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GROUND-WATER CONDITIONS IN THE GRAND COUNTY AREA, UTAH, WITH EMPHASIS ON THE MILL CREEK-SPANISH VALLEY AREA

by

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Prepared by the
United States Geological Survey
in cooperation with the
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Division of Water Rights

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CONTENTS

ILLUSTRATIONS
[Plates are in pocket]

TABLES

CONVERSION FACTORS AND RELATED INFORMATION

For use of 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 unit	By	To obtain metric unit
acre	0.4047	square hectometer
	0.004047	square kilometer
acre-foot (acre-ft)	0.001233	cubic hectometer
	1233.	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon	3.785	liter
	0.003785	cubic meter
gallon per minute (gal/min)	0.06309	liter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
inch	25.4	millimeter
	2.54	centimeter
mile	1.609	kilometer
square mile	2.590	square kilometer

Chemical concentration and water temperature are given only 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 concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter. Milliequivalents per liter is numerically equal to equivalents per million.

Radioactivity is measured in picocuries per liter (pCi/L), or one-trillionth of a curie per liter. One picocurie is equal to 3.7×10^{-2} disintegrations per second.

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

$$°F = 1.8\ (°C) + 32$$

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 "Sea Level Datum of 1929."

GROUND-WATER CONDITIONS IN THE GRAND COUNTY AREA, UTAH,

WITH EMPHASIS ON THE MILL CREEK-SPANISH VALLEY AREA

By Paul J. Blanchard

ABSTRACT

The Grand County area includes all of Grand County, the Mill Creek and Pack Creek drainages in San Juan County, and the area between the Colorado and Green Rivers in San Juan County. The Grand County area includes about 3,980 square miles, and the Mill Creek-Spanish Valley area includes about 44 square miles. The three principal consolidated-rock aquifers in the Grand County area are the Entrada, Navajo, and Wingate aquifers in the Entrada Sandstone, the Navajo Sandstone, and the Wingate Sandstone, and the principal consolidated-rock aquifer in the Mill Creek-Spanish Valley area is the Glen Canyon aquifer in the Glen Canyon Group, comprised of the Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone.

Recharge to the Entrada, Navajo, and Glen Canyon aquifers typically occurs where the formations containing the aquifers crop out or are overlain by unconsolidated sand deposits. Recharge is enhanced where the sand deposits are saturated at a depth of more than about 6 feet below the land surface, and the effects of evaporation begin to decrease rapidly with depth. Recharge to the Wingate aquifer typically occurs by downward movement of water from the Navajo aquifer through the Kayenta Formation, and primarily occurs where the Navajo Sandstone, Kayenta Formation, and the Wingate Sandstone are fractured.

The principal area of discharge from the Glen Canyon aquifer in the Mill Creek-Spanish Valley area occurs in and near the City of Moab well field, near the northeast canyon wall of Spanish Valley. Discharge from one well in the well field is reportedly as large as 2,000 gallons per minute, and discharge from one spring near the well field is reportedly as large as 390 gallons per minute.

Discharge from springs issuing from the Entrada, Navajo, and Wingate aquifers typically is less than about 10 gallons per minute, and discharge from wells completed in these aquifers ranges from 5 to 30 gallons per minute. In the Mill Creek-Spanish Valley area, discharge from springs issuing from the Glen Canyon aquifer ranges from 15 to 390 gallons per minute, and discharge from wells completed in the Glen Canyon aquifer ranges from less than 10 to more than 1,000 gallons per minute. The larger discharge rates occur where the formations in the Glen Canyon Group are fractured and faulted.

Water levels in the Glen Canyon aquifer declined from the early 1960's to about 1979, and rose as much as 39.5 feet from 1979 to 1987. The larger-than-normal amount of precipitation beginning in 1977 probably is a substantial factor in the rising water levels.

Water-quality characteristics typical of water in the Entrada, Navajo, Wingate, and Glen Canyon aquifers are: (1) Concentrations of dissolved solids are less than about 220 milligrams per liter; (2) the water type is calcium bicarbonate or calcium magnesium bicarbonate; and (3) the water is moderately

hard to hard. In the Mill Creek-Spanish Valley area, concentrations of dissolved solids and sulfate increase west and south of the City of Moab well field because an increasingly larger proportion of the ground water comes from other sources to the southeast, farther up Spanish Valley, and a smaller proportion comes from the Glen Canyon aquifer. Concentrations of dissolved solids in the Navajo aquifer also are higher along the Moab fault.

Other consolidated-rock aquifers investigated were in the Cedar Mountain Formation, the Brushy Basin Shale and Salt Wash Sandstone Members of the Morrison Formation, the undifferentiated Cutler Formation, and the White Rim Sandstone Member of the Cutler Formation. Concentrations of dissolved solids ranged from 270 milligrams per liter in water from the White Rim Sandstone Member in Canyonlands National Park to 3,450 milligrams per liter in water from the undifferentiated Cutler Formation in Castle Valley. Water from the undifferentiated Cutler Formation in Castle Valley also had the largest concentration of selenium, 30 micrograms per liter, which is three times the State of Utah primary drinking-water standard of 10 micrograms per liter.

INTRODUCTION

The temperate climate and appealing scenery in the Grand County area have attracted growing numbers of people, creating increased demands for ground water in the area. Federal, State, and local water managers, water users, and other interested parties need information about the availability and quality of ground water in consolidated-rock aquifers of the Grand County area in order to plan for future development of ground-water resources. In order to provide the interested parties with current (1987) information on ground-water quantity and quality in the consolidated-rock aquifers, a study was conducted by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Rights.

The area investigated includes all of Grand County, the Mill Creek and Pack Creek drainages in San Juan County, and the area between the Colorado and Green Rivers in San Juan County and will be referred to as the Grand County area in this report. The Mill Creek-Spanish Valley area includes parts of the Mill Creek and Pack Creek drainages (fig. 1). The Grand County area includes about 3,980 square miles, including about 300 square miles in San Juan County. Altitudes in the Grand County area range from about 3,900 feet above sea level where the Green River enters the Colorado River to 12,646 feet above sea level at the summit of Mt. Mellenthin in the La Sal Mountains. The Mill Creek-Spanish Valley area includes about 44 square miles.

Purpose and Scope

This report presents results of a reconnaissance of ground-water conditions in the bedrock aquifers of Grand County and small parts of San Juan County, Utah, with emphasis on ground-water conditions in the Entrada Sandstone, the Navajo Sandstone, and the Wingate Sandstone of the Glen Canyon Group. Ground-water conditions in the Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone of the Glen Canyon Group in the Mill Creek-Spanish Valley area near Moab, Utah, were investigated in more detail because this area is where most ground-water development is expected to occur.

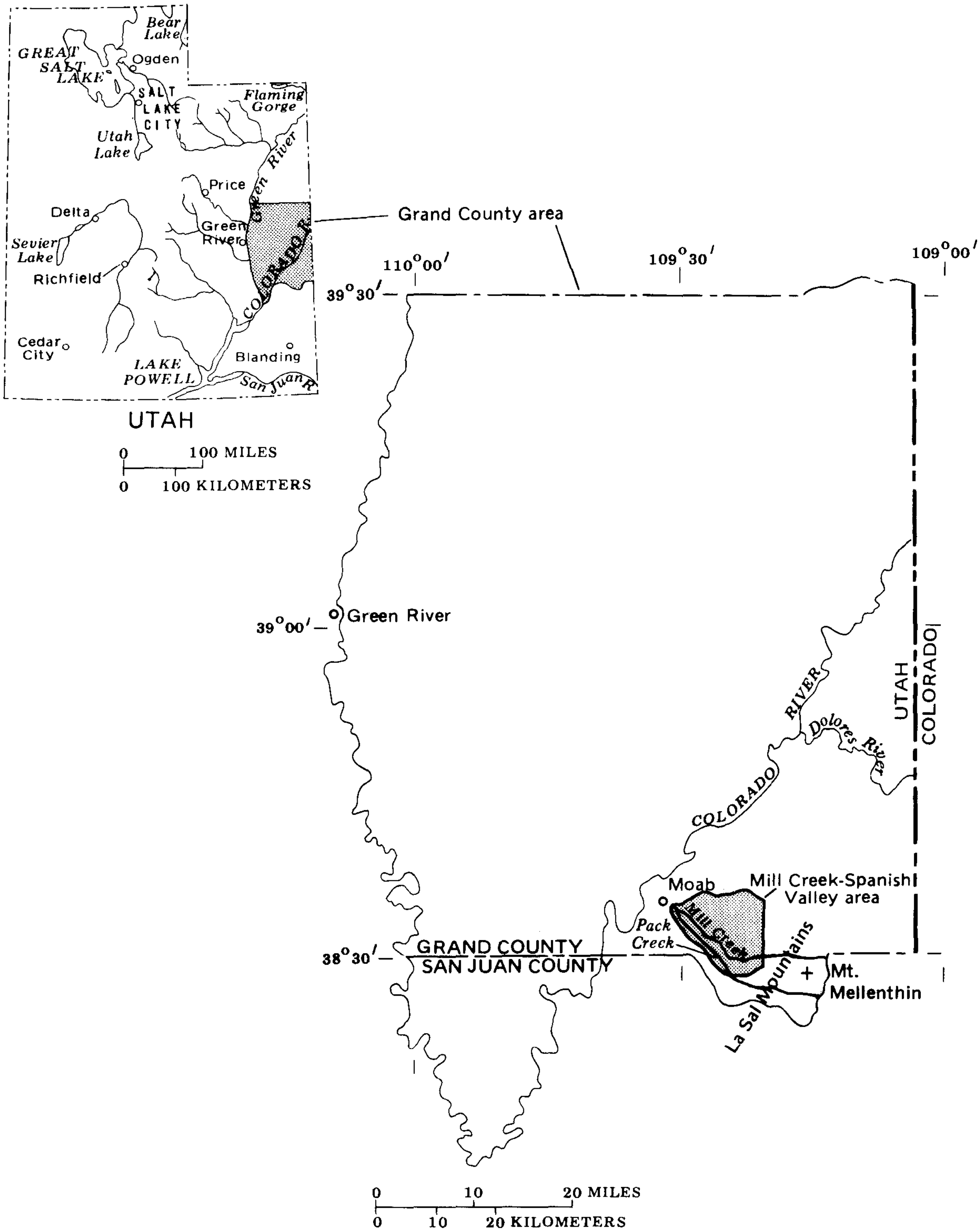


Figure 1.--Location of the Grand County and Mill Creek-Spanish Valley areas.

Field work was conducted from April 1985 through October 1986, and consisted of an inventory of wells and springs in the area, monthly measurements of water levels in wells in the Mill Creek-Spanish Valley area, a streamflow gain-loss study in the Mill Creek and the North Fork Mill Creek drainages, and an 8-day, multiple-well aquifer test in the City of Moab well field. The inventory of wells and springs included water-level measurements at wells, and discharge measurements, on-site water-quality measurements, and water-sample collection at wells and springs. The inventoried sites are shown on plate 1. Chemical analyses of water samples were made by the National Water-Quality Laboratory of the U.S. Geological Survey in Denver, Colorado.

Previous Investigations

Several hydrologic studies have been conducted in the Grand County area. Sumsion (1971) studied the geology and water resources of the Spanish Valley area, and Eychaner (1977) developed a digital model of the same area, using data from Sumsion (1971). Both studies primarily addressed the water resources of unconsolidated Quaternary deposits. Two studies addressed aquifer characteristics at specific wells drilled for the U.S. Department of Energy (Rush and others, 1980; Wollitz and others, 1982). Three studies addressed the regional hydrology of parts of the Paradox Basin (Rush and others, 1982; Weir, Maxfield, and Hart, 1983; Weir, Maxfield, and Zimmerman, 1983). Parts of each of the areas addressed are in the Grand County area.

General Description of the Grand County Area

The Grand County area contains known and potential reserves of oil, gas, coal, and uranium. Uranium has been mined and processed intermittently in the area since the 1950's, and continual exploration for oil, coal, and gas is occurring. Potash is presently solution-mined, and further development of potash reserves is anticipated. Further development of any of these resources would require additional development of water resources.

The Grand County area is a center for recreation. National Parks, a National Recreation Area, U.S. National Forest campgrounds, and U.S. Bureau of Land Management campgrounds and primitive areas are in and near the study area. The City of Moab is a center for accommodations for tourists, and further development of tourism will require additional development of water resources.

The climate of most of the Grand County area is dry according to the classification of Trewartha (1968, p. 248-250), with annual potential evaporation exceeding annual precipitation. A highland climate (Trewartha, 1968, p. 358-369) occurs at higher altitudes in the La Sal Mountains and in the Book Cliffs. At Monticello, about 40 miles south of the Grand County area, the altitude is about 7,000 feet above sea level, and the mean annual temperature is 46.0 °F. The mean annual temperature at Monticello is representative of similar altitudes in the Grand County area. At Moab, the altitude is about 4,000 feet above sea level, and the mean annual temperature is 56.6 °F. The mean annual temperature of the plateaus in the Grand County area is between that at Monticello and that at Moab, depending on altitude. Two formation classes of vegetation in the Grand County area are "semidesert" in the canyons and on the plateaus, and "needleleaf forest" at higher altitudes in the La Sal Mountains and in the Book Cliffs (Strahler, 1970, p. 235-240).

Most of the land in the Grand County area is administered by the Federal government. Arches National Park, Canyonlands National Park, and the Glen Canyon National Recreation Area are administered by the National Park Service, and the Manti-La Sal National Forest is administered by the U.S. Forest Service. The extreme northwestern part of the Grand County area is part of the Uintah and Ouray Indian Reservation. The remainder of the Federally owned land is administered by the U.S. Bureau of Land Management. Most of the land in Spanish Valley is privately owned, and there are small private land holdings throughout the Grand County area within the Federally owned land administered by the U.S. Bureau of Land Management.

Population of the Grand County area presently (1987) is about 8,000 persons and, therefore, the average population density is about two persons per square mile. Most of the population is concentrated in the Moab-Spanish Valley area. About 5,000 people live in Moab and about 2,000 people live in the unincorporated part of Spanish Valley. Several hundred people live in Castle Valley. Only about 300 people live northwest of the Colorado River.

Numbering System for Hydrogeologic-Data Sites

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well, spring, or other site, describes its position on the land net. In the land-survey system, the State is divided into four quadrants by the Salt Lake Base Line and Meridian, and these quadrants are designated by the upper-case letters A, B, C, and D, indicating, respectively, the northeast, northwest, southwest, and southeast quadrants. Numbers designating, respectively, the township and range follow the quadrant letter, and all three are enclosed in parentheses. For half townships or ranges the letter "T" or "R", respectively, precedes the parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section--generally 10 acres[1]. 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 well or spring within the 10-acre tract; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus (D-26-22)22aab-1 designates the first well constructed or visited in the NW$\frac{1}{4}$ NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22, T. 26 S., R. 22 E., and (D-27-19)22bbc-S1 designates the first spring inventoried in the SW$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 22, T. 27 S., R. 19 E. The numbering system without serial numbers is used to show the location of data sites other than wells and springs. The numbering system is illustrated in figure 2.

[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

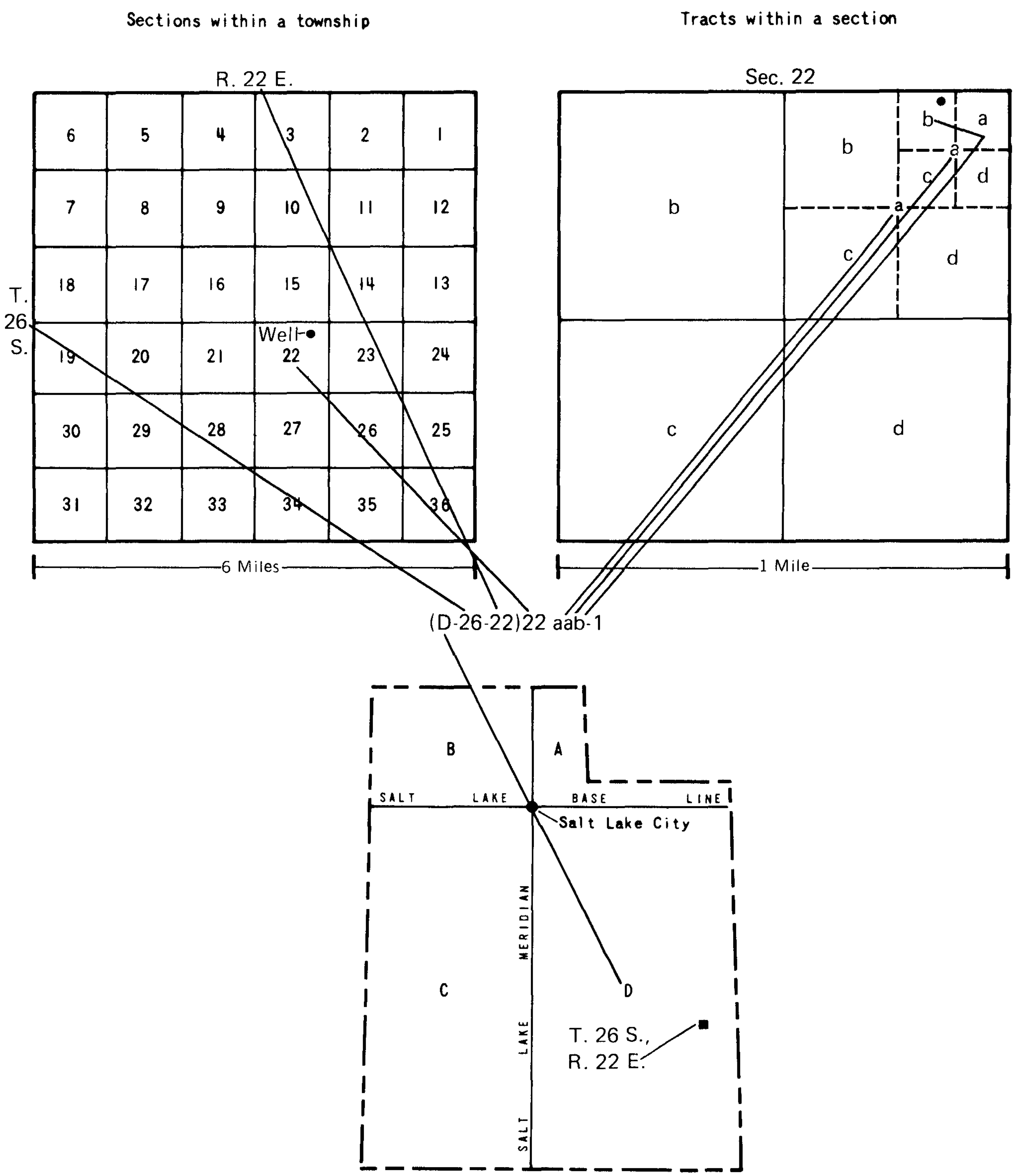


Figure 2.--Numbering system for hydrogeologic-data sites.

Locally, there may be some inconsistency between locations based on geographic features and those based on the land-survey system because of the small scale of some maps used in this report. Where such inconsistency exists, data sites have been plotted with reference to the local geography, resulting in apparent mislocation with reference to the land-survey system.

Terms Describing Aquifer Characteristics and Water Quality

The hydraulic conductivity (K) of a water-bearing material is the volume of water that will move through a unit cross section of the material in unit time under a unit hydraulic gradient (Lohman, 1979, p. 6). The units for K are cubic feet per day per square foot, which reduces to feet per day (ft/d).

Transmissivity (T) is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1979, p. 6). The units for T are cubic feet per day per foot, which reduces to feet squared per day (ft^2/d).

Specific capacity is a measure of the productivity of a well and is calculated by dividing the pumping rate of the well by the drawdown in the well. The units for specific capacity are gallons per minute per foot of drawdown [(gal/min)/ft].

In this report, chemical classification of water is according to the system of Davis and DeWiest (1966, p. 119). In the system, only ions present in quantities greater than 20 percent of the total milliequivalents per liter of cations or anions are used to name the water type. An ion present in quantities greater than 60 percent of the total milliequivalents of cations or anions is used alone to name the cation or anion type. In mixed water types, ions present in quantities greater than 20 percent, but less than 60 percent, of the total milliequivalents of cations or anions present are listed in descending order of concentration. For example, for the sample collected from well (D-25-21)20add-2 on August 19, 1986 (table 9), 38 percent of the total cation milliequivalents was sodium, 36 percent was calcium, and 24 percent was magnesium. Forty-one percent of the total anion milliequivalents was sulfate, 36 percent was bicarbonate, and 23 percent was chloride. This water sample is classified as a sodium calcium magnesium sulfate bicarbonate chloride type.

Classification of water in terms of concentration of dissolved solids is as described by Robinove and others (1958):

Classification	Concentration (milligrams per liter)
Fresh	Less than 1,000
Slightly saline	1,000-3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
Briny	More than 35,000

Classification of water in terms of hardness is as described by Durfor and Becker (1964, p. 27):

Classification	Range of hardness (milligrams per liter)
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Acknowledgments

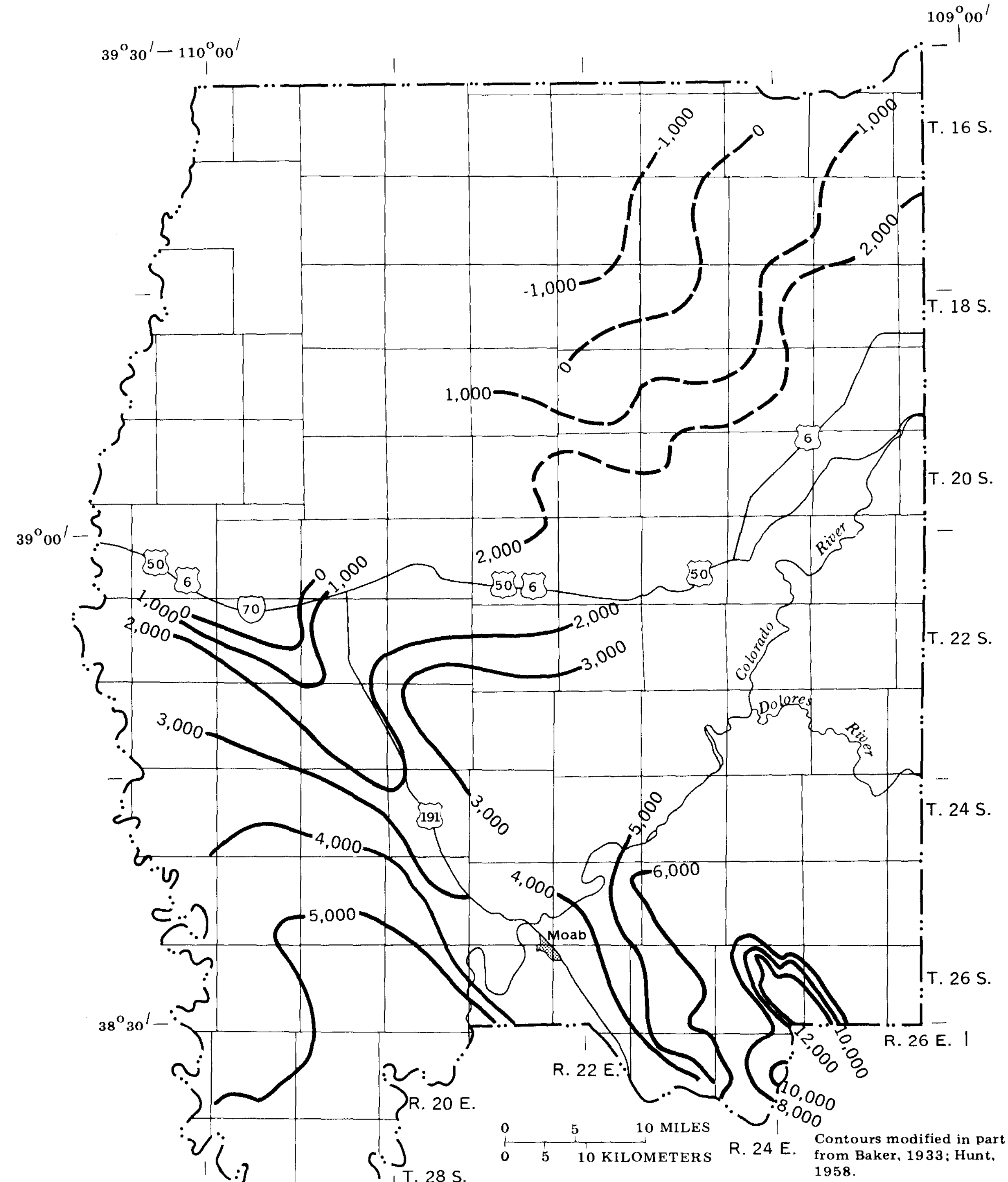
Special thanks are given to people in the following Federal agencies and offices that contributed significantly to this study: The U.S. Bureau of Land Management, Moab District and Grand Resource Area offices, and the U.S. National Park Service at Arches and Canyonlands National Parks. Mark Page of the State of Utah Department of Natural Resources, Division of Water Rights office in Price, Utah, provided valuable information. John Keough and Larry Johnson of the City of Moab and Dale Pierson of the Grand County Water Conservancy District provided information and records of their agencies, knowledge of the area, and technical support during the study.

