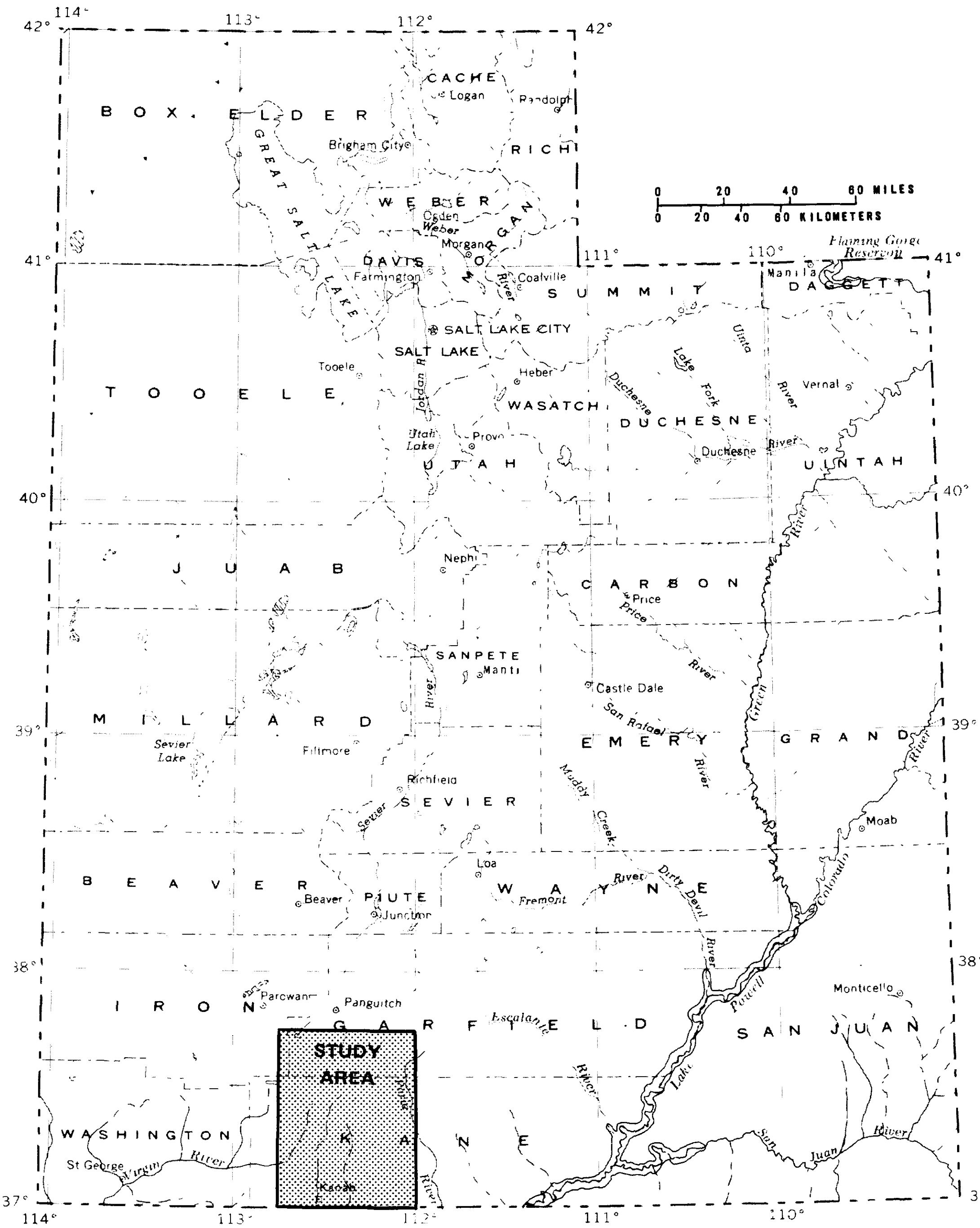



Figure 1.—Location of the study area.

Geohydrologic investigations of the study area and vicinity date back to the late 1950's, however, because of the meagerness of available data previous investigations have failed to clearly define (1) the direction and rate of ground-water movement, (2) the sources and rates of recharge and discharge, and (3) the effects of faults, fracturing, and lithologic variability in geologic formations on the movement of ground water. Additional data have recently been collected by representatives of the coal company, at the request of the Utah Division of Oil, Gas, and Mining, to help resolve discrepancies in past interpretations.

## Purpose and Scope

The purpose of this report is to describe the geohydrology of the Navajo Sandstone in western Kane, southwestern Garfield, and southeastern Iron Counties, and to evaluate the geohydrologic description and the components of the ground-water budget on the basis of available data. Additional data collection that is needed for improving knowledge and understanding of the ground-water resources is identified.

The scope of this investigation was limited to evaluating results of previous investigations and did not include collection of new data. Recently collected (1986-87) water-level data and spring inventory data by representatives of the coal company were included in the evaluation. In order to evaluate estimates of water-budget components for the study area by previous investigators, it was useful to look at estimates of recharge to, discharge from, and lithologic and hydrologic properties of the Navajo Sandstone for areas outside of, but relatively similar to, this study area.

## Previous Investigations

Previous investigations of the geology and hydrology of the Navajo Sandstone in southwestern Utah are numerous, and are cited throughout this report. The hydrologic system of the Navajo Sandstone in the study area has been investigated by the State of Utah, the U.S. Geological Survey, coal company hydrologists, and private consultants, and several aspects of hydrologic properties and ground-water movement have been discussed in the reports resulting from these studies. Reports of particular interest to this investigation include those by Bingham Engineering (1973, 1974, 1979, 1981a, 1981b, and 1987); Blanchard (1986); Cordova (1981); Doelling and Graham (1972); Feltis (1966); Goode (1964, 1966); Gregory (1951); Hintze (1963); Sandberg (1979); and Todd (1987), because they contain most of the historic geologic and hydrologic data for the area. The reports by Bingham Engineering include descriptions of the hydrology, geology, and drilling program in the Navajo Sandstone conducted by the coal company. Blanchard (1986) describes ground-water conditions in the Navajo Sandstone for the area to the east of this study area, the Kaiparowits Plateau, and includes estimates of recharge. Cordova (1981) describes the hydrology of the upper Virgin River and the Kanab Creek drainage basins and summarizes the recharge, discharge, movement, and chemical quality of the water in the Navajo Sandstone. Doelling and Graham (1972) describe the coal resources of the three principal coal fields in southwestern Utah; Alton, Kaiparowits Plateau, and Kolob-Harmony. Feltis (1966) and Goode (1964, 1966) provide earlier descriptions of the occurrence and movement of water in the Navajo Sandstone for this study area and for surrounding areas. Gregory (1951) and Hintze (1963) provide descriptions of the lithology, stratigraphy, and faulting that may affect the hydrology of the study area. Sandberg (1979) provides a hydrologic description of the area that is to be strip mined, and Todd (1987) documents the development of a three-dimensional ground-water flow model for the Kanab Creek drainage basin.

### Data-site numbering

The system for identifying and locating hydrologic- and geologic-data sites in Utah is based on the cadastral land-survey system of the U.S. Government. An assigned number, in addition to designating a well, spring, or related 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 (see figure 2). These quadrants are designated by the uppercase letters A, B, C, and D, indicating, respectively, the northeast, northwest, southwest, and southeast quadrants. Numbers designating the township and range follow the quadrant letter, and all three are enclosed in parentheses. The number after the parenthesis 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. The letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the wells or springs within the 10-acre tract. The letter S preceding the serial number denotes a spring. A number having all three quarter designations, but without the letter S and without a serial number indicates a data site other than a well or spring. Such data sites include locations where geologic cores and outcrop samples were collected. For the half ranges found within the study area, the letter "R" precedes the parenthesis. If a site cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus (C-40-5)24bad-1 designates the first well visited in the southeast quarter of the northeast quarter of the northwest quarter of section 24, T. 40 S., R. 5 W. (fig. 2).

## LOCATION, GENERAL SETTING, CLIMATE, AND VEGETATION

The area considered in this report generally includes the upper drainage basins of the East Fork of the Virgin River, Kanab Creek, the Sevier River, and the Paria River in western Kane, southwestern Garfield, and southeastern Iron Counties (fig. 3). The drainage in Johnson Canyon is intermittent yet is a major tributary to Kanab Creek. The stream is officially named Johnson Wash, but is better known to area residents as Johnson Creek. The ideal boundaries of the area would be the natural hydrologic boundaries of the Navajo aquifer system. But because data needed to precisely identify these boundaries are not available, the study area is necessarily larger than the hydrologic system under investigation. The area roughly extends northward from the Utah-Arizona State line, at about latitude 37 degrees north, to about 37 degrees 45 minutes north, near the northern boundary of Bryce Canyon National Park. From east to west, the study area begins at longitude 112 degrees west and ends at about 112 degrees 45 minutes west. This rectangular area with dimensions of 45 minutes of latitude by 45 minutes of longitude encompasses approximately 2,100 $mi^2$.

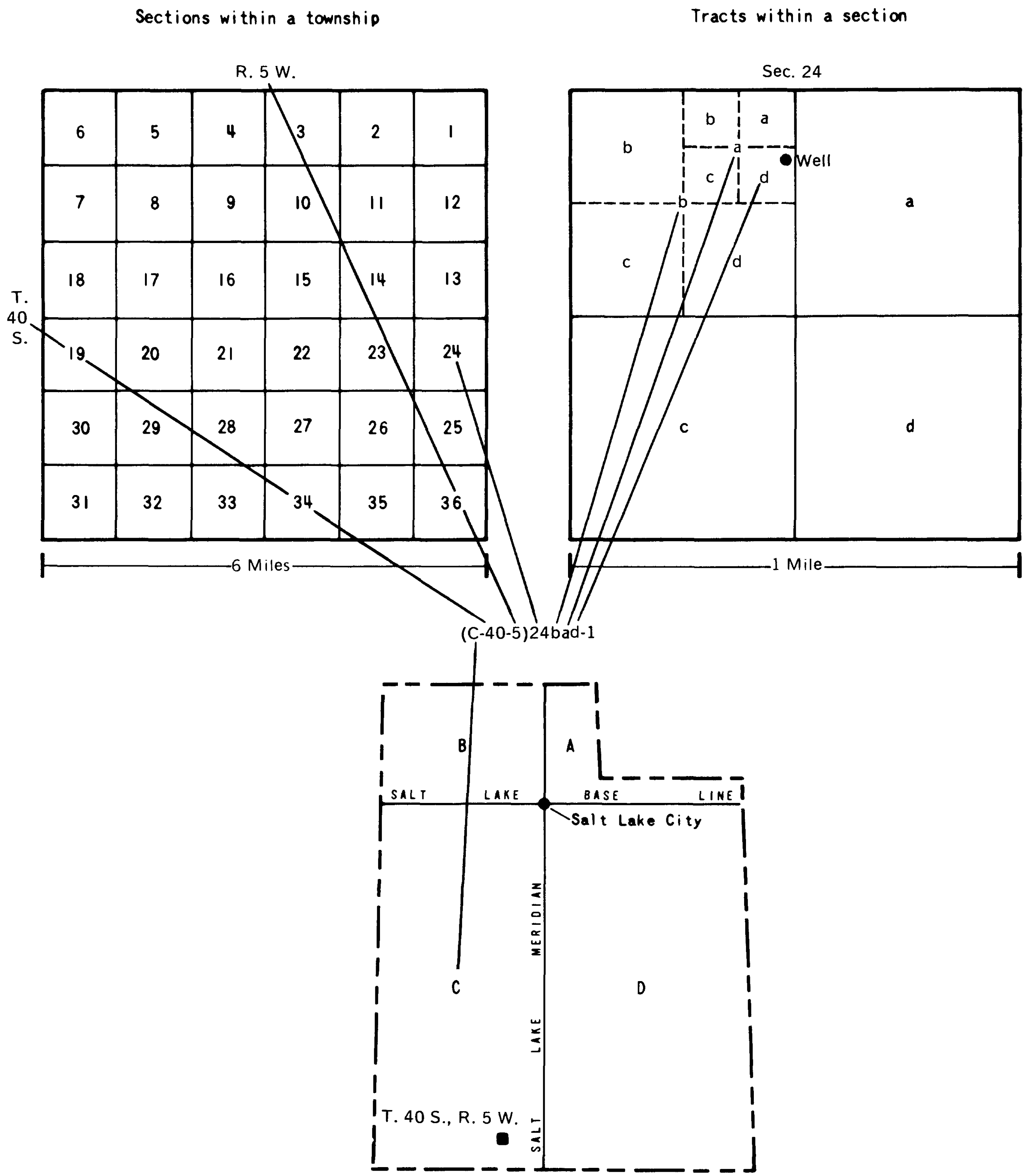
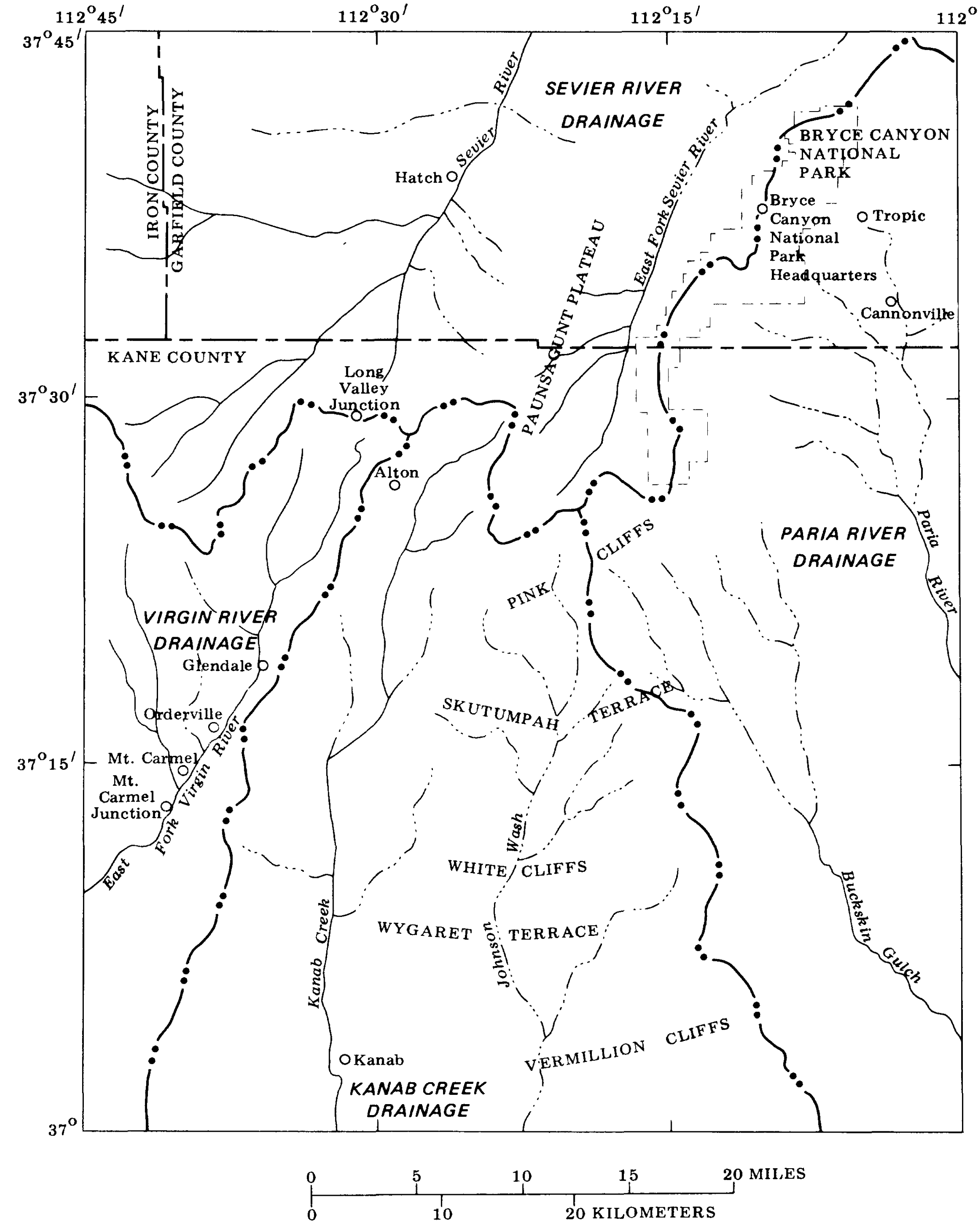



Figure 2.—Numbering system for geohydrologic-data sites in Utah.




EXPLANATION

——••—— DRAINAGE DIVIDE

Figure 3.—Geographic setting of the study area.

The study area is distinguished by a set of parallel, east-west trending arcuate cliffs (fig. 3) of striking colors, successively higher in altitude from south to north. The cliffs are separated by relatively flat terraces (fig. 3) ranging in width from 5 to 15 mi. The terraces have been deeply incised by the streams that form the Kanab Creek and Paria River drainage systems. Altitudes are 5,000 to 5,300 ft above sea level south of the Vermillion Cliffs; 5,600 to 6,000 ft on the Wygaret Terrace between the Vermillion and White Cliffs; 6,600 to 7,000 ft on the Skutumpah Terrace between the White and Pink Cliffs; and 8,000 to 9,000 ft north of the Pink Cliffs. Average annual precipitation, potential evapotranspiration, and vegetation density are closely related to altitude. Areas at the higher altitudes receive more precipitation, have a smaller evapotranspiration rate, and have denser vegetation than areas at the lower altitudes.

Precipitation and temperature data are available for Bryce Canyon National Park, Alton, and Kanab from the U.S. Department of Commerce. Records for these climatologic stations generally represent conditions in the study area, but cannot describe the local variability in annual precipitation. Annual precipitation (fig. 4) during the period of record for these three stations is extremely variable, ranging from about 6 to 26 in. During the period 1978 through 1983, average annual precipitation generally has been above the long-term average for 1931-86. Monthly precipitation during fall and winter tends to be about the same at all stations in contrast to monthly precipitation during the spring and summer (fig. 5). From October through March average precipitation is about 1 to 1.5 in per month; but from April through September, average precipitation ranges from less than 0.5 in at Kanab in June to more than 2.25 in at Bryce Canyon National Park in August. Torrential rains contribute to large monthly totals in July, August, and September.

Estimates of potential evapotranspiration for the study area vary because altitude, temperature, vegetation type and density, and air movement are not uniform. Based on available solar energy, annual potential evapotranspiration is less than 18 in on the Paunsaugunt Plateau, but is as large as 30 in south of the White Cliffs (Jeppson and others, 1968, fig. 25). Using a method suggested by Thornthwaite (1954), Jeppson and others (1968, table 7) predicted that about 25 percent of the annual potential evapotranspiration at Alton is during October through March. Annual consumptive use due to evapotranspiration, calculated using the Blaney-Criddle formula, is 32 to 36 in for the area between the Vermillion and White Cliffs (Huber and others, 1982, pl. 1).

Most of the study area supports a growth of pinyon-juniper, whereas smaller areas on the terraces are covered with sagebrush. Alluvial deposits in the main valleys usually are covered with natural grasses where these deposits are not or have not been cultivated previously. The density of plant growth depends somewhat on altitude and on the quantity of water available for consumption. Density and areal coverage of natural vegetation ranges from nearly barren in active flood plains and dune-covered uplands to thick in small areas surrounding seeps and springs.