Appreciation is expressed to well owners who allowed access to their wells for inventory. In addition to allowing access to their wells, Bob Norman provided well records and other information for significant parts of the study area, and Doctor and Mrs. Dail Magee provided weather and climatological data for the Mill Creek-Spanish Valley area.

GEOLOGIC SETTING

The Grand County area is part of the Colorado Plateaus physiographic province (Fenneman, 1931, p. 274-325). Parts of two sections of the province are included in the Grand County area: The Uinta Basin section is north of the Book Cliffs and the Canyon Lands section is south of the Book Cliffs. According to Fenneman, the Colorado Plateaus physiographic province generally consists of nearly flat-lying sedimentary strata that have been deeply incised by streams and interrupted by generally north-south trending monoclines, synclines, anticlines, and elongate structural domes and basins. Extrusive and intrusive igneous features are widely scattered throughout the province.

Strata in the Grand County area generally dip gently to the north and northwest, typically at less than 10 degrees. Consequently, continuously younger strata crop out in a generally northerly direction (pl. 2). Rocks of Permian age crop out in Canyonlands National Park and rocks of Tertiary age crop out north of the Book Cliffs. The general decrease in altitude in a northerly direction of a particular stratigraphic horizon is illustrated in figure 3, which shows the altitudes of the top of the Entrada Sandstone and the base of the Wingate Sandstone for selected parts of the Grand County area.



EXPLANATION

— — 1,000 — — STRUCTURE CONTOUR--Shows approximate altitude of top of Entrada Sandstone. Contour interval 1,000 feet. Datum is sea level

——1,000—— STRUCTURE CONTOUR--Shows approximate altitude of base of Wingate Sandstone. Contour interval 1,000 and 2,000 feet. Datum is sea level

Figure 3.--Approximate altitude of the top of the Entrada Sandstone and the base of the Wingate Sandstone.

The principal structural feature in the Grand County area is a series of northwest-trending salt anticlines, described by Weir, Maxfield, and Hart (1983) as "elongated wrinkles" (pl. 2). A series of synclines alternates with and generally parallels the salt anticlines. Areas where strata dip more than 10 degrees are located near the Salt Valley anticline, the Elephant Butte folds, and Spanish Valley (pl. 2). In the canyon walls which bound Spanish Valley, strata dip as much as 26 degrees near the southern end of the Courthouse syncline and near the Spanish Valley syncline.

Porphyritic intrusive igneous rocks of Tertiary age form the cores of the La Sal Mountains. The intrusions have caused doming of the otherwise gently dipping strata, and the dip of the strata on the flanks of the mountains is in some places as much as 80 degrees (pl. 2).

The age of consolidated sedimentary rocks exposed in the study area ranges from Pennsylvanian to Tertiary (pl. 2). Location of outcrops and brief descriptions of the geologic and hydrologic characteristics of the exposed geologic units are described in table 1.

The oldest exposed consolidated sedimentary-rock unit in the Grand County area is the Paradox Member of the Hermosa Formation of Pennsylvanian age. It is exposed in small areas of Salt Valley, Moab Valley, and in the Onion Creek drainage (pl. 2). The youngest exposed sedimentary-rock unit is the Parachute Creek Member of the Green River Formation of Tertiary age. It is extensively exposed north of the Book Cliffs. Igneous rocks of Precambrian age are exposed near the Colorado River in the eastern part of the Grand County area, and igneous rocks of Tertiary age are exposed in the La Sal Mountains.

The principal formations investigated in this report are, from oldest to youngest, the Wingate Sandstone of Triassic age, the Kayenta Formation of Triassic(?) age, the Navajo Sandstone of Triassic(?) and Jurassic age, and the Entrada Sandstone of Jurassic age. The Wingate Sandstone, the Kayenta Formation, and the Navajo Sandstone form the Glen Canyon Group. Typical outcrops of the Wingate, Kayenta, and Navajo are shown in figure 4, and typical outcrops of the Navajo and the Dewey Bridge, Slick Rock, and Moab Sandstone Members of the Entrada Sandstone are shown in figure 5.

The Wingate Sandstone is a massive, fine-grained, thickly crossbedded, eolian sandstone (fig. 4). It erodes to vertical cliffs, which are commonly coated with a dusky-red desert varnish. Thickness of the Wingate ranges from about 300 to 400 feet.

The Kayenta Formation is an irregularly interbedded fluvial fine- to coarse-grained sandstone, siltstone, and shale (fig. 4). Thin beds of shale-pellet conglomerate and freshwater limestone locally are present. The sandstone facies predominate. In many places there is a prominent siltstone bed near the top of the formation, which locally perches water in the overlying parts of the Kayenta Formation and the Navajo Sandstone. The Kayenta erodes to cliffs and benches, and caps many mesas and narrow benches. Thickness of the Kayenta is about 240 feet in the western part of the Grand County area and decreases to nearly zero in the eastern part of the area.

Table 1.--*Description of geologic units exposed in the Grand County area*

[Geologic characteristics modified from Stokes (1964), Williams (1964), and Cashion (1973)]

Geologic unit	Principal outcrop locations (plate 2)	Geologic characteristics	Hydrologic characteristics
Relatively younger alluvial deposits: primarily along active streams	Southwest and southeast of the Book Cliffs, in Tenmile Canyon, along the Green River upstream from the City of Green River, in Spanish and Castle Valleys near the Colorado River.	Sand, silt, and gravel.	Yields freshwater to wells in Spanish Valley and Castle Valley.
Gravel surfaces	Intermittent throughout southern half of Grand County area.	Mainly terraces and pediments undergoing erosion. May not be associated with active streams.	Recharge medium.
Glaciated ground and moraines, undifferentiated	Small areas on flanks of La Sal Mountains.	Includes bare rock and moraines of all types.	Not known to yield water.
Covering deposits	Intermittent throughout southern half of Grand County area.	Chiefly windblown silt lacking dune form. Includes some patches of soil and alluvium. Underlain by thick valley fill in Spanish Valley and Castle Valley.	Valley fill yields freshwater to wells in Spanish Valley and Castle Valley. In Spanish Valley, dissolved-solids concentrations range from about 700 to 900 milligrams per liter.
Tertiary and Quaternary deposits or surfaces, undifferentiated	Castle Valley.	Conglomerate.	May yield small amounts of water of unknown quality to springs.
Tertiary porphyritic intrusive rocks	Southeastern part of Grand County area.	Diorite porphyry.	Not known to yield water.
Green River Formation Parachute Creek Member	Northern part of Grand County area.	Chiefly marlstone and oil shale, with some sandstone, siltstone, and tuff.	Yields freshwater to springs, from less than 1 to about 20 gallons per minute.
Wasatch Formation	do.	Chiefly continental deposits, ranging from coarse conglomerate to fine claystone.	Known to yield freshwater to one spring, about 30 gallons per minute.
North Horn Formation	Northwestern part of Grand County area.	Fluvial sandstone, variegated shale, and some conglomerate.	Not known to yield water.
Tuscher Formation	Southwestern part of the Book Cliffs.	Conglomeratic, fluvial sandstone.	Do.
Mesaverde Group	Southern and southeastern part of the Book Cliffs.	Mixed sandstone, shale, and coal beds.	Do.

Table 1.--*Description of geologic units exposed in the Grand County area*—Continued

Geologic unit	Principal outcrop locations (plate 2)	Geologic characteristics	Hydrologic characteristics
Price River Formation	Southwestern part of the Book Cliffs.	Interbedded sandstone and mudstone.	Not known to yield water.
Castlegate Sandstone	Band along margin of the Book Cliffs.	Cliff-forming, deltaic sandstone.	Do.
Blackhawk Formation	Band along southern and southwestern margin of the Book Cliffs.	Sandstone, mudstone, shale, and coal.	Known to yield freshwater to one spring, about 18 gallons per minute.
Mancos Shale	South, southwest, and southeast of the Book Cliffs.	Gray to black marine shale with thin sandstone beds at various horizons.	Not known to yield water.
Ferron Sandstone Member	In a band southwest, south, and southeast of the Book Cliffs.	Fine-grained, thin-bedded sandstone and sandy shale near base of Mancos Shale.	Do.
Tununk Shale Member	do.	Gray marine siltstone and claystone.	Do.
Dakota Sandstone	East-west trending band about 10 miles south of the Book Cliffs.	Sandstone and conglomeratic sandstone with interbedded carbonaceous shale.	Do.
Burro Canyon Formation	Southeast part of Grand County area, east of the Colorado River only.	Fine- to coarse-grained sandstone interbedded with siltstone, shale, mudstone, and impure limestone.	Do.
Cedar Mountain Formation	East-west trending band about 10 miles south of the Book Cliffs, west of the Colorado River only.	Nodular shale with fluvial sandstone beds.	Occasionally yields fresh to slightly saline water to seeps.
Morrison Formation	East-west trending band about 10 miles south of the Book Cliffs; eastern part of area just north of the Colorado River; southeastern part of area.		
Brushy Basin Shale Member		Bentonitic mudstone and siltstone with a few lenses of fluvial sandstone, limestone, and conglomerate.	Known to yield slightly saline water, less than 1 gallon per minute, to one flowing well.
Salt Wash Sandstone Member		Interbedded fluvial sandstone and fluvial mudstone, with thin limestone lenses near base.	Yields water of unknown quality to seeps and small springs in outcrop area; yields slightly saline water to one spring on South Mesa.

Table 1.--*Description of geologic units exposed in the Grand County area*--Continued

Geologic unit	Principal outcrop locations (plate 2)	Geologic characteristics	Hydrologic characteristics
Summerville Formation	Small areas in central and east-central part of Grand County area.	Sandstone, sandy shale, siltstone, and mudstone.	Not known to yield water; is a confining unit.
Entrada Sandstone	Southern half of Grand County area.		Entrada aquifer.
Moab Sandstone Member		Medium-grained, massive, crossbedded sandstone.	Recharge occurs, especially where fractured.
Slick Rock Member		Medium-grained, massive, crossbedded, eolian sandstone.	Principal water-yielding sandstone of the Entrada aquifer. Yields freshwater, generally less than 5 gallons per minute, to seeps and springs throughout its outcrop area.
Dewey Bridge Member		Fine-grained sandstone and siltstone.	Confining unit. Substantially less transmissive than overlying Slick Rock Member.
Carmel Formation	South of the City of Green River.	Marine gypsum, limestone, shale, and calcareous sandstone.	Not known to yield water.
Navajo Sandstone	Southern half of Grand County area.	Fine-grained, crossbedded eolian sandstone with prominent vertical joints in most outcrops. Limestone horizons near top of formation.	Navajo aquifer. Recharge occurs where outcrops are fractured or jointed, or where formation is mantled by unconsolidated deposits. Yields freshwater to seeps, springs, and wells. Spring discharge ranges from less than 5 to more than 300 gallons per minute. Well discharge is as much as 2,000 gallons per minute.
Kayenta Formation	do.	Interbedded shale, siltstone, and fine- to coarse-grained sandstone.	Less permeable than the overlying Navajo Sandstone and the underlying Wingate Sandstone. Generally functions as a confining unit. Is more permeable in the Mill Creek-Spanish Valley area and, along with the Navajo Sandstone and the Wingate Sandstone, forms the Glen Canyon aquifer.
Wingate Sandstone	Intermittent areas in southern half of Grand County area.	Fine-grained, massive crossbedded, eolian sandstone. Forms vertical cliffs in most exposures.	Wingate aquifer. Yields freshwater to seeps and springs in the Moab Valley-Colorado River area.

Table 1.--*Description of geologic units exposed in the Grand County area*—Continued

Geologic unit	Principal outcrop locations (plate 2)	Geologic characteristics	Hydrologic characteristics
Chinle Formation	South and southeastern parts of Grand County area.	Terrestrial sedimentary rocks, siltstone interbedded with sandstone and shale.	Confining unit.
Moss Back Member	Canyonlands National Park.	Calcareous fluvial sandstone, grit, and mudstone.	Not known to yield water.
Moenkopi Formation	South and southeastern part of Grand County area.	Shale, sandy mudstone, sandstone, conglomerate, and locally, gypsum beds.	Confining unit.
Cutler Formation	South and southeastern part of Grand County area.	Mostly fluvial arkose and arkosic conglomerate.	Yields water to wells on southwestern side of Castle Valley.
White Rim Sandstone Member	Canyonlands National Park.	Medium- to coarse-grained, crossbedded eolian sandstone.	Yields slightly saline water to wells in Taylor Canyon; yields freshwater to seeps along margin of outcrop.
Cedar Mesa Sandstone Member	Near confluence of Green and Colorado Rivers.	Fine-grained, thickly crossbedded, eolian sandstone.	May be an aquifer, but not known to yield water in study area.
Rico Formation	do.	Fine- to medium-grained, crossbedded, fluvial sandstone; cherty, marine limestone, and micaceous shale.	Do.
Hermosa Formation	In canyon of Colorado River in northeast part of Canyonlands National Park; Moab Valley near Colorado River.	Limestone, siltstone, arkose, and conglomerate.	Do.
Paradox Member	Salt Valley; Onion Creek drainage; Moab Valley near Colorado River.	Salt, gypsum, anhydrite, shale, sandstone, and limestone.	Yields moderately saline to very saline water to wells in Salt Valley and very saline water to one spring in Onion Creek drainage.
Precambrian crystalline rocks	Eastern part of Grand County area near Colorado River.	Crystalline rocks.	May yield water to springs where fractured.

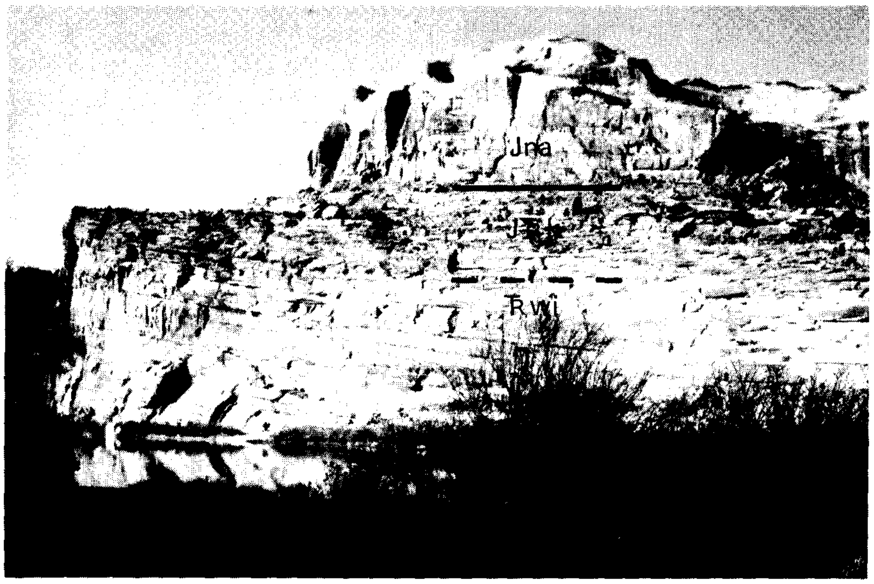


Figure 4.--Outcrop of the Navajo Sandstone (Jna), Kayenta Formation (J₸k), and Wingate Sandstone (₸wi), at location (D-25-21)26b.

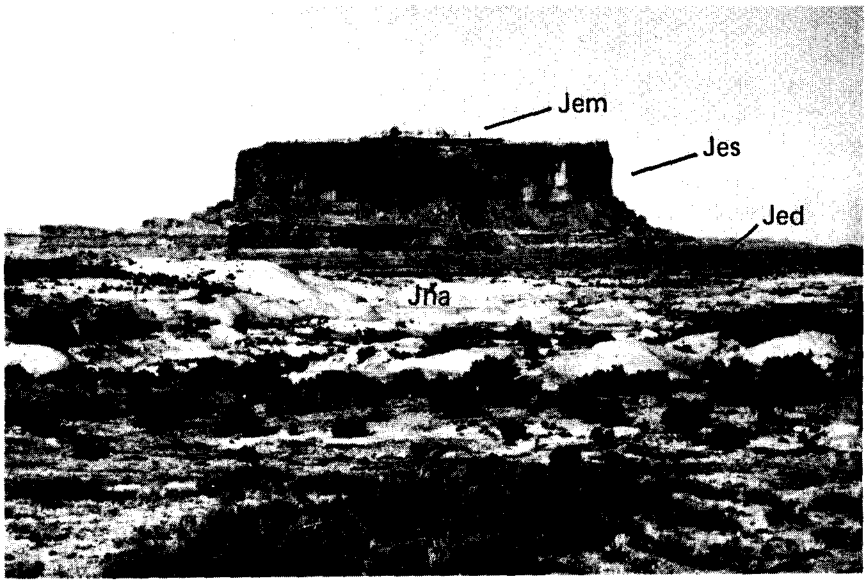


Figure 5.--Outcrop of the Moab Sandstone (Jem), Slick Rock (Jes), and Dewey Bridge (Jed) Members of the Entrada Sandstone, and the Navajo Sandstone (Jna), at location (D-25-20)5b.

The Navajo Sandstone is a massive, fine-grained, thickly crossbedded, eolian sandstone (fig. 4). The Navajo is characterized by large-scale, high-angle crossbedding in sets generally from 20 to 50 feet thick, and it erodes to massive cliffs and domes alternating with depressions (fig. 5). Thickness of the Navajo is about 400 feet in the western part of the Grand County area and decreases to the east. The Navajo is absent in the extreme eastern part of the area.

The Entrada Sandstone is divided into three members: The Dewey Bridge Member, the Slick Rock Member, and the Moab Sandstone Member (fig. 5). The Dewey Bridge Member is composed of siltstone and fine-grained sandstone. The Slick Rock Member is a massive, medium-grained, crossbedded, eolian sandstone. The Moab Sandstone Member is a single crossbed set of medium-grained, massive, sandstone at the top of the formation. Thickness of the Entrada Sandstone is as much as 550 feet in the western part of the area and decreases to the east.

HYDROLOGIC SETTING

Precipitation

Average annual precipitation in the Grand County area generally increases with altitude and ranges from less than 6 inches along the Green River near the city of Green River to more than 30 inches in the La Sal Mountains (pl. 1). Average May through September precipitation also generally increases with altitude and ranges from less than 3 inches along the Green River to more than 10 inches in the La Sal Mountains (pl. 1). Average annual precipitation on the Book Cliffs ranges from about 10 to about 20 inches. Between the Book Cliffs and the Colorado River, average annual precipitation is generally less than 8 inches, and it increases nearly uniformly from about 8 inches at the Colorado River to about 20 inches at the base of the La Sal Mountains.

Summer precipitation usually is in the form of thunderstorms, which are localized, intense, and short-lived. There is little time for precipitation from such storms to infiltrate the rocks and recharge the ground-water system, and most of the precipitation becomes evapotranspiration or runoff. Winter precipitation is less localized, less intense, and of longer duration. At higher altitudes it usually is in the form of snow. The gradual melting of the snow allows more time for precipitation to infiltrate the rocks and recharge the ground-water system, especially at higher altitudes during spring melting of the winter snowpack. The rate of evapotranspiration also is much smaller during winter and spring.

Except in the La Sal Mountains, May-September precipitation constitutes about four-tenths of the annual precipitation. In the La Sal Mountains, above about 10,000 feet, May-September precipitation constitutes about one-third of the annual precipitation.

The variation in annual precipitation at the Moab airport for 1951-86 is shown in figure 6. In figure 6, a horizontal line segment would indicate no change in departure from the average annual precipitation, and therefore would indicate precipitation of 8 inches. A downward-trending line segment indicates a time period when precipitation was less than 8 inches, and an

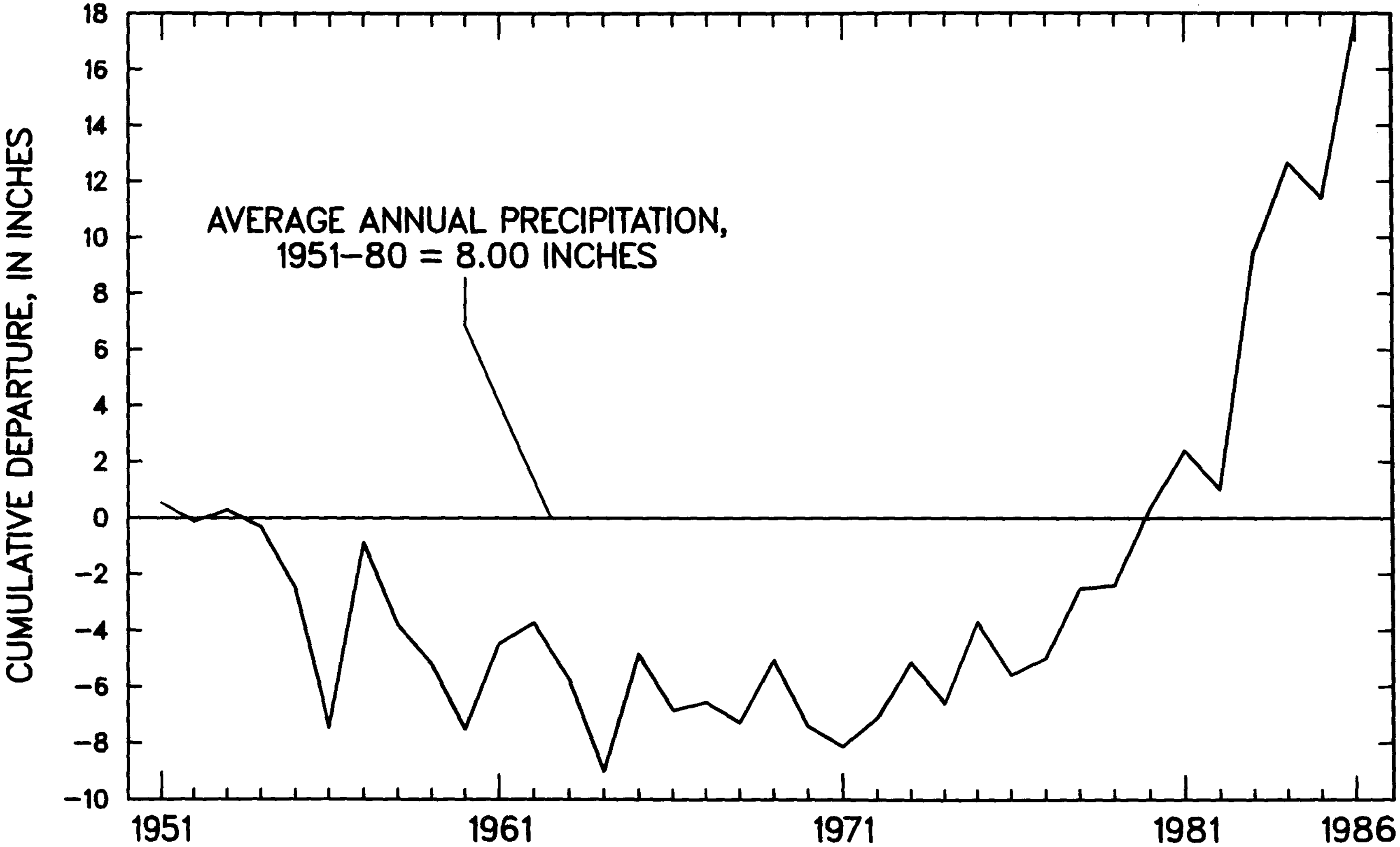


Figure 6.--Cumulative departure from average annual 1951-80 precipitation at Moab Airport, for years shown.

upward-trending line segment indicates a period when precipitation was more than 8 inches. The general downward trend in figure 6 from 1951 to 1971 shows that precipitation generally was less than 8 inches per year for that period, and the general upward trend from 1971 to 1986 shows that precipitation generally was more than 8 inches per year for that period.

Surface Water

Three major, perennial streams flow within or along the borders of the Grand County area: The Dolores River, the Green River, and the Colorado River. The Dolores and the Green Rivers are tributary to the Colorado River.

North of the Book Cliffs, in the Uinta Basin section of the Colorado Plateaus physiographic province, runoff generally is to the north and drains into the Green River. South of the Book Cliffs, in the Canyon Lands section of the Colorado Plateaus physiographic province, surface water drains to the Colorado River and, in the western part of the area, to the Green River. Water that runs off of the La Sal Mountains to the north and east drains into the Dolores River.

Active and discontinued U.S. Geological Survey streamflow-gaging stations are shown on plate 1, and a summary of data collected at both active and discontinued stations is presented in table 2. Mill Creek and Pack Creek, both near Moab, and Cottonwood Wash near I-70 are the only other streams besides the Dolores, Green, and Colorado Rivers that do not have recorded periods of no flow.

Ground Water

At several locations water was observed discharging from Quaternary unconsolidated deposits; however, the quantity and quality of water discharging from these deposits was not investigated during this study. In two areas, water from the unconsolidated deposits is used extensively. There are drillers' reports on file with the State Engineer's Office for about 100 wells completed in Quaternary unconsolidated deposits in the Castle Valley area, and Sumsion (1971) reported records of about 200 wells completed in Quaternary unconsolidated deposits in the Spanish Valley area. The dissolved-solids concentration of samples collected from 9 wells ranged from 169 to 1,020 mg/L (Sumsion, 1971). Other unconsolidated Quaternary deposits that can be recharged by the large precipitation associated with the La Sal Mountains may also contain usable quantities of ground water.

Rush and others (1982), Weir, Maxfield, and Hart (1983), and Weir, Maxfield, and Zimmerman (1983) have divided the stratigraphic section in the Grand County area into two ground-water systems: The "upper ground-water system", which includes all stratigraphic units above the Paradox Member of the Hermosa Formation, and the "lower ground-water system", which includes all stratigraphic units below the Paradox Member. The upper ground-water system is the main focus of this report.

Table 2.—*Selected streamflow data from the Grand County area*

[From published records of the U.S. Geological Survey. Abbreviations: mi², square miles; ft³/s, cubic feet per second; acre-ft/yr, acre-feet per year; --, no data]

Station number (plate 1)	Station name	Drainage area (mi²)	Period of record	Average discharge			Discharge extremes			
							Maximum		Minimum	
				ft³/s	acre-ft/yr	years	ft³/s	date	ft³/s	date
09315000	Green River at Green River	44,850	Oct. 1894-Oct. 1899 Oct. 1904-present	6,391	4,630,000	86	68,100	6/27/17	255	11/26/31
09316100	Floy Wash near Green River	56.6	Apr. 1983-present	.94	678	2	2,170	7/29/85	(1)	--
09163675	Cottonwood Wash near I-70	170	Apr. 1973-Sept. 1986	6.16	4,460	3	541	8/29/86	0.3	7/19/85
09180000	Dolores River	4,580	Oct. 1950-present	835	605,000	35	17,400	4/21/58	3.4	9/23/56
09180500	Colorado River near Cisco	24,100	Jan. 1895-present	7,724	5,596,000	74	76,800	6/19/17	558	7/21/34
09181500	Rock (Professor) Creek near Moab	--	July 1950-Sept. 1953	2.11	1,530	3	3,330	8/29/51	(1)	--
09182000	Castle Creek above diversions	7.6	July 1950-Sept. 1955 Apr. 1957-Sept. 1975	1.16	840	23	27	8/11/67	(1)	--
09182500	Castle Creek near Moab	53.1	July 1950-Sept. 1955 May 1957-Sept. 1958	5.25	3,800	6	11,000	8/13/54	(1)	--
09182900	Courthouse Wash at Arches highway crossing	143	Oct. 1958-July 1966	1.47	1,060	7	4,530	9/09/61	(1)	--
09183000	Courthouse Wash near Moab	162	Oct. 1949-Sept. 1955 Apr. 1957-Sept. 1957 July 1966-present	1.86	1,350	25	12,300	8/05/57	(1)	--
09183500	Mill Creek near Sheley tunnel	27.4	Oct. 1954-Sept. 1959	11.4	8,250	5	204	8/30/57	(1)	--
09184000	Mill Creek near Moab	74.9	July 1949-Sept. 1971 Oct. 1972-present	14.3	10,360	30	5,110	8/21/53	0.2	2/15/54
09184500	Pack Creek at M-4 Ranch	15.8	Oct. 1954-Sept. 1959	2.54	1,840	5	1,200	7/26/55	0.3	9/02/56 9/04/56
09185000	Pack Creek near Moab	57	Oct. 1954-Sept. 1959	4.02	2,910	5	510	10/08/54	0.7	8/27/56

(1) No flow at times.

In this report, the upper ground-water system is divided into four hydrologic units: The Parachute Creek aquifer; the upper confining unit in Tertiary and Cretaceous rocks; the sandstone aquifers in Mesozoic rocks; and the lower confining unit in Mesozoic and Upper Paleozoic rocks. The Parachute Creek aquifer consists of the Parachute Creek Formation. The upper confining unit in Tertiary and Cretaceous rocks includes the stratigraphic section from the top of the Wasatch Formation to the bottom of the Mancos Shale. The sandstone aquifers in Mesozoic rocks include the stratigraphic section from the top of the Dakota Sandstone to the bottom of the Wingate Sandstone. The Entrada, Navajo, Wingate, and Glen Canyon aquifers are included in this unit. The lower confining unit in Mesozoic and Upper Paleozoic rocks includes the stratigraphic section from the top of the Chinle Formation to the top of the Paradox Member of the Hermosa Formation. The latter three units are analogous to the "Tertiary and Cretaceous confining beds", "Mesozoic sandstone aquifer", and "Mesozoic and Upper Paleozoic confining beds" of Rush and others (1982), Weir, Maxfield, and Hart (1983), and Weir, Maxfield, and Zimmerman (1983). The hydrologic units used in this report and the geologic units they contain are shown in table 3.

Table 3.--*Correlation of geologic units and hydrologic units in the upper ground-water system*

Hydrologic units	Geologic units
Parachute Creek aquifer	Parachute Creek Member of Green River Formation
Upper confining unit in Tertiary and Cretaceous rocks	Tuscher Formation
	Mesaverde Group
	Price River Formation
	Castlegate Sandstone
	Blackhawk Formation
	Mancos Shale
	Ferron Sandstone Member
	Tununk Shale Member
Sandstone aquifers in Mesozoic rocks	Dakota Sandstone
	Burro Canyon Formation
	Cedar Mountain Formation
	Morrison Formation
	Brushy Basin Shale Member
	Salt Wash Sandstone Member
	Summerville Formation
Entrada aquifer	Entrada Sandstone
	Moab Sandstone Member
	Slick Rock Member
	Dewey Bridge Member
	Carmel Formation
Navajo aquifer	Navajo Sandstone
Glen Canyon aquifer	Kayenta Formation
Wingate aquifer	Wingate Sandstone
Lower confining unit in Mesozoic and upper Paleozoic rocks	Chinle Formation
	Moss Back Member
	Moenkopi Formation
	Cutler Formation
	White Rim Sandstone Member
	Cedar Mesa Sandstone Member
	Rico Formation
	Hermosa Formation

About 60 wells and springs were inventoried during this study. At wells and springs, discharge rates and on-site water-quality parameters (water temperature, specific conductance and pH) were measured and water-quality samples were collected. Water levels were measured at wells. Discharge and water-quality data collected during previous studies were used to supplement the data collected during this study. The results of about 50 water-quality analyses for major ions and selected trace elements are given in table 4. In addition, the results of 16 analyses for uranium, 17 analyses for alpha-particle and beta-particle activity, and 15 analyses for radium activity are given in table 5.

Occurrence, Discharge, and Water Quality

The U.S. Forest Service has identified over 200 springs on the flanks of the La Sal Mountains. Nearly all of the springs occur at altitudes higher than 7,500 feet above sea level. Several representative spring sites were visited, and all were discharging from unconsolidated material overlying the upper ground-water system. Most of the springs identified by the U.S. Forest Service also probably discharge from unconsolidated material.

Feltis (1966, p. 52-69) reported values for concentrations of dissolved solids in water that was collected from the lower ground-water system in nine petroleum-exploration holes. The sites are located in western and southwestern parts of the Grand County area, and the concentrations of dissolved solids ranged from about 7,100 to about 230,000 mg/L.

Parachute Creek aquifer and the upper confining unit in Tertiary and Cretaceous rocks

About 70 springs north of the Book Cliffs, in the Uinta Basin section of the Colorado Plateaus physiographic province, are identified on U.S. Geological Survey $7\frac{1}{2}$- and 15-minute topographic maps. Nearly all of the springs discharge from the Parachute Creek Member of the Green River Formation of Tertiary age, the youngest consolidated sedimentary rock unit in the Grand County area.

Discharge and water-quality information has been collected by previous investigators at 12 of the springs north of the Book Cliffs, 11 that discharge from the Parachute Creek Member of the Green River Formation and one that discharges from the Wasatch Formation of Tertiary age (Conroy and Fields, 1977, p. 202-242; Conroy, 1979, p. 168-190; Conroy, 1980, p. 160-163). Discharge typically ranges from less than 1 to about 20 gal/min. Concentrations of dissolved solids were less than 500 mg/L in samples from the Parachute Creek Member and about 600 mg/L in samples from the Wasatch Formation. The water type is mixed, typically calcium magnesium bicarbonate. Concentrations of selected trace elements were all less than the State of Utah primary drinking-water standards listed in table 4.

Table 4.—*Chemical analyses of selected major*

[Abbreviations used in headings: °C, degrees Celsius; µS/cm,
milligrams per liter; µg/L, micrograms per liter; <, the actual value

State of Utah primary drinking-water standard: Maximum Contaminant Level (MCL) allowable by Utah Department of Health.
U.S. Environmental Protection Agency (EPA) criterion: Recommended limit for human health (H) or welfare (W).
Well or spring number: See "Numbering system for hydrogeologic-data sites", p. 5 and figure 2.
Geologic Source: 112ALVM, alluvium of Quaternary age; 200MSZC, Mesozoic undifferentiated; 217CDRM, Cedar Mountain Formation; 221ENRD, Entrada Sandstone; 227GLNC, Glen Canyon Group; 227NVJO, Navajo Sandstone; 231WNGT, Wingate

Well or spring number	Geo-logic source	Date sampled	Temper-ature (°C)	Spe-cific conduct-ance (µS/cm)	pH (stand-ard units)	Solids, residue at 180 °C dis-solved	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)
State of Utah primary drinking-water standard					6.5-9.0	[1]2,000				
EPA Criterion										
(D-22-23)25bac- 1	217CDRM	07-21-86	22.5	2,670	8.3	1,470	11	4.0	530	4.3
(D-22-23)29ada- 1	221BRSB	08-18-85	26.5	1,630	7.6	1,020	48	18	290	5.1
(D-23-21)27bcd- 1	231WNGT	08-07-86	20.0	515	7.8	280	28	29	35	6.0
(D-24-20)19caa- 1	221ENRD	11-24-85	14.0	335	7.8	182	39	17	5.5	3.8
(D-25-20)21dbb- 1	231WNGT?	10-29-85	15.0	1,190	--	1,120	14	15	390	7.1
(D-25-21)20add- 2	227NVJO	08-07-86	19.0	1,000	7.4	584	70	29	85	6.1
(D-25-21)21bdc- 1	227NVJO	08-07-86	19.0	1,690	7.4	1,000	97	38	200	10
(D-25-22)12aad- 1	310CTLR	09-30-86	16.0	3,260	7.3	2,740	380	130	150	14
(D-25-23)18baa- 1	310CTLR	09-30-86	15.0	3,950	7.5	3,450	500	160	260	14
(D-25-23)20adb- 1	310CTLR	09-30-86	15.0	1,940	7.3	1,420	250	66	85	4.1
(D-26-22) 8bad- 1	227GLNC	09-05-85	15.5	365	7.6	203	38	13	17	1.7
(D-26-22) 9ddc- 1	227GLNC	07-11-86	18.0	265	7.8	151	31	12	5.5	1.2
(D-26-22)14cba- 1	227GLNC	06-22-86	16.0	255	8.2	150	30	11	5.3	1.1
(D-26-22)15acb- 1	227GLNC	08-05-86	15.0	270	7.7	150	30	11	5.1	1.1
(D-26-22)15cca- 1	227GLNC	08-09-86	16.0	330	7.7	194	36	15	9.2	1.3
(D-26-22)15daa- 2	227GLNC	08-15-85	15.5	255	7.8	154	33	11	5.7	1.1
(D-26-22)15dca- 1	227GLNC	03-06-69	15.0	268	8.0	154	30	16	5.4	1.2
Do.		08-15-85	15.0	360	7.7	214	41	14	16	1.2
(D-26-22)22aab- 1	227GLNC	11-19-68	13.5	273	7.6	218	30	13	6.5	1.0
(D-26-22)22aac- 1	227GLNC	11-19-68	15.0	286	7.4	166	32	14	7.6	1.0
Do.		08-16-85	15.5	280	7.9	165	33	12	6.9	1.2
(D-26-22)22abc- 1	227GLNC	08-05-86	15.0	620	7.4	388	72	28	12	1.7
(D-26-22)22dad- 1	227GLNC	07-12-86	16.5	380	7.7	238	42	17	13	1.6
(D-26-22)22dcd- 1	112ALVM	07-09-68	16.0	930	7.6	664	110	38	48	2.2
(D-26-22)23cdd- 1	227GLNC	08-28-85	16.0	445	7.8	283	54	19	15	1.7
(D-26-22)26acd- 1	227GLNC	08-09-86	17.0	685	7.5	420	67	25	25	2.2
(D-26-22)26dbd- 1	227GLNC	08-19-85	17.0	920	7.5	674	120	33	47	2.7
(D-26-22)26dda- 1	227GLNC	07-12-86	18.0	705	7.6	503	81	29	33	2.4
(D-26-22)35ada- 1	110ALVM	07-08-69	14.0	1,230	7.6	962	180	38	54	2.1
(D-26-22)35bdd- 2	110ALVM	09-05-68	10.0	980	7.7	739	140	28	43	2.1
(D-21-24)36bbc-S1	200MSZC	09-08-85	15.0	5,480	8.0	4,240	730	44	600	8.4
(D-22-21)32aac-S1	217CDRM	12-13-85	--	1,600	8.4	1,020	14	5.0	360	1.6
(D-22-25)12bda-S1	400PCMB	09-07-85	15.0	680	8.2	406	79	36	26	4.2
(D-22-25)18cdb-S1	200MSZC	09-08-85	15.5	1,100	7.4	666	130	16	86	4.0
(D-23-21)23dad-S1	221ENRD	08-08-86	14.0	255	8.2	146	41	4.1	4.6	1.7

constituents and trace elements at selected sites

microsiemens per centimeter at 25 degrees Celsius; mg/L,
is unknown but is less than the indicated value; --, no data]

Formation; 221BRSB, Brushy Basin Shale Member of Morrison Formation; 221SLWS, Salt Wash Sandstone Member of Morrison
Sandstone; 310CTLR, Cutler Formation; 400PCMB, Precambrian crystalline rocks.

Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Alkalinity, lab, (mg/L as $CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Silica, dissolved (mg/L as SiO_2)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Arsenic, dissolved (μg/L as As)	Barium, dissolved (μg/L as Ba)	Iron, dissolved (μg/L as Fe)	Selenium, dissolved (μg/L as Se)	Strontium, dissolved (μg/L as Sr)
	[2]1,000							50	1,000	300	10	
250 W	250 W							0 H	1,000 H	300 W	10 H	
560	160	0.6	275	2.6	10	46	0	<1	<100	100	<1	1,500
30	400	.8	365	18	11	200	0	1	21	2,100	<1	1,900
38	41	.3	172	5.3	9.4	190	18	<1	30	<10	2	820
6.1	16	.3	147	4.5	9.2	170	21	<1	110	5	1	390
440	79	.9	290	--	5.6	97	0	7	30	380	--	470
78	190	.3	174	13	12	300	120	<1	20	20	8	1,600
280	260	.4	188	14	12	400	210	<1	10	<10	5	2,600
160	1,700	.4	115	11	17	1,500	1,400	<1	<100	40	21	7,700
140	2,300	.3	--	0	15	1,900	0	<1	<100	30	30	11,000
150	760	.7	140	14	14	900	760	<1	16	6	4	4,800
15	28	.2	123	6.0	9.5	150	26	1	87	14	<1	430
1.8	31	.2	104	3.2	9.5	130	23	<1	82	27	<1	440
1.9	33	.2	99	1.2	9.2	120	22	<1	82	7	<1	400
2.0	28	.2	96	3.7	9.1	120	25	<1	40	<10	<1	450
4.0	64	.1	104	4.0	9.6	150	48	<1	40	10	1	570
44	46	.1	93	2.8	9.2	130	35	<1	100	14	<1	450
2.4	48	.4	--	1.9	7.7	140	42	--	--	570	--	--
6.4	60	.2	108	4.2	.7	160	53	<1	68	26	1	550
2.7	38	.3	--	4.9	9.5	130	26	10	--	90	0	--
2.9	39	.4	--	8.1	11	140	33	10	--	170	0	--
2.4	41	.1	91	2.2	.3	130	41	1	58	11	<1	480
8.0	150	.3	164	13	12	300	130	<1	30	40	4	1,000
7.0	70	.1	116	4.5	11	180	60	<1	44	12	1	660
16	300	.5	--	8.7	14	420	240	--	--	20	--	--
10	98	.6	103	3.2	11	210	110	<1	56	25	2	760
17	190	.2	119	7.3	11	270	150	<1	45	12	4	1,200
27	210	.3	137	8.4	14	440	300	<1	27	210	5	2,000
16	220	.3	124	6.0	12	320	200	<1	56	14	4	1,400
30	450	.5	--	9.7	17	610	410	--	--	100	--	--
11	310	.9	--	8.4	14	470	260	10	--	--	0	--
820	1,700	3.6	152	2.9	20	2,000	1,900	1	100	80	<1	8,100
100	310	1.2	418	3.2	10	56	0	3	27	23	2	540
13	31	2.2	325	3.9	30	350	22	1	180	22	<1	930
120	190	2.1	201	15	16	390	190	3	29	3	2	1,200
4.4	11	.1	116	1.4	8.7	120	4	<1	360	<3	<1	220

Well or spring number	Geo-logic source	Date sampled	Temper-ature (°C)	Spe-cific conduct-ance (µS/cm)	pH (stand-ard units)	Solids, residue at 180 °C dis-solved	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)
(D-23-22)17cab-S1	221ENRD	06-10-85	15.0	255	8.2	146	45	4.5	4.8	2.3
(D-23-23)11dbc-S1	227NVJO	11-23-85	12.5	560	7.9	349	39	32	34	6.8
(D-23-23)12dba-S1	227NVJO	12-17-85	13.0	670	7.6	385	57	27	59	13
(D-24-18) 7aaa-S1	227NVJO	11-26-85	12.5	220	8.2	135	35	4.9	6.8	1.6
(D-24-19)10dcd-S1	221ENRD	11-26-85	14.0	205	7.9	119	32	4.7	3.9	2.9
(D-24-21)31dab-S1	221ENRD	09-15-70	13.0	225	7.7	143	43	3.2	2.3	1.6
(D-25-18) 9ddc-S1	227NVJO	06-21-86	17.0	320	7.7	182	37	13	7.0	3.3
(D-25-21) 5abb-S1	221ENRD	09-15-70	12.5	270	8.0	157	49	4.1	3.8	1.7
(D-25-21) 5bbb-S1	221ENRD	09-15-70	13.0	250	7.4	145	49	3.3	2.6	1.1
(D-25-21)26bdc-S1	231WNGT	10-08-58	17.0	300	8.1	—	33	10	—	--
(D-25-21)26bdc-S2	231WNGT	08-17-85	16.0	295	8.0	161	30	12	12	2.0
(D-25-21)35aaa-S1	231WNGT	10-19-67	14.5	296	7.5	168	32	12	13	0.6
Do.		08-15-85	17.5	290	8.0	174	32	13	14	1.7
(D-26-22)14acc-S1	227NVJO	11-19-68	16.0	305	7.6	171	35	16	5.3	1.2
(D-26-22)15cbb-S1	227GLNC	10-19-67	14.0	295	7.6	172	35	12	8.2	.5
(D-26-22)15cdc-S1	227GLNC	08-16-85	16.0	460	7.6	287	49	21	14	1.7
(D-26-22)22aaa-S1	227GLNC	08-16-85	15.0	280	7.6	163	33	12	6.5	1.3
(D-26-22)22aad-S1	227GLNC	08-15-85	16.0	285	7.4	174	34	13	8.1	1.2
(D-26-23)26dcc-S1	221SLWS	07-27-86	15.0	1,640	7.6	1,160	120	72	130	3.7
(D-27-19)22bbc-S1	227NVJO	07-10-86	15.0	190	8.2	102	21	9.5	2.3	1.8

[1] If the concentration of dissolved solids is larger than 1,000 mg/L, the supplier shall satisfactorily demonstrate that water with a smaller concentration of dissolved solids is not available.

[2] If the concentration of sulfate is larger than 500 mg/L, the supplier shall satisfactorily demonstrate that water with a smaller concentration of sulfate is not available, and the water shall not be available for human commercial establishments.

Formations in the Mesaverde Group and the Mancos Shale, both of Cretaceous age, crop out in a band about 10 to 20 miles wide southwest, south, and southeast of the Book Cliffs (pl. 2). None of these formations yields substantial quantities of water to wells or springs in the Grand County area, and the Mesaverde Group and the Mancos Shale probably effectively inhibit downward movement of water into the underlying sandstone aquifers in Mesozoic rocks in most places. Several springs shown on U.S. Geological Survey 7½- and 15-minute topographic maps are located where they would appear to discharge from the Mesaverde Group or the Mancos Shale, but typically they discharge from overlying alluvium.