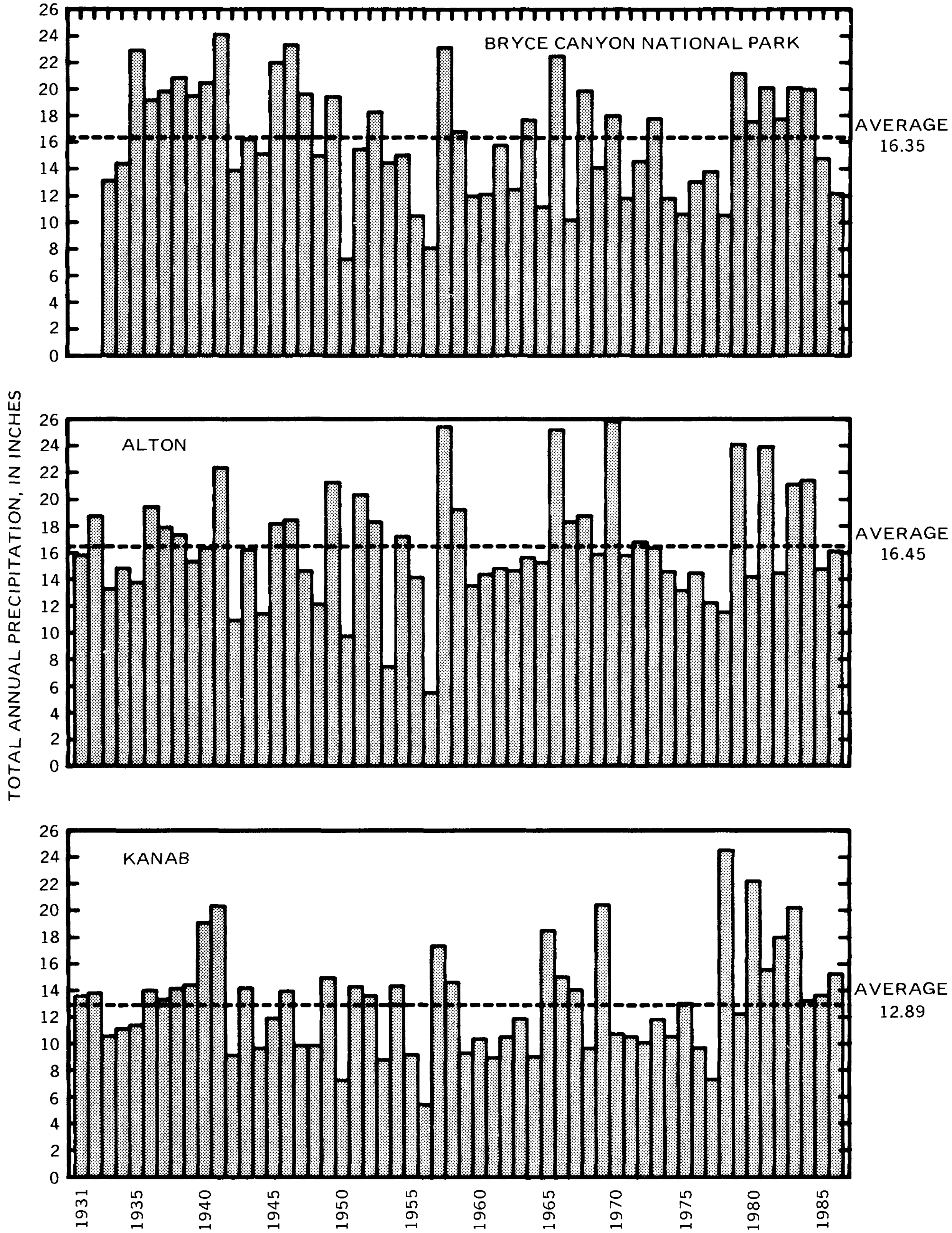



Figure 4.—Annual precipitation at the Bryce Canyon National Park, Alton, and Kanab climatologic stations 1931-86.

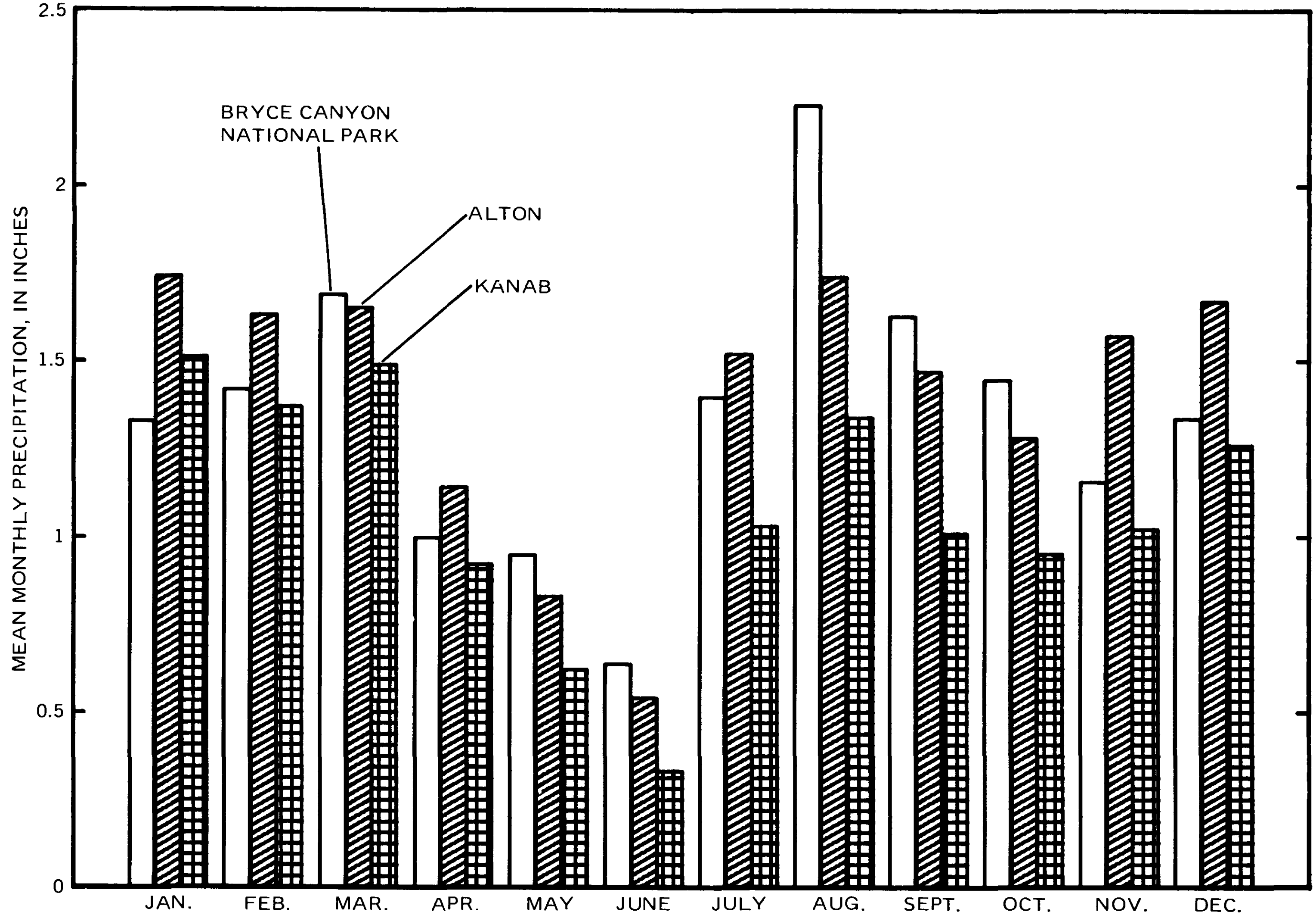



Figure 5.—Monthly variation in precipitation at the Bryce Canyon National Park, Alton, and Kanab climatologic stations (1931-86).

## GEOLOGIC SETTING

Two main concerns of this investigation were the determination of hydrologic boundaries and the occurrence and movement of ground water in the Navajo Sandstone. Understanding the geology of the Navajo Sandstone and adjacent formations within the study area is of great importance to understanding the occurrence and movement of ground water and to identifying and locating hydrologic boundaries. The formations in the study area do not lie horizontally, but are slightly warped into a synclinal shape that is more defined under the Paunsaugunt Plateau (Doelling and Graham, 1972, p. 10). This syncline plunges gently to the north-northeast. The Navajo Sandstone crops out only south of Skutumpah Terrace (pl. 1), and the Sandstone's depth increases northward. According to the driller's log of petroleum-test well (C-36-4)1adc-1, drilled near the entrance to Bryce Canyon National Park, the top of the Navajo Sandstone is at a depth of about 6,200 ft below land surface. This test well was drilled on the upthrown side of the Ahlstrom Hollow fault, and the depth to the Navajo Sandstone south of this fault may be several hundred feet more than indicated in the log.

### Faults and Fracturing

Most major faults trend north-south or north northeast-south southeast (pl. 1). Displacement along the Sevier fault, in the western part of the study area, varies from less than 100 to as much as 2,000 ft (Gregory, 1951). Displacement generally decreases from south to north, and is 2,000 ft in Yellow Jacket Canyon, from 1,000 to 2,000 ft between Mt. Carmel Junction and Long Valley Junction, and less than 1,000 ft north of Long Valley Junction. Displacement along the Paunsaugunt fault, in the eastern part of the study area, varies from 200 to 1,500 ft and increases from south to north. These two faults significantly displace the Navajo Sandstone along their length, and drag folding along each fault plane has been recognized (Bingham Engineering, 1987, p. III-6). The effect of these two major faults on ground-water movement across or parallel to them is not clear because of the variability in displacement and the uncertainty about the hydrologic effects of rock deformation in the vicinity of the fault planes. The Bald Knoll fault, located in the south-central part of the study area, is a normal fault upthrown to the west, with displacement as much as 500 ft (Doelling and Graham, 1972, p. 11). Faults in Kanab and Johnson Canyons have less than 200 ft of displacement (Cordova, 1981, p. 11). The only major east-west trending faults are the Ahlstrom Hollow fault near the northern border of the study area and a parallel fault 1 to 3 mi farther north (Gregory, 1951, p. 80). These two faults form a horst with a throw of about 500 ft.

Fracturing of the rocks has occurred as a result of regional deformation and of faulting. Descriptions of the problems encountered during drilling of test wells by the coal company indicate that fractured rock was encountered in several of the wells, perhaps because of their proximity to faults. Cordova (1981, p. 11) states that jointing is common in the area, but this jointing is more highly developed in the upper Virgin River basin than in the upper Kanab Creek basin.

## Stratigraphy and Lithologic Character

Throughout the study area the Navajo Sandstone of Early Jurassic and Late Triassic (?) age overlies the main part of the Kayenta Formation or intertongues with the Tenney Canyon Tongue of the Kayenta Formation of Late Triassic (?) age. The Kayenta and its Tenney Canyon Tongue consist principally of siltstone and very-fine-grained sandstone and are significantly less transmissive than the fine-grained, loosely cemented, massive-bedded Navajo Sandstone. The main part of the Kayenta Formation forms the lower hydrologic boundary for the Navajo Sandstone. Although the Kayenta Formation is not an impermeable boundary, it is effective in impeding the vertical movement of ground water, as indicated by the number of springs and seeps located where the contact between the Kayenta Formation and Navajo Sandstone is exposed along the Vermillion Cliffs. The Kayenta Formation is less than 200 ft thick in the study area (Cordova, 1981).

The Navajo Sandstone is divided into a lower member designated the Lamb Point Tongue and an unnamed upper member and are separated by the Tenney Canyon Tongue of the Kayenta Formation (see section on plate 1). Aggregate thickness of the Navajo is typically about 2,000 ft. The Lamb Point Tongue thickens slightly from west to east and from south to north. Maximum thickness of the Lamb Point is probably more than 650 ft in the northern half of the study area. The Tenney Canyon Tongue overlies the Lamb Point Tongue and thins to the north and east. The Tenney Canyon is generally less than 100 ft thick in most of the study area and pinches out west of the Paunsaugunt fault and east of Johnson Canyon.

Generally, the Navajo Sandstone consists of fine to very-fine, well rounded, well sorted, quartz grains cemented usually by calcite and less commonly by silica or hematite. Uygur (1980) noted that the degree of cementation increases from the upper to the lower parts of the Navajo Sandstone.

Other formations or deposits that may affect the hydrology of the Navajo Sandstone are the overlying Carmel Formation, Quaternary basalt flows, and unconsolidated Quaternary deposits. The Carmel Formation of Middle Jurassic age overlies the Navajo Sandstone north of the White Cliffs, and consists of limestone, shale, sandstone, and gypsum beds which total from 100 to 200 ft thick (Gregory, 1951, p. 23). Basalt from volcanic cones north of the White Cliffs overlies the Navajo Sandstone in small areas along the floor of Kanab and Johnson Canyons. These Quaternary flows are generally less than 30 ft thick. Alluvial sand and gravel overlie the Navajo Sandstone along many of the stream channels. Thickness of alluvial material may be more than 100 ft. Colluvium and dune sand overly the Navajo Sandstone in some higher areas of the Wygaret Terrace.

## GEOHYDROLOGY OF THE NAVAJO SANDSTONE

The saturated part of the Navajo Sandstone forms two principal aquifers in the part of the study area west of Johnson Canyon, the upper Navajo aquifer and the Lamb Point aquifer. East of where the Tenney Canyon Tongue pinches out, between Johnson Canyon and the Paunsaugunt Fault, the Navajo Sandstone is a single aquifer (table 1). Where the Tenney Canyon Tongue is absent and members of the Navajo Sandstone are not differentiated, the saturated part of the Navajo Sandstone is termed the Navajo aquifer.

**Table 1.—Geohydrologic terminology used in this report**

| Geologic Formation | Aquifers and confining units |
|---|---|
| Carmel Formation | Carmel confining unit |
| Upper unnamed member of the Navajo Sandstone | Upper Navajo aquifer* (saturated part) |
| Tenney Canyon Tongue of the Kayenta Formation | Tenney Canyon confining unit |
| Lamb Point Tongue of the Navajo Sandstone | Lamb Point aquifer* (saturated part) |
| Kayenta Formation | Kayenta confining unit |
| Moenave Formation | Moenave aquifer (saturated part) |

*Principal aquifer

According to well records, the upper Navajo aquifer south of the White Cliffs is unconfined, but is thought to be confined at some unknown distance north of the White Cliffs. The Lamb Point aquifer is confined everywhere except in areas where it crops out along the southern part of the Wygaret Terrace. Because the upper Navajo and Lamb Point aquifers are not isotropic and homogeneous either horizontally or vertically, springs and seeps may be discharging from locally perched ground-water reservoirs or local zones of the main reservoir that owe their existence to variations in permeability that occur because of changing lithologic character or sedimentary structures.

### Physical and Hydrologic Character of the Aquifers

Characteristics that describe the two Navajo aquifers include (1) the geometric configuration of the the upper Navajo and Lamb Point aquifers and of the Tenney Canyon confining unit between the aquifers, (2) the location and character of the natural hydrologic boundaries of these aquifers, and (3) the hydrologic properties of the principal aquifers and the Tenney Canyon confining unit, and how these properties vary laterally and vertically because of fracturing or changes in lithologic character. Faults preferentially oriented north-south, fault gouge, and fractures associated with the fault zones probably create anisotropic conditions in the principal aquifers, especially from east to west. Displacement of rock along a fault is usually accompanied by local microfracturing on each side of the zone of shearing, thus possibly imparting a larger hydraulic conductivity to this zone. Alternatively, if lateral compression of the rock was significant during the shear deformation, gouge material may have been produced along the fault plane, and hydraulic-conductivity values across the fault would be decreased (Teufel, 1987). The horizontal hydraulic conductivity in the north-south direction near the north-south faults may be several times greater than the horizontal hydraulic conductivity perpendicular to or across faults. Vertical ground-water movement near these fault planes may also be more pronounced than vertical movement in areas away from the fracturing associated with faulting.

### Geometric Configuration

Thickness of the lithostratigraphic units forming the principal aquifers and the confining units in the study area can be estimated reasonably well from thickness measured in outcrops from the Vermillion to the White Cliffs and by using data from the few wells whose logs indicate altitude of formation contacts (table 2). Thickness of the Lamb Point aquifer was estimated from the difference in altitude between the top and bottom of the Lamb Point Tongue because the Lamb Point is usually fully saturated. Thickness of the upper Navajo aquifer was estimated from the difference between the potentiometric surface and the top of the Tenney Canyon Tongue because the upper Navajo is not usually fully saturated. Figure III-5 in a report by Bingham Engineering (1987) depicts the geometry, west to east, of the upper Navajo and Lamb Point aquifers across the entire outcrop area of the Navajo Sandstone in the study area. A diagrammatic section (pl. 1) in this report depicts a west-east section north of the White Cliffs across the Skutumpah Terrace, but does not give aquifer thickness in this area because of the lack of water-level data. The Bingham Engineering report indicates that water in the Lamb Point aquifer east of Johnson Canyon is unconfined, and the saturated thickness of the Lamb Point aquifer at Johnson Canyon is about 250 ft, and thins to less than 100 ft to the east. The Lamb Point aquifer is largely confined west of Johnson Canyon, but becomes unconfined again near the Sevier fault. Bingham Engineering's interpretation probably was based on spring altitudes in the deeply incised canyons in the area. Saturated thickness of the Lamb Point aquifer is as much as 400 ft just to the west of Johnson Canyon, but the aquifer thins farther west because the Lamb Point Tongue itself thins to less than 200 ft near the Sevier fault.

The upper unnamed member of the Navajo Sandstone is virtually unsaturated east of Johnson Canyon, but 150 to 200 ft of the member is saturated in the area between Johnson and Kanab Canyons and to the west of Kanab Canyon.

North of the outcrop area, water-level data are scarce. Water levels in wells in the Bald Knoll area indicate that the Lamb Point Tongue is entirely saturated, and that the upper unnamed member of the Navajo Sandstone is only partially saturated. The Lamb Point aquifer is 628 ft thick and the upper Navajo aquifer is 1,079 ft thick at Bald Knoll (Bingham Engineering, 1981, p. 5). North, east, and west of Bald Knoll, saturated thicknesses are unknown.