Sandstone aquifers in Mesozoic rocks

The Dakota Sandstone, and the Cedar Mountain, Burro Canyon, and Morrison Formations crop out in a band about 5 miles wide, about 10 to 20 miles south

Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Alkalinity, lab, (mg/L as $CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Silica, dissolved (mg/L as SiO_2)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Iron, dissolved (µg/L as Fe)	Selenium, dissolved (µg/L as Se)	Strontium, dissolved (µg/L as Sr)
4.9	11	.2	100	1.2	9.8	130	32	<1	480	3	1	350
20	71	.3	207	5.0	10	230	24	1	76	3	5	2,000
24	85	.4	251	12	13	260	5	<1	75	<3	3	2,100
5.2	14	.2	88	1.1	8.2	110	20	<1	110	4	1	260
3.4	9.9	.1	94	2.0	8.5	100	6	2	200	13	<1	240
3.5	6.5	.4	--	4.2	10	120	0	0	--	0	37	--
9.9	22	.3	125	4.8	11	150	21	<1	100	5	1	280
5.0	12	.5	--	2.5	11	140	11	0	--	0	55	--
5.0	10	.5	--	9.4	9.5	140	0	0	--	0	89	--
12	36	--	--	1.7	11	120	0	--	--	--	--	--
9.8	30	.2	99	1.9	9.0	120	26	<1	77	4	1	410
14	31	.3	--	6.4	11	130	0	--	--	0	--	--
11	32	.2	100	1.9	9.3	130	34	1	80	7	<1	420
2.7	11	.1	--	7.3	8.9	150	2	0	--	--	0	--
4.3	39	.3	--	5.3	8.9	140	0	--	--	0	--	--
9.3	100	.1	112	5.4	10	210	98	<1	50	5	2	780
2.3	39	.2	94	4.6	9.4	130	38	1	72	8	<1	480
2.9	46	.2	93	7.2	9.7	140	46	<1	64	18	<1	510
81	480	.4	269	13	18	600	330	2	41	3	8	2,800
2.7	4.4	.2	90	1.1	10	92	2	<1	370	<3	<1	110

of the Book Cliffs, and locally on the flanks of the La Sal Mountains (pl. 2). These formations locally yield water to seeps, springs, and flowing wells. Discharge typically is less than 1 gal/min.

South of the Book Cliffs, concentrations of dissolved solids in water samples from a flowing well [(D-22-23)25bac-1] and a spring [(D-22-21)32aac-S1] discharging from the Cedar Mountain Formation and from a flowing well [(D-22-23)29ada-1] discharging from the Brushy Basin Shale Member of the Morrison Formation ranged from 1,020 mg/L to 1,470 mg/L (table 4). Sodium was the cation type at all three sites, but the anion type varied from site to site. On the flanks of the La Sal Mountains, the concentration of dissolved solids in water discharging from a spring in the Salt Wash Sandstone Member of the Morrison Formation was 1,160 mg/L (table 4), and the water type was mixed, calcium magnesium sodium sulfate bicarbonate.

Table 5.—*Chemical analyses of selected radionuclides in ground water at selected sites*

[Abbreviations used in headings: pCi/L, picocuries per liter; <, the actual value is unknown but is less than the indicated value; --, no data]

State of Utah primary drinking-water standard: Maximum Contaminant Level (MCL) allowable by Utah Department of Health.
Well or spring number: See "Numbering system for hydrogeologic-data sites", p. 5 and figure 2.
Geologic source: 200MSZC, Mesozoic undifferentiated; 217CDRM, Cedar Mountain Formation; 221BRSB, Brushy Basin Shale Member of Morrison Formation; 221ENRD, Entrada Formation; 227GLNC, Glen Canyon Group; 227NVJO, Navajo Sandstone; 231WNGT, Wingate Sandstone.

Well or spring number	Geologic source	Date sampled	Uranium, natural, dissolved (pCi/L as U)	Radium 226, dissolved, radon method (pCi/L)	Gross alpha, dissolved (pCi/L as U-Nat)	Gross beta, dissolved (pCi/L as Cs-137)	Gross beta, dissolved (pCi/L as Sr/Yt-90)
State of Utah primary drinking-water standard:				[1]5	15	50	50
(D-22-23)29ada- 1	221BRSB	08-18-85	13.6	0.06	15	23	15
(D-24-20)19caa- 1	221ENRD	11-24-85	0.9	--	0.7	5.2	3.9
(D-25-20)21dbb- 1		10-29-85	0.5	0.02	<6.5	16	9.9
(D-26-22) 8bad- 1	227GLNC	09-05-85	0.6	0.08	1.1	2.7	2.2
(D-26-22)15daa- 2	227GLNC	08-15-85	0.8	0.05	0.9	1.1	0.9
(D-26-22)23cdd- 1	227GLNC	08-28-85	1.3	0.05	3.7	3.5	2.5
(D-26-22)26dbd- 1	227GLNC	08-19-85	2.1	0.03	2.9	5.3	3.4
(D-21-24)36bbc-S1	200MSZC	09-08-85	0.3	--	<31	13	9.1
(D-22-21)32aac-S1	217CDRM	12-13-85	<0.3	0.08	<6.1	5.2	3.5
(D-22-25)18cdb-S1	200MSZC	09-08-85	6.7	0.08	10.9	6.6	6.9
(D-23-21)23dad-S1	221ENRD	08-08-86	--	0.09	1.1	2.0	1.6
(D-23-22)17cab-S1	221ENRD	06-10-85	0.6	0.19	<2.3	2.7	2.3
(D-23-23)11dbc-S1	227NVJO	11-23-85	<0.3	0.12	3.3	9.8	7.3
(D-23-23)12dba-S1	227NVJO	12-17-85	2.4	0.05	4.3	16	12
(D-24-19)10dcd-S1	221ENRD	11-26-85	<0.3	0.15	1.4	5.5	4.3
(D-25-21)35aaa-S1	231WNGT	08-15-85	0.7	0.06	1.3	3.1	2.3
(D-26-22)22aaa-S1	227GLNC	08-16-85	0.9	0.05	2.2	2.2	1.6
Median value for Grand County area:			0.8	0.06	2.2	5.2	3.5

[1]Radium 226 and 228, combined.

Water discharging from the unnamed spring in the Cedar Mountain Formation had beta and radium activities near the median values for the Grand County area (table 5). The uranium activity was less than one-half the median value of 0.8 pCi/L (picocuries per liter) for the Grand County area.

Water discharging from the flowing well in the Brushy Basin Shale Member of the Morrison Formation had the largest beta and uranium activities and the second-largest alpha activity of all the samples in the Grand County area; however, the beta activity was less than one-half of the State of Utah primary drinking-water standard of 50 pCi/L, and the alpha activity was 15 pCi/L, which is equal to the State of Utah primary drinking-water standard (table 5). A relatively large quantity of radionuclide activity in water from the Morrison is not unexpected. The Morrison contains large, commercially important quantities of uranium, and the formation has been mined for uranium in the Grand County area.

Feltis (1966, p. 44-69) reported the concentrations of dissolved solids and major ions in water samples from four oil-test holes and one water well completed in the Morrison Formation (table 6). The depth to the Morrison in these wells ranged from about 400 to 2,500 feet below land surface. Concentrations of dissolved solids in water samples from these wells ranged from 2,090 to 25,700 mg/L, and the water type typically was sodium chloride (fig. 7; table 6). Unpublished data from the files of the U.S. Geological Survey indicate that the concentration of dissolved solids in water collected from the Morrison Formation at two sites ranged from about 10,000 to 22,900 mg/L, and the concentration of dissolved solids in water collected from the Dakota Sandstone at one site was 1,800 mg/L (fig. 7; table 6).

The Entrada Sandstone, the Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone crop out extensively in the southern one-third of the Grand County area (pl. 2) and contain the principal aquifers of the area. Regionally, the Kayenta Formation is considered a confining unit because it is less permeable than the overlying Navajo Sandstone and underlying Wingate Sandstone. In the Mill Creek-Spanish Valley area, however, the Kayenta is sandy, and the Navajo Sandstone, Kayenta Formation, and Wingate Sandstone of the Glen Canyon Group form a single aquifer, designated the Glen Canyon aquifer in this report.

Discharge from the Entrada Sandstone, the Navajo Sandstone, and the Wingate Sandstone typically occurs as seeps and small springs near the bases of the formations, typically where canyons cut through the formations. Water is perched in each of the formations by less permeable underlying units. The Moab Sandstone and Slick Rock Members of the Entrada Sandstone are underlain by the less permeable Dewey Bridge Member of the Entrada Sandstone. The Slick Rock and Dewey Bridge Members of the Entrada Sandstone are not shown individually on the geologic map (pl. 2) but are included in the map unit, Je. The Navajo Sandstone is underlain by the generally less permeable Kayenta Formation, and the Wingate Sandstone is underlain by the less permeable Chinle Formation. Rates of discharge from the formations range from nearly zero at seeps from canyon walls to a reported 2,000 gal/min from well (D-26-22)15dca-1 in the City of Moab well field, where the aquifer is fractured.

Concentrations of dissolved solids in water from the principal aquifers near their outcrop areas typically range from about 100 to about 500 mg/L (table 4). The water type typically is calcium bicarbonate, calcium magnesium bicarbonate, or calcium magnesium bicarbonate sulfate.

<u>Lower confining unit in Mesozoic and upper Paleozoic rocks</u>

On the southwestern side of Castle Valley, the undifferentiated Cutler Formation is the source of water for about 30 wells. Thirteen of the wells were tested for specific capacity following drilling. Specific capacity of eight of the wells ranged from less than 0.01 (gal/min)/ft, where a well produced 1 gal/min for 1 hour with 260 feet of drawdown, to 4.0 (gal/min)/ft, where a well produced 20 gal/min for 1 hour with 5 feet of drawdown. Five wells were pumped for 2 hours at discharge rates ranging from 20 to 40 gal/min with no measurable drawdown.

Table 6.--*Dissolved-solids concentration in ground water at selected sites*

Site number: See "Numbering system for hydrogeologic-data sites in Utah", p. 5 and figure 2.
Geologic source: Kd, Dakota Sandstone; Jm, Morrison Formation; Je, Entrada Sandstone; Pwr, White Rim Sandstone Member of Cutler Formation.
Dissolved solids: mg/L, milligrams per liter.
Interval sampled: Feet below land surface; --, no data.
Source of information: Unpublished data of the U.S. Geological Survey.

Site number	Geologic source	Dissolved solids (mg/L)	Interval sampled (feet)	Source of information
(D-21-20)17bcb	Kd	1,800	—	USGS
(D-19-24)35dbc	Jm	25,700	1,484-1,508	Feltis, 1966
(D-19-25)10abd	Jm	7,350	595- 602	Do.
(D-20-21)23bba	Jm	22,900	—	USGS
(D-20-22)30bd	Jm	22,600	2,388-2,456	Feltis, 1966
(D-20-23)14baa	Jm	9,960	—	USGS
(D-20-24)29cda	Jm	6,880	384- 400	Feltis, 1966
Do.	Jm	5,510	762- 772	Do.
Do.	Jm	2,090	872- 888	Do.
(D-22-19)16abb	Jm	13,900	1,118-1,155	Do.
T(D-15-22)35cdd	Je	104,000	—	USGS
(D-16-26)29ccb	Je	47,500	—	Do.
Do.	Je	13,500	—	Do.
(D-17-24) 9dca	Je	86,600	5,247-5,290	Feltis, 1966
(D-17-24)12dca	Je	58,400	5,160	Do.
(D-17-25)11dab	Je	4,330	—	USGS
Do.	Je	4,850	—	Do.
(D-19-21)29dbb	Je	6,800	—	Do.
(D-19-25)10abd	Je	9,470	875- 905	Feltis, 1966
(D-21-19)33cdd	Je	10,300	1,736-1,758	Do.
R(D-27-17) 1ddc	Pwr	2,730	260- 380	Huntoon, 1977
Do.	Pwr	1,990	do.	Do.
(D-27-18) 9baa	Pwr	2,570	415- 585	Do.
(D-27-18)10aaa	Pwr	1,720	485- 585	Do.
(D-28-19)11aac-S	Pwr	270	—	Do.
(D-28-19)15bbb-S	Pwr	308	—	Do.

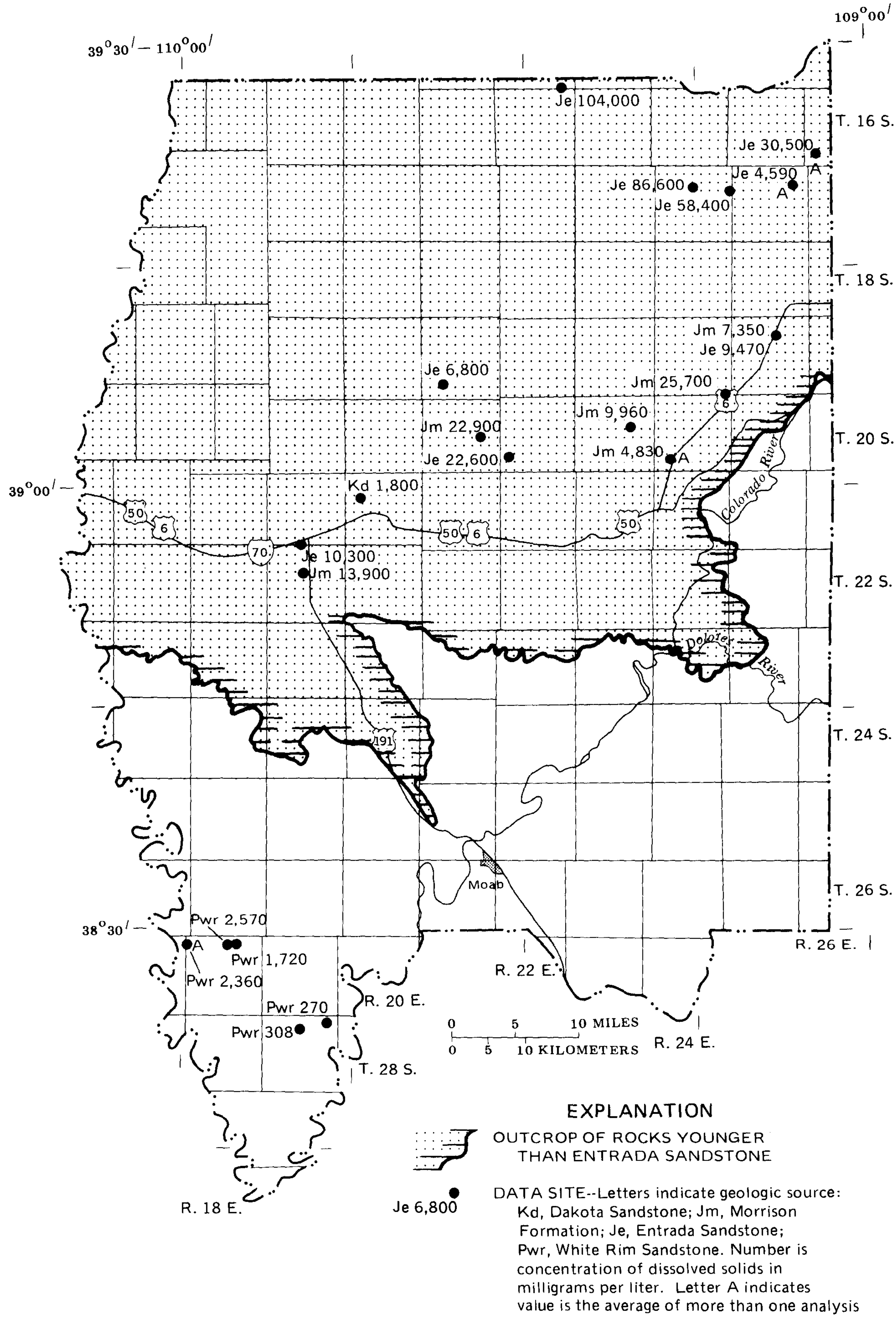


Figure 7.--Concentration of dissolved solids in ground water at selected sites.

Water from three wells completed in the undifferentiated Cutler Formation was collected and analyzed during this study. Concentrations of dissolved solids ranged from 1,420 to 3,450 mg/L, and the water type was either calcium magnesium sulfate or calcium magnesium sodium sulfate. The water was very hard, ranging from 900 to 1,900 mg/L. At two of the wells, the concentration of sulfate was larger than the State of Utah primary drinking-water standard of 1,000 mg/L (table 4). At the same two wells, concentrations of selenium were two and three times the State of Utah primary drinking-water standard of 10 µg/L (table 4).

Huntoon (1977) characterized the White Rim Sandstone Member of the Cutler Formation in Canyonlands National Park and in the area immediately north of the Park. Where the White Rim is cut by canyons, ground water discharges in "an almost continuous series of small springs and seeps along its lower contact." Huntoon reported the chemical quality of ground water in the White Rim that was collected from two springs and three wells (fig. 7 and table 6). Concentrations of dissolved solids in water from the two springs were 270 mg/L and 308 mg/L, and the water types were calcium magnesium bicarbonate and calcium magnesium sodium bicarbonate. Dissolved-solids concentrations of four samples collected from the three wells ranged from 1,720 to 2,730 mg/L. The water types were mixed, and varied from sample to sample.

Quality of water near faults

Ground-water discharges at several locations near the trace of the Moab fault. Sites of discharge include Brink Spring, (D-24-19)10dcd-S1; a flowing well in Tusher Canyon, (D-24-20)19caa-1; and two water-supply wells completed in the Navajo Sandstone in Arches National Park, (D-25-21)20add-2 and (D-25-21)21bdc-1 (pl. 1).

The Entrada Sandstone may be the source of water for Brink Spring and the flowing well. In the area of the two sites, the Entrada is at the surface on the upthrown side of the Moab fault, and the water quality resembles that of the Entrada at other locations. Concentrations of dissolved solids at the two sites were less than 200 mg/L (table 4), and the water types were calcium bicarbonate and calcium magnesium bicarbonate.

The two water-supply wells in Arches National Park are completed in the Navajo Sandstone, but the quality of water in the wells is different from that in the Navajo aquifer at other locations. The concentration of dissolved solids in well (D-25-21)20add-2 was 584 mg/L (table 4), and the water type was sodium calcium magnesium sulfate bicarbonate chloride. The concentration of dissolved solids in well (D-25-21)21bdc-1 was 1,000 mg/L (table 4), and the water type was sodium calcium chloride sulfate bicarbonate.

Ground-water discharge also occurs in an area of faulting in the eastern part of the Grand County area, southeast of the Colorado River. Water samples from Cane Spring, (D-21-24)36bbc-S1, and from an unnamed spring, (D-22-25)18cdb-S1, were collected and analyzed. The geologic setting is similar at both springs: Each spring is located near a fault and, at both sites, the Kayenta Formation is at the surface on the upthrown side of the fault. At Cane Spring, the Summerville Formation is at the surface on the downthrown side of the fault, and at the unnamed spring, the Entrada Sandstone is at the surface on the downthrown side of the fault.

The concentration of dissolved solids in water from Cane Spring was 4,240 mg/L (table 4), and the water type was calcium sodium sulfate chloride. The concentration of dissolved solids in water from the unnamed spring was 666 mg/L (table 4), and the water type was calcium sodium bicarbonate sulfate chloride.

Water from the two springs had some similarities, but also had major differences. Calcium and sodium were significant cations and sulfate and chloride were significant anions at both springs, but bicarbonate was not significant at Cane Spring. At Cane Spring, the concentration of dissolved solids was about six times that at the unnamed spring.

It appears that in areas of faulting, the chemical quality of the ground-water resource is not predictable. It may, or may not, resemble the chemical quality of ground water in the formations that are at the surface on either side of the fault.

Recharge and Ground-Water Movement

The La Sal Mountains (pl. 1) are a principal recharge area for the aquifers in consolidated sedimentary rocks in the Grand County area. The La Sal Mountains with winter snowpack are shown in figure 8. Average annual precipitation in the mountains is about 30 inches, and about two-thirds of the precipitation falls from October to April, mostly as snow. The peaks of the mountains mostly are talus slopes, and these slopes probably accept a substantial amount of the winter snowpack as recharge when the snowpack melts in the spring. Sedimentary strata are upturned and fractured on the flanks of the mountains, and are capable of accepting more recharge than is possible when the strata are not fractured. Recharge in the the La Sal Mountains ultimately provides water to unconsolidated Quaternary deposits in Spanish Valley and Castle Valley. Sumsion (1971) estimated recharge to the part of the La Sal Mountains area that is drained by Mill Creek and Pack Creek to be about 22,000 acre-ft/yr (acre-feet per year), and the Mill Creek and Pack Creek drainages are only a small part of the entire La Sal Mountains area.

The approximate altitude of the potentiometric surface and the general direction of ground-water movement in the upper ground-water system were modified from Rush and others (1982), Weir, Maxfield, and Hart (1983), and Weir, Maxfield, and Zimmerman (1983), and are shown in figure 9. General movement of ground water is toward the major perennial streams. Northwest of the Colorado River, the direction of ground-water movement is toward the Colorado River and the Green River, with a ground-water divide separating the two directions of flow. Southeast of the Colorado River, the direction of ground-water movement generally is from the La Sal Mountains toward the Colorado River.

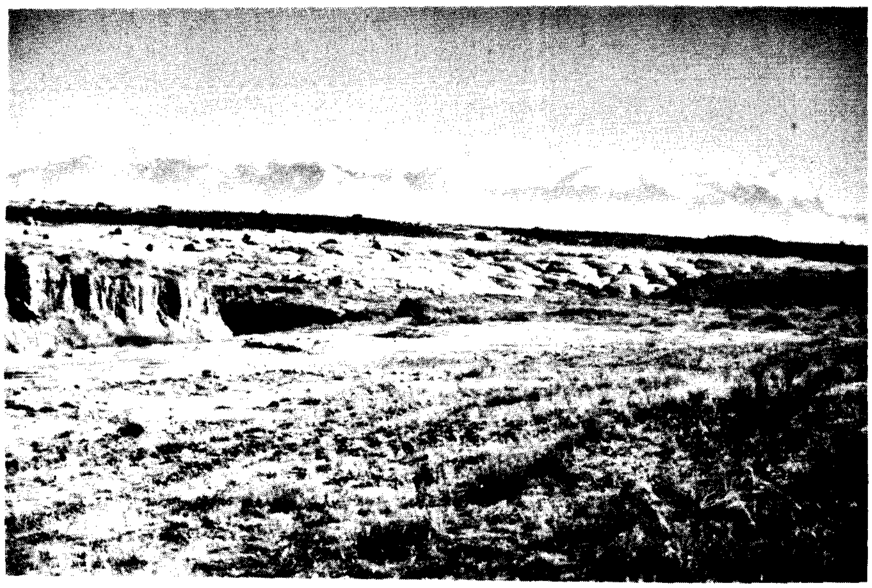


Figure 8.--La Sal Mountains with winter snowpack.

Principal Bedrock Aquifers

This section presents data and interpretation of ground-water conditions in the three principal aquifers in the Grand County area: The Entrada aquifer, the Navajo aquifer, and the Wingate aquifer. Areas of recharge and discharge, direction of ground-water movement, chemical quality of water in the aquifers, and characteristics of the aquifers will be discussed. Ground-water conditions in the Glen Canyon aquifer in the Mill Creek-Spanish Valley area will be discussed in a separate section.

The Entrada aquifer

The Entrada Sandstone crops out primarily in and near Arches National Park, east of Arches National Park, in the upper reaches of the Mill Creek drainage, and south and west of the Moab fault in T. 24 S., R. 19 and 20 E. (pl. 2). The Entrada aquifer is contained in the Entrada Sandstone.

Recharge to the Entrada aquifer probably occurs where the Entrada Sandstone crops out or where it is mantled by unconsolidated deposits. The rate of infiltration to the Entrada aquifer probably is much larger where the Entrada Sandstone is fractured or jointed. In the Arches National Park area, recharge probably occurs on the flanks of the Salt Valley anticline, and movement of water is away from the anticline, particularly toward the Courthouse syncline to the west.

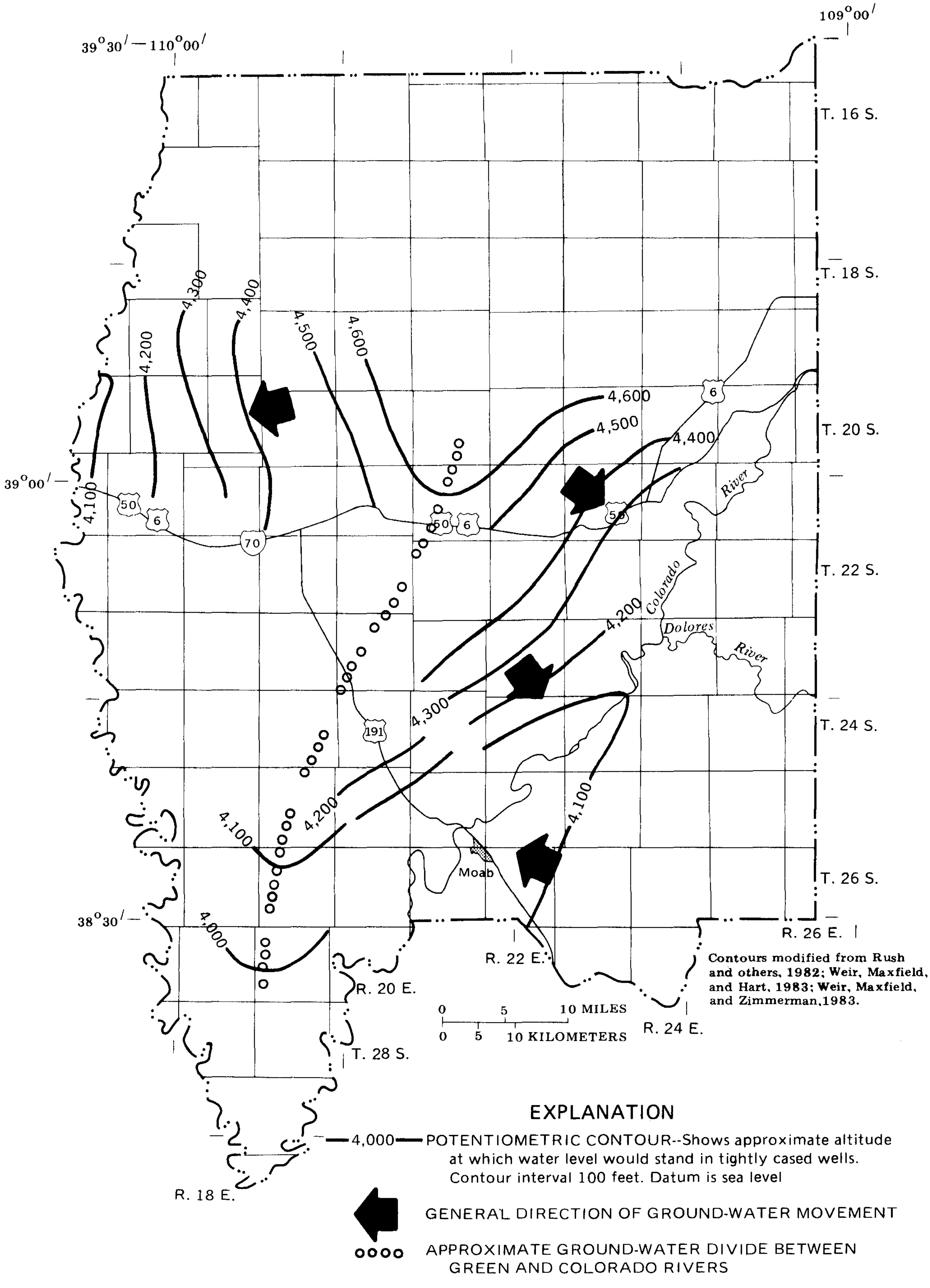


Figure 9.--Approximate potentiometric surface and general direction of movement of water in the upper ground-water system.

Spring and seep discharge from the Entrada aquifer occurs where vertical hydraulic conductivity is decreased by contacts between crossbed sets or by the finer grained Dewey Bridge Member of the Entrada Sandstone that underlies the Slick Rock Member of the Entrada Sandstone. Several alcoves at the base of the Slick Rock Member are shown in figure 10. The alcoves are the result of ground water discharging from the Slick Rock Member because the underlying Dewey Bridge Member impedes further downward flow. Ground water moving to the discharge area dissolves the calcium carbonate cement from the sandstone of the Slick Rock Member, which weakens the sandstone, and it eventually crumbles off the outcrop.

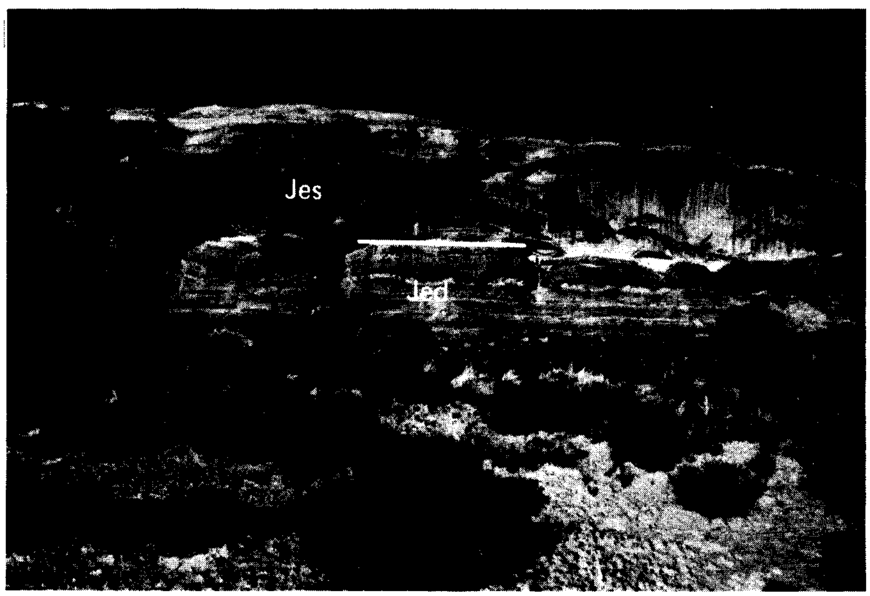


Figure 10.--Alcoves at different stages of development at the base of the Slick Rock Member of the Entrada Sandstone (Jes), at location (D-25-19)11d. Dewey Bridge Member of Entrada Sandstone (Jed), underlies Slick Rock Member.

One of the principal areas of spring discharge from the Entrada aquifer is in the canyon of Courthouse Wash and in Sevenmile Canyon near its mouth (pl. 1). Courthouse Wash and the axis of the Courthouse syncline are coincident in this area. Seepage occurs from the walls of both canyons, and several springs discharge from alcoves in the northeast canyon wall of Courthouse Wash. Several of the springs were inventoried by Sumsion (C.T. Sumsion, U.S. Geological Survey, written commun., 1971), and discharge from the springs ranged from 0.1 to 11.1 gal/min. Information collected during the inventory at Alcove Spring [(D-24-21)31dab-S1], Antler Pool Spring [(D-25-21)5abb-S1], and Mossy Pool Spring [(D-25-21)5bbb-S1], is shown in table 7.

Two springs, Lost Spring [(D-23-22)17cab-S1] and an unnamed spring [(D-23-21)23dad-S1], are known to discharge from the Entrada aquifer east of the Salt Valley anticline, and Brink Spring [(D-24-19)10dcd-S1] and a flowing well [(D-24-20)19caa-1] are known to discharge along the Moab fault (pl. 1; tables 7 and 8). These sites were inventoried during this study. Discharge from the springs ranged from 0.5 to 2.5 gal/min, and discharge from the flowing well was about 15 gal/min. The discharge point of the unnamed spring, at an intersection of a fracture and a contact between crossbed sets, is shown in figure 11A. Water moves from the discharge point in a rivulet under watercress and other vegetation for about 200 feet, and then appears flowing over talus (fig. 11B).

Water samples from Alcove Spring, Antler Pool Spring, and Mossy Pool Spring inventoried by Sumsion (C.T. Sumsion, U.S. Geological Survey, written commun., 1971), and from the three springs and the flowing well inventoried during this study were collected and analyzed. Results of the analyses are given in table 4.

Concentrations of dissolved solids ranged from 143 to 157 mg/L in the Arches National Park area and from 119 to 182 mg/L along the Moab Fault. The water type was calcium carbonate in the Arches National Park area and calcium carbonate or calcium magnesium carbonate along the Moab Fault. Hardness ranged from 100 to 170 mg/L, or from hard to very hard. Concentrations of arsenic, barium, iron, and selenium were less than the State of Utah primary drinking-water standards.

Four water samples from a well completed in the Entrada aquifer at location (D-24-19)17abc were collected and analyzed in 1982 and 1983 (J.L. Proffitt, written commun., 1983). The median concentration of dissolved solids in the four samples was 300 mg/L, and the water type of all four samples was magnesium calcium bicarbonate.

Feltis (1966, p. 44-69) reported concentrations of major ions and dissolved solids in water samples that were collected from the Entrada aquifer in three oil-test holes and one water well. The sites are located north of the Entrada Sandstone outcrop area (fig. 7), and the depth to the Entrada Sandstone ranged from about 900 to about 5,300 feet below land surface. The concentration of dissolved solids ranged from 9,470 mg/L to about 86,600 mg/L, and the water type at each site was sodium chloride (fig. 7; table 6). In unpublished data from the files of the U.S. Geological Survey, the concentration of dissolved solids in water collected from the Entrada aquifer at four sites located north of the Entrada Sandstone outcrop area ranged from 4,330 to 104,000 mg/L (fig. 7; table 6).

Table 7.--*Records of selected springs*

[Abbreviations: gal/min, gallons per minute; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

Spring number: See "Numbering system for hydrogeologic-data sites", p. 5 and figure 2.
Geologic source: 200MSZC, Mesozoic undifferentiated; 217CDRM, Cedar Mountain Formation; 221SLWS, Salt Wash Sandstone Member of Morrison Formation; 221ENRD, Entrada Sandstone; 227GLNC, Glen Canyon Group; 227NVJO, Navajo Sandstone; 231WNGT, Wingate Sandstone.
Altitude: In feet above sea level.
Discharge: Method of measurement--P, modified Parschall flume; V, volumetrically; M, not specified; H, Hoff meter; F, in-line flowmeter; E, estimated.

Spring number	Spring name	Geologic source	Altitude (feet)	Discharge (gal/min)		Date discharge measured	Temperature (°C)	Specific conductance (µS/cm)	pH (units)	Date parameters measured
(D-21-24)36bbc-S1	Cane Spring	200MSZC	4,200	43.5	P	09-08-85	15.0	5,290	8.0	09-08-85
(D-22-21)32aac-S1	Unnamed Spring	217CDRM	4,700	--		--	--	1,600	8.4	12-13-85
(D-22-25)12bda-S1	Burn Spring	400PCMB	5,720	42.0	V	09-07-85	15.0	680	8.2	09-07-85
(D-22-25)18cdb-S1	Unnamed Seep	200MSZC	4,520	20.0	E	09-08-85	15.5	1,100	7.4	09-08-85
(D-23-20)32dca-S1	Burro Seep	--	4,580	.2	V	07-26-86	22.5	610	7.0	07-26-86
(D-23-21)23dad-S1	Unnamed Spring	221ENRD	4,520	2.0	V	08-08-86	14.0	255	8.2	08-08-86
(D-23-22)17cab-S1	Lost Spring	221ENRD	4,660	.5	V	06-10-85	15.0	255	8.2	06-10-85
(D-23-23)11dbc-S1	Unnamed Spring	227NVJO	4,420	--		--	12.5	560	7.9	11-23-85
(D-23-23)12dba-S1	Buck Spring	227NVJO	4,240	2.5	V	12-17-85	13.0	670	7.6	12-17-85
(D-24-18) 7aaa-S1	Dripping Spring	227NVJO	4,400	2.5	E	11-26-85	12.5	220	8.2	11-26-85
(D-24-19)10dcd-S1	Brink Spring	221ENRD	4,720	2.5	V	11-26-85	14.0	205	8.0	11-26-85
(D-24-21)31dab-S1	Alcove Spring	221ENRD	4,240	8.2	M	09-01-70	13.0	225	7.7	09-15-70
(D-24-24)21ddb-S1	Stinking Spring	324PRDX	4,960	2.0	E	07-13-86	15.0	18,000	--	07-13-86
(D-25-18) 9ddc-S1	Deadman Spring	227NVJO	5,040	.3	V	06-21-86	17.0	320	7.7	06-21-86
(D-25-21) 5abb-S1	Antler Pool Spring	221ENRD	4,240	6.0	M	09-15-70	12.5	270	8.0	09-15-70
(D-25-21) 5bbb-S1	Mossy Pool Spring	221ENRD	4,240	11.0	M	09-15-70	13.0	250	7.4	09-15-70
(D-25-21)26bdc-S1	Lions Club Spring	231WNGT	4,040	7.0	M	01-00-68	17.0	300	8.1	10-08-58
(D-25-21)26bdc-S2	Goatman Spring	231WNGT	4,040	--		--	16.0	295	8.0	08-17-85
(D-25-21)26bdd-S1	Matrimony Spring	231WNGT	4,000	6.5	V	07-26-86	16.0	285	8.1	11-06-86
(D-25-21)35aaa-S1	Skakel Spring	231WNGT	4,080	240	E	10-19-67	17.5	290	8.0	08-15-85
(D-26-22)14acc-S1	Deep Cut Spring	227NVJO	4,660	90.0	M	11-19-68	16.0	305	7.6	11-19-68
(D-26-22)15cbb-S1	Birch Spring	227GLNC	4,460	90.0	E	10-00-67	14.0	295	7.6	10-19-67
(D-26-22)15cca-S1	Somerville Spring	227GLNC	4,480	15.0	V	08-09-86	15.0	350	7.7	11-06-86
(D-26-22)15cdc-S1	Moab Spring Number 1	227GLNC	4,480	50.0	M	03-01-69	16.0	460	7.6	08-16-85
(D-26-22)22aaa-S1	Moab Spring Number 2	227GLNC	4,580	330	H	08-29-85	15.0	280	7.6	08-16-85
(D-26-22)22aad-S1	Moab Spring Number 3	227GLNC	4,580	390	F	08-29-85	16.0	285	7.4	08-15-85
(D-26-23)26dcc-S1	Unnamed Spring	221SLWS	7,440	0.25	V	07-27-86	15.0	1,640	7.6	07-27-86
(D-27-19)22bbc-S1	Neck Spring	227NVJO	5,680	<5	E	07-10-86	15.0	190	8.2	07-10-86

A.

B.

Figure 11.--A) unnamed spring (D-23-21)23dad-S1, discharging from the Entrada aquifer at the intersection of a fracture and a contact between crossbed sets; and B) discharge surfacing about 200 feet from point of discharge from bedrock.

Table 8.--*Records of selected*

[Abbreviations used in headings: gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot of

Well number: See "Numbering system for hydrogeologic-data sites", p. 5 and figure 2.
Geologic source: 110ALVM, alluvium of Quaternary age; 217CDRM, Cedar Mountain Formation; 221BRSB, Brushy Basin Shale Member of 310CTLR, Cutler Formation.
Type of opening: P, perforated; X, open hole without casing.

Well number	Owner	Date of construction	Altitude of land surface (feet)	Geologic source	Diameter of well (inches)	Diameter of casing (inches)	Depth of well (feet)	Depth to aquifer (feet)	Bottom of casing (feet)
(D-22-23)25bac- 1	U.S. Bureau of Land Management	--	4,220	217CDRM	--	--	--	--	--
(D-22-23)29ada- 1	U.S. Bureau of Land Management	--	4,380	221BRSB	--	--	--	0	--
(D-23-21)27bcd- 1	U.S. National Park Service	10-00-62	5,200	231WNGT	8.00	6.00	900	765	900
(D-24-18)25dba- 1	U.S. Bureau of Land Management	02-00-37	5,300	227NVJO	--	8.25	604	--	19.0
(D-24-19)36bba- 1	U.S. Bureau of Land Management	--	4,880	227NVJO	--	5.5	--	--	--
(D-24-20)19caa- 1	U.S. Bureau of Land Management	--	4,680	221ENRD	--	--	--	0	--
(D-25-20)21dbb- 1	U.S. Bureau of Land Management	--	5,080	--	--	--	--	--	--
(D-25-20)32dbc- 1	U.S. Bureau of Land Management	--	5,240	--	--	7.0	225	--	--
(D-25-21)20add- 2	U.S. National Park Service	11-12-58	4,120	227NVJO	8.00	8.0	123	0	123
(D-25-21)21bdc- 1	U.S. National Park Service	05-19-78	4,080	227NVJO	12.00	8.0	172	0	172
(D-25-22)12aad- 1	Devore, Kenneth	04-13-80	4,600	310CTLR	4.00	4.00	233	40	233.0
(D-25-23)18baa- 1	D'Agnese, Denise	07-15-78	4,800	310CTLR	6.00	6.00	166	35	40.0
(D-25-23)20adb- 1	Degles, Robert	11-20-77	5,040	310CTLR	--	6.00	230	40	40.0
(D-26-22) 8bad- 1	Grand Co. Water Cons. District	06-30-80	4,240	227GLNC	--	--	610	0	--
(D-26-22) 8dbb- 1	Dunkin, E.	07-25-83	4,520	227GLNC	5.5	6.63	460	0	100
(D-26-22) 8dda- 1	Norman, L.	11-12-79	4,460	227GLNC	5.62	7.00	150	15	28.0
(D-26-22) 8dda- 2	Haaland, Martin	07-17-85	4,440	227GLNC	5.88	4.5	188	0	188
(D-26-22) 9ddc- 1	Norman, Robert R.	--	4,600	227GLNC	--	--	--	--	--
(D-26-22)14cba- 1	Norman, Robert R.	07-27-84	4,820	227GLNC	10.62	6.63	460	3	102
(D-26-22)14cbd- 1	Redd, Thomas	06-20-78	4,780	227GLNC	6.75	6.00	320	0	320
(D-26-22)15acb- 1	Turvey, Paul	05-03-78	4,660	227GLNC	7.00	6.00	270	5	270
(D-26-22)15acc- 1	Larsen, Ray	06-03-77	4,600	227GLNC	8.00	6.00	200	10	200
(D-26-22)15bbb- 1	Cochran, John M.	08-17-77	4,560	227GLNC	6.00	5.50	250	0	236
(D-26-22)15bcc- 1	Magee, Dail	01-03-78	4,520	227GLNC	6.00	6.00	140	10	20
(D-26-22)15bdb- 1	Grand Co. Water Cons. District	12-03-64	4,620	227GLNC	8.00	6.00	160	2	20
(D-26-22)15cca- 1	Day, Max	08-05-77	4,480	227GLNC	8.0	6.6	119	4	111
(D-26-22)15daa- 2	City of Moab Well Number 10	07-15-76	4,660	227GLNC	12.0	10.0	300	0	300
(D-26-22)15dca- 1	City of Moab Well Number 6	02-01-69	4,600	227GLNC	14.0	14.0	181	25	181
(D-26-22)15ddc- 1	City of Moab Well Number 7	10-27-72	4,590	227GLNC	16.0	16.0	325	15	325
(D-26-22)17aaa- 2	McCormick, Richard E.	03-15-81	4,460	227GLNC	8.8	10.8	180	1	16.0
(D-26-22)17aba- 3	Oliver, Harold	10-21-62	4,320	227GLNC	7.0	7.0	100	0	100
(D-26-22)22aab- 1	City of Moab Well Number 4	05-18-61	4,580	227GLNC	12.0	12.8	100	16	63.0
(D-26-22)22aab- 2	City of Moab Well Number 4A	10-00-72	4,580	227GLNC	--	16.0	222	--	222
(D-26-22)22aac- 1	City of Moab Well Number 5	08-20-62	4,570	227GLNC	12.8	12.8	238	11	238
(D-26-22)22abc- 1	Ritchie, Robert	08-05-65	4,520	227GLNC	6.0	6.0	80	6	66
(D-26-22)22daa- 1	Broughton, B.	04-30-69	4,600	227GLNC	12.0	12.0	200	18	150
(D-26-22)22dad- 1	Rattle, Paul S.	03-23-73	4,600	227GLNC	8.0	8.0	110	0	87
(D-26-22)22dcd- 1	White, George M.	06-19-59	4,580	110ALVM		16.0	70	0	
(D-26-22)23bba- 1	City of Moab Well Number 9	04-07-75	4,640	227GLNC	14.0	14.0	450	18	235
(D-26-22)23cdd- 1	Grand Co. Water Cons. District	02-25-71	4,680	227GLNC	16.0	16.0	174	8	120
(D-26-22)26acd- 1	Whitney, Susan	--	4,740	227GLNC	--	--	--	--	--
(D-26-22)26dbc- 1	Axtell, Larry	04-25-79	4,700	110ALVM	6.0	6.0	235	0	234
(D-26-22)26dbd- 1	City of Moab Well Number 11	07-29-70	4,710	227GLNC	16.0	14.0	210	140	190
(D-26-22)26dda- 1	Jolly, James	00-00-75	4,740	227GLNC	5.0	5.0	220	0	156
(D-26-22)35ada- 1	Bull, L.W.	02-18-62	4,740	110ALVM	5.5	5.5	185	0	185
(D-26-22)35bdd- 2	Callor, J.	04-01-63	4,740	110ALVM	6.0	6.0	247	0	247

water wells

ʳawdown; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

ɔrrison Formation; 221ENRD, Entrada Sandstone; 227GLNC, Glen Canyon Group; 227NVJO, Navajo Sandstone; 231WNGT, Wingate Sandstone;

Top of open nterval (feet)	Type of opening	Water level (feet)	Date water level measured	Discharge (gal/min)	Drawdown (feet)	Pumping period (hours)	Specific capacity [(gal/min)/ft]	Date measured	Temper-ature (°C)	Specific conductance (µS/cm)	pH (units)	Date parameters measured
--	-	--	--	0.20	--	--	--	07-21-86	22.5	2,670	8.3	07-21-86
--	-	--	--	.20	--	--	--	08-18-85	26.5	1,630	7.6	08-18-85
819	P	747	10-30-62	8.00	--	--	--	04-16-79	20.0	515	7.8	08-07-86
19.0	X	562	06-20-86	5.00	20.0	--	0.25	02-05-37	--	--	--	--
--	-	193	09-04-85	--	--	--	--	--	--	--	--	--
--	-	--	--	15.0	--	--	--	11-24-85	14.0	335	7.8	11-24-85
--	-	400	10-16-85	--	--	--	--	--	15.0	1,190	--	10-29-85
--	-	65.0	10-17-85	--	--	--	--	--	--	--	--	--
98.4	P	91.7	12-20-58	12.0	7.00	6.0	1.7	12-20-58	19.0	1,000	7.4	08-07-86
112	P	114	05-19-78	30.2	2.08	24.0	14.5	05-23-78	19.0	1,690	7.4	08-07-86
200	P	172	04-13-80	15.0	--	--	--	04-13-80	16.0	3,260	7.3	09-30-86
40.0	X	100	07-15-78	25.0	0	2.0	--	07-15-78	15.0	3,950	7.5	09-30-86
40.0	X	190	11-30-77	10.0	0	1.0	--	11-20-77	15.0	1,940	7.3	09-30-86
--	-	56.9	07-25-86	360	--	--	--	06-30-80	15.5	365	7.6	09-05-85
100	X	332	04-30-86	--	--	--	--	--	--	--	--	--
28.0	X	101	07-11-86	--	--	--	--	--	--	--	--	--
120	P	114	04-29-86	10.0	--	--	--	--	--	--	--	--
--	-	--	--	--	--	--	--	--	18.0	265	7.8	07-11-86
102	X	215	06-22-86	--	--	--	--	07-27-84	16.0	255	8.2	06-22-86
310	P	156	06-22-86	12.0	0	2.0	--	06-20-78	15.0	245	7.6	11-05-86
251	P	125	03-26-86	12.0	0	3.0	--	05-03-78	15.0	270	7.7	08-05-86
170	P	77.8	03-25-86	8.0	0	4.0	--	06-03-77	--	--	--	--
220	P,X	185	03-26-86	10.0	40.0	4.0	0.25	08-17-77	15.0	260	7.9	11-05-86
20	X	51.6	03-26-86	--	--	--	--	--	15.0	385	7.8	11-05-86
20	X	90.5	11-20-85	42.5	21.0	5.3	2.0	05-08-77	--	--	--	--
111	X	15.5	03-26-86	20.0	4.00	1.00	5.0	08-05-77	16.0	330	7.7	08-09-86
180	P	122	01-10-87	750	22.0	--	34.1	10-00-78	15.5	255	7.8	08-15-85
105	P	49.8	01-27-86	938	12.0	--	78.2	10-00-78	15.0	360	7.7	08-15-85
105	P	30.5	01-10-87	322	33.0	--	9.8	10-00-78	15.0	370	7.7	11-05-86
16.0	X	105	03-25-86	35.0	1.5	1.00	23.3	03-15-81	16.5	285	7.8	11-05-86
89.0	P	31.8	03-25-86	32.0	0	3.00	--	10-21-62	--	--	--	--
20.0	P,X	26.4	01-10-87	600	40.0	8.00	15.0	05-18-61	13.5	275	7.6	11-19-68
70.0	P	27.2	01-10-87	1,190	30.0	--	39.7	12-00-72	--	--	--	--
114	P	2.4	01-10-87	180	231	--	0.8	08-00-78	15.5	280	7.9	08-16-85
66.0	X	11.9	02-26-86	25	0	1.0	--	08-05-65	15.0	620	7.4	08-05-86
77.0	X	10.8	02-26-86	200	20.0	24.0	10.0	04-30-69	--	--	--	--
87.0	X	10.4	02-26-86	160	--	--	--	03-23-73	16.5	380	7.7	07-12-86
		34.0	06-19-59	100	51.0	--	2.0	06-19-59	16.0	930	7.6	07-09-68
110	P,X	12.9	01-10-87	180	205	--	0.9	10-00-78	--	--	--	--
120	X	75.0	03-09-71	1,600	48	1.0	33.3	02-25-71	16.0	445	7.8	08-28-85
--	-	125	02-26-86	--	--	--	--	--	17.0	685	7.5	08-09-86
--	P	80.2	02-26-86	50.0	13	6.0	3.8	04-25-79	15.0	1,050	7.2	11-05-86
140	P,X	101	02-26-86	1,500	9	12	167	07-29-70	17.0	920	7.5	08-19-85
156	X	137	02-26-86	--	--	--	--	--	18.0	705	7.6	07-12-86
185	P	154	02-18-62	7.0	0	1.0	--	02-18-62	14.0	1,230	7.6	07-08-69
230	P	--	--	30.0	0	1.0	--	04-01-63	10.0	980	7.7	09-05-68

The data discussed in the preceding paragraphs indicate that the Entrada aquifer typically contains freshwater in and near outcrop areas of the Entrada Sandstone, but the water is hard to very hard. Water in the Entrada aquifer is moderately saline at two locations about 6 miles north of the outcrop area, and generally is more saline farther north of the outcrop area, where the Entrada Sandstone is more deeply buried (fig. 7). Based on this evidence, fresh water in the Entrada aquifer probably is present only for a short distance north of the outcrop area.