**Table 2.--Wells in the study area with logs that indicate depths to the top of formations that form the aquifers and confining units**

Well location number: for explanation of numbering system, see section on data-site numbering.
Altitude of land surface: feet above sea level.
Depths: x, depth probably reflects an eroded surface rather than original top of formation; y, depth reported by driller as moist sand, possible water table. All depths are feet below land surface.

| Well location number | Altitude of land surface | Depth to top of saturated zone | Depth to top of upper Navajo Sandstone | Depth to top of Tenney Canyon Tongue | Depth to top of Lamb Point Tongue | Depth to top of Kayenta Formation | Saturated thickness of Navajo Sandstone |
|---|---|---|---|---|---|---|---|
| (C-39-5)18bcd-1 | 6,900 | - | 1,430 | - | - | - | - |
| 30bdc-1 | 6,850 | - | 1,200 | - | - | - | - |
| R(C-40-4)33cba-2 | 6,060 | 553 | 228 | - | - | - | - |
| (C-40-5)16cdc-1 | 6,645 | 1,243 | 960 | 1,869 | 2,434 | - | - |
| 21abb-1 | 6,649 | 1,250 | 950 | - | - | - | - |
| 21abc-1 | 6,612 | 1,213 | 902 | 2,292 | 2,354 | 2,982 | 1,707 |
| (C-40-6)35acd-1 | 6,230 | - | 285 | - | - | - | - |
| (C-41-5) 5aaa-1 | 6,275 | 950y | 220 | - | - | - | - |
| (C-41-7)19cdc-2 | 5,200 | - | 85 | - | - | - | - |
| 30bba-1 | 5,190 | - | 200x | - | - | - | - |
| (C-41-9)15dcd-1 | 5,970 | - | 117x | - | - | - | - |
| (C-42-4) 3bac-1 | 6,124 | 293 | - | - | 26x | 116 | - |
| (C-42-5)11bdb-1 | 5,540 | - | 98x | 200 | 236 | - | - |
| 15bdc-1 | 5,480 | - | 128x | - | - | - | - |
| 20cbb-1 | 5,810 | 450 | - | 270 | 370 | - | - |
| 21dda-1 | 5,665 | 206 | - | 218 | 310 | 900 | 602 |
| 23bbb-1 | 5,470 | - | 101x | - | - | - | - |
| 26ccc-1 | 5,420 | - | 109x | - | - | - | - |
| 34dbb-1 | 5,400 | - | 65x | - | - | - | - |
| (C-42-6)19bdc-1 | 5,500 | - | 18x | 198 | - | - | - |
| 30cda-1 | 5,300 | - | 15x | - | - | - | - |
| (C-43-5) 2bdb-1 | 5,380 | - | 50x | - | - | - | - |
| (C-43-8)12ddd-1 | 6,387 | 285 | 7x | 350 | - | - | - |

## Aquifer Boundaries

The eastern hydrologic boundary of the upper Navajo aquifer is the line where the Tenney Canyon confining unit thins to extinction east of Johnson Canyon. East of this line, the interval represented by the upper Navajo aquifer is part of the main body of the Navajo aquifer, but essentially is unsaturated. This line is not known precisely, but was shown in a report by Bingham Engineering (1987, fig. III-2) to extend from about Section 31, Township 42 S., Range 4½ W., to Section 24, Township 39 S., Range 4 W., where it ends at the Paunsaugunt fault. Ground-water movement in the upper Navajo aquifer in the area where the Tenney Canyon confining unit pinches out is uncertain. The character or exact location of the eastern hydrologic boundary of the upper Navajo aquifer north of Township 39 S. is unknown because in this area no wells penetrate younger rocks to the buried Navajo Sandstone. The southern hydrologic boundary of the upper Navajo aquifer is defined as the outcrop of its contact with the Tenney Canyon confining unit. Springs and seeps at the contact indicate that ground water discharges at selected points along this boundary. On the basis of altitudes of springs, the western hydrologic boundary of the upper Navajo aquifer within the Kanab Creek drainage is a ground-water divide between the Virgin and Kanab drainages due west of Kanab. To the north, along the Sevier fault, no data are available to indicate the location and character of this western boundary. The location of the northern hydrologic boundary of the upper Navajo aquifer is unknown. The upper Navajo aquifer is deeply buried to the north and no water wells tap it.

The eastern hydrologic boundary of the Lamb Point aquifer probably lies near a surface-water divide between the Kanab and Paria drainages. This is presumed because spring altitudes in the outcrop area of the Lamb Point aquifer in the Paria drainage indicate that ground water moves eastward (pl. 2) to the tributaries of the Paria River. Water-level data are lacking, and the character and location of this eastern boundary could differ to the north. Only by drilling additional test wells can the location and character of this boundary be identified. The southern boundary of the Lamb Point aquifer is the outcrop of its contact with the Kayenta confining unit, exposed in the Vermillion Cliffs. Springs discharge at a few places along this contact, thus the southern boundary is a discharge boundary. The character of the western boundary of the Lamb Point aquifer is not known. Because it is buried even deeper than the upper Navajo aquifer, no wells tap the Lamb Point aquifer for a water supply. Thus, no water levels are available to indicate whether the western boundary is a ground-water divide or a boundary with ground water moving across it. The character of the northern hydrologic boundary of the Lamb Point aquifer also is not known.

Hydrologic boundaries such as ground-water divides or where a finite quantity of water is moving across are not permanent. Their location and character can be altered by water-level declines or rises caused by climatic changes or by water-level declines caused by pumping.

The lower boundary of the Lamb Point aquifer is the Kayenta confining unit. Direction and rate of vertical flow through the Kayenta confining unit is unknown because no wells have penetrated underlying aquifers in the area where the Navajo Sandstone also is present; thus no water levels have been measured in the Moenave aquifer beneath the Kayenta confining unit.

## Hydrologic Properties

Hydrologic properties used to determine the rate of flow and the quantity of water stored in the aquifers include horizontal hydraulic conductivity of the aquifers, vertical and lateral anisotropy of the aquifers, vertical hydraulic conductivity of the confining units, transmissivity of the aquifers, storage coefficient of confined aquifers, and specific yield of unconfined aquifers. These properties also are used in determining how water levels will change because of the stresses imposed by pumping. Other properties that are commonly used to help characterize an aquifer or a confining unit are effective porosity, grain-size distribution and sorting, and the degree of grain cementation. Specific capacity of a well is generally used to estimate the wells productivity, but specific capacity can also be used to qualitatively characterize the aquifer the well is tapping.

It has been determined that wells yield water more readily when they tap fractured Navajo Sandstone than when they tap unfractured Navajo Sandstone. This is indicated by relatively large [greater than 5 (gal/min)/ft] specific-capacity values (computed by dividing discharge, in gallons per minute, by drawdown, in feet). Kanab City well No. 5, (C-24-6)30cda-2, is located in the Kanab Creek fault zone and was pumped at 520 gal/min for 110 hours with 38 ft of drawdown [specific capacity of about 14 (gal/min)/ft]; test well (C-40-5)21abc-1, drilled near the Bald Knoll fault, yielded more than 1,300 gal/min for 30 days with less than 90 ft of drawdown [specific capacity of about 14 (gal/min)/ft]; and, a test well outside the study area near Caineville, Utah, drilled into fractured Navajo Sandstone associated with synclinal flexures was pumped at a rate of 2,800 gal/min for 35 days with 512 ft of drawdown [specific capacity of 5.5 (gal/min)/ft]. Well yields from the Navajo Sandstone in the study area apparently are related to their proximity to fault zones. Specific-capacity values for wells in the Navajo Sandstone (Cordova, 1981, table 9) are generally greater if the well is within 2,000 ft of a known fault. Specific-capacity values for wells within 2,000 ft of a fault ranged from 0.7 to 23 (gal/min)/ft. Specific-capacity values for wells greater than 2,000 ft away from faults ranged from 0.03 to 2.9 (gal/min)/ft.

Eighteen rock samples from the Navajo Sandstone were collected by Uygur (1980), the U.S. Geological Survey (Cordova, 1981), and the coal company, and analyzed for hydrologic properties. Horizontal hydraulic conductivity, measured in 13 outcrop samples and well cores from the upper Navajo aquifer, ranged from 0.12 to 6.1 ft/d (table 3). Values for three samples from the Lamb Point aquifer ranged from 0.002 to 4.2 ft/d. The ratio of horizontal to vertical hydraulic conductivity for all the rock samples from the Navajo Sandstone ranged from 0.38 to 8.3. Three of the 16 samples had vertical hydraulic-conductivity values larger than horizontal hydraulic-conductivity values, two in the upper Navajo aquifer and one in the Lamb Point aquifer; but generally, horizontal hydraulic conductivity measured in the laboratory is about 2.5 times larger than vertical hydraulic conductivity. Analysis of data from an aquifer test with a pumping well at Bald Knoll, (C-40-5)21abb-1, indicated that horizontal hydraulic conductivity was 15 times larger than vertical hydraulic conductivity. The accuracy of this large ratio is uncertain, however, because the pumping well was withdrawing water from both the upper Navajo and Lamb Point aquifers. Anisotropy in the horizontal direction was not determined.

**Table 3.--Hydrologic properties for the Navajo aquifer, the upper Navajo aquifer, the Lamb Point aquifer, and the Tenney Canyon confining unit in the study area**

Site location numbers: for explanation of numbering system, see section on data-site numbering.
Hydraulic conductivity: Horiz, horizontal hydraulic conductivity; Vert, vertical hydraulic conductivity; ft/d, feet per day.
Transmissivity: $ft^2/d$, feet squared per day.
Information source: Uygur, 1980; USGS, unpublished data from the files of the U.S. Geological Survey; B.E., 1981 and 1987, Bingham Engineering Reports; Cordova, 1981.
Part of aquifer tested: UNAV, Upper Navajo aquifer; LMBP, Lamb Point aquifer; TNNC, Tenney Canyon confining unit.
--, no data.

| Site location number | Hydraulic conductivity (ft/d) Horiz | Hydraulic conductivity (ft/d) Vert | Storage coefficient | Transmissivity ($ft^2/d$) | Effective porosity (percent) | Site type or test type | Information source | Part of aquifer tested |
|---|---|---|---|---|---|---|---|---|
| (C-39-2) 5dc | 0.64 | 0.41 | -- | -- | 23 | Outcrop core | Uygur, 1980 | UNAV |
| 5dca | .38 | .22 | -- | -- | 26 | Outcrop core | USGS | UNAV |
| R(C-40-4)33cba | 2.0 | .24 | -- | -- | -- | Well core | B.E., 1981 | UNAV |
| (C-40-5)16cdc-1 | 7.5 | .53 | .07 | 13,300 | 22 | Aquifer test | Do. | UNAV + LMBP |
| 21abb | .78 | .27 | -- | -- | -- | Well core | Do. | UNAV |
| 21abb-1 | 7.6 | .50 | .07 | 13,435 | 22 | Aquifer test | Do. | UNAV + LMBP |
| 21abc-1 | -- | -- | -- | -- | 22 | Well sample | Do. | UNAV |
| (C-41-5)13bcc | 3.4 | 2.0 | -- | -- | 25 | Outcrop core | USGS | UNAV |
| 24dba | 3.2 | .7 | -- | -- | 15 | Outcrop core | Uygur, 1980 | UNAV |
| (C-41-8)25dda | 1.9 | 5.0 | -- | -- | 24 | Outcrop core | USGS | UNAV |
| (C-41-9)19bd | 3.0 | .8 | -- | -- | 17 | Outcrop core | Uygur, 1980 | UNAV |
| | 1.6 | .3 | -- | -- | 15 | Outcrop core | Do. | UNAV |
| (C-42-5)11bdb-1 | -- | -- | -- | 5,900 | -- | Aquifer test | Cordova, 1981 | LMBP |
| 21dda-1 | 2.4 | -- | .0013 | 1,200 | -- | Aquifer test | B.E., 1987 | LMBP |
| 21dda-2 | .33 | -- | -- | 3.3 | -- | Slug test | Do. | TNNC |
| 21dda-3 | 1.7 | -- | -- | 8.6 | -- | Slug test | Do. | TNNC |
| | .006 | -- | -- | .03 | -- | Slug test | Do. | TNNC |
| | .055 | -- | -- | 1.1 | -- | Slug test | Do. | TNNC |
| 21dda-4 | .21 | -- | -- | 1.0 | -- | Slug test | Do. | TNNC |
| 23bbb | 4.2 | 2.2 | -- | -- | 28 | Outcrop core | USGS | LMBP |
| 26ccc | -- | -- | -- | -- | 30 | Outcrop core | Do. | LMBP |
| 26ccc-2 | -- | -- | .012 | 7,400 | -- | Aquifer test | Cordova, 1981 | LMBP |
| 26cda-2 | -- | -- | -- | 14,000 | -- | Aquifer test | Do. | LMBP |
| 27aaa-1 | -- | -- | -- | 13,000 | -- | Aquifer test | Do. | LMBP |
| 27add-1 | -- | -- | .0012 | 2,500 | -- | Aquifer test | Do. | LMBP |
| (C-42-6)19bdc-1 | -- | -- | .0024 | 5,300 | -- | Aquifer test | Do. | UNAV |
| 19bdc-2 | -- | -- | -- | 4,200 | -- | Aquifer test | Do. | UNAV |
| 19cdb | 5.0 | 2.3 | -- | -- | 19 | Outcrop core | Uygur, 1980 | UNAV |
| 30abb | 4.5 | 4.6 | -- | -- | 27 | Outcrop core | USGS | UNAV |
| 30cda-2 | -- | -- | -- | 5,200 | -- | Aquifer test | Cordova, 1981 | LMBP |
| 31dac | .002 | .005 | -- | -- | 15 | Outcrop core | USGS | LMBP |
| (C-42-7) 3cba | .12 | .099 | -- | -- | 11 | Outcrop core | Uygur, 1980 | UNAV |
| 4dda | -- | .17 | -- | -- | 14 | Outcrop core | Do. | UNAV |
| 10bdd | 6.1 | 4.5 | -- | -- | 30 | Outcrop core | USGS | UNAV |
| (C-43-5)13dc | .3 | .11 | -- | -- | 11 | Outcrop core | Uygur, 1980 | LMBP |

The aquifer test at Bald Knoll indicated that the horizontal hydraulic conductivity of the Navajo aquifer near the Bald Knoll fault is about 7.5 ft/d. The aquifer test at Oak Canyon, with pumping well (C-42-5)21dda-1, indicated that horizontal hydraulic conductivity in the Lamb Point aquifer near the Johnson Canyon fault system is about 2.4 ft/d. Other tests of the upper Navajo and Lamb Point aquifers in Johnson Canyon and in tributary canyons to Kanab Creek, where faulting is common, yielded transmissivity values that ranged from 2,500 to 14,000 $ft^2/d$. No aquifer tests have been conducted in areas unaffected by faulting. From the results of an investigation that chiefly used modeling techniques of the Navajo Sandstone near Lake Powell, about 40 mi east of the study area, Thomas (1986, p. 38) concluded that fracturing caused by structural deformation increases hydraulic conductivity about three times as compared to values in unfractured areas. Hydraulic conductivity values used by Thomas to represent the Navajo aquifer near Lake Powell ranged from 0.25 ft/d in some unfractured areas to 3.5 ft/d in some fractured areas.

Vertical hydraulic conductivity in the Tenney Canyon confining unit was determined from the results of an aquifer test, using pumping well (C-42-5)21dda-1, which was specifically designed for that purpose (Bingham Engineering, 1987, p. V-5). Using the ratio method of Neuman and Witherspoon (1972) and an assumed specific storage value of $5 \times 10^{-6}$ $ft^{-1}$, vertical hydraulic conductivity of the Tenney Canyon confining unit was estimated to range from 0.0063 to 0.042 ft/d (Bingham Engineering, 1987, table V-1). Because values of specific storage of the Tenney Canyon confining unit could be an order of magnitude larger, values of vertical hydraulic conductivity of the unit could be correspondingly larger.

The quantity of water stored in the Navajo Sandstone is determined by its effective porosity, or the ratio of the volume of interconnected void spaces in the rock to the volume of the rock. However, the quantity of water stored is much larger than the quantity of water that can be pumped economically from the aquifers. Effective porosity values for the Navajo Sandstone generally range from 11 to 30 percent (table 3). From laboratory analysis of samples from the Navajo Sandstone, Uygur (1980) concluded that effective porosity and hydraulic conductivity decrease with depth as a result of increased cementation and a decrease in mean grain size. Specific yield is the quantity of water that will drain from the aquifer under the influence of gravity; and is a better property to use in estimating the quantity of water that can be withdrawn from unconfined aquifers. Specific-yield values for the Navajo Sandstone generally range from 5 to 10 percent (Hood and Danielson, 1979, p. 34). A specific-yield value obtained from the results of the aquifer test using the pumping well at Bald Knoll (C-40-5)21abb-1, was 7 percent (Bingham Engineering, 1981, p. 1). The storage coefficient is the corresponding property used to estimate the quantity of water that can be withdrawn from confined aquifers under unit declines in water levels. Based on other aquifer tests, values of the storage coefficient for the Navajo Sandstone in areas where the aquifer is confined range from $1.2 \times 10^{-3}$ to $2.4 \times 10^{-3}$.

## Ground-water Movement

Goode (1964) indicated that the upper Navajo, the Lamb Point, and the Navajo aquifers are recharged by precipitation where they crop out, and ground water in the upper Navajo aquifer moves north under Skutumpah Terrace towards the Paunsaugunt Plateau and south to Kanab and Johnson Canyons. Movement of water in the Navajo Sandstone was interpreted by Cordova (1981) to be generally from surface-water divides, where recharge was occurring, to Kanab and Johnson Canyons where springs and seeps discharge. Bingham Engineering (1987, p. VI-2) reported ground-water mounds beneath outcrop areas along the Wygaret Terrace, and inferred movement from these recharge areas to Kanab and Johnson Canyons, where water is discharged at springs and seeps. Moreover, Bingham Engineering indicated that an east-to-west regional component of flow exists across the study area north of the White Cliffs. Bingham Engineering refined the configuration of the potentiometric surface for the area south of the White Cliffs using water levels from nine test wells drilled by the coal company in 1986; however, ground-water movement north of the White Cliffs remains uncertain because water-level data are lacking.

### Direction and Gradient

Maps showing the altitude of the potentiometric surface in the upper Navajo and Lamb Point aquifers (pl. 2) suggest that the outcrop areas of the Navajo Sandstone are recharge areas, as first described by Goode (1964). Water levels in wells at Bald Knoll are at an altitude of about 5,400 ft, and are as much as 200 ft lower than water levels in the upper Navajo aquifer 9 to 15 mi to the south. However, about 3 mi south of the Bald Knoll wells, the coal company drilled a well, (C-41-5)5aaa-1, which penetrated to an altitude of about 5,330 ft before moist sand was encountered. If this moist sand represents the water level in the upper Navajo aquifer, then the gradient of the potentiometric surface between Bald Knoll and this well is at least 20 ft/mi to the south. More water-level data are needed north of the White Cliffs in order to resolve all differences in interpretations and conclusively determine the direction and rate of ground-water flow in the upper Navajo aquifer.

### Vertical Movement

Differences in the altitude of water levels in the upper Navajo aquifer and the Lamb Point aquifer indicate the potential for vertical movement of water is downward. In August 1986 the water level in well (C-42-5)21dda-1, screened in the Lamb Point aquifer, was 54 ft lower than the water level in well (C-42-5)21dda-3, screened in the upper Navajo aquifer (table 4). While drilling a well for the U.S. Bureau of Land Management (USBLM) near Red Butte, (C-42-5)20cbb-1, the driller noted that the water level in the upper Navajo aquifer was more than 200 ft higher than the water level in the Lamb Point aquifer, where the well was eventually completed. A comparison of the potentiometric-surface maps of Plate 2 indicates water levels in the upper Navajo aquifer are about 50 ft higher than in the Lamb Point aquifer in the Johnson Canyon area and as much as 200 ft higher west of Kanab Canyon.

## Table 4.—Wells and water levels in the study area

Well location number: for explanation of numbering system, see section on data-site numbering.
Altitude of land surface: refers to distance above or below sea level.
Formation well is open to: JRSC, Jurassic formations undivided; UNAV, upper Navajo Sandstone; NVJO, Navajo Sandstone undivided; LMBP, Lamb Point Tongue of the Navajo Sandstone; MONV, Moenave Formation.
Name/Owner: BHP-UII, BHP-Utah International, Inc.; BLM, Dept. of Interior, Bureau of Land Management.
Information source: GWSI, ground-water site-inventory data file of the U.S. Geological Survey; B.E., 1974, 1979, and 1987, Bingham Engineering Reports.
Entries are queried if uncertain.

| Well location number | | Altitude of land surface (feet) | Depth to water (feet) | Date measured | Formation well is open to | Well depth (feet) | Name or owner of well | Information source and remarks |
|---|---|---|---|---|---|---|---|---|
| R(C-40-4) | 33cba-1 | 6,060 | 553? | 12/77 | JRSC? | 885 | Red Wash 2, BHP-UII | Cordova, 1981, reported water level may represent overlying aquifers. B.E., 1987, reported water level may be artificially high because of residue in the well |
| (C-40-5) | 16cdc-1 | 6,634 | 1,240 | 12/74 | UNAV | 2,694 | Bald Knoll 1, BHP-UII | GWSI |
| | 21abb-1 | 6,647 | 1,250 | 12/78 | UNAV | 1,825 | Bald Knoll 3, BHP-UII | B.E., 1979 |
| | 21abc-1 | 6,610 | 1,213 | 12/80 | UNAV | 3,006 | Bald Knoll 4, BHP-UII | GWSI |
| (C-40-6) | 35acd-1 | 6,230 | -- | -- | UNAV | 1,420 | Falls 1, BHP-UII | B.E., 1979 |
| (C-41-3) | 4bca-1 | 5,780 | 134 | 6/86 | NVJO | 250 | BLM | GWSI |
| (C-41-5) | 5aaa-1 | 6,280 | 950? | 6/74 | UNAV | 957 | Ford Pasture 1, BHP-UII | B.E., 1974, moisture reprted by driller near bottom of hole |
| | 26dac-1 | 5,652 | 187 | 12/86 | UNAV | 266 | MW2-BHP-UII | B.E., 1987 |
| | 36c | 5,680 | 250 | 6/84 | LMBP | -- | G. Robinson | B.E., 1987 |
| (C-41-7) | 3cbc-1 | 5,620 | 338 | 12/81 | UNAV? | 730 | Orderville | B.E., 1987 |
| | 18dca-1 | 5,295 | 350 | 7/77 | UNAV? | 526 | Mt. Carmel Pipeline | B.E., 1987 |
| | 19ccd-1 | 5,200 | 235 | 54 | UNAV? | 350 | E. and B. Rife | B.E., 1987 |
| | 19cdc-2 | 5,200 | 242 | 11/66 | UNAV? | 295 | Golden Hand Motel | GWSI |
| | 30bba-1 | 5,190 | 233 | 6/77 | UNAV? | 310 | Thunderbird Motel | GWSI |
| (C-41-8) | 35cca-1 | 5,038 | 80 | 7/75 | UNAV? | 150 | L. H. Foote | GWSI |
| (C-41-9) | 10cdd-1 | 6,235 | 123 | 3/66 | JRSC | 186 | Drews | GWSI |
| | 13bbc-1 | 6,160 | 280 | 12/70 | NVJO | 350 | Hall | GWSI |
| | 15aad-1 | 6,120 | 104 | 4/66 | JRSC | 147 | Drews | GWSI |
| | 15dbb-1 | 5,980 | 193 | 12/61 | NVJO | 231 | Baca | GWSI |
| | 15dcd-1 | 5,970 | 193 | 11/77 | NVJO | 245 | Drews | GWSI |
| | 20bdb-1 | 5,690 | 865 | 7/62 | NVJO | 925 | U.S. Park Service | GWSI |
| (C-42-4) | 3bac-1 | 6,121 | 293? | 8/86 | MONV? | 326 | MW10-BHP-UII | B.E., 1987, formation is Kayenta or Moenave |
| | 19adb-1 | 5,762 | 197 | 12/86 | NVJO | 226 | MW9-BHP-UII | B.E., 1987 |
| R(C-42-4) | 9bbc-1 | 6,060 | 559 | 10/67 | LMBP | 585 | Johnson | GWSI |
| (C-42-5) | 1ba | 5,608 | 95 | 10/48 | LMBP | -- | G. Swapp | B.E., 1987 |
| | 1bab-1 | 5,600 | 130 | 10/48 | LMBP | 225 | Bunting | GWSI |
| | 11ac | 5,560 | 112 | 4/86 | LMBP | -- | E. Swapp | B.E., 1987 |
| | 11bab-1 | 5,530 | 97 | 10/76 | LMBP | 160 | BLM | GWSI |
| | 11bdb-1 | 5,540 | 86 | 6/78 | LMBP | 245 | Judd | GWSI (see fig. 6) |
| | 11cd | 5,510 | 75 | 9/82 | LMBP | -- | J. West | B.E., 1987 |
| | 11db | 5,510 | 84 | 5/82 | LMBP | -- | D. Benson | B.E., 1987 |
| | 14cb | 5,500 | 112 | 12/85 | LMBP | -- | T. Kilby | B.E., 1987 |
| | 15bcc-1 | 5,483 | 37 | 12/86 | UNAV | 65 | MW7-BHP-UII | B.E., 1987 |
| | 15bdc-1 | 5,460 | 88 | 3/76 | LMBP | 200 | Bunting | GWSI |
| | 20cbb-1 | 5,820 | 222 | 6/83 | UNAV | 503 | Red Butte-BLM | BLM-driller's log |
| | | | 442 | 6/83 | LMBP | 503 | Red Butte-BLM | B.E., 1987 |
| | 21dda-1 | 5,663 | 260 | 12/86 | LMBP | 493 | PW8-BHP-UII | B.E., 1987 |
| | 21dda-3 | 5,663 | 206 | 12/86 | UNAV | 288 | MW8-BHP-UII | B.E., 1987 |
| | 23bbb-1 | 5,470 | 33 | 10/60 | LMBP | 183 | Bunting | GWSI |
| | 26ccb-1 | 5,360 | 21 | 2/77 | LMBP | 285 | Judd | B.E., 1987 |
| | 26ccc-1 | 5,420 | 21 | 2/77 | LMBP | 226 | Judd | GWSI |
| | 26ccc-2 | 5,420 | 25 | 10/76 | LMBP | 285 | Judd | GWSI |
| | 26cda-1 | 5,400 | 11 | 10/76 | LMBP | 26.5 | Johnson | GWSI |
| | 26cda-2 | 5,400 | 13 | 10/76 | LMBP | 380 | Johnson | GWSI |
| | 27aaa-1 | 5,400 | 1 | 2/77 | LMBP | 165 | Little | GWSI |
| | 27add-1 | 5,420 | 41 | 9/76 | LMBP | 125 | Smirl | GWSI |
| | 27add-2 | 5,440 | 45 | 10/76 | LMBP | 130 | Smirl | GWSI |
| | 30ada-1 | 5,811 | 117 | 12/86 | UNAV | 148 | MW5-BHP-UII | B.E., 1987 |

Table 4.--Wells and water levels in the study area—Continued

| Well location number | | Altitude of land surface (feet) | Depth to water (feet) | Date measured | Formation well is open to | Well depth (feet) | Name or owner of well | Information source and remarks |
|---|---|---|---|---|---|---|---|---|
| (C-42-5) | 34dbb-1 | 5,400 | 6 | 6/77 | LMBP | 200 | Judd | GWSI |
| | 35bbb-1 | 5,600 | 26 | 5/77 | LMBP | 220 | Carner | GWSI |
| | 35bcc-1 | 5,340 | 4 | 8/70 | LMBP | -- | Judd | B.E., 1987 |
| | 35bdc-3 | 5,400 | 29 | 10/76 | LMBP | 120 | Scribner | GWSI |
| | 35ca | 5,325 | 7 | 12/72 | LMBP | -- | Judd | B.E., 1987 |
| (C-42-6) | 11cab-1 | 5,555 | -- | 8/86 | UNAV | 146 | MW3-BHP-UII | B.E., 1987, no water |
| | 19baa-1 | 5,660 | 166 | 2/77 | LMBP | 560 | Kanab City 7 | GWSI (see fig. 6) |
| | 19bdc-1 | 5,500 | 47 | 5/77 | UNAV | 271 | Kanab City 1 | GWSI |
| | 19bdc-2 | 5,520 | 54 | 5/77 | UNAV | 250 | Kanab City 2 | GWSI |
| | 19bdc-3 | 5,488 | 211 | 9/86 | LMBP | -- | Kanab City 9 | B.E., 1987 |
| | 21ddb-1 | 5,561 | 150 | 12/86 | UNAV | 205 | MW4-BHP-UII | B.E., 1987 |
| | 30baa-1 | 5,452 | 211 | 9/84 | LMBP | 468 | Kanab City 12 | B.E., 1987 |
| | 30cda-1 | 5,300 | 51 | 8/64 | LMBP | 332 | Kanab City 3 | GWSI |
| | 30cda-2 | 5,300 | 65 | 2/77 | LMBP | 300 | Kanab City 5 | GWSI |
| | 31dac-1 | 5,240 | 46 | 6/73 | LMBP | 185 | Kanab City 4 | GWSI |
| | 30dcb-1 | 5,317 | 52 | 11/64 | LMBP | 368 | Kanab City 13 | B.E., 1987 |
| | 31dbd-1 | 5,249 | 60 | 3/79 | LMBP | 425 | Kanab City 10 | B.E., 1987 |
| | 32cbb-1 | 5,195 | 43 | 5/83 | LMBP | 205 | Kanab City 11 | B.E., 1987 |
| (C-42-7) | 19bdd-1 | 5,640 | 550 | 56 | UNAV | 600 | BLM | Goode, 1964, water level reported by driller |
| | 25dcb-1 | 5,520 | 260 | 1/79 | LMBP | -- | L. Hollis | B.E., 1987 |
| (C-43-5) | 2bad-1 | 5,350 | 4 | 11/73 | LMBP | -- | LDS Church | B.E., 1987 |
| | 2bbd-1 | 5,380 | 7 | 10/76 | LMBP | 210 | LDS Church | GWSI |
| | 2bd | 5,355 | 10 | 2/78 | LMBP | -- | LDS Church | B.E., 1987 |
| | 8ccc-1 | 6,127 | 100? | 8/86 | UNAV | 115 | MW6-BHP-UII | B.E., 1987 |
| | 12bdc-1 | 5,250 | 10 | 6/84 | LMBP | -- | LDS Church | B.E., 1987 |
| (C-43-6) | 5ada-1 | 5,290 | 80 | 3/77 | LMBP | -- | Kanab Ck. Ranches | B.E., 1987 |
| (C-43-7) | 12bdb-1 | 6,000 | 204 | 6/77 | UNAV | 265 | Jacobs | Cordova, 1981 |
| | 13cbc-1 | 6,146 | 210 | 11/82 | UNAV | -- | Canyonlands Exped. | B.E., 1987 |
| | 16bcc-1 | 5,760 | 151 | 5/77 | LMBP | 330 | Fredonia 4 | Cordova, 1981 |
| | 16bdd-1 | 5,680 | 91 | 5/77 | LMBP | 175 | Fredonia 3 | Cordova, 1981 |
| | 16dba-1 | 5,660 | 56 | 5/77 | LMBP | 159 | Fredonia 1 | Cordova, 1981 |
| | 16dbb-1 | 5,660 | 75 | 7/67 | LMBP | 165 | Fredonia 2 | Cordova, 1981, reported water level |
| (C-43-8) | 12ddd-1 | 6,385 | 285 | 12/86 | UNAV | 370 | MW1-BHP-UII | B.E., 1987 |
| (C-43-8) | 34bbb-1 | 5,925 | 847 | 9/71 | NVJO? | 912 | Coral Dunes State Park | Cordova, 1981, reported water level. |

Well location number: For explanation of numbering system, see section on data-site numbering.
Specific conductance: *µS/cm, microsiemens per centimeter at 25 °C.*
Dissolved solids: Numbers preceded by * indicate that dissolved solids were measured as residue remaining after the sample was was evaporated at 180 °C.
Dissolved Nitrite plus Nitrate: Numbers preceded by * were reported as dissolved nitrate only.
Analyzing laboratory: BHP-UII, BHP-Utah International, Inc.; U.S.G.S., U.S. Geological Survey.
Hydrologic unit of origin: UNAV, Upper Navajo aquifer; LMBP, Lamb Point aquifer; NVJO, Navajo aquifer undivided; CRML, Carmel

| Well location number | Date sampled | Sampling interval (feet) | Well depth (feet) | Temperature (deg C) | Specific conductance (µS/cm) | Dissolved solids (sum of constituents) (mg/L) | pH (standard units) | Hardness (mg/L as $CaCO_3$) | Bicarbonate (mg/L) | Nitrite plus nitrate, dissolved (mg/L as N) | Phosphate (mg/L as P) | Sulfate, dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (C-40-5)16cdc-1 | 12-20-74 | 1,240-1,449 | 2,694 | 17.0 | 1,310 | **810 | 7.13 | 120 | 190 | -- | 0.15 | 430 |
| (C-40-5)21abb-1 | 03-16-79 | 1,260-1,705 | 1,825 | -- | 600 | **392 | 7.30 | 304 | 142 | 0.03 | -- | 190 |
| | 03-16-79 | 1,260-1,705 | 1,825 | -- | 595 | **385 | 7.50 | 288 | 146 | .03 | -- | 190 |
| (C-40-5)21abc-1 | 02-10-81 | 1,403-2,989 | 3,006 | -- | 770 | **500 | 7.10 | 348 | 217 | .27 | .0 | 231 |
| | 03-13-81 | 1,403-2,989 | 3,006 | -- | 730 | **472 | 7.20 | 336 | 200 | .34 | .37 | 225 |
| (C-41-3) 4bca-1 | 06-12-81 | -- | 250 | 12.5 | 415 | 210 | 7.55 | 220 | — | .0 | -- | 28 |
| (C-41-5) 5aaa-1 | 12-27-74 | 65-100 | 957 | -- | 4,630 | **3,190 | 7.01 | 2,260 | 225 | * .9 | .5 | 2,100 |
| (C-41-5)11bda-1 | 07-02-76 | -- | -- | 15.0 | 620 | 390 | 7.70 | 310 | 190 | 2.6 | .03 | 160 |
| | 06-18-77 | -- | -- | 16.0 | 570 | 370 | 7.80 | 290 | 180 | 2.5 | .03 | 140 |
| (C-41-5)26dac-1 | 09-14-86 | 245-265 | 266 | -- | 2,010 | **1,495 | 7.11 | 832 | 261 | 1.2 | .06 | 810 |
| (C-42-4) 3bac-1 | 09-14-86 | 296-316 | 326 | -- | 458 | [1]**300 | 7.07 | 153 | 253 | .28 | .06 | 18 |
| (C-42-4)19adb-1 | 09-14-86 | 201-221 | 226 | -- | 379 | **280 | 7.23 | 180 | 197 | 2.27 | .04 | 8 |
| R(C-42-4) 9bbc-1 | 10-21-76 | 137-585 | 585 | 13.5 | 320 | 180 | -- | 150 | 190 | 1.9 | .06 | 11 |
| (C-42-5)11bdb-1 | 08-29-64 | 100-110 | 160 | 13.5 | -- | *738 | 7.80 | 465 | — | *3.8 | -- | 264 |
| | 07-30-82 | 100-110 | 160 | 13.5 | 930 | 630 | 7.70 | 460 | — | 3.2 | -- | 290 |
| | 07-19-83 | 100-110 | 160 | 13.5 | 780 | 510 | 7.20 | 370 | — | 3.3 | -- | 220 |
| | 08-29-77 | 100-110 | 160 | 13.5 | 580 | 360 | 6.50 | 280 | 180 | -- | -- | 140 |
| (C-42-5)15bdc-1 | 10-07-76 | 128-200 | 200 | 12.0 | 880 | 600 | -- | 480 | 270 | 4.5 | .15 | 260 |
| (C-42-5)15bcc-1 | 09-15-86 | 45- 65 | 65 | -- | 309 | [1]**200 | 7.17 | 153 | 180 | .7 | .04 | 6 |
| (C-42-5)21dda-2 | 09-12-86 | 374-474 | 511 | -- | 667 | **495 | 7.35 | 319 | 205 | 4.55 | .02 | 147 |
| | 09-16-86 | 374-474 | 511 | -- | 663 | **505 | 7.39 | 323 | 208 | 4.35 | .03 | 147 |
| | 09-18-86 | 374-474 | 511 | -- | 647 | **485 | 7.51 | 343 | 208 | 4.35 | .04 | 140 |
| | 09-20-86 | 374-474 | 511 | -- | 646 | **485 | 7.58 | 313 | 208 | 4.42 | .02 | 135 |
| (C-42-5)23bbb-1 | 10-14-76 | 105-183 | 183 | -- | -- | 150 | -- | 120 | — | -- | .12 | -- |
| (C-42-5)26ccc-1 | 10-07-76 | -- | 226 | -- | 405 | 240 | -- | 200 | 190 | 1.3 | .34 | 52 |
| (C-42-5)26cda-2 | 10-15-76 | 165-185 | 380 | 13.0 | 320 | 170 | -- | 160 | 170 | 2.6 | .18 | 11 |
| | 06-23-77 | 165-185 | 380 | 13.0 | 320 | 170 | 6.50 | 160 | 170 | 2.4 | .0 | 8.9 |
| (C-42-5)27aaa-1 | 10-01-76 | 37-150 | 165 | 13.5 | 300 | 170 | -- | 160 | 160 | 1.4 | .03 | 19 |
| | 05-16-77 | 37-150 | 165 | 13.0 | 310 | 170 | 6.50 | 150 | 160 | 1.4 | .18 | 13 |
| | 05-18-77 | 37-150 | 165 | 13.0 | 300 | 170 | 6.50 | 150 | 160 | 1.2 | .09 | 16 |
| (C-42-5)27add-1 | 10-07-76 | 55-117 | 125 | -- | 380 | 210 | -- | 190 | 190 | .58 | .03 | 29 |
| (C-42-5)27add-2 | 10-07-76 | 70-130 | 130 | -- | 380 | 210 | -- | 190 | 190 | 8.0 | .03 | 29 |
| | 04-27-77 | 70-130 | 130 | 13.0 | 480 | 290 | 6.50 | 240 | 220 | .79 | .06 | 68 |
| (C-42-5)30ada-1 | 09-15-86 | 127-147 | 148 | -- | 295 | **245 | 7.35 | 86 | 152 | 1.08 | .05 | 21 |
| (C-42-5)34dbb-1 | 08-24-77 | 57-64 | 200 | 18.0 | 500 | 290 | -- | 200 | 130 | -- | -- | 130 |
| (C-42-5)35bbb-1 | 04-27-77 | 100-220 | 220 | 13.0 | 370 | 220 | -- | 190 | 190 | 1.1 | .21 | 33 |
| | 05-25-77 | 100-200 | 220 | 13.0 | 340 | 210 | 6.50 | 180 | 190 | .96 | .03 | 30 |
| | 05-28-77 | 100-200 | 220 | 13.0 | 365 | 210 | 6.50 | 180 | 190 | .97 | .0 | 28 |
| | 06-01-77 | 100-200 | 220 | 13.0 | 370 | 200 | 6.50 | 180 | 180 | .92 | .09 | 29 |
| (C-42-6)19baa-1 | 08-28-77 | -- | 560 | 14.5 | 190 | 140 | 6.50 | 88 | 100 | -- | -- | 34 |
| (C-42-6)19bdc-1 | 09-28-76 | -- | 271 | 14.5 | 300 | 170 | -- | 160 | 160 | 2.5 | .06 | 15 |
| (C-42-6)19bdc-2 | 05-27-77 | 155-199 | 250 | 13.5 | 270 | 150 | -- | 140 | 150 | 2.7 | .0 | 11 |
| | 05-29-77 | 155-199 | 250 | 13.5 | 280 | 150 | -- | 140 | 150 | 2.6 | .0 | 10 |
| | 06-01-77 | 155-199 | 250 | 13.5 | 270 | 150 | 6.50 | 140 | 150 | 2.5 | .06 | 10 |
| | 08-16-79 | 155-199 | 250 | 13.5 | 270 | 140 | 7.90 | 130 | — | 2.6 | -- | 12 |
| | 08-21-80 | 155-199 | 250 | 14.0 | 275 | 130 | 8.00 | 120 | — | 3.0 | -- | 5.1 |
| | 07-30-81 | 155-199 | 250 | 15.0 | 245 | -- | -- | -- | — | -- | -- | -- |
| | 07-30-82 | 155-199 | 250 | 15.0 | 235 | -- | -- | -- | — | -- | -- | -- |
| | 07-19-83 | 155-199 | 250 | 19.0 | 250 | 150 | 7.60 | 130 | — | 2.5 | -- | 8.0 |
| | 06-14-84 | 155-199 | 250 | 15.0 | 245 | -- | -- | -- | — | -- | -- | -- |
| (C-42-6)21ddb-1 | 09-15-86 | 184-204 | 205 | -- | 384 | **300 | 7.2 | 174 | 210 | 2.2 | .04 | 9 |
| (C-42-6)30cda-2 | 09-28-76 | 50-296 | 300 | 12.0 | 460 | 140 | -- | 130 | 140 | 2.7 | .06 | 6.6 |
| | 10-04-77 | 50-296 | 300 | 11.5 | 480 | 280 | 6.50 | 270 | 310 | -- | -- | 9.0 |
| (C-42-6)31dac-1 | 09-28-76 | 50-185 | 185 | 14.5 | 380 | 210 | -- | 190 | 230 | 1.5 | .03 | 6.9 |
| (C-43-5) 2bbd-1 | 07-15-77 | 56-205 | 210 | 13.5 | 690 | 440 | 6.50 | 350 | 220 | 4.7 | .03 | 170 |
| (C-43-5) 8ccc-1 | 09-15-86 | 95-115 | 115 | -- | 380 | **290 | 7.14 | 162 | 200 | 1.5 | .04 | 6 |
| (C-43-7)12bdb-1 | 06-14-77 | 200-255 | 265 | -- | 340 | 204 | 6.5 | 190 | 210 | -- | -- | 5.9 |
| (C-43-7)16bcc-1 | 08-29-66 | 148-330 | 330 | -- | -- | 160 | -- | 122 | -- | -- | <.01 | 7 |
| (C-43-7)16bdd-1 | 08-07-64 | 82-175 | 175 | -- | -- | 694 | -- | 272 | — | -- | -- | -- |
| | 06-17-77 | 82-175 | 175 | 13.0 | 360 | 198 | 6.5 | 180 | 210 | .20 | .0 | 5.8 |
| (C-43-7)16dba-1 | 06-17-77 | 55-155 | 159 | 13.0 | 360 | 206 | 6.5 | 200 | 210 | 1.6 | .03 | 8.2 |
| (C-43-7)16dbb-1 | 08-29-66 | 47-155 | 155 | -- | -- | 210 | -- | 168 | — | <.01 | <.01 | 8 |
| | 05-11-77 | 47-155 | 155 | 13.0 | 345 | 198 | -- | 180 | 210 | 2.0 | .09 | 5.8 |
| (C-43-8)34bbb-1 | 05-01-77 | 852-912 | 912 | 14.0 | 230 | 138 | -- | 120 | 130 | .97 | .12 | 6.5 |

[1]Reported as being too low possibly because of loss of $CO_2$ during heating.