Water from the unnamed spring and Lost Spring near the eastern border of Arches National Park, and from well (D-24-20)19caa-1 and Brink Spring near the Moab fault was analyzed for the activity of radionuclides (table 5). The activities of radium in water from Lost Spring and Brink Spring (0.19 pCi/L and 0.15 pCi/L) were the two largest of 15 samples collected and analyzed in the Grand County area; however, the activity was less than 5 percent of the State of Utah primary drinking-water standard of 5.0 pCi/L. Alpha and beta activities were about 10 percent or less of the State of Utah primary drinking-water standards of 15 and 50 pCi/L. Beta activities near the Moab fault, however, were about twice as large as those near the eastern border of Arches National Park.

Jobin (1962, figs. 23 and 24) estimated values of hydraulic conductivity and transmissivity for the Entrada aquifer in the Grand County area. Jobin's estimate of hydraulic conductivity ranged from about 0.1 ft/d in the western part of the area to more than 1.1 ft/d in the eastern part of the area, and his estimate of transmissivity ranged from about 50 ft^2/d in the western part of the area to more than 150 ft^2/d in the eastern part of the area.

The Navajo aquifer

The Navajo Sandstone crops out extensively in the southern part of the Grand County area. Principal areas of outcrop are in the southern part of Arches National Park, east of Arches National Park along the Colorado River, east of Spanish Valley in the Mill Creek drainage, west of Spanish Valley, in and directly north of Canyonlands National Park, and in a large area about 10 to 15 miles north of Canyonlands National Park (pl. 2). The Navajo Sandstone contains the Navajo aquifer. Two water-supply wells in Arches National Park are completed in the Navajo aquifer, and small springs provide water from the Navajo aquifer for stock watering in several locations.

Recharge to the Navajo aquifer typically occurs by direct infiltration of precipitation where the Navajo Sandstone is at the surface or by indirect infiltration of precipitation where the Navajo Sandstone is overlain by unconsolidated deposits. Typically, the exposed surface of the Navajo Sandstone has small domes or knolls alternating with depressions, and the depressions are enclosed drainages (fig. 4). Precipitation runs off the domes or knolls and collects in the depressions, where it either evaporates or infiltrates into the Navajo Sandstone. The rate of recharge to the Navajo aquifer probably is much larger where the formation is fractured or jointed.

Recharge is enhanced where the depressions in the surface of the Navajo Sandstone contain thick, unconsolidated deposits. The deposits typically are erosional products of the formations of the Glen Canyon Group, are sandy, and are capable of holding water in storage for infiltration into the Navajo

Sandstone. Freeze and Cherry (1979, p. 152) estimated the porosity of nonindurated sands to be from 30 to 50 percent. Where water in the unconsolidated deposits is more than about 10 feet below the surface, evapotranspiration probably is insignificant, and most of the stored precipitation recharges the Navajo aquifer. The rate of evaporation of water from unconsolidated sand decreases rapidly below a depth of about 6 feet below the land surface to nearly zero at a depth of about 10 feet below the land surface (Ripple and others, 1972). Movement of water in the Navajo aquifer generally is from recharge areas to canyons that cut through the Navajo Sandstone. Discharge of water from the Navajo aquifer by springs is not concentrated in any part of the Grand County area, but may occur wherever canyons cut through part of the thickness of the Navajo Sandstone and the Navajo Sandstone is at the surface nearby.

Neck Spring [(D-27-19)22bbc-S1] in Canyonlands National Park, is an example of a large seep from the Navajo aquifer (fig. 12). At Neck Spring, there are two horizontal bands of discharge, each at the bottom of a crossbed set. The seepage face on the largest band (the lower band) is about 350 to 400 feet long, and about 6 feet wide. The spring is recessed in an alcove which faces generally north, and direct sunlight reaches it for only short periods on the longest days of the year. The sites of largest discharge are drips and, except for evaporation, discharge from the entire seepage face is probably less than 5 gal/min.

At many seeps, a large part of the discharge, and at some seeps, all of the discharge, is evaporated from the canyon wall, and there is little or no water on the wall. The only evidence of ground-water discharge is a white, scaly or powdery mineral residue, as near Buck Spring (fig. 13).

Sandy unconsolidated deposits can play a role in the use of discharge from the Navajo aquifer. An area of discharge from the Navajo aquifer at the head of a canyon at location (D-26-18)27abb is shown in figure 14. Originally, ground water discharged into thick, sandy unconsolidated deposits. A pipe had been installed in the unconsolidated deposits, and enough water collected to supply a nearby stock tank. In an attempt to increase production, the sandy unconsolidated material was removed, and explosives were set off to fracture the Navajo Sandstone. There presently are several drips from the vertical surface of the Navajo Sandstone, but because the sandy unconsolidated material is no longer present, most of the discharge evaporates and no water is supplied to the stock tank.

Water samples were collected and analyzed from two wells completed in the Navajo aquifer and five springs discharging from the Navajo aquifer. The dissolved-solids concentrations and major ion chemistry of the springs reflect the distance of the sites from recharge areas and the distance that water has traveled in the aquifer.

Figure 12.--Two seepage faces (arrows) above contacts between crossbed sets in the Navajo Sandstone at Neck Spring, (D-27-19) 22bbc-S1.

Figure 13.--White mineral residue as evidence of discharge from canyon wall near Buck Spring, at location (D-23-23)12d.

Figure 14.--Seepage face (arrow) created by removal of unconsolidated material at head of canyon, at location (D-26-18)27abb. Water from Navajo aquifer no longer recharges unconsolidated material.

At Dripping Spring [(D-24-18)7aaa-S1] and Neck Spring, the dissolved-solids concentrations were 135 mg/L and 102 mg/L, the water types were calcium bicarbonate and calcium magnesium bicarbonate, and the water was moderately hard (table 4). The springs discharge from the Navajo aquifer near where the formation is recharged. The Navajo Sandstone is at the surface at both sites, and the springs discharge from canyon walls near the surface at contacts between crossbed sets.

At Deep Cut Spring [(D-26-22)14acc-S1], the concentration of dissolved solids was 171 mg/L, the water type was calcium magnesium bicarbonate, and the water was hard (table 4). The area where water is recharged to the Navajo aquifer may be several miles upgradient from Deep Cut Spring, but the recharge is from precipitation directly on the Navajo Sandstone or overlying sandy unconsolidated deposits. The water type is similar to Dripping Spring and Neck Spring, but the concentration of dissolved solids is larger and the water is harder because of the longer flow path through the Navajo aquifer.

At Buck Spring and at an unnamed spring [(D-23-23)11dbc-S1], dissolved-solids concentrations were 385 mg/L and 349 mg/L, the water types were calcium sodium magnesium bicarbonate and magnesium calcium sodium bicarbonate, and the water was very hard (table 4). The larger dissolved-solids concentration and the presence of sodium may be due to either contamination of surface water by movement across the nearby younger Summerville and Morrison Formations prior to recharging the Navajo aquifer, or by downward movement of water from those formations into the Navajo aquifer.

Two water samples from a well completed in the Navajo aquifer at location (D-24-18)12aca were collected and analyzed during 1982 and 1983 (J.L. Proffitt, written commun., 1983). Concentrations of dissolved solids in the two samples were 210 mg/L and 360 mg/L. The water types were magnesium sodium bicarbonate sulfate and magnesium sodium bicarbonate chloride sulfate.

Jobin (1962, figs. 20 and 21) estimated values of hydraulic conductivity and transmissivity for the Navajo aquifer in the Grand County area. Jobin's estimate of hydraulic conductivity ranged from less than 0.4 ft/d in the northeast to about 1 ft/d in the southwest, and his estimate of transmissivity ranged from nearly zero in the east where the formation pinches out to nearly 700 ft^2/d in the southwest.

Specific capacities of two water-supply wells in Arches National Park completed in the Navajo aquifer were 1.7 (gal/min)/ft at well (D-25-21)20add-2 and 14.5 (gal/min)/ft at well (D-25-21)21bdc-1 (table 8). The specific capacity at well (D-24-18)25dba-1 was 0.25 (gal/min)/ft (table 8).

The Wingate aquifer

The outcrop area of the Wingate Sandstone is small because the overlying, less permeable Kayenta Formation is generally resistant to erosion, and it caps the Wingate Sandstone in most places. The Wingate Sandstone generally crops out in canyon walls and floors, and in places as narrow benches at the tops of canyon walls. The Wingate Sandstone contains the Wingate aquifer. The outcrop area of the Wingate Sandstone is shown on plate 2.

Recharge to the Wingate aquifer generally occurs only where the Kayenta Formation is either sufficiently permeable or sufficiently fractured to allow downward movement of water through it from the land surface, from the Navajo aquifer, or from unconsolidated material. Movement of water in the Wingate aquifer is from areas of recharge toward canyons that cut through at least part of the Wingate Sandstone.

The principal area of discharge from the Wingate aquifer occurs near where Moab Valley meets the Colorado River. Discharge from springs ranges from less than 10 gal/min at Matrimony Spring [(D-25-21)26bdd-S1] to about 240 gal/min at Skakel Spring [(D-25-21)35aaa-S1]. One well completed in the Wingate aquifer, (D-23-21)27bcd-1, is used for water supply at Arches National Park.

Evidence of discharge from the Wingate aquifer in other areas includes alcoves formed in canyon walls, scaly or powdery mineral residue on canyon walls, or phreatophytes growing on the floor of canyons cut into the Wingate Sandstone. Discharge from the Wingate aquifer in Sevenmile Canyon at location (D-25-20)4d, as indicated by phreatophyte growth on the canyon floor, is shown in figure 15.

The concentration of dissolved solids in three water samples from springs discharging from the Wingate aquifer in the Moab Valley-Colorado River area ranged from 161 to 174 mg/L, the water type was calcium magnesium bicarbonate, and the water was moderately hard to hard (table 4). Recharge to the Wingate aquifer probably occurs nearby by downward movement from the

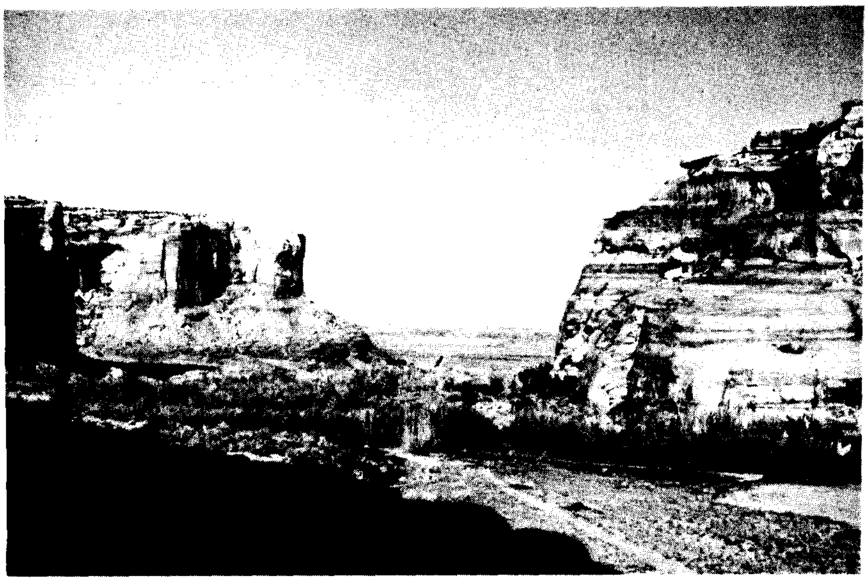


Figure 15.--Discharge from the Wingate aquifer into overlying unconsolidated material in Sevenmile Canyon, at location (D-25-20)4d. Discharge is evidenced by phreatophyte growth on canyon floor.

Navajo aquifer. The area is on a limb of the Moab Anticline (plate 2); the Navajo Sandstone is at the surface; and the Navajo Sandstone and the Wingate Sandstone, along with the intervening Kayenta Formation, are fractured and faulted. The small concentrations of dissolved solids and the water type indicate that recharge occurs nearby.

The concentration of dissolved solids in water from well (D-23-21)27bcd-1, in Arches National Park, was 280 mg/L, the water type was magnesium sodium calcium bicarbonate, and the water was very hard (table 9). The top of the Wingate Sandstone is 765 feet below land surface at this site and the recharge area is uncertain, but the flow path appears to be longer than that in the Moab Valley-Colorado River area.

Four water samples from a well completed in the Wingate aquifer at location (D-24-18)13caa were collected and analyzed during 1982 and 1983 (J.L. Proffitt, private consultant, written commun., 1983). The well was converted to an observation well from a uranium-exploration hole that was drilled by the Tennessee Valley Authority. The median concentration of dissolved solids for the four samples was about 45,000 mg/L, and the water type was sodium chloride.

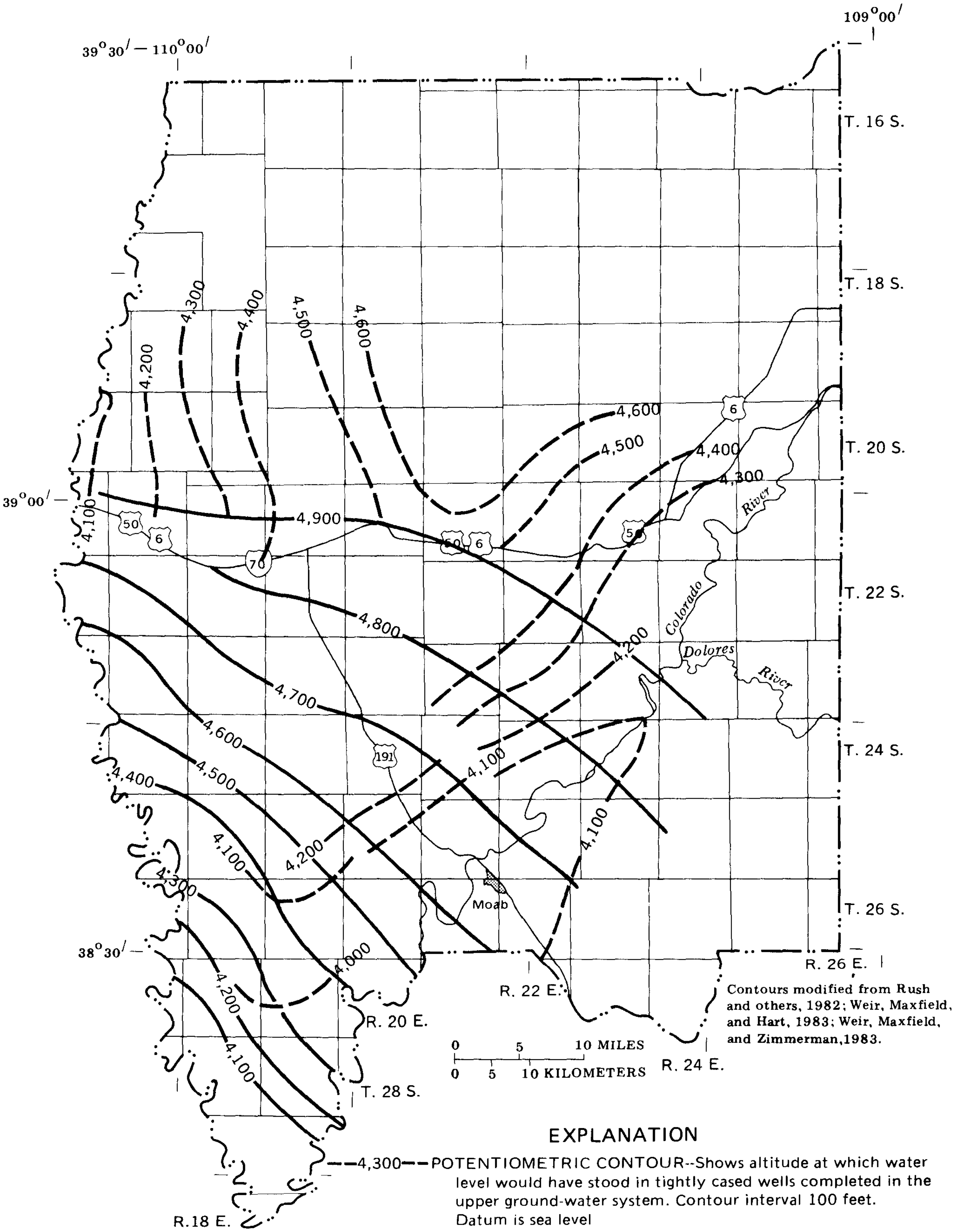
The large concentration of dissolved solids in water from the well located at (D-24-18)13caa is atypical for water in the upper ground-water system in this area. South of the outcrop area of rocks of younger age than the Entrada Sandstone, the concentration of dissolved solids in water samples collected from several formations that are part of the upper ground-water system ranged from 102 to 2,570 mg/L (fig. 7; tables 4 and 6). It is possible that the unusually large concentration of dissolved solids in water in the Wingate aquifer at location (D-24-18)13caa is caused by upward movement of water from the lower ground-water system or from the Paradox Member of the Hermosa Formation into the Wingate aquifer. Rush and others (1982; p. 12, fig. 5) indicate that the potential for upward leakage from the lower ground-water system to the upper ground-water system is present in this area, and Feltis (1966, p. 54-56) reported dissolved solids concentrations larger than 100,000 mg/L in water from the lower ground-water system and from the Paradox Member near location (D-24-18)13caa.

Extrapolation of potentiometric contours of the two ground-water systems as determined by Rush and others (1982; pl. 2, fig. 15) indicates that the potentiometric surface in the lower ground-water system is about 200 feet higher than that in the upper ground-water system at location (D-24-18)13caa (fig. 16). Feltis (1966, p. 54-56) reported dissolved-solids concentrations ranging from 160,000 to 230,000 mg/L in water from wells completed in the lower ground-water system about 10 miles northwest of location (D-24-18)13caa, and 300,000 mg/L in water from a well completed in the Paradox Member about 4 miles south of location (D-24-18)13caa.

Rush and others (1982, p. 12) indicated that movement of water from the lower ground-water system to the upper ground-water system could occur where salt beds of the Paradox Member have been removed by solution or plastic flow, or where faulting has caused the lower and upper ground-water systems to be juxtaposed, but these conditions are not known to exist near location (D-24-18)13caa. Poorly plugged petroleum-test or uranium-test holes that have been drilled through the upper ground-water system and into the Paradox Member or the lower ground-water system may provide pathways for movement of water from the lower ground-water system to the upper ground-water system.

J.L. Proffitt (private consultant, written commun., 1983) reported that seven uranium-test holes were drilled into the top of the Paradox Member in T. 24 S., R. 18 and 19 E. One of these wells is located 0.5 mile from (D-24-18)13caa, and another is located about 1.5 miles away from (D-24-18)13caa. Proffitt reported that all of the holes were plugged and abandoned; however, if plugging was not successful, these wells could provide a pathway for water containing large concentrations of dissolved solids to move upward from the Paradox Member into the Wingate aquifer and mix with water from the Wingate aquifer, resulting in water containing unusually large concentrations of dissolved solids in the Wingate aquifer.

Jobin (1962, figs. 14 and 15) estimated values of hydraulic conductivity and transmissivity for the Wingate aquifer in the Grand County area. Jobin's estimate of hydraulic conductivity ranged from about 0.1 ft/d in the north to more than 0.4 ft/d in the south, and his estimate of transmissivity ranged from about 40 ft^2/d in the north to more than 150 ft^2/d in the southwest.



EXPLANATION

—4,300— (dashed) POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells completed in the upper ground-water system. Contour interval 100 feet. Datum is sea level

—4,300— (solid) POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells completed in the lower ground-water system. Contour interval 100 feet. Datum is sea level

Figure 16.--Approximate potentiometric surface of water in the upper and lower ground-water systems.

GROUND-WATER CONDITIONS IN THE GLEN CANYON AQUIFER OF THE MILL CREEK-SPANISH VALLEY AREA

The Mill Creek-Spanish Valley area is located primarily in T. 26 and 27 S., R. 22 and 23 E. (fig. 17). The area includes about 37 square miles in the Mill Creek drainage and about 7 square miles in the Pack Creek drainage, southwest of the Mill Creek drainage. The Entrada Sandstone and the formations of the underlying Glen Canyon Group (the Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone) are exposed in most of the area (fig. 18). East of the Mill Creek-Spanish Valley area, the Summerville and the Morrison Formations are exposed.

In most of the Mill Creek drainage, the Entrada Sandstone and Glen Canyon Group dip to the west and southwest generally at less than 10 degrees (fig. 18). In the western part of the Mill Creek drainage and in the Pack Creek drainage, the geologic structure is more complex. Spanish Valley is in an eroded salt anticline (Weir, Maxfield, and Hart, 1983, p. 13); the area is faulted, and formations dip in various directions (fig. 18).

In the Mill Creek-Spanish Valley area, the Navajo and Wingate aquifers probably are in hydraulic connection because the intervening Kayenta Formation is mostly sandstone, and all three formations are jointed and fractured. The Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone form the Glen Canyon Group, and in this area contain one aquifer, designated the Glen Canyon aquifer. In the eastern part of the area, the Entrada aquifer also probably is in hydraulic connection with the underlying Glen Canyon aquifer. Areas of substantial discharge of ground water at the base of the Entrada aquifer were not observed; thus, suggesting that discharge is likely from the Entrada aquifer to the underlying Glen Canyon aquifer.

The Glen Canyon aquifer is the major consolidated-rock aquifer in the Grand County area. Most of the water supplied by the City of Moab is from wells and springs discharging from the Glen Canyon aquifer, and the principal culinary water-supply well for the Grand County Water Conservancy District is completed in the Glen Canyon aquifer.