**water from wells in the study area**

evaporated at 105 °C. Numbers preceded by ** indicate that dissolved solids were measured as residue remaining after the sample

confining unit; MONV, Moenave aquifer; ?, queried where uncertain.

| Chloride, dissolved (mg/L) | Fluoride, dissolved (mg/L) | Calcium dissolved (mg/L) | Magnesium, dissolved (mg/L) | Sodium, dissolved (mg/L) | Potassium, dissolved (mg/L) | Silica, dissolved (mg/L) | Boron, dissolved (µg/L) | Iron, dissolved (µg/L) | Manganese, dissolved (µg/L) | Analyzing laboratory | Hydrologic unit of origin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 0.89 | 35 | 6.7 | 220 | 8.5 | 0.8 | 0 | 6 | 0 | Ford Chemical, Salt Lake City | UNAV |
| 16 | 0.3 | 91 | 18 | 18 | 2.2 | 10 | 50 | 13 | 64 | Ford Chemical, Salt Lake City | UNAV |
| 4.0 | 0.3 | 91 | 14 | 18 | 2.2 | 10 | 40 | 58 | 61 | Ford Chemical, Salt Lake City | UNAV |
| 2.0 | 0.2 | 104 | 21 | 25 | 15 | 12 | 5 | 65 | 5 | Ford Chemical, Salt Lake City | NVJO |
| 2.1 | 0.2 | 89 | 27 | 27 | 2.7 | 12 | 40 | 80 | 20 | Ford Chemical, Salt Lake City | NVJO |
| 4.1 | 0.0 | 39 | 29 | 6.4 | 1.8 | 8.1 | -- | 30 | -- | U.S.G.S. | NVJO |
| 38 | 1.5 | 508 | 238 | 72.9 | 15.4 | .88 | <10 | 760 | 150 | Ford Chemical, Salt Lake City | CRML |
| 7.6 | 0.2 | 75 | 29 | 16 | 2.2 | 10 | 60 | -- | -- | U.S.G.S. | UNAV |
| 7.6 | 0.2 | 71 | 27 | 17 | 2.3 | 12 | 70 | -- | -- | U.S.G.S. | UNAV |
| 21 | 0.4 | 160 | 105 | 125 | 5.2 | -- | 70 | <100 | 100 | BHP-UII Minerals Laboratory | UNAV |
| 7.4 | 0.19 | 39.3 | 13.3 | 36.7 | 2.6 | -- | 30 | <100 | 160 | BHP-UII Minerals Laboratory | MONV? |
| 8.0 | 0.12 | 44.7 | 16.5 | 6 | 1.9 | -- | 10 | <100 | 180 | BHP-UII Minerals Laboratory | NVJO |
| 6.4 | 0.2 | 40 | 13 | 7.3 | 2.0 | 11 | <20 | -- | -- | U.S.G.S. | LMBP |
| 16 | -- | 117 | 42 | -- | -- | 14 | -- | 70 | -- | Utah State Chemist-Dept. Agric. | LMBP |
| 10 | 0.2 | 110 | 45 | 33 | 3.5 | 12 | 90 | 260 | 51 | U.S.G.S. | LMBP |
| 12 | 0.2 | 88 | 37 | 25 | 2.9 | 12 | 80 | 13 | 3 | U.S.G.S. | LMBP |
| 7.7 | 0.2 | 68 | 27 | 16 | 2.7 | 12 | 60 | 40 | 20 | U.S.G.S. | LMBP |
| 8.6 | 0.2 | 110 | 49 | 24 | 3.2 | 11 | 70 | -- | -- | U.S.G.S. | LMBP |
| 3.1 | 0.13 | 50.6 | 6.4 | 5.7 | 1.3 | -- | <10 | <100 | <20 | BHP-UII Minerals Laboratory | UNAV |
| 8.2 | 0.12 | 85 | 26 | 15.2 | 1.8 | -- | 30 | 100 | 20 | BHP-UII Minerals laboratory | LMBP |
| 9.8 | 0.11 | 85 | 27 | 15.2 | 2.1 | -- | 20 | <100 | 30 | BHP-UII Minerals laboratory | LMBP |
| 8.5 | 0.13 | 79 | 27 | 15.7 | 2.1 | -- | 30 | <100 | 20 | BHP-UII Minerals laboratory | LMBP |
| 8.7 | 0.11 | 84 | 25 | 14.5 | 2.1 | -- | 10 | <100 | 30 | BHP-UII Minerals laboratory | LMBP |
| -- | -- | -- | -- | -- | -- | 7.5 | -- | -- | -- | U.S.G.S. | LMBP |
| 6.3 | 0.2 | 48 | 20 | 7.9 | 2.1 | 9.9 | 40 | -- | -- | U.S.G.S. | LMBP |
| 6.1 | 0.2 | 35 | 17 | 4.9 | 1.6 | 12 | <20 | -- | -- | U.S.G.S. | LMBP |
| 6.4 | 0.1 | 36 | 16 | 5.0 | 1.6 | 11 | <20 | 50 | <10 | U.S.G.S. | LMBP |
| 6.9 | 0.1 | 39 | 14 | 5.7 | 1.7 | 10 | <20 | -- | -- | U.S.G.S. | LMBP |
| 5.7 | 0.1 | 38 | 13 | 4.4 | 1.5 | 11 | 30 | -- | -- | U.S.G.S. | LMBP |
| 5.7 | 0.1 | 39 | 13 | 4.5 | 1.4 | 11 | 30 | -- | -- | U.S.G.S. | LMBP |
| 6.4 | 0.2 | 44 | 19 | 7.5 | 1.3 | 11 | 40 | -- | -- | U.S.G.S. | LMBP |
| 6.2 | 0.2 | 44 | 19 | 7.5 | 1.3 | 11 | 40 | -- | -- | U.S.G.S. | LMBP |
| 7.2 | 0.2 | 58 | 24 | 10 | 2.4 | 9.7 | 0 | -- | -- | U.S.G.S. | LMBP |
| 3.5 | 0.18 | 27.5 | 4.2 | 31.5 | 0.6 | -- | 40 | <100 | 40 | BHP-UII Minerals Laboratory | UNAV |
| 7.8 | 0.1 | 42 | 23 | 19 | 4.0 | 3.1 | 40 | 430 | 180 | U.S.G.S. | LMBP |
| 7.0 | 0.2 | 43 | 20 | 7.8 | 1.7 | 9.6 | 60 | -- | -- | U.S.G.S. | LMBP |
| 6.2 | 0.2 | 42 | 19 | 7.5 | 1.8 | 9.4 | 50 | 20 | 30 | U.S.G.S. | LMBP |
| 6.2 | 0.2 | 42 | 19 | 7.5 | 1.8 | 9.5 | 50 | <10 | 20 | U.S.G.S. | LMBP |
| 6.3 | 0.2 | 42 | 19 | 8.0 | 1.8 | 9.5 | 50 | 20 | 40 | U.S.G.S. | LMBP |
| 8.3 | 0.2 | 19 | 9.9 | 18 | 2.4 | 0.2 | 50 | 130 | <10 | U.S.G.S. | LMBP |
| 5.8 | 0.1 | 31 | 19 | 4.3 | 2.5 | 14 | 30 | -- | -- | U.S.G.S. | UNAV |
| 4.1 | 0.1 | 27 | 17 | 4.0 | 2.4 | 13 | 30 | 20 | 5 | U.S.G.S. | UNAV |
| 4.1 | 0.1 | 29 | 17 | 4.0 | 2.4 | 13 | 30 | <10 | 8 | U.S.G.S. | UNAV |
| 4.3 | 0.1 | 28 | 17 | 4.0 | 2.3 | 13 | 30 | 30 | <10 | U.S.G.S. | UNAV |
| 4.0 | 0.1 | 26 | 16 | 4.5 | 2.2 | 14 | <20 | -- | -- | U.S.G.S. | UNAV |
| 4.9 | 0.1 | 23 | 15 | 3.8 | 2.8 | 14 | 70 | 10 | 3 | U.S.G.S. | UNAV |
| -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | U.S.G.S. | UNAV |
| -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | U.S.G.S. | UNAV |
| 3.8 | <0.1 | 26 | 17 | 4.1 | 2.4 | 14 | 30 | 4 | 1 | U.S.G.S. | UNAV |
| -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | U.S.G.S. | UNAV |
| 8.5 | 0.12 | 40 | 18 | 9 | 2 | -- | 80 | <100 | 20 | BHP-UII Minerals Laboratory | UNAV |
| 4.9 | 0.1 | 24 | 16 | 3.8 | 2.2 | 13 | 30 | -- | -- | U.S.G.S. | LMBP |
| 7.9 | 0.1 | 60 | 29 | 6.8 | 2.8 | 13 | 50 | 30 | 4 | U.S.G.S. | LMBP |
| 8.1 | 0.1 | 47 | 18 | 7.1 | 2.4 | 8.7 | 30 | -- | -- | U.S.G.S. | LMBP |
| 8.1 | 0.1 | 77 | 38 | 20 | 2.8 | 11 | 60 | 60 | <10 | U.S.G.S. | LMBP |
| 6.4 | 0.17 | 47.2 | 10.7 | 9.8 | 0.8 | -- | 20 | <100 | 20 | BHP-UII Minerals Laboratory | UNAV |
| 7.0 | 0.2 | 53 | 15 | 5.9 | 0.9 | 13 | 40 | -- | -- | U.S.G.S. | UNAV |
| 2.0 | <0.1 | 30 | 11 | .4 | -- | -- | -- | <50 | -- | Arizona State Health Dept. | LMBP |
| 38 | 0.9 | 67 | 25 | 106 | -- | -- | -- | 80 | -- | Arizona State Health Dept. | LMBP |
| 4.0 | 0.1 | 52 | 13 | 3.9 | 2.9 | 12 | 40 | 70 | 0 | U.S.G.S. | LMBP |
| 3.2 | 0.1 | 55 | 14 | 2.9 | 2.9 | 9.2 | 30 | 60 | 10 | U.S.G.S. | LMBP |
| 4.0 | 0.2 | 44 | 14 | 4 | -- | -- | -- | -- | -- | Arizona State Health Dept. | LMBP |
| 2.6 | 0.2 | 49 | 14 | 2.4 | 2.6 | 9.4 | 20 | -- | -- | U.S.G.S. | LMBP |
| 4.0 | 0.1 | 29 | 11 | 2.8 | 3.5 | 13 | 10 | -- | -- | U.S.G.S. | UNAV |

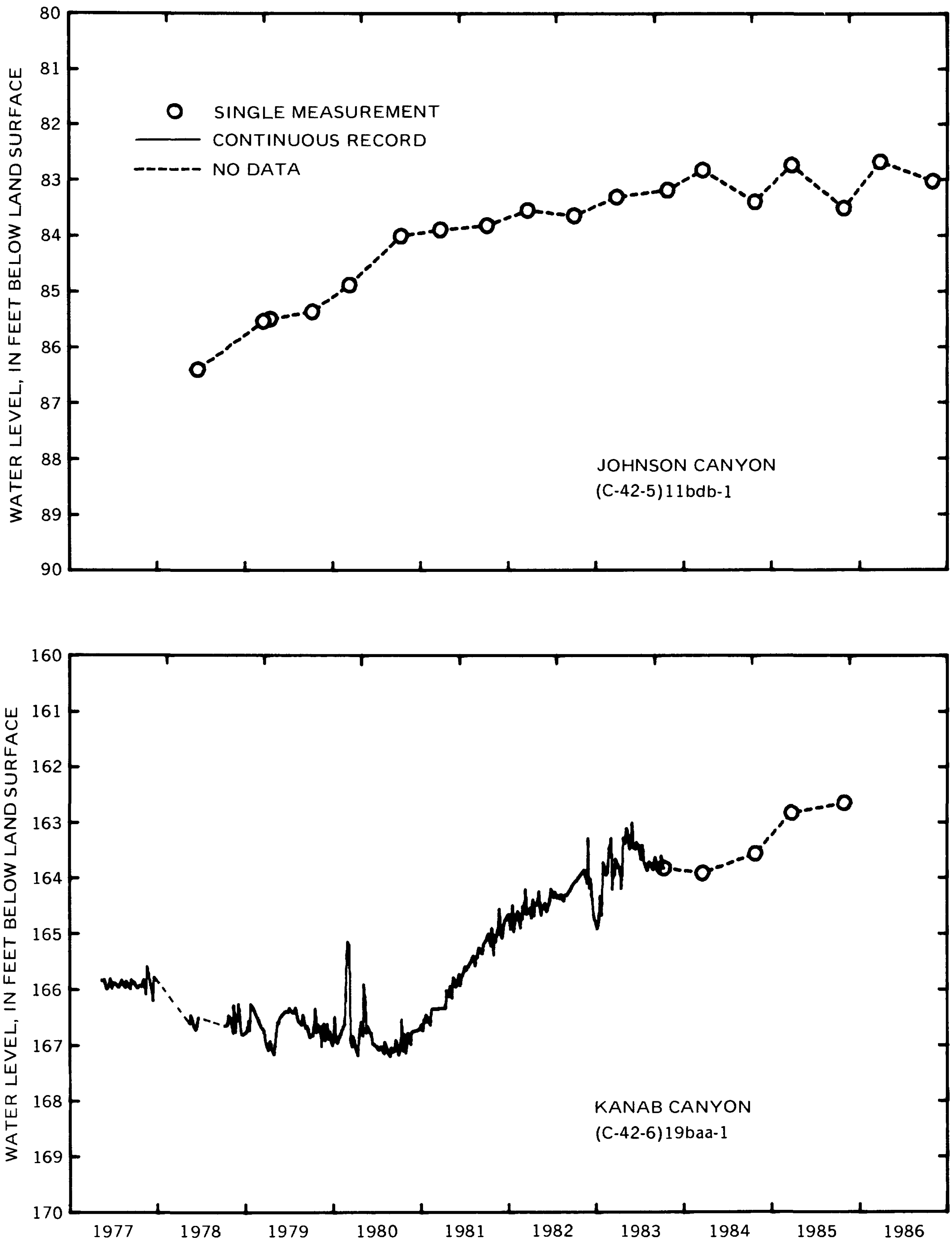



Figure 6.—Typical water-level changes in wells tapping the Lamb Point aquifer in Johnson and Kanab Canyons.

Vertical movement of ground water may also be indicated by differences in the quality of water from wells tapping the upper Navajo aquifer (table 5). If sulfate concentration of water in the Navajo Sandstone does not change with time, the slightly smaller sulfate concentration in water from a USBLM well, (C-41-5)11bda-1, when compared to water in the Bald Knoll wells, (C-40-5)21abb-1 and 21abc-1 (pl. 2) may indicate that vertical leakage from the Carmel Formation, which contains gypsum, may be less at this USBLM well than in the Bald Knoll area. This could further indicate that faulting increases vertical hydraulic conductivity and downward vertical movement because the Bald Knoll wells were drilled near a fault, whereas the USBLM well was not. Reasons for the large concentrations of sodium, calcium, magnesium, and sulfate in water from well (C-41-5)26dac-2, about 3.5 mi south of well (C-41-5)11bda-1, are unknown. In general, the Lamb Point aquifer typically contains a larger concentration of sulfate than water in the overlying upper Navajo aquifer. The median sulfate concentration for 34 water samples from the Lamb Point aquifer was 29 mg/L. The median sulfate concentration for 19 water samples from the upper Navajo aquifer was 11 mg/L. Leakage downward through the Tenney Canyon confining unit may be the source of the slightly larger concentrations in the Lamb Point aquifer; sulfate possibly may be leached from shales or siltstones in the Tenney Canyon Tongue of the Kayenta Formation.

## Inflow of Water to the Navajo Sandstone

Water likely moves into the upper Navajo and Lamb Point aquifers in the study area in several different ways: (1) Recharge by direct infiltration of rainfall and snowmelt where the Navajo Sandstone is exposed and infiltration of runoff along main stream channels traversing exposed Navajo Sandstone; (2) by vertical inflow of water from overlying or underlying formations; (3) by lateral inflow across the hydrologic boundaries of the area; or (4) by infiltration of excess applied irrigation water. Because specific inflow data are lacking, estimates of the quantity of water moving into the Navajo Sandstone from each of these sources may have significant error.

### Recharge from Precipitation

Rising water levels in wells following periods of above normal precipitation is an indication that precipitation is the main source of recharge to the principal aquifers of the study area. Water levels in two wells tapping the Lamb Point aquifer, one in Kanab Canyon and the other in Johnson Canyon, rose 3 to 4 ft from 1978 to 1985, most likely in response to the higher-than-average precipitation that fell in the period 1978-84 (fig. 6). Measuring the quantity of precipitation that actually moves from the land surface through the unsaturated zone into an aquifer is impractical on a large scale because the components that control this process are numerous and extremely variable in space and time. About 12 to 14 in of precipitation fall on the outcrop area of the Navajo Sandstone annually. The 7 to 9 in that fall from October through April is commonly called winter precipitation (Utah Division of Water Resources, 1983, fig. 12). The outcrop area supports a pinyon-juniper vegetation cover, and this type of vegetation transpires water year-round at varying rates (Miller and others, 1987) that depend partly on the quantity of soil moisture available (Lane and Barnes, 1987). Investigations by Gifford and Shaw (1973) and Gifford (1975) of pinyon-juniper areas near Blanding and Milford, Utah, indicate that nearly all precipitation at those sites is consumed by evapotranspiration or interception by foliage. No deep percolation occurs, and runoff varies from 0 to about 3 percent. Potential annual evapotranspiration exceeds total annual precipitation throughout the area of the present study where the Navajo Sandstone is exposed.

Opinions differ as to the percentage of precipitation that infiltrates and moves downward to recharge the upper Navajo and Lamb Point aquifers. On the basis of a ratio of base flow to precipitation, Cordova (1981, p. 28) estimated that 4 percent of precipitation recharges the ground-water system of the Upper Virgin River and Kanab Creek basins. Using soil-moisture measurements with neutron-moisture probes and tensiometers, Danielson and Hood (1984) concluded that 14 percent of precipitation recharged the Navajo Sandstone where winter precipitation was about 20 in, but that virtually no recharge occurred at a second site where winter precipitation was slightly less than 8 in. This infiltration study was conducted north of the study area at sites where the Navajo Sandstone is exposed. Studies of the Navajo Sandstone in southern and south-central Utah by Thomas (1986) and Weiss (1987) that used ground-water flow models concluded that recharge ranges from 1 to 6 percent of annual precipitation. Based on studies done by the U.S. Bureau of Reclamation, Blanchard (1986) concluded that potential recharge for three drainage basins in the Kaiparowits area, just to the east of the study area, ranges between 0.5 and 3 percent of annual precipitation. Goode (1966, p. 35) used water-budget calculations to estimate recharge to the Navajo Sandstone, and concluded that maximum recharge could be 20 percent of annual precipitation. Bingham Engineering (1987, p. VI-6), using several different approaches, concluded that evapotranspiration may consume 75 to 95 percent of total precipitation, and that a reasonable estimate of recharge would be about 20 percent of winter precipitation.

If total annual precipitation falling on the exposed Navajo Sandstone in the study area ranges from 12 to 14 in and winter precipitation ranges from 7 to 9 in, recharge to all the Navajo aquifers could range from 0.1 to about 2.8 in/yr. If quantified for the area of outcrop of all Navajo aquifers, that is equivalent to a range of 1,500 to 40,000 acre-ft/yr, with a median value of about 20,000 acre-ft/yr.

### Seepage from Streams

To estimate the quantity of water that recharges the upper Navajo and Lamb Point aquifers by seepage from streams, a per-mile loss of streamflow would be needed; preferably determined at a time when discharge of shallow ground water along streams by evapotranspiration is negligible. Seepage-investigation data of this type are not available. Bingham Engineering (1987) estimated the recharge to the upper Navajo and Lamb Point aquifers from stream seepage to be 25,700 acre-ft/yr. This estimate was based on average runoff-precipitation ratios for the drainage to the west of the Kanab Creek drainage, determined by the Utah Division of Water Resources (1983). This extrapolation is subject to considerable error because the average annual precipitation in the adjacent drainage was somewhat larger (16.75 to 20.80 in) than the average annual precipitation in the Kanab Creek (14.88 in) and Johnson Wash (13.72 in) drainages, thus the likely result is runoff-precipitation ratios that are somewhat larger than actual ratios.

## Inflow from Overlying and Underlying Formations

Downward vertical movement into the upper Navajo aquifer, where it is buried, is theoretically feasible because water levels in overlying aquifers are higher than water levels in the upper Navajo aquifer. The quantity of water that moves into the upper Navajo aquifer can be estimated using the head difference between aquifers, the average vertical hydraulic conductivity of the rock between the aquifers, the area where vertical movement occurs, and the distance the water must travel. Few, if any, of these components are known.

Differences in dissolved chemical constituents in the water in the upper Navajo aquifer and the water in the Carmel confining unit indicate vertical downward movement is occurring. Water from the overlying Carmel confining unit is a calcium sulfate type water containing dissolved-solids concentrations of more than 3,000 mg/L. The dissolved-solids concentration in water from wells drilled in the Navajo Sandstone outcrop area, where recharge from precipitation is presumed to occur, generally is less than 500 mg/L, and the water is a calcium bicarbonate type with small concentrations of sulfate. Water from two wells drilled by the coal company in the Bald Knoll area and from a stock well drilled about 4 mi south of Bald Knoll (pl. 2) contained larger concentrations of sulfate, which indicates that water from the overlying Carmel confining unit may be moving downward and mixing with the water in the upper Navajo aquifer. The areal distribution of this source of water or the rate of downward flow cannot be determined because of the lack of monitoring wells in the area north of the White Cliffs.

Hydraulic-head data or water-quality data are not available to determine if the Lamb Point aquifer is being recharged by upward flow from underlying aquifers, such as the Moenave Formation.

## Inflow across Hydrologic Boundaries

Movement of water into the Navajo Sandstone of the study area as subsurface inflow from the Paria River drainage basin, as postulated by Bingham Engineering (1987, p. VI-7), cannot be confirmed without additional water levels in the Kanab Creek and Paria River drainage basins to more accurately define the potentiometric surface. The Paunsaugunt fault on the east side of the study area closely parallels the surface-water divide between the Kanab Creek drainage and the Paria River drainage. Altitudes of springs discharging from the Navajo aquifer east of the fault indicate that ground water moves from this topographically high divide area to the east, precluding subsurface inflow to the study area across the fault in the outcrop area. Spring altitudes and water levels in wells to the west of the fault indicate that ground water also moves west from this area. Accordingly, it can be inferred that a ground-water divide approximately coincides with the surface-water divide and the fault; however, water-level data are not numerous enough to precisely locate the ground-water divide. Because the Paunsaugunt fault has about the same location as the possible ground-water divide, it is difficult to determine if there is flow across this fault, or the direction and rate of this flow.

Two wells were drilled by the coal company on opposite sides of the Paunsaugunt fault in the Navajo outcrop area. The well on the west side, (C-42-4)19adb-1, is screened in Navajo Sandstone and the well on the east side, (C-42-4)3bac-1 is screened in a water-bearing sandstone within or beneath the Kayenta Formation (possibly the Moenave Formation). The Navajo Sandstone was unsaturated in this east-side well. Logs indicate that the throw of the fault between these wells is more than 468 ft, still leaving the two saturated sandstones in contact. Water-level measurements in the two wells indicate a water-level difference of about 263 ft in the 4 mi between the wells. If the two wells are hydraulically connected across the fault zone, ground-water flow from northeast to southwest is indicated.

Based on water-quality analyses by the coal company, predominant ions in the water from the well west of the fault, completed in the Navajo Sandstone, are calcium and bicarbonate. Predominant ions in water from the well east of the fault, completed in the Kayenta or Moenave Formation, are calcium, sodium, and bicarbonate. Concentrations of sodium, potassium, bicarbonate, sulfate, fluoride, and zinc are all notably larger in water from the east-side well (Bingham Engineering, 1987, Appendix B). Because the concentrations of these constituents are smaller in the west well, east to west flow of ground water between these wells seems unlikely. Without obtaining more water levels on each side of the fault along its 38-mi length, flow across this fault cannot be verified. Extended pumping in one well while observing the water level in the other could be used to establish the connection in the aquifer intervals between the wells; however, the distance separating these two wells may be too great to make such a test practical on a short-term basis. More water levels, the knowledge of variability of fault displacement to determine if permeable zones are in contact, and knowledge of the hydrologic properties of rocks in the fault zone are needed to determine the direction and rate of cross-fault flow of ground water. Given the hydrologic information presently (1987) available, the most likely hydrologic characterization of this area is a ground-water divide, probably closely paralleling the surface-water divide between the Kanab Creek and Paria River drainages. Accordingly, any ground-water flow across the Paunsaugunt fault is a function of the fault's position relative to the ground-water divide. If the fault lies west of the divide, ground water likely flows across it from east to west. If the fault lies east of the divide, ground water will flow across it from west to east.

### Excess Applied Irrigation Water

The process of irrigating cropland in the north end of Johnson Canyon may constitute a small part of inflow of water to the Navajo Sandstone. But, because the quantity of water used for irrigation is generally less than 500 acre-ft/yr, the excess water applied to the cropland that infiltrates back into the saturated part of the Navajo Sandstone is likely small.

## Outflow of Water from the Navajo Sandstone

Ground water moves out of or discharges from the Navajo Sandstone in the study area by: (1) Discharge by springs, seeps, and stream baseflow where the water table intersects the land surface; (2) discharge by evapotranspiration where the water table is within about 10 ft of land surface and riparian growth is abundant; (3) lateral subsurface outflow from the study area across hydrologic boundaries; and (4) discharge by wells. The quantity of ground water being pumped from wells and the quantity discharging from springs and as stream baseflow can be measured directly, but the quantity discharged by means of all other mechanisms is unknown.

### Discharge by Springs and Seeps

Previous spring inventories, topographic maps, and infrared photographs indicate that there are more than 200 springs or seeps discharging water from the Navajo Sandstone in the study area (table 6). Several of the seeps have no surface discharge and were identified by the type and density of riparian growth near them. An estimate of the quantity of discharge at inventoried springs is 5,145 acre-ft/yr, with about 50 percent discharging from the upper Navajo aquifer. The largest part of this discharge, 2,880 acre-ft/yr, is in Kanab and Cottonwood Canyons on the west side of the study area. The remaining discharge occurs in the canyons of Johnson Wash, 2,200 acre-ft/yr; the Paria River drainage, 35 acre-ft/yr; and the Virgin River drainage, 30 acre-ft/yr. Because most discharge values were from a spring inventory that followed a 5-year period in which precipitation was greater than normal, the total spring discharges given may be greater than the long-term average. Discharge at the uninventoried seepage areas takes place as evapotranspiration.

### Evapotranspiration

Direct evaporation from the water table is known to occur where ground water is within about 10 ft of the land surface, and can vary from less than 5 percent to more than 80 percent of that from a 12-ft evaporation pan (White, 1932, fig. 26), depending on soil type, depth to water, and temperature. Evaporation rates are larger where the water table is less than 1 ft below land surface, a condition that is common around seep areas. Plants can transpire water derived from greater depths, and transpiration varies with the type of vegetation, the density of vegetation, the depth to the water table, and the quality of the water. Using aerial photographs in conjunction with a field reconnaissance, Cordova (1981, pl. 2) identified areas where he believed evapotranspiration to be important. The quantity of water discharged by evapotranspiration around seeps, around springs, and along streams that owe their existence to ground water from the Navajo Sandstone was estimated by Cordova (1981, table 12) to be 1,500 acre-ft/yr.

### Seepage to Streams

The ground-water discharge from the Navajo Sandstone makes up part of gains in streamflow. Bingham Engineering (1987) estimated this discharge to be 9,000 acre-ft/yr, based on the same runoff-precipitation ratios used to estimate seepage from streams (see page 26). Cordova (1981, table 11), using base-flow measurements made at various times on seven of the streams within the area, estimated seepage of ground water from the Navajo to streams in the Kanab Creek drainage to be 4,245 acre-ft/yr, and in Johnson Wash to be 460 acre-ft/yr. This is a total discharge of about 4,700 acre-ft/yr. Detailed seepage investigations are needed to more accurately ascertain this discharge quantity.

Table 6.--Springs discharging from the Navajo Sandstone in the study area

Spring location number: For explanation, see section on data-site numbering.
Altitude of land surface: Refers to distance above sea level in feet.
Hydrologic unit: NVJO, Navajo aquifer undivided; UNAV, upper Navajo aquifer; LMBP, Lamb Point aquifer; DUNE, dune sand aquifer.
Discharge: In gallons per minute.
Specific conductance: In microsiemens per centimeter at 25 °C.
Temperature: In degrees Celcius.
Information source: Map--"name", refers to U.S. Geological Survey 7.5 or 15 minute topographic maps; B.E., Bingham Engineering, Salt Lake City.

| Spring location number | Altitude of land surface | Hydro-logic unit | Dis-charge | Speci-fic conduc-tance (μS/cm) | Tem-pera-ture | General location or name of spring | Information source |
|---|---|---|---|---|---|---|---|
| (C-40-2)29dcb-S1 | 5,460 | NVJO | - | - | - | Kitchen Canyon | Blanchard, 1986 |
| 30cca-S1 | 5,550 | NVJO | - | - | - | Nipple Lake | Blanchard, 1986 |
| 30ccd-S1 | 5,550 | NVJO | 1 | - | - | Nipple Lake | Blanchard, 1986 |
| 30cdc-S1 | 5,550 | NVJO | - | - | - | Nipple Lake | Blanchard, 1986 |
| 32aaa-S1 | 5,430 | NVJO | - | - | - | Kitchen Canyon-Middle Spring | Map-Deer Range Point |
| 33baa-S1 | 5,320 | NVJO | - | - | - | Kitchen Canyon | Blanchard, 1986 |
| (C-41-3) 7ddc-S1 | 5,800 | NVJO | 4 | - | - | Deer Spring Wash | B.E., 1987 |
| 18acc-S1 | 5,760 | NVJO | 1 | 603 | 15.5 | Wildcat Spring-Deer Spring Wash | Blanchard, 1986 |
| | 5,820 | NVJO | 7 | 391 | 8.0 | Wildcat Spring-Deer Spring Wash | B.E., 1987 |
| (C-41-4) 1bac-S1 | 5,910 | NVJO | 1.5 | - | - | Sand Spring-Deer Spring Wash | Blanchard, 1986 |
| | 5,920 | NVJO | 2.2 | 59 | 11.0 | Sand Spring-Deer Spring Wash | B.E., 1987 |
| 36cbd-S1 | 6,240 | NVJO | 1.5 | - | 11.0 | Nephi Wash | B.E., 1987 |
| R(C-41-4)34bbb-S1 | 6,600 | UNAV | .75 | - | 12.8 | Timber Mountain-Cottonwood Canyon | Goode, 1966 |
| (C-42-4)18dab-S1 | 5,845 | UNAV | .2 | - | - | Johnson Lakes Canyon | B.E., 1987 |
| 21caa-S1 | 6,120 | LMBP | 1.6 | 379 | 12.0 | Johnson Lakes canyon | B.E., 1987 |
| 21cad-S1 | 6,160 | LMBP | 6.5 | 317 | 12.0 | Johnson Lakes canyon | B.E., 1987 |
| R(C-42-4)32dab-S1 | 5,480 | LMBP | 15 | 410 | 14.0 | Johnson Lakes | Goode, 1966; Cordova, 1981 |
| | 5,475 | LMBP | 45 | 300 | 10.0 | Johnson Lakes (north) | B.E., 1987 |
| 32dba-S1 | 5,470 | LMBP | - | - | 16.7 | Johnson Lakes | Goode, 1966 |
| | 5,480 | LMBP | 5.1 | - | - | Johson Lakes (middle) | B.E., 1987 |
| 32dcb-S1 | 5,450 | LMBP | 14 | - | 14.4 | Johnson Lakes | Goode, 1966 |
| | 5,450 | LMBP | 24 | 225 | 13.0 | Johnson Lakes (south) | B.E., 1987 |
| (C-42-5)22aba-S1 | 5,420 | UNAV | 10 | 525 | 7.0 | Johnson Lakes (south) | B.E., 1987 |
| 22adb-S1 | 5,380 | UNAV | 10 | 725 | 16.5 | Johnson Canyon-Pool | Cordova, 1981 |
| 25ccd-S1 | 5,400 | LMBP | - | 223 | 13.0 | Middle of Meadow Canyon | Goode, 1966 |
| 25cdc-S1 | 5,400 | LMBP | - | - | - | Middle of Meadow Canyon | Goode, 1966 |
| 26dad-S1 | 5,400 | LMBP | 38 | - | - | Johnson Canyon-Miner Spring | B.E., 1987 |
| 26dbc-S1 | 5,360 | LMBP | 300 | 424 | 14.0 | Johnson Canyon-DeGraw Spring | B.E., 1987 |
| 28abd-S1 | 5,520 | UNAV | 4.5 | 340 | 6.0 | Oak Canyon-Oak Spring | B.E., 1987 |
| 34c-S | 5,360 | LMBP | 200-450 | - | 13.3 | Dairy Canyon Spring | Goode, 1966 |
| 34dab-S1 | 5,380 | LMBP | 5.5 | - | - | Dairy Canyon | B.E., 1987 |
| 35abd-S1 | 5,400 | LMBP | 2.5 | - | - | Johnson Canyon-Dick's Spring | B.E., 1987 |
| 35adb-S1 | 5,360 | LMBP | .25 | - | 19.4 | W.L. Johnson Spring | Goode, 1966 |
| | 5,400 | LMBP | 40 | - | - | Johnson Canyon-Sand Spring | B.E., 1987 |
| 35bdb-S1 | 5,360 | LMBP | .25 | - | 18.3 | Alvin Judd Spring | Goode, 1966 |
| 35bca-S1 | 5,360 | LMBP | - | 350 | 16.0 | Dairy Canyon-Judd-Scribner | B.E., 1987 |
| 35cbc-S1 | 5,360 | LMBP | - | - | - | Dairy Canyon | B.E., 1987 |
| 36bba-S1 | 5,450 | LMBP | 45 | - | - | Meadow Canyon | B.E., 1987 |
| 36bbd-S1 | 5,360 | LMBP | 34.5 | - | 13.9 | Meadow Canyon | Goode, 1966 |
| | 5,450 | LMBP | 4.5 | 238 | 12.0 | Meadow Canyon-Rock Spring | B.E., 1987 |
| 36bbd-S2 | 5,450 | LMBP | 32 | - | - | Meadow Canyon | B.E., 1987 |
| 36bcb-S1 | 5,360 | LMBP | 30 | - | - | Meadow Canyon | Goode, 1966 |
| 36bcd-S1 | 5,450 | LMBP | 45 | 300 | 16.6 | Meadow Canyon | B.E., 1987 |
| (C-42-6) 4cbb-S1 | 5,400 | UNAV | 20 | 380 | 20.0 | Kanab Creek-Pool | Cordova, 1981 |
| 4cbc-S1 | 5,380 | UNAV | 25 | - | - | Kanab Creek-headwaters | Goode, 1964; 1966 |
| | 5,390 | UNAV | 18 | 1,100 | 15.0 | Kanab Creek-headwaters | B.E., 1987 |
| 4ccc-S1 | 5,360 | UNAV | 100 | 655 | 15.0 | Kanab Creek-Lower headwaters | Goode, 1966; Cordova, 1981 |
| | 5,360 | UNAV | 100 | 625 | 13.0 | Kanab Creek-Lower headwaters | B.E., 1987 |
| 9bbd-S1 | 5,360 | UNAV | 15 | 390 | 24.5 | Kanab Creek-Red Canyon | Goode, 1964; 1966 |
| | 5,450 | UNAV | 30.5 | 329 | 13.0 | Kanab Creek-Red Canyon | B.E., 1987 |
| 15cba-S1 | 5,400 | UNAV | 80 | 200 | 13.0 | Brown Wash-J.R. Brown Spring | B.E., 1987 |