Average annual precipitation in the Mill Creek-Spanish Valley area ranges from about 9 inches in the western part of the area near the mouth of North Fork of Mill Creek, to about 16 inches in the eastern part of the area near the eastern edge of the outcrop of the Entrada Sandstone (fig. 17). May-September precipitation ranges from less than 4 inches in the western part of the area to more than 6 inches in the eastern part. Precipitation increases with the altitude of the land surface: The altitude of the land surface increases from about 4,400 feet above sea level in the western part of the area to about 7,000 feet above sea level in the eastern part.

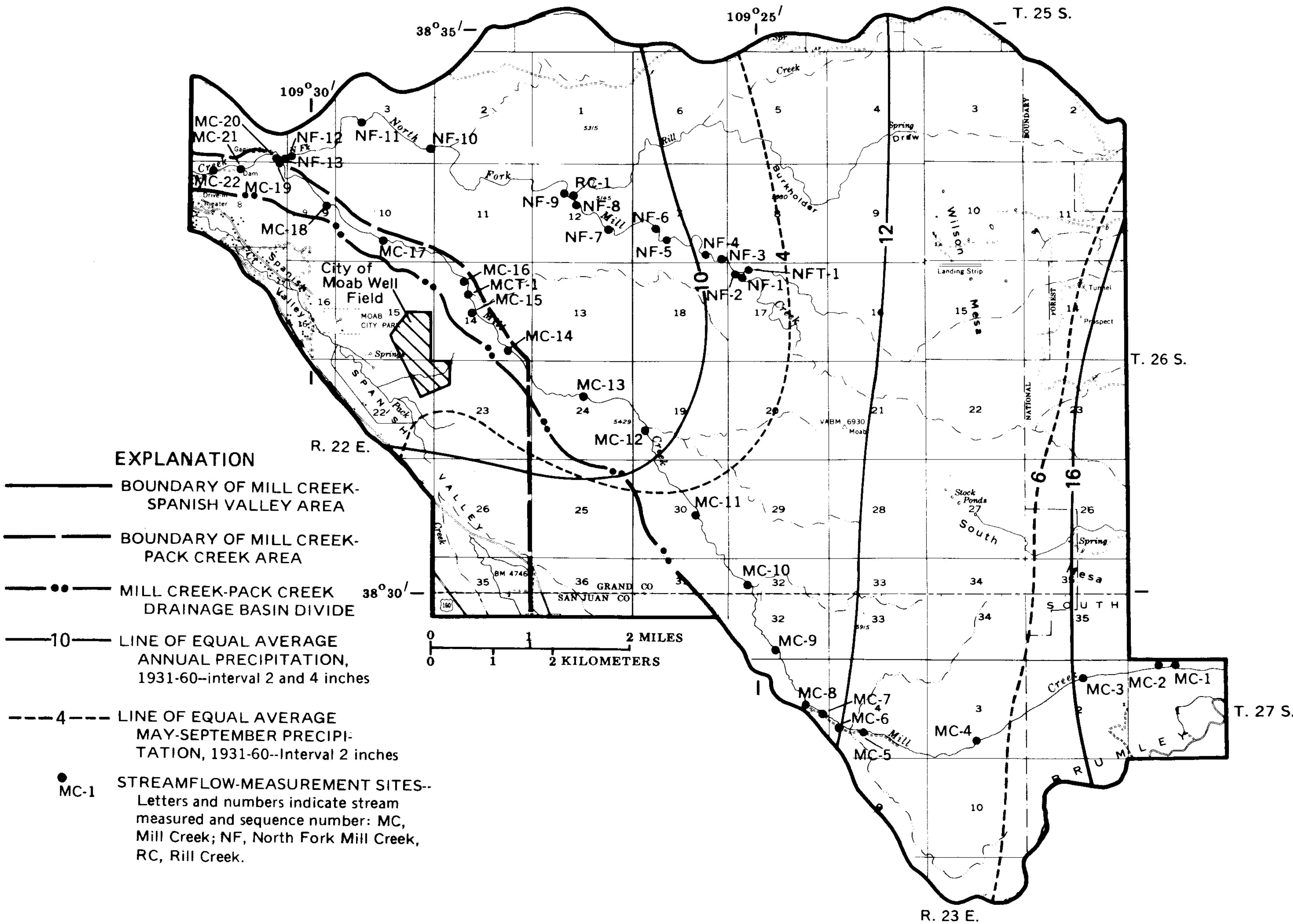


Figure 17.--Selected hydrologic data in the Mill Creek-Spanish Valley area.

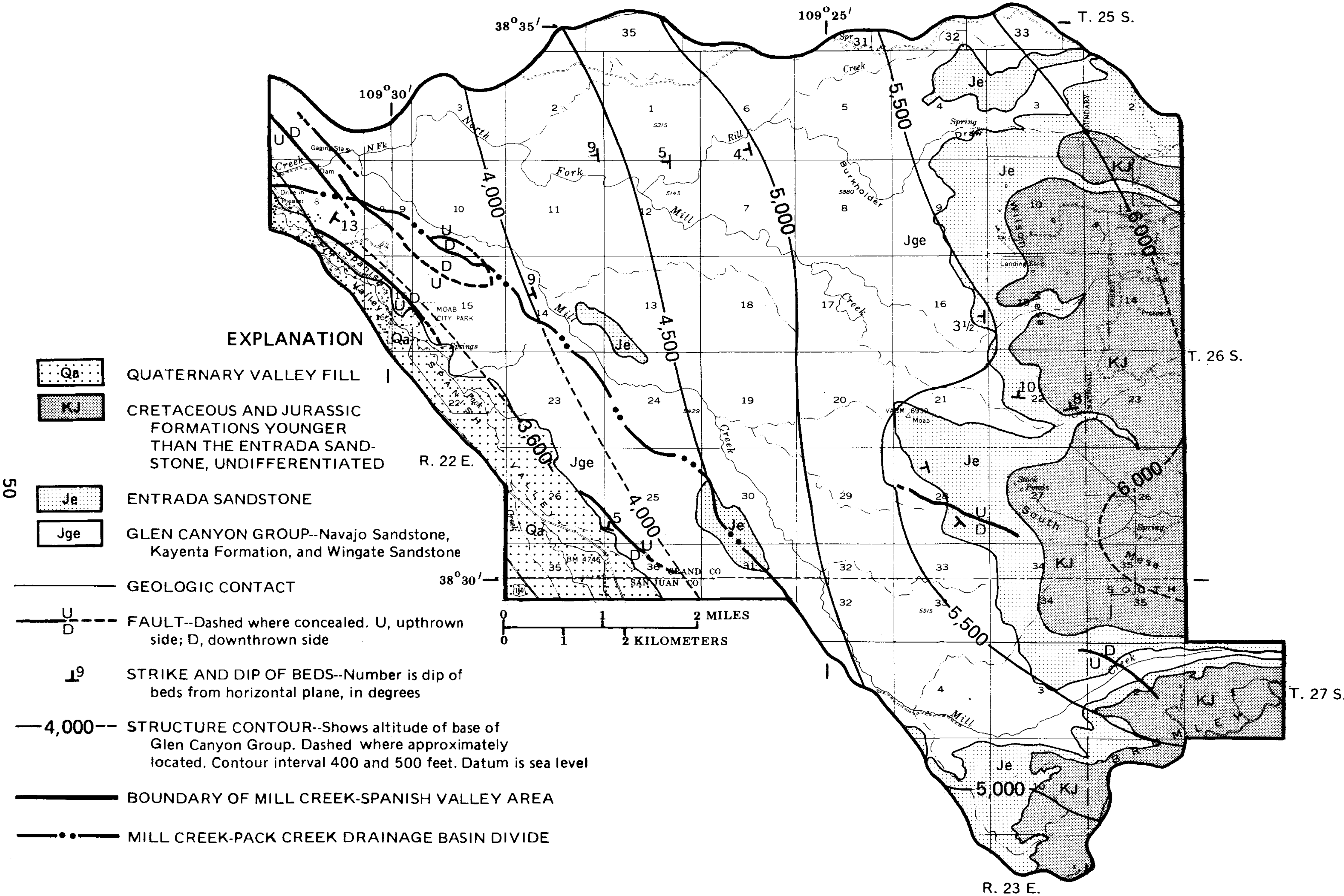


Figure 18.--Geology of the Mill Creek-Spanish Valley area.

Recharge, Movement, and Discharge

Most of the outcrop areas of formations in the Glen Canyon Group probably receive some recharge. The surface of the outcrop generally has small domes and knolls alternating with enclosed depressions, and the depressions typically contain loose sand that has eroded from the outcrops. Precipitation that falls on the knolls runs off into the depressions and is retained there along with the precipitation that falls directly on the depressions. Where the loose sand in the depressions is more than about 6 feet thick, it aids in retention of precipitation by reducing the evaporation rate (Ripple and others, 1972). Additional recharge to the Glen Canyon aquifer occurs by streamflow loss along some reaches of Mill Creek.

In the Mill Creek-Spanish Valley area, the direction of movement of water in the upper ground-water system is generally to the west and west-northwest (fig. 9). The Glen Canyon aquifer is part of the upper ground-water system. Ground water moves downdip and westward from all parts of the outcrop area where recharge occurs, to some reaches of Mill Creek and the North Fork of Mill Creek and to Spanish Valley, where discharge occurs from seepage, springs, and wells.

In the Mill Creek-Pack Creek area, which is located in T. 26 S., R. 22 E. and is defined in figure 17, the direction of ground-water movement in the Glen Canyon aquifer generally is to the west and southwest, in places subperpendicular to the northeast canyon wall of Spanish Valley (fig. 19). The direction of movement of water in the Glen Canyon aquifer is oblique and in some places nearly perpendicular to that of water in the unconsolidated deposits of Spanish Valley, as shown by Sumsion (1971, pl. 2).

In the Mill Creek-Pack Creek area, discharge from the Glen Canyon aquifer occurs from wells and springs. Most of the discharge occurs along the northeast canyon wall of Spanish Valley in parts of sections 15, 22, and 23, and is from wells and springs owned by the City of Moab and the Grand County Water Conservancy District. From 1978 to 1986, average annual discharge from wells and springs owned by the two municipal water suppliers was about 2,000 acre-feet per year (fig. 20). In addition, about 200 acre-feet is discharged from privately owned domestic wells and springs. The total discharge from municipal wells and springs increased by about 40 percent from 1983 through 1986 as shown in figure 20. Spring discharge increased by about 200 percent, and well discharge decreased about 20 percent.

Streamflow gain-loss studies were conducted on Mill Creek and on the North Fork of Mill Creek during October 1985, to determine areas and approximate quantities of recharge and discharge along the streams (fig. 17; tables 9 and 10). In the following analysis, the streams were at or near base flow, and the values of instantaneous streamflow, in cubic feet per second, were converted to annual discharge, in acre-feet per year, by multiplying the instantaneous streamflow by 723.97. Gains and losses are reported in terms of streamflow; therefore, an increase in streamflow is equal to ground-water discharge, or loss of water from the Glen Canyon aquifer. Conversely, a decrease in streamflow is equal to ground-water recharge, or gain of water to the Glen Canyon aquifer.

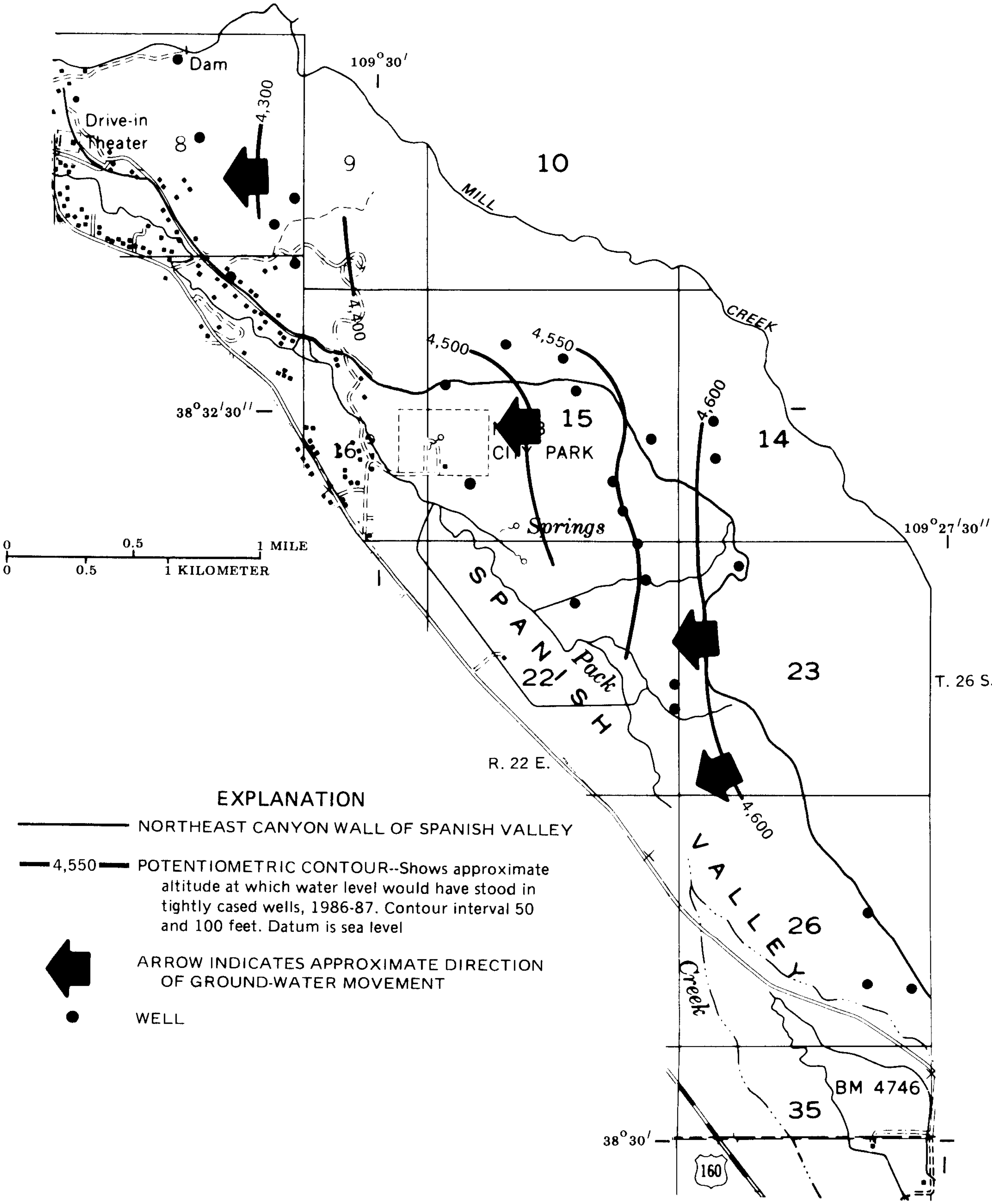


Figure 19.--Approximate potentiometric surface and direction of movement of water in the Glen Canyon aquifer in the Mill Creek-Pack Creek area, 1986-87.

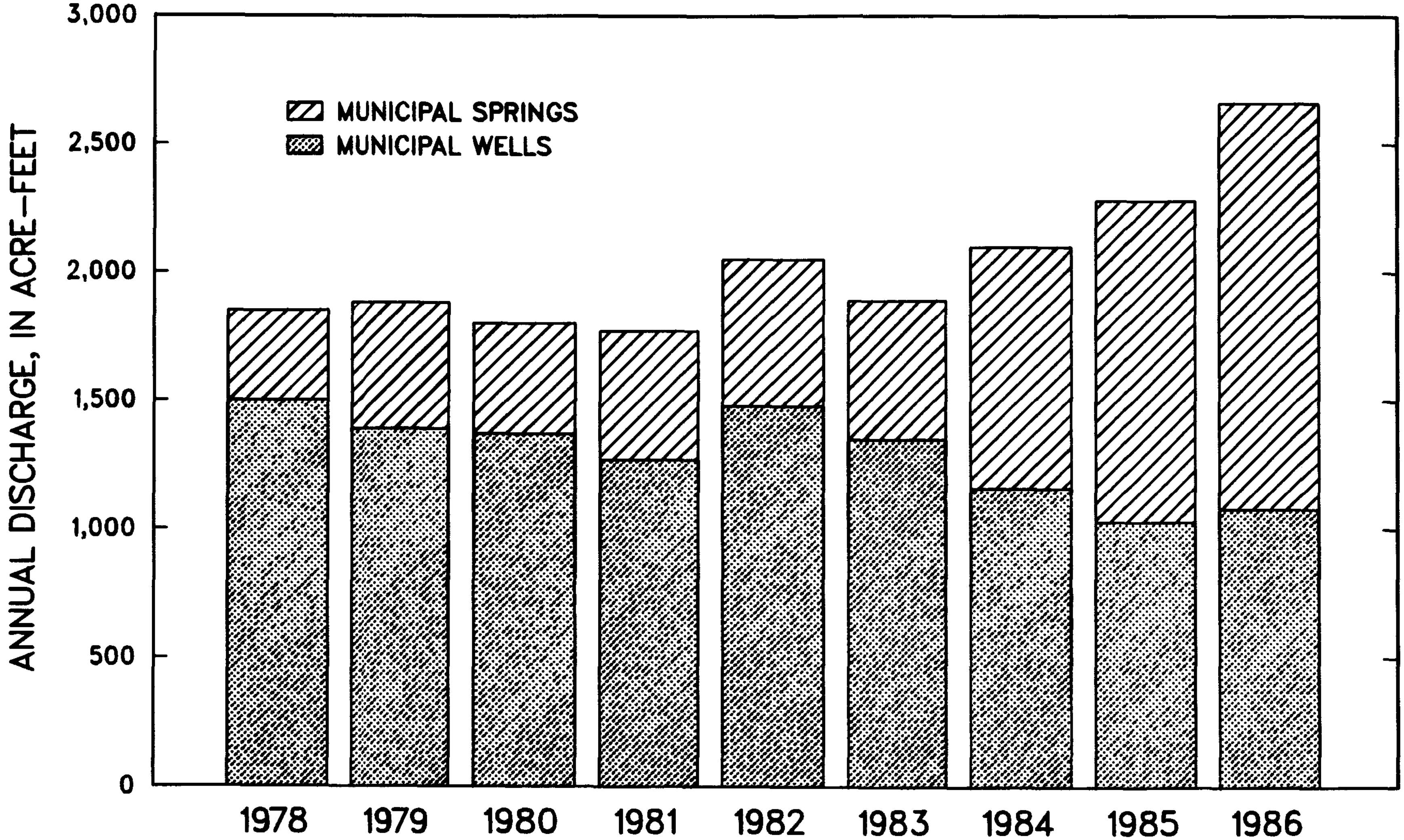


Figure 20.--Municipal well and spring discharge in the Mill Creek-Spanish Valley area, 1978-86.

Table 9.—*Miscellaneous streamflow measurements in Mill Creek and at points of tributary inflow*

[Abbreviations used in headings: ft^3/s, cubic feet per second; acre-ft/yr, acre-feet per year]

Measurement site (fig. 17)	Miles downstream from MC- 1	Date	Discharge	
			(ft^3/s)	(acre-ft/yr)
MC- 1	—	10-21-85	10.20	7,384
MC- 2	0.2	do.	10.55	7,638
MC- 5	3.4	do.	13.14	9,513
MC- 6	3.7	do.	13.46	9,745
MC- 7	3.9	do.	12.66	9,165
MC- 8	4.1	do.	3.99	2,889
MC- 9	4.8	do.	3.44	2,490
MC-10	5.5	do.	3.53	2,556
MC-11	6.4	do.	3.44	2,490
MC-12	7.5	do.	3.52	2,548
MC-13	8.4	do.	3.85	2,787
MC-14	9.4	do.	3.47	2,512
MC-15	9.9	do.	3.21	2,324
MCT-1	—	do.	0.32	232
MC-16	10.2	do.	3.58	2,592
MC-17	11.2	do.	3.45	2,498
MC-18	11.9	do.	3.33	2,411
MC-19	12.7	do.	3.09	2,237
NF-13	—	do.	3.73	2,700
MC-20	12.8	do.	6.90	4,995
MC-21	13.1	do.	7.18	5,198
MC- 5	3.4	10-23-85	13.03	9,433
MC- 6	3.7	do.	12.80	9,267
MC- 7	3.9	do.	11.90	8,615
MC- 1	--	10-24-85	9.27	6,711
MC- 3	1.0	do.	8.97	6,494
MC- 4	2.2	do.	9.90	7,167
MC- 5	3.4	do.	10.42	7,544
MC-21	13.1	10-14-86	6.74	4,880
MC-22	13.4	do.	6.41	4,641

Table 10.--*Miscellaneous streamflow measurements in the North Fork of Mill Creek and at points of tributary inflow*

[Abbreviations used in headings: ft^3/s, cubic feet per second; acre-ft/yr, acre-feet per year]

Measurement site (fig. 17)	Miles downstream from NF- 1	Date	Discharge (ft^3/s)	Discharge (acre-ft/yr)
NF- 1	--	10-24-85	0.42	304
NFT-1	--	do.	.34	246
NF- 2	0.1	do.	.76	550
NF- 3	.3	10-22-85	1.01	731
NF- 4	.5	do.	1.17	847
NF- 5	1.1	10-23-85	1.32	956
NF- 6	1.4	do.	2.18	1,578
NF- 7	2.0	do.	3.03	2,194
NF- 8	2.5	do.	2.66	1,926
		10-22-85	2.76	1,998
RC- 1	--	do.	.13	94
NF- 9	2.6	do.	2.80	2,027
NF-10	4.7	do.	3.19	2,309
NF-11	5.6	do.	3.21	2,324
NF-12	6.5	do.	3.28	2,375
NF-13	6.6	10-21-85	3.73	2,700

Water discharges from consolidated rock to Mill Creek in the eastern part of the Mill Creek-Spanish Valley area. In the 3.4 stream miles between sites MC-1 and MC-5 (fig. 17; table 9), streamflow in Mill Creek increased by about 2,100 acre-ft/yr on October 21, 1985, and about 800 acre-ft/yr on October 24, 1985. In the next 0.5 stream mile, between sites MC-5 and MC-7, the flow in Mill Creek decreased by about 350 acre-ft/yr on October 21, 1985, and decreased by about 800 acre-ft/yr on October 23, 1985. The net discharge from bedrock between sites MC-1 and MC-7 ranged from 0 to 1,750 acre-ft/yr.

The streamflow in Mill Creek is affected by the Sheley diversion between sites MC-7 and MC-8. The decrease in streamflow between these two sites primarily is a result of the diversion of streamflow and not the loss of streamflow to the ground-water system. Some streamflow may be gained from or lost to the ground-water system between MC-7 and MC-8, but the amount is unknown. Downstream from the Sheley diversion, in the 8.6-mile reach between sites MC-8 and MC-19, streamflow in Mill Creek decreased by about 650 acre-ft/yr (table 9). Water from Mill Creek recharges the ground-water system in this reach.

Ground water discharges to the North Fork of Mill Creek throughout most of its reach, and most of the discharge occurs in the upper reaches of the North Fork. In the 2.4 stream miles between sites NF-2 and NF-8, streamflow increased by about 1,400 acre-ft/yr (table 10). In the next 4 stream miles, between sites NF-9 and NF-12, streamflow increased about 350 acre-ft/yr. The total streamflow in the North Fork is about 2,700 acre-ft/yr, and this amount is equal to discharge from the Glen Canyon aquifer.

The total increase in streamflow, or ground-water discharge, in the Mill Creek drainage ranged from about 2,050 to about 3,800 acre-ft/yr--from about -650 to about 1,100 acre-ft/yr in Mill Creek and about 2,700 acre-ft/yr in North Fork. The combined annual discharge to streams in the Mill Creek drainage and discharge from springs and wells in the Mill Creek-Pack Creek area, then, is 4,200 to 6,000 acre-ft.