Table 6.--Springs discharging from the Navajo Sandstone in the study area--Continued

| Spring location number | Altitude of land surface | Hydro-logic unit | Dis-charge | Speci-fic conduc-tance (µS/cm) | Tem-pera-ture | General location or name of spring | Information source |
|---|---|---|---|---|---|---|---|
| (C-42-6)17aaa-S1 | 5,280 | UNAV | 50-100 | 300 | 24.0 | Kanab Creek-Stanley | Goode, 1966; Cordova, 1981 |
| | 5,320 | UNAV | 37 | - | - | Kanab Creek-Stanley | B.E., 1987 |
| 17aad-S1 | 5,280 | UNAV | 100 | 210 | 21.0 | Kanab Creek | Goode, 1966; Cordova, 1981 |
| | 5,320 | UNAV | 17 | - | - | Kanab Creek | B.E., 1987 |
| 17caa-S1 | 5,350 | UNAV | 100-125 | - | 15.6 | Big Lake Spring | Goode, 1964 |
| | 5,369 | UNAV | 21 | 139 | 13.0 | Big Lake Spring | B.E., 1987 |
| 17caa-S2 | 5,363 | UNAV | 23 | 163 | 11.0 | Big Lake Spring | B.E., 1987 |
| 17daa-S1 | 5,280 | UNAV | - | 280 | 21.0 | Big Lake mouth no.1 | Cordova, 1981 |
| 17dac-S1 | 5,350 | UNAV | 25 | - | 13.9 | Big Lake mouth no.2 | Goode, 1964; Feltis, 1966 |
| | 5,340 | UNAV | 27 | 240 | 11.0 | Big Lake mouth no.2 | B.E., 1987 |
| 17dba-S1 | 5,360 | UNAV | - | 175 | 14.0 | Big Lake Main | Cordova, 1981 |
| 17dba-S2 | 5,360 | UNAV | - | 200 | 12.0 | Big Lake-Cold | Cordova, 1981 |
| 17dbb-S1 | 5,358 | UNAV | 45 | 148 | 13.0 | Big Lake Springs | B.E., 1987 |
| 17dbb-S2 | 5,360 | UNAV | 45 | 147 | 13.0 | Big Lake Springs | B.E., 1987 |
| 17dbb-S3 | 5,360 | UNAV | 26 | 158 | 13.0 | Big Lake Springs | B.E., 1987 |
| 17dda-S1 | 5,320 | UNAV | 2.5 | 205 | 11.0 | Kanab Creek-Honey Bee Spring | B.E., 1987 |
| 17ddc-S1 | 5,400 | UNAV | 15 | 266 | 10.5 | Kanab Creek-Dugway | Cordova, 1981 |
| 19cdd-S1 | 5,460 | UNAV | 100-200 | - | - | Upper 3 Lakes Canyon | Goode, 1964 |
| | 5,460 | UNAV | 10 | 780 | 15.5 | Upper 3 Lakes Canyon | B.E., 1987 |
| 19cdd-S2 | 5,460 | UNAV | 8.5 | - | - | Upper 3 Lakes Canyon | B.E., 1987 |
| 20aaa-S1 | 5,320 | UNAV | 7.5 | 329 | 8.5 | Kanab Creek | B.E., 1987 |
| 20aac-S1 | 5,375 | UNAV | 10-50 | - | - | Kanab Creek-Main Canyon | Goode, 1964 |
| 20adb-S1 | 5,320 | UNAV | 1.7 | 247 | 9.0 | Kanab Creek-Big Spring | B.E., 1987 |
| 20dab-S1 | 5,320 | UNAV | 1.6 | 300 | 15.5 | Kanab Creek-Upper Green | Cordova, 1981 |
| 20dba-S1 | 5,350 | UNAV | 44 | 232 | 6.5 | Kanab Creek-Upper Green | B.E., 1987 |
| 20dcd-S1 | 5,325 | UNAV | 6.5 | 243 | 11.5 | Kanab Creek-Middle Green no.1 | B.E., 1987 |
| 20dcd-S2 | 5,300 | UNAV | 5.1 | 620 | 9.0 | Kanab Creek-Middle Green no.2 | B.E., 1987 |
| 20ddb-S1 | 5,320 | UNAV | 7 | 255 | 11.0 | Kanab Creek-Hollywood Bowl Spring | B.E., 1987 |
| 20ddb-S2 | 5,320 | UNAV | 5 | - | - | Kanab Creek-Middle Green Spring | B.E., 1987 |
| 20ddc-S1 | 5,300 | UNAV | 2.2 | 340 | 11.0 | Kanab Creek-Middle Green | Cordova, 1981 |
| 21cbb-S1 | 5,360 | UNAV | 2 | - | - | Kanab Creek | B.E., 1987 |
| 21cbd-S1 | 5,360 | UNAV | 2.6 | - | - | Kanab Creek | B.E., 1987 |
| 21cdb-S1 | 5,360 | UNAV | 14.1 | 293 | 5.5 | Kanab Creek-BLM Cave | B.E., 1987 |
| 28bba-S1 | 5,400 | UNAV | 10-15 | - | - | Kanab Creek-Main Canyon | Goode, 1964 |
| | 5,320 | UNAV | 21.3 | 339 | 13.0 | Kanab Creek-Water Canyon Spring | B.E., 1987 |
| 28bba-S2 | 5,320 | UNAV | 1.5 | - | - | Kanab Creek | B.E., 1987 |
| 28bca-S1 | 5,340 | UNAV | 39 | 342 | 11.0 | Kanab Creek | B.E., 1987 |
| 29aba-S1 | 5,280 | UNAV | 1.3 | 340 | 15.0 | Kanab Creek-Lower Green | Cordova, 1981 |
| | 5,340 | UNAV | 19 | 283 | 15.0 | Kanab Creek-Lower Green | B.E., 1987 |
| 29dcd-S1 | 5,360 | UNAV | 2.1 | 310 | 14.0 | Kanab Creek-Rockhouse | Cordova, 1981 |
| 29dcb-S1 | 5,320 | UNAV | 16 | 311 | 14.0 | Kanab Creek-Hackleberry Spring no.1 | B.E., 1987 |
| 29dcc-S1 | 5,340 | UNAV | 16 | - | - | Kanab Creek-Hackleberry Spring no.2 | B.E., 1987 |
| 30baa-S1 | 5,450 | UNAV | 100-200 | - | - | Three Lakes Canyon Middle Lake Spring | Goode, 1964 |
| | 5,455 | UNAV | 40 | 271 | 13.0 | Three Lakes Canyon Middle Lake Spring | B.E., 1987 |
| 30bda-S1 | 5,425 | UNAV | 100-200 | - | - | Three Lakes Canyon Lower Lake Spring | Goode, 1964 |
| | 5,435 | UNAV | 35 | 300 | 13.0 | Three Lakes Canyon Lower Lake Spring | B.E., 1987 |
| 30bdd-S1 | 5,400 | UNAV | 40 | 353 | 13.0 | Three Lakes Canyon | B.E., 1987 |
| 30cbb-S1 | 5,480 | UNAV | 8.5 | 364 | 13.0 | Cave Lakes Canyon | B.E., 1987 |
| 30cca-S1 | 5,490 | UNAV | 3.6 | 263 | 12.0 | Cave Lakes Canyon | B.E., 1987 |
| 30ccb-S1 | 5,500 | UNAV | 10 | 340 | 11.5 | South Cave Lakes Canyon | Cordova, 1981 |
| 30dbb-S1 | 5,400 | UNAV | - | 320 | 12.5 | 3 Lakes Canyon-Cave | Cordova, 1981 |
| 31bac-S1 | 5,540 | UNAV | 15.3 | 482 | 11.0 | Three Lakes Canyon | B.E., 1987 |
| 31cad-S1 | 5,633 | UNAV | 5.5 | 270 | 12.0 | Three Lakes Canyon Chicken Spring | B.E., 1987 |
| 33bca-S1 | 5,420 | UNAV | 4.4 | 416 | 12.0 | Kanab Creek | B.E., 1987 |

**Table 6.--Springs discharging from the Navajo Sandstone in the study area--Continued**

| Spring location number | Altitude of land surface | Hydrologic unit | Discharge | Specific conductance (µS/cm) | Temperature | General location or name of spring | Information source |
|---|---|---|---|---|---|---|---|
| (C-42-6)34cbd-S1 | 5,480 | UNAV | 3 | 472 | 17.0 | Hog Canyon | B.E., 1987 |
| (C-42-7)22aaa-S1 | 5,950 | UNAV | 1.6 | - | - | Three Lakes Canyon-Red Knoll no.2 | B.E., 1987 |
| 22aac-S1 | 5,950 | UNAV | 1.1 | 60 | 15.0 | Three Lakes Canyon-Red Knoll no.1 | B.E., 1987 |
| 25ccc-S1 | 5,600 | UNAV | - | - | - | Cave Lakes Canyon-Kanab City no.1 | Cordova, 1981 |
| | 5,610 | UNAV | 1 | - | - | Cave Lakes Canyon-Kanab City no.1 | B.E., 1987 |
| 25ccc-S2 | 5,620 | UNAV | 1 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25ccd-S1 | 5,600 | UNAV | 21.5 | 245 | 13.0 | Cave Lakes Canyon | B.E., 1987 |
| 25ccd-S2 | 5,600 | UNAV | 1 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25cda-S1 | 5,560 | UNAV | 4 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25cda-S2 | 5,560 | UNAV | 10.5 | - | - | Cave Lakes Canyon-Hay Cave Spring | B.E., 1987 |
| 25cdb-S1 | 5,600 | UNAV | 1.5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25cdc-S1 | 5,600 | UNAV | 5 | 291 | 19.5 | Cave Lakes Canyon | B.E., 1987 |
| 25cdc-S2 | 5,560 | UNAV | 12.3 | 279 | 19.0 | Cave Lakes Canyon | B.E., 1987 |
| 25cdc-S3 | 5,560 | UNAV | 12.3 | 279 | 19.0 | Cave Lakes Canyon | B.E., 1987 |
| 25cdd-S1 | 5,560 | UNAV | 12.3 | 279 | 19.0 | Cave Lakes Canyon | B.E., 1987 |
| 25dac-S1 | 5,480 | UNAV | 9.5 | 232 | 15.0 | Cave Lakes Canyon | B.E., 1987 |
| 25dca-S1 | 5,440 | UNAV | 5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25dca-S2 | 5,480 | UNAV | 1.4 | 269 | B.0 | Cave Lakes Canyon | B.E., 1987 |
| 25dca-S3 | 5,440 | UNAV | 1.5 | 250 | 14.0 | Cave Lakes Canyon | B.E., 1987 |
| 25dcb-S1 | 5,520 | UNAV | 4 | - | - | Cave Lakes Canyon-Big Spring | B.E., 1987 |
| 25dda-S1 | 5,480 | UNAV | 1 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 25dda-S2 | 5,480 | UNAV | 1 | - | - | Cave Lakes Canyon-Little Spring | B.E., 1987 |
| 25ddb-S1 | 5,480 | UNAV | 1 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26dcd-S1 | 5,680 | UNAV | 3 | 300 | 17.0 | Cave Lakes Canyon | B.E., 1987 |
| 26dda-S1 | 5,630 | UNAV | 2.3 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26ddb-S1 | 5,650 | UNAV | 1.5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26ddb-S2 | 5,650 | UNAV | 1.5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26ddb-S3 | 5,640 | UNAV | 1.5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26ddd-S1 | 5,610 | UNAV | 5 | - | - | Cave Lakes Canyon | B.E., 1987 |
| 26ddd-S2 | 5,630 | UNAV | 1 | - | - | Cave Lakes Canyon | B.E., 1987 |
| (C-42-8)36ddc-S1 | 6,170 | UNAV | .25 | - | - | Yellow Jacket no.2 | Goode, 1966 |
| R(C-43-4) 5ccc-S1 | 5,340 | LMBP | - | - | - | Johnson Lakes Canyon | Map-Johnson |
| 5ddc-S1 | 5,370 | LMBP | - | - | - | Flood Canyon | Goode, 1966 |
| (C-43-5) 1b -S | 5,320 | LMBP | - | - | - | Rock Canyon | Goode, 1966 |
| 1bac-S1 | 5,310 | LMBP | 25 | 311 | 14.0 | Johnson Canyon | B.E., 1987 |
| 1bdc-S1 | 5,300 | LMBP | 17.5 | 610 | 13.0 | Johnson Canyon-Reservoir Spring | B.E., 1987 |
| 1c -S | 5,310 | LMBP | 100 | - | - | Johnson Canyon | Goode, 1966 |
| 1ccd-S1 | 5,320 | LMBP | - | - | - | Mackelprany South Pond | Cordova, 1981 |
| 2b -S | 5,350 | LMBP | 25-50 | - | - | Needle Rock Canyon Spring | Goode, 1966 |
| 2bac-S1 | 5,320 | LMBP | 25 | - | 15.0 | LDS Church-Johnson Canyon | B.E., 1987 |
| 2bbd-S1 | 5,360 | LMBP | - | 1,080 | 20.0 | LDS Church-Johnson Canyon | Cordova, 1981 |
| 2db -S1 | 5,300 | LMBP | 50 | - | - | Johnson Canyon | Goode, 1966 |
| 2dbc-S1 | 5,360 | LMBP | 1.2 | - | - | Needle Rock Canyon Spring | B.E., 1987 |
| 2dbd-S1 | 5,300 | LMBP | 25 | - | - | Johnson Canyon-Frank Spring | B.E., 1987 |
| 2ddc-S1 | 5,298 | LMBP | 25 | 610 | 8.0 | Johnson Canyon-Anna Spring | B.E., 1987 |
| 2ddd-S1 | 5,370 | LMBP | - | 850 | 16.0 | LDS Church-Johnson Canyon | Goode, 1966; Cordova, 1981 |
| 5baa-S1 | 5,840 | UNAV | 6.3 | 250 | 16.0 | Dairy Canyon-Ram Spring | B.E., 1987 |
| 5bdd-S1 | 5,890 | UNAV | 6.3 | 221 | 11.0 | Dairy Canyon-Sheep Spring (south) | B.E., 1987 |
| 5bdd-S2 | 5,840 | UNAV | .3 | 435 | 12.0 | Dairy Canyon-Sheep Spring (north) | B.E., 1987 |
| 6bbd-S1 | 5,780 | UNAV | 10.1 | 350 | 12.0 | Hog Canyon Spring | B.E., 1987 |
| 7abd-S1 | 5,940 | UNAV | 1.5 | 349 | 11.0 | Hog Canyon | B.E., 1987 |
| 7acb-S1 | 5,960 | UNAV | 3 | 310 | 9.0 | Hog Canyon | B.E., 1987 |
| 7acd-S1 | 5,980 | UNAV | 1.5 | 338 | 14.0 | Hog Canyon | B.E., 1987 |
| 7adc-S1 | 5,960 | UNAV | 2.1 | 385 | 9.0 | Hog Canyon-Tom's Spring | B.E., 1987 |
| 7dbd-S1 | 5,960 | UNAV | 1.6 | 330 | 5.0 | Hog Canyon | B.E., 1987 |
| 7dca-S1 | 6,000 | UNAV | 2.7 | 328 | 6.0 | Hog Canyon | B.E., 1987 |
| 7dcc-S1 | 6,020 | UNAV | 1.6 | 440 | 5.0 | Hog Canyon | B.E., 1987 |
| 9dcd-S1 | 5,650 | LMBP | - | - | - | Willis Spring | Map-Johnson |
| 11aa -S | 5,300 | LMBP | 15-25 | - | 15.0 | Johnson Canyon | Goode, 1966 |
| 11aac-S1 | 5,300 | LMBP | 30 | 680 | 13.0 | Johnson Canyon-Sam Bring Spring | B.E., 1987 |
| 11add-S1 | 5,320 | LMBP | - | 530 | 22.5 | LDS Church-Johnson Canyon | Cordova, 1981 |
| | 5,320 | LMBP | 3.5 | 438 | 18.0 | LDS Church-Johnson Canyon | B.E., 1987 |

Table 6.--Springs discharging from the Navajo Sandstone in the study area--Continued

| Spring location number | Altitude of land surface | Hydro-logic unit | Dis-charge | Speci-fic conduc-tance (µS/cm) | Tem-pera-ture | General location or name of spring | Information source |
|---|---|---|---|---|---|---|---|
| (C-43-5)12bda-S1 | 5,280 | LMBP | 1.3 | - | - | Johnson Canyon-J. Mackelprany | Cordova, 1981 |
| 12cba-S1 | 5,320 | LMBP | 5 | - | 25.0 | Johnson House Spring | Goode, 1966 |
| | 5,300 | LMBP | 3.5 | 421 | 19.0 | Johnson House Spring | B.E., 1987 |
| 12cca-S1 | 5,320 | LMBP | - | 490 | 19.5 | LDS Church-Johnson Canyon | Cordova, 1981 |
| 20bcb-S1 | 5,680 | LMBP | 12.5 | 288 | 14.5 | Maringer Canyon | B.E., 1987 |
| 20cca-S1 | 5,720 | LMBP | 8.5 | 300 | 11.0 | Maringer Canyon | B.E., 1987 |
| 20cdd-S1 | 5,760 | LMBP | 2.4 | 298 | 10.0 | Maringer Canyon | B.E., 1987 |
| 29abb-S1 | 5,800 | LMBP | 5.4 | 349 | 6.0 | Maringer Canyon | B.E., 1987 |
| (C-43-6) 2ccb-S1 | 5,300 | LMBP | 8.3 | 353 | 11.0 | Hog Canyon | B.E., 1987 |
| 6dbc-S1 | 5,200 | LMBP | 40 | 338 | 13.0 | Tiny Canyon | B.E., 1987 |
| 7dba-S1 | 5,680 | UNAV | 2.6 | 291 | 13.0 | Tiny Canyon | B.E., 1987 |
| 10add-S1 | 5,280 | LMBP | 23.1 | - | - | Hog Canyon | B.E., 1987 |
| 10daa-S1 | 5,400 | LMBP | 23 | 188 | 14.0 | Hog Canyon | B.E., 1987 |
| 10dbd-S1 | 5,400 | LMBP | 9 | 295 | 13.0 | Hog Canyon | B.E., 1987 |
| 10dcc-S1 | 5,400 | LMBP | 6.8 | 341 | 12.0 | Hog Canyon | B.E., 1987 |
| 15cac-S1 | 5,590 | LMBP | 1.5 | - | - | Dry Spring-Dry Canyon | B.E., 1987 |
| (C-43-7) 1aac-S1 | 5,620 | UNAV | 4.4 | 283 | 17.0 | Tiny Canyon | B.E., 1987 |
| 1abd-S1 | 5,620 | UNAV | 19.8 | 240 | 16.0 | Tiny Canyon | B.E., 1987 |
| 3cbc-S1 | 5,820 | UNAV | 18 | 261 | 19.0 | Cottonwood Canyon | B.E., 1987 |
| 3ccb-S1 | 5,860 | UNAV | 4.6 | 320 | 20.5 | D. Riggs no.1-Cottonwood Canyon | Goode, 1966; Cordova, 1981 |
| 3ccb-S2 | 5,860 | UNAV | 2.0 | 270 | 16.0 | D. Riggs no.2-Cottonwood Canyon | Cordova, 1981 |
| 3ccb-S3 | 5,860 | UNAV | 1.4 | - | - | D. Riggs no.3-Cottonwood Canyon | Cordova, 1981 |
| 3ccc-S1 | 5,840 | UNAV | 5 | - | 12.8 | D. Riggs no.4-Cottonwood Canyon | Goode, 1966; Cordova, 1981 |
| | 5,800 | UNAV | 12.5 | 215 | 11.0 | Cottonwood Canyon-House Spring | B.E., 1987 |
| 3ccd-S1 | 5,820 | UNAV | 25 | - | - | Cottonwood Canyon | Goode, 1966 |
| | 5,800 | UNAV | 60 | - | - | Cottonwood Canyon | B.E., 1987 |
| 9dbd-S1 | 5,880 | UNAV | 15 | - | 12.2 | Farm Canyon | Goode, 1966 |
| | 5,880 | UNAV | 25 | 122 | 17.0 | Farm Canyon no.1 | B.E., 1987 |
| 9dca-S1 | 5,800 | UNAV | 3 | - | 12.8 | Farm Canyon | Goode, 1966 |
| | 5,900 | UNAV | 3.5 | 280 | 16.0 | Farm Canyon no.2 | B.E., 1987 |
| 10acc-S1 | 5,800 | UNAV | 4.1 | 373 | 13.0 | Upper Cottonwood Creek | B.E., 1987 |
| 10bbb-S1 | 5,820 | UNAV | 4.5 | - | - | Cottonwood Creek | B.E., 1987 |
| 10bbb-S2 | 5,800 | UNAV | 33 | 252 | 13.0 | Cottonwood Canyon | B.E., 1987 |
| 10bbb-S3 | 5,800 | UNAV | 10 | 212 | 12.0 | Cottonwood Canyon | B.E., 1987 |
| 10bbd-S1 | 5,760 | UNAV | 3-5 | - | 12.8 | Upper Cottonwood | Goode, 1966 |
| | 5,800 | UNAV | 10 | - | - | Upper Cottonwood | B.E., 1987 |
| 10dbd-S1 | 5,840 | UNAV | 2.4 | 310 | 13.0 | Cottonwood Creek-Cliff House Spring | B.E., 1987 |
| 12aba-S1 | 5,760 | UNAV | 8.5 | 282 | 12.0 | Tiny Canyon | B.E., 1987 |
| 14dcb-S1 | 5,500 | LMBP | 8-10 | - | - | Scotty Corral-Cottonwood Canyon | Goode, 1966 |
| | 5,560 | LMBP | 16 | 366 | 19.0 | Scotty Corral-Cottonwood Canyon | B.E., 1987 |
| 15acd-S1 | 5,490 | LMBP | 10-15 | - | 16.7 | Cottonwood Canyon | Goode, 1966 |
| | 5,480 | LMBP | 8.9 | 421 | 19.0 | Cottonwood Canyon | B.E., 1987 |
| 16acb-S1 | 5,990 | UNAV | .5 | - | - | Indian Canyon | B.E., 1987 |
| 16dbd-S1 | 5,990 | UNAV | 15 | - | - | Indian Canyon-Indian Cave Spring | B.E., 1987 |
| 16dda-S1 | 5,530 | LMBP | 8 | - | - | Water Canyon | B.E., 1987 |
| 16ddd-S1 | 5,520 | LMBP | 150 | - | 14.4 | Water Canyon no.2 | Goode, 1966 |
| ddb | 5,600 | LMBP | 9 | 319 | 15.0 | Water Canyon no.2 | B.E., 1987 |
| 17aca-S1 | 6,000 | UNAV | 20.2 | 102 | 12.0 | Indian Canyon Dripping Cave Spring | B.E., 1987 |
| 17acb-S1 | 5,900 | UNAV | - | - | - | Indian Canyon | Cordova, 1981 |
| 17acb-S2 | 5,900 | UNAV | - | - | - | Lower Ledge-Indian Canyon | Cordova, 1981 |
| 17ada-S1 | 6,000 | UNAV | 23 | 147 | 12.0 | Indian Canyon Little Catchment Spring | B.E., 1987 |
| 17ada-S2 | 5,980 | UNAV | 79.5 | 112 | 12.0 | Indian Canyon | B.E., 1987 |
| 17bcc-S1 | 6,250 | DUNE | - | - | - | Sand Dune Spring-Indian Canyon | Cordova, 1981 |
| (18ada) | 6,210 | DUNE | 1.6 | - | - | Indian Canyon-Sand Spring | B.E., 1987 |
| 17bda-S1 | 5,960 | UNAV | 16.6 | 165 | 12.0 | Indian Canyon | B.E., 1987 |
| 17bdb-S1 | 6,000 | UNAV | 4.8 | 159 | 12.0 | Indian Canyon | B.E., 1987 |
| 17dca-S1 | 5,960 | UNAV | 28.6 | 218 | 13.0 | Indian Canyon | B.E., 1987 |

Table 6.—Springs discharging from the Navajo Sandstone in the study area—Continued

| Spring location number | Altitude of land surface | Hydro-logic unit | Dis-charge | Speci-fic conduc-tance (μS/cm) | Tem-pera-ture | General location or name of spring | Information source |
|---|---|---|---|---|---|---|---|
| (C-43-7)20aca-S1 | 6,000 | UNAV | - | - | - | South Fork Indian Canyon | Cordova, 1981 |
| | 6,000 | UNAV | 40 | 249 | 13.0 | South Fork Indian Canyon | B.E., 1987 |
| 21aab-S1 | 5,540 | LMBP | 10-15 | - | 16.6 | Water Canyon no.1 | Goode, 1966 |
| | 5,560 | LMBP | 15.8 | 319 | - | Water Canyon no.1 | B.E., 1987 |
| 24acb-S1 | 5,920 | UNAV | 4.3 | 400 | 15.0 | Tiny Canyon | B.E., 1987 |
| 25dad-S1 | 5,680 | UNAV | 1 | - | - | Water Canyon | B.E., 1987 |
| 28bcd-S1 | 6,210 | UNAV | 5 | 263 | 7.0 | Hell Dive Canyon | B.E., 1987 |
| 28caa-S1 | 6,200 | UNAV | 4.4 | 285 | 8.0 | Hell Dive Canyon | B.E., 1987 |
| 30bcd-S1 | 6,590 | UNAV | .1 | - | - | Water Canyon | B.E., 1987 |
| 30dda-S1 | 6,200 | UNAV | 35 | - | - | Water Canyon | B.E., 1987 |
| (C-43-8) 1aca-S1 | 6,120 | UNAV | .26 | 260 | 64.0 | Yellow Jacket no.1 | Goode, 1966 |
| 9dbb-S1 | 6,350 | UNAV | 3 | - | - | Harris Spring 67 | Goode, 1966 |
| 9dbc-S1 | 6,350 | UNAV | - | - | - | Harris Spring 73 | Goode, 1966 |
| 17add-S1 | 6,460 | UNAV | - | - | - | Block Mesa | Map-Elephant Butte |
| 17cba-S1 | 6,490 | UNAV | - | - | - | Block Mesa | Map-Elephant Butte |
| 17dca-S1 | 6,480 | UNAV | - | - | - | Esplin Spring-Rosy Canyon | Map-Elephant Butte |
| 36dbb-S1 | 6,760 | UNAV | .5 | - | - | Water Canyon | B.E., 1987 |
| 36dcc-S1 | 6,740 | UNAV | .5 | - | - | Water Canyon | B.E., 1987 |
| (C-44-8) 2dbc-S1 | 6,040 | LMBP | 12 | - | 13.0 | Sand Canyon-Chris' Spring | B.E., 1987 |

## Outflow across Hydrologic Boundaries

Discharge from the study area by lateral subsurface outflow into the Virgin River drainage basin, as postulated by Bingham Engineering (1987, p. VI-8), cannot be confirmed without additional water-level data in the Kanab Creek and Virgin River drainage basins to better define the potentiometric surfaces in the upper Navajo and Lamb Point aquifers. The Sevier fault, on the west side of the study area, closely parallels the surface-water divide between Kanab Creek and the East Fork of the Virgin River. Spring altitudes in the Coral Pink Dunes State Park area generally are highest along this surface-water divide and decrease to the east and west. If these springs are not representing perched aquifers, then they indicate a ground-water divide. Further north along the Sevier fault, spring altitudes or water-level data needed to determine the direction and rate of ground-water flow across the fault are not available at this time. Water levels in the wells at Bald Knoll, about 9 mi east of the fault, are about 5,400 ft above sea level. The water level in the Orderville well, (C-41-7)3cbc-1, completed in the Navajo Sandstone just west of the fault, stands at about 5,280 ft above sea level which indicates a difference in hydraulic head of about 120 ft and a potential for movement west across the fault.

To determine movement, or even hydraulic connection, between the two sites numerous additional water-level control points are needed to define direction of flow in the upthrown east block of the Sevier fault. The fault simply may separate the Navajo aquifer into two unrelated systems because of its large vertical displacement. To establish that a hydraulic connection exists between the upthrown east block and the downthrown west block, wells located close to the fault on its east side need to be pumped and water-level changes in wells located on the west side of the fault need to be monitored. In addition, several evenly spaced water-level monitoring wells are needed between Bald Knoll and the Sevier fault to determine the direction and rate of ground-water movement in the east block north of the White Cliffs.

## Discharge by Wells

Discharge of water from wells in the Navajo Sandstone within the study area has changed only slightly over the past nine years (1977-85). Cordova (1981, p. 35) estimated that annual ground-water withdrawals during 1976 and 1977 from wells in the upper Navajo and Lamb Point aquifers in Kanab and Johnson Canyons were about 1,000 acre-ft/yr (620 gal/min) for community supplies and another 400 acre-ft/yr (250 gal/min) for irrigation. During the same period other pumpage from the Navajo Sandstone probably was about 180 acre-ft/yr (110 gal/min), for a total of about 1,600 acre-ft/yr (980 gal/min). Johnson and others (1985, p. 62-63; 1988, p. 58-59) reported that the City of Kanab pumped about 780 acre-ft in 1982 (490 gal/min), 770 acre-ft in 1983 (480 gal/min), 850 acre-ft in 1984 (530 gal/min), and 880 acre-ft in 1985 (550 gal/min). Ground-water withdrawal for irrigation remained about the same or decreased slightly from 1977 to 1985 while withdrawal for public and domestic supplies has increased slightly.

## Summary of Water Moving into and out of the Principal Aquifers

Values for the components of the ground-water budget for the principal aquifers of the study area are based on limited data. The quantity of spring discharge likely is the most reliable value because of the comprehensive inventory conducted in 1987 by the staff of Bingham Engineering. But this discharge likely is greater than average because precipitation was greater than average during the period just prior to this inventory. Data on public-supply withdrawals from the Navajo aquifers have been collected by the Utah Division of Water Rights and should be relatively accurate. Irrigation pumpage has not been determined accurately, but could be reasonably estimated if an irrigation-withdrawal inventory was conducted in the Johnson Canyon area. An accurate estimate of components such as subsurface flow into or out of the study area cannot be made until more water-level data are available for the northern part of the study area and for both sides of the Sevier and Paunsaugunt faults. Estimates of other components of the budget, such as recharge from precipitation or seepage from streams, vary greatly, and have resulted in a large margin of error. A summary of the estimates of the ground-water budget components follow (table 7): The range of some estimates and the absence of other estimates indicate the large degree of uncertainty in the ground-water budget, which points out the need for additional data collection.

# NEED FOR FUTURE STUDY

Many factors related to the rates of water moving into or out of the Navajo Sandstone, direction of ground-water movement, the nature and location of hydrologic boundaries, aquifer anisotropy, and variability in hydrologic properties owing to faulting, have not been investigated, and are unknown or unavailable to use in determining the effects of proposed pumping.

At least two alternatives are feasible for improving knowledge of the geohydrology of the Navajo Sandstone so that the effects of proposed pumping from these aquifers can be evaluated. The first alternative would be: (1) Collect additional data to more accurately describe the ground-water flow system, and (2) compute analytically the effects of pumping, by use of refined estimates of hydrologic properties, flow rates and directions, and hydrologic-boundary conditions. The data-collection efforts that would be needed, as identified by Bingham Engineering, are summarized in the following list:

1. Conduct seepage runs on Kanab Creek and Johnson Wash at several times during the year to more accurately determine seepage from and to streams in these drainages. Runoff characteristics could be assessed more accurately if continuous streamflow-gaging stations were installed at two sites on Kanab Creek and two sites on Johnson Wash.

2. Drill wells east, west, and north of Bald Knoll into the Navajo Sandstone to determine the direction and rate of ground-water movement north of the White Cliffs. Where sufficient wells exist which can provide additional water-level data, no new drilling is necessary.

Table 7.—Components of the ground-water budget

| Water moving into the Navajo Sandstone | | Water moving out of the Navajo Sandstone | |
|---|---|---|---|
| Component | Quantity | Component | Quantity |
| Recharge by precipitation on the outcrop | 1,500 to 40,000 acre-ft/yr | Discharge by springs and seeps | 5,100 acre-ft/yr |
| Recharge by seepage from streams | 25,700 acre-ft/yr | Discharge by evapotranspiration | 1,500 acre-ft/yr |
| Inflow by upward vertical leakage through the Kayenta Formation | No data | Outflow by vertical leakage to the Kayenta Formation | No data |
| Inflow by downward vertical leakage through the Carmel Formation | No data | Discharge by seepage to streams | 4,700 to 9,000 acre-ft/yr |
| Subsurface inflow across hydrologic boundaries | Insufficient data | Subsurface outflow across hydrologic boundaries | Insufficient data |
| Recharge from excess applied irrigation water | Probably small but has not been studied | Discharge by wells | More than 880 acre-ft/yr (1985) |

3. Drill pairs of wells straddling the Sevier and Paunsaugunt faults in the area north of the White Cliffs. Pump one well of each pair while observing water-level changes in the other to determine the degree of hydraulic connection across these faults.

4. Establish a water-level monitoring network in the Paria River and Virgin River drainages to determine the direction and rate of ground-water movement outside of the Kanab Creek drainage. The water-level data also could be used to determine the quantity of flow moving into or out of the study area.

5. Establish two recharge-monitoring sites in the Navajo Sandstone outcrop area, one in a pinyon-juniper forest, and the other in a barren dune area. Maintain precipitation-recording equipment at each site. These sites would be used to measure water use by pinyon-juniper and deep percolation; methods employed would be those developed by Gifford and Shaw (1973). At each site soil moisture would be monitored over a 2-year period to determine variability in recharge with seasonal fluctuations in precipitation.

6. Install inflatable packers to isolate the upper Navajo and Lamb Point aquifers in well (C-40-5)21abb-1, and monitor water levels to determine the magnitude and variation of the head differential between the two aquifers at this location. This approach is valid only if the annulus between the casing and the borehole has been cemented or otherwise sealed.

7. Conduct several aquifer tests in areas distant from the effects of faulting to determine values of horizontal hydraulic conductivity in the upper Navajo aquifer, and values of vertical hydraulic conductivity in the Tenney Canyon confining unit. Both of these hydraulic-conductivity values may be more applicable to the overall study area than values determined in faulted areas.

8. Conduct compressibility tests on cores from the Tenney Canyon Tongue of the Kayenta Formation to obtain specific storage values that can be used to more accurately determine vertical hydraulic conductivity.

9. Collect water samples from wells completed in the Navajo Sandstone at Orderville, Mt. Carmel Junction, Coral Pink Dunes State Park, Kanab Canyon, Bald Knoll, Johnson Canyon, and in the Paria River basin for analysis of stable isotopes to determine relative age of the ground water. These relative ages will be useful in determining the direction and rate of ground-water circulation in the principal aquifers.

10. Collect water samples from well (C-42-5)21dda-1 and, where possible, from other wells completed in the upper Navajo aquifer, the Tenney Canyon confining unit, and the Lamb Point aquifer for isotope and other chemical analyses to identify direction and approximate rate of vertical movement of water through the Tenney Canyon confining unit.

The second alternative is more qualitative in nature and less objective. However, it may be useful in examining over a relatively short time period various alternative concepts of the hydrologic system. This alternative would involve developing several three-dimensional ground-water flow models, based on all reasonable representations of the system, to characterize the system and to estimate the likely range in effects of pumping. The range of model simulations would extend from the representation that results in the most pronounced effect, to the representation that results in the smallest effect, and would roughly correspond to the range in uncertainty of the system components. This alternative would involve developing and calibrating several steady-state models, each representing a possible description of the Navajo aquifer hydrologic system. Collection of additional data could reduce the number of possible representations, and thus the number of models required. Each of these models would incorporate the measured values of hydraulic head and hydrologic properties at the locations where data are available. However, each of these models would represent different combinations of the other unknown parameters, which only can be estimated. Alternative simulations need to include model runs that:

1. Vary areal recharge from 1,500 to 40,000 acre-ft/yr,
2. represent the east and west boundaries as ground-water divides and the north boundary as impermeable,
3. vary hydraulic conductivity from 0.3 to 7.5 ft/d, using the smaller values to represent areas of unfractured Navajo Sandstone and larger values to represent fault zones or other suspected highly fractured areas,
4. vary vertical hydraulic conductivity of the Tenney Canyon confining unit from 0.006 to 0.4 ft/d,
5. vary recharge by seepage from streams,
6. vary discharge by seepage to streams,
7. vary the quantity of downward vertical leakage through the Carmel confining unit into the upper Navajo aquifer north of the White Cliffs,
8. and include upward leakage from underlying aquifers into the Lamb Point aquifer in a model run.

When simulating the effects of various pumping arrays:

1. Vary specific yield from 0.05 to 0.1,
2. vary discharge rate of the pumping wells to determine the maximum withdrawal rate possible without affecting existing water users,
3. and vary location and spacing of the pumping wells.

## CONCLUSIONS

Aquifers in the Navajo Sandstone are the principal source of water for the city of Kanab, irrigation, stock, and for rural homes in the study area. In 1985 withdrawal of water from these two aquifers for the City of Kanab public supply was about 880 acre-ft. Total withdrawal in 1985 is unknown, but has probably increased slightly since 1977. Geologic and hydrologic information from wells that penetrate the Navajo Sandstone in western Kane, southwestern Garfield, and southeastern Iron Counties, Utah, indicate that in the part of the study area south of the White Cliffs where the Navajo Sandstone crops out, two major aquifers--the upper Navajo aquifer and the Lamb Point aquifer--are present. The two aquifers are separated by the poorly permeable Tenney Canyon confining unit, a tongue of the Kayenta Formation. In the eastern part of the study area the Tenney Canyon confining unit is absent and only one aquifer is present, the eastward extension of the Lamb Point aquifer. Infiltration of precipitation and streamflow in the outcrop area between Kanab Creek and Johnson Wash, forms a principal recharge area of the upper Navajo aquifer. Ground water moves from the recharge area toward the canyon bottoms of Kanab Creek and Johnson Wash drainages at lower altitude. The Lamb Point aquifer may be recharged in the same areas as the upper Navajo aquifer. Its potentiometric surface is at a lower altitude than that of the upper Navajo aquifer. This indicates that water leaks downward from the upper Navajo aquifer to the Lamb Point aquifer.

In the area north of the White Cliffs the direction and rate of ground-water movement cannot be accurately described because of the lack of data--few wells penetrate the saturated part of the Navajo Sandstone in this area. Aquifer-test data and water-quality analyses from this area indicate that ground water likely moves to deeper aquifers at a larger rate in the vicinity of faults.

The eastern, western, and northern hydrologic boundaries of the aquifers within the Navajo Sandstone are not well defined. The upper Navajo and Lamb Point aquifers are deeply buried by younger formations to the north, and no wells tap the aquifers. Major faults with displacements as large as 2,000 ft, oriented in a north-south direction, approximately coincide with the surface-water drainage divides that separate the Kanab Creek drainage from the Virgin River drainage to the west and from the Paria River drainage to the east. The fault block that includes much of the Kanab Creek drainage, is upthrown relative to the fault block that includes much of the eastern part of the Virgin River drainage and downthrown relative to the the fault block that includes much of the Paria River drainage. One interpretation is that the structural control of the faults might result in regional movement of ground water from east to west in the Navajo aquifers. Comparison of the water levels in the upper Navajo aquifer in the Bald Knoll area with water levels in the upper Navajo aquifer in the valley of the East Fork of the Virgin River support this interpretation. However, on the basis of comparison of altitudes of springs in Navajo Sandstone outcrops adjacent to the faults, the area of the faults could also be interpreted to be ground-water divides. Additional water-level data are needed to define the actual hydrologic function of these faults in outcrop areas and, more importantly, in the areas where the upper Navajo and Lamb Point aquifers are buried.

Hydrologic properties of the aquifers in the Navajo Sandstone, determined from aquifer tests, indicate that the aquifers can yield large quantities of water to wells where several hundred feet of the Navajo are saturated. A fully penetrating well drilled near Bald Knoll yielded 1,300 gal/min for 30 days with only 90 ft of drawdown. Saturated thickness of the Navajo Sandstone at this site is about 1,700 ft. However, because this well is located near the Bald Knoll fault, the hydraulic conductivity of the upper Navajo and Lamb Point aquifers in this area likely is larger than in undisturbed parts of the aquifers. The specific capacity of wells distant from faults is approximately one order of magnitude smaller than the specific capacity of wells drilled near faults. More aquifer tests are needed to identify the effect that faults have on hydraulic conductivity and well yield.

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