Aquifer Characteristics

The City of Moab well field is located on the limb of the salt anticline in which Spanish Valley is located. Near the well field, the Glen Canyon aquifer is faulted (fig. 18), and the fractures in the Glen Canyon aquifer were observed in the field. Springs discharge from the Glen Canyon aquifer in the well field. These geologic and hydrologic conditions could result in anisotropic conditions caused by fractures, impermeable boundary conditions caused by faults, or recharge boundaries caused by springs.

In order to determine which of these conditions are present in the Glen Canyon aquifer, and in order to estimate which conditions might dominate, an 8-day aquifer test was conducted in the City of Moab well field. One discharging well and seven observation wells were used in the test. The discharging well was City of Moab well number 6, (D-26-22)15dca-1.

Plots of the drawdown data from each well did not fit standard drawdown curves. Plots of data from the discharging well and four observation wells showed excess drawdown at late time, indicating the presence of impermeable boundaries. Plots of water-level data from two observation wells showed no drawdown, also indicating impermeable boundaries.

Specific-capacity values were reported for 14 wells completed in the Glen Canyon aquifer and inventoried in the Mill Creek-Spanish Valley area. The values ranged from 0.25 to 167 (gal/min)/ft (fig. 21; table 8), and the median value was 12.5 (gal/min)/ft. The wide range of values also suggests that impermeable boundaries are present in the Glen Canyon aquifer.

At well (D-26-22)26dbd-1, the specific capacity was 167 (gal/min)/ft, more than twice as much as at any of the other 14 wells. At this well, the saturated Glen Canyon aquifer is overlain by 36 feet of saturated valley fill. The valley fill may be hydraulically connected to the Glen Canyon aquifer, and may contribute to the relatively large specific capacity of the well.

The above evidence indicates that in the City of Moab well-field area, the Glen Canyon Group is structurally complex, and that aquifer characteristics of the Glen Canyon aquifer vary considerably in short distances. The value of aquifer characteristics of the Glen Canyon aquifer at any given location can be accurately estimated only by site-specific investigation.

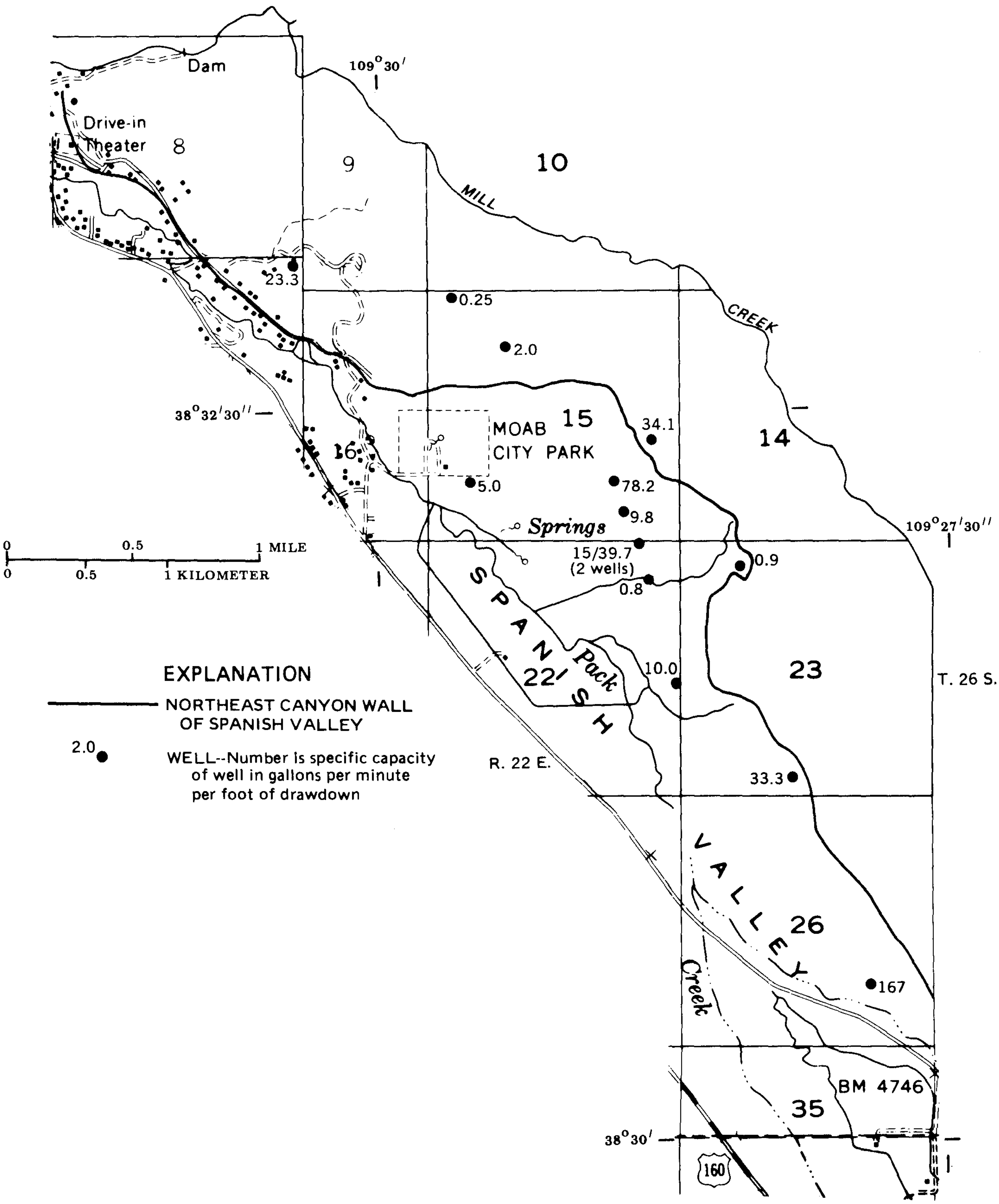


Figure 21.--Specific capacity of wells completed in the Glen Canyon aquifer in the Mill Creek-Pack Creek area.

Storage and Water Levels

The total quantity of water stored in the Glen Canyon aquifer in the Mill Creek-Spanish Valley area is unknown because water levels are only available in the Mill Creek-Pack Creek area, and the thickness of the aquifer is not well known in any part of the area. Available water levels, however, indicate substantial variations in storage with time in the City of Moab well field. Observations about variations in storage with time include: (1) Water levels were lower in 1987 than in 1961 and 1962, (2) water levels declined from the early 1960's to about 1979, and then rose through 1987, (3) there is a correlation between precipitation and water levels, and (4) there is substantial drawdown during the summer pumping season and subsequent recovery during the fall and winter. Water levels for selected wells in the City of Moab well field are shown in table 11, and hydrographs for these wells are shown in figure 22.

Data from City of Moab well numbers 4 and 5 indicate that 1987 water levels were lower than those of 1961 and 1962. The January 1987 water level was about 11.6 feet lower in well number 4 and 1.4 feet lower in well number 5 (table 11). Data from well numbers 5, 7, and 10 indicate that water levels declined between the early 1960's and about 1979, and rose from about 1979 to the present (1987). In well number 5, the water level declined between 1962 and 1979; in well number 7, the water level declined between 1972 and 1979; and in well number 10, the water level declined between 1976 and 1979. The decline in water level in well number 10 between 1976 and 1979 indicates that the lowest water level occurred after 1976, but there are no water-level data available between 1976 and 1979 or between 1979 and 1985 to determine in what year water-level declines ceased, and water levels began rising.

Water levels in wells 5, 7, and 10 rose about 15, 37, and 35 feet, respectively, between January 1979 and January 1986, and the water level in well 9 rose about 24 feet between October 1978 and January 1986. The large rises between 1978 or 1979 and 1986 suggest that water levels began rising considerably before 1985, and possibly as early as about 1979. Between January 1986 and January 1987, the rise in water levels in wells 4, 5, 7, and 10 ranged from about 1.4 to 3.0 feet, and between March 1986 and March 1987, the rise in the water level in well 9 was about 3.5 feet, indicating that the trend in rising water levels continued from 1986 to 1987.

Precipitation at the Moab Airport was larger than normal in every year between 1977 and 1986 except 1982 and 1985, and it was several inches above normal in 1978, 1980-81, 1983-84, and 1986 (fig. 6). The period of rise in water levels roughly correlates to the period of larger-than-normal precipitation, and the time correlation suggests that ground-water levels in the area respond fairly rapidly to changes in annual precipitation.

Water-level recovery from seasonal pumping in the City of Moab well field has been documented for three seasons: 1978-79, 1985-86, and 1986-87 (fig. 22; table 11). Water-level increases in wells 5, 7, and 10 ranged from 5 to 18 feet between October 1978 and January 1979. Water-level increases in wells 4, 5, 7, and 10 ranged from about 1.6 to 6.9 feet between September 1985 and January 1986; and from about 2.9 to 7.3 feet between August 1986 and January 1987. The water-level recovery period normally extends into April when seasonal pumping begins, but the previously-discussed aquifer test was

Table 11.--*Water levels in selected observation wells*

Well number: See "Numbering system for hydrogeologic-data sites", p. 5 and figure 2.
Altitude of well: Altitude of land surface, in feet above sea level; altitudes interpolated from U.S. Geological Survey topographic maps.
Water level: Measured water level, in feet below land surface.

(D-26-22)15daa- 2
City of Moab well number 10
Altitude of well: 4,640 feet

Date	Water level	Date	Water level	Date	Water level	Date	Water level
07/15/76	146.00	10/01/78	174.00	01/01/79	160.00	08/15/85	132.66
09/27/85	131.16	10/29/85	129.14	11/27/85	127.40	12/28/85	125.95
01/16/86	125.29	01/24/86	125.02	01/28/86	124.70	02/14/86	127.46
03/26/86	127.14	04/29/86	125.61	05/31/86	126.34	06/22/86	127.47
07/27/86	128.41	08/31/86	128.47	09/30/86	127.31	11/04/86	125.64
01/10/87	122.31						

(D-26-22)15ddc- 1
City of Moab well number 7
Altitude of well: 4,600 feet

Date	Water level	Date	Water level	Date	Water level	Date	Water level
10/27/72	68.00	10/01/78	88.00	01/01/79	70.00	08/15/85	41.64
09/26/85	40.32	10/28/85	37.20	11/27/85	35.43	12/28/85	34.00
01/16/86	33.40	01/24/86	33.11	01/28/86	32.83	02/14/86	35.69
03/26/86	36.84	04/29/86	34.32	07/27/86	38.74	08/31/86	37.79
09/30/86	35.52	11/04/86	33.94	01/10/87	30.50		

(D-26-22)22aab- 1
City of Moab well number 4
Altitude of well: 4,580 feet

Date	Water level	Date	Water level	Date	Water level	Date	Water level
05/18/61	16.00	03/01/69	31.00	09/26/85	35.33	10/28/85	32.92
11/27/85	31.17	12/28/85	29.79	01/16/86	30.11	01/23/86	29.62
01/28/86	28.66	01/31/86	31.64	02/05/86	34.52	02/10/86	32.03
02/15/86	31.38	02/20/86	30.73	02/25/86	30.29	02/28/86	30.46
03/05/86	30.46	03/10/86	30.84	03/15/86	30.39	03/20/86	30.68
03/25/86	31.36	03/26/86	31.88	03/31/86	31.28	04/05/86	30.34
04/10/86	30.51	04/15/86	30.48	04/20/86	30.31	04/25/86	31.56
04/30/86	29.77	05/05/86	30.30	05/10/86	30.12	05/15/86	31.70
05/20/86	30.46	05/25/86	30.42	05/31/86	33.99	06/05/86	34.25
06/10/86	32.66	06/15/86	32.27	06/20/86	32.20	06/25/86	32.45
06/30/86	33.32	07/05/86	36.52	07/10/86	33.63	07/15/86	33.09
07/20/86	34.47	07/25/86	33.11	07/31/86	33.56	08/05/86	34.43
08/10/86	33.86	08/15/86	33.49	08/20/86	33.87	08/25/86	34.32
08/31/86	33.50	09/05/86	32.96	09/10/86	32.46	09/15/86	32.74
09/20/86	36.16	09/25/86	32.38	09/30/86	31.34	10/15/86	30.52
10/20/86	30.05	10/25/86	31.94	10/31/86	30.43	11/04/86	29.65
01/06/87	27.63	01/07/87	27.63	01/08/87	27.54	01/09/87	27.57
01/10/87	27.63	03/11/87	26.94				

(D-26-22)22aac- 1
City of Moab well number 5
Altitude of well: 4,580 feet

Date	Water level	Date	Water level	Date	Water level	Date	Water level
08/20/62	1.00	10/01/78	24.00	01/01/79	19.00	08/16/85	6.39
09/26/85	6.87	10/28/85	5.23	11/27/85	4.53	12/28/85	4.05
01/16/86	3.82	01/24/86	3.72	01/28/86	3.65	02/14/86	3.79
03/26/86	3.99	04/29/86	3.84	05/31/86	5.59	06/22/86	5.49
07/27/86	5.16	08/31/86	5.29	09/30/86	4.40	11/04/86	3.24
01/10/87	2.41						

(D-26-22)23bba- 1
City of Moab well number 9
Altitude of well: 4,720 feet

Date	Water level	Date	Water level	Date	Water level	Date	Water level
04/07/75	32.00	10/01/78	40.00	09/26/85	17.91	10/28/85	17.31
11/27/85	16.97	12/28/85	16.54	01/16/86	16.32	01/25/86	18.83
01/28/86	16.12	01/31/86	15.99	02/05/86	15.90	02/10/86	15.96
02/15/86	15.81	02/20/86	15.80	02/25/86	15.89	02/28/86	15.80
03/05/86	15.74	03/10/86	15.52	03/15/86	15.57	03/20/86	15.84
03/25/86	15.49	03/31/86	15.44	04/05/86	15.45	04/10/86	15.29
04/15/86	15.24	04/20/86	15.33	04/25/86	14.99	04/30/86	15.16
05/05/86	14.96	05/10/86	15.00	05/15/86	15.03	05/20/86	14.86
05/25/86	14.96	05/31/86	14.78	06/05/86	14.76	06/10/86	15.00
06/15/86	14.77	06/20/86	14.77	06/25/86	14.80	06/30/86	14.74
07/05/86	14.71	07/10/86	14.69	07/15/86	14.70	07/20/86	14.68
07/25/86	14.62	07/31/86	14.54	08/05/86	14.50	08/10/86	14.51
08/15/86	14.43	08/20/86	14.49	08/25/86	14.38	08/31/86	14.28
09/05/86	14.26	09/10/86	14.17	09/15/86	14.09	09/20/86	14.06
09/25/86	13.94	09/30/86	13.91	03/11/87	12.10		

conducted in January and February 1986, and pumping during the test disrupted the normal recovery of water levels during that period. Drawdown of water levels due to pumping in wells 4, 5, 7, and 10 ranged from about 1.5 to 4.4 feet between January 16, 1986, when the aquifer test began, and August 31, 1986, which was about the end of the pumping season.

Chemical Quality

Water samples from 15 wells and 4 springs were analyzed to determine water-quality characteristics of the Glen Canyon aquifer in the Mill Creek-Pack Creek area (table 4). The concentration of dissolved solids ranged from 150 to 674 mg/L. The cation type in all of the samples was calcium magnesium, but the anion type varied from bicarbonate to bicarbonate sulfate to sulfate bicarbonate, and the ratio of milliequivalents of bicarbonate to sulfate ranged from 12.9:1 to 0.5:1. The shift in anion type from bicarbonate to sulfate bicarbonate, the increase in concentration of dissolved solids, and the decrease in the ratio of bicarbonate to sulfate all occurred from the north and east to the south and west (figs. 23 and 24).

In T. 26 S., R. 22 E., section 26, the chemistry of water is representative of the Glen Canyon aquifer where it is overlain by saturated valley fill. In the Glen Canyon aquifer, the water type is calcium magnesium sulfate bicarbonate, the dissolved-solids concentration of the water is larger than 400 mg/L, and the bicarbonate-to-sulfate ratio is less than one. Water in several wells completed in the valley fill has similar chemical characteristics (figs. 23 and 24; table 4). These observations suggest that the valley fill and the underlying Glen Canyon aquifer are hydraulically connected.

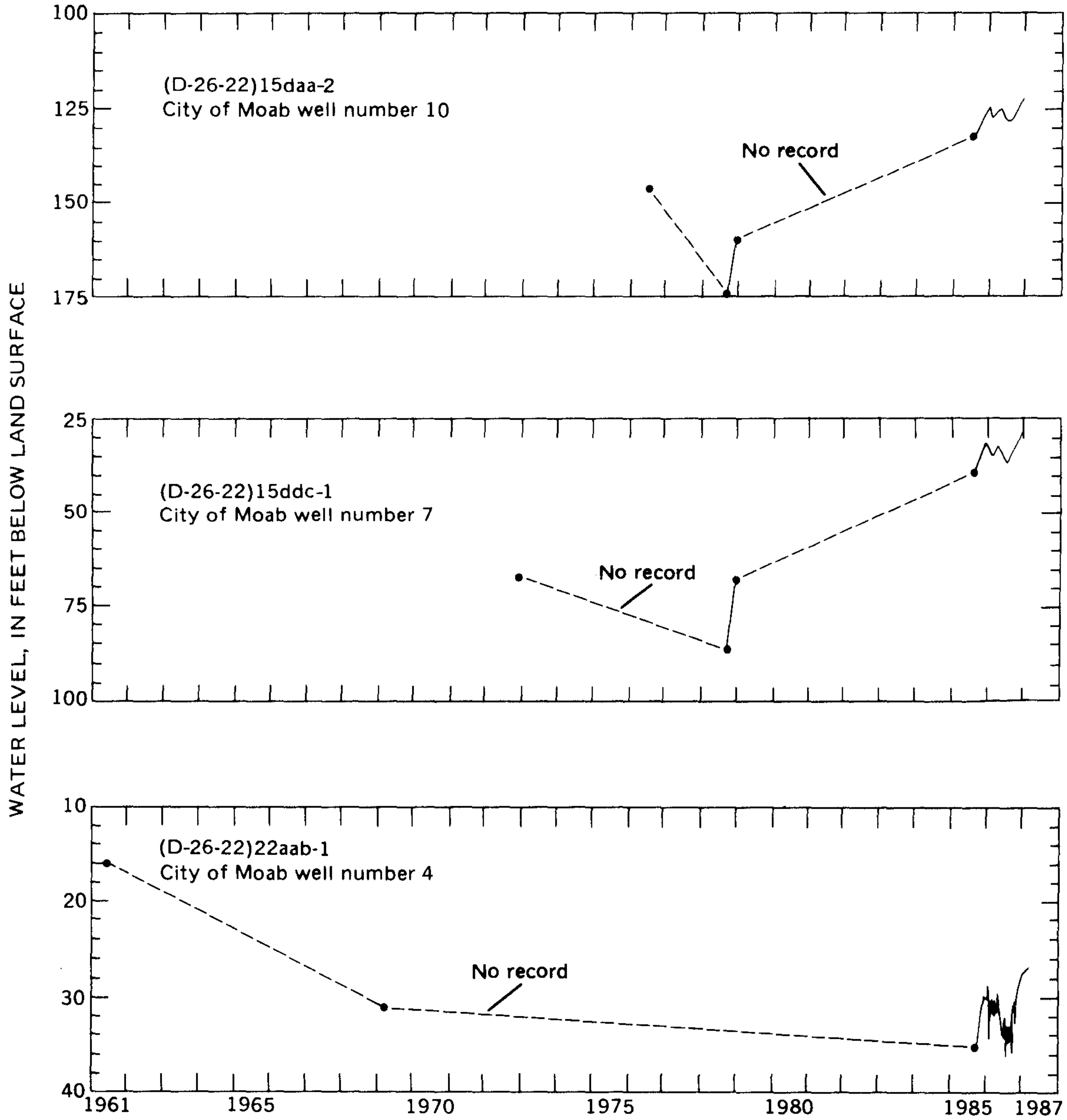


Figure 22.--Hydrographs of wells in the City of Moab well field.

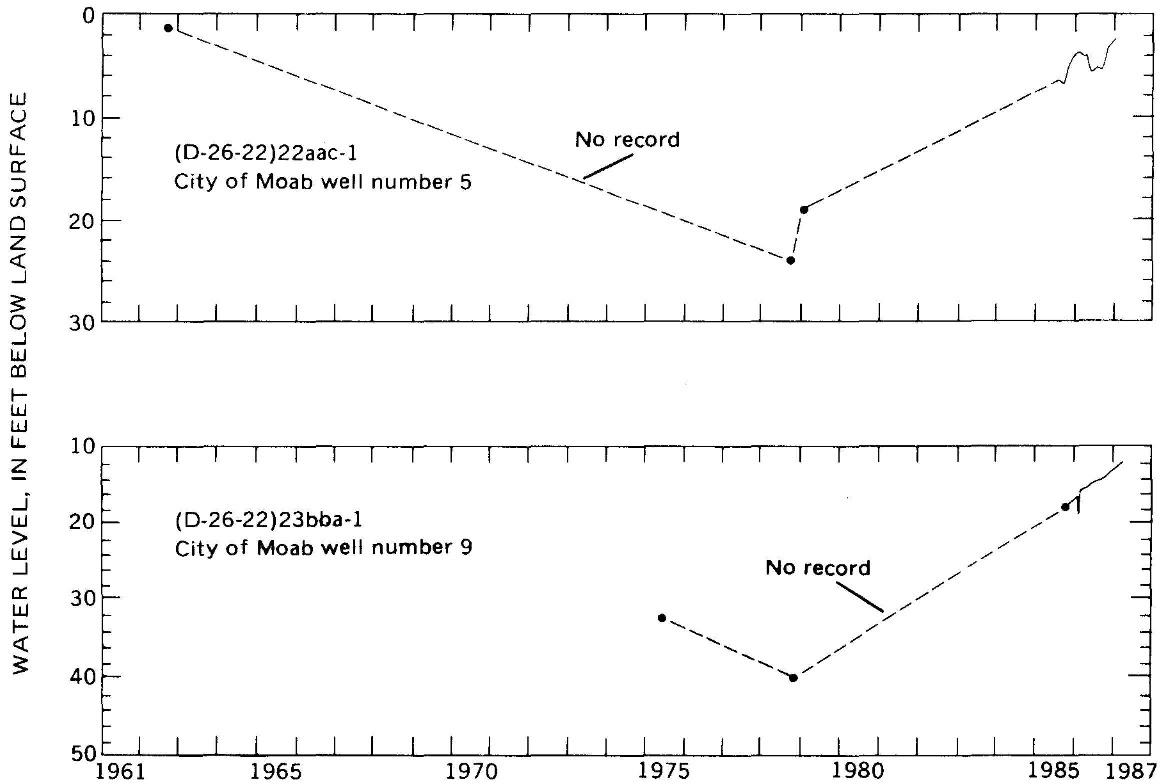


Figure 22.--Hydrographs of wells in the City of Moab well field--Continued.

In sections 8, 9, 14, and the northern part of 15, north of the northeast canyon wall of Spanish Valley, the chemistry of water from the Glen Canyon aquifer where it is not overlain by valley fill is similar to that of water in the Glen Canyon aquifer near the recharge area to the east. The water type is calcium magnesium bicarbonate, the dissolved-solids concentration of the water is about 150 mg/L [about 200 mg/L at well (D-26-22)8bad-1], and the bicarbonate-to-sulfate ratio is more than about three. These characteristics are typical of ground water in recharge areas (Freeze and Cherry, 1979, p. 241-244).

The spatial variation in the water-quality characteristics in the Glen Canyon aquifer probably results from mixing of ground water from the valley fill in Spanish Valley with water from the Glen Canyon aquifer. Sumsion (1971, pl. 2) indicated that water in the valley fill in Spanish Valley generally moves down-valley from southeast to northwest, in a direction nearly parallel to the canyon walls on the sides of Spanish Valley (the deviations from this direction in T. 26 S., R. 22 E., sections 15 and 22, are because the water-level contours in that area are based in part on water levels in the Glen Canyon aquifer, rather than solely on water levels in the valley fill). Water in the Glen Canyon aquifer moves west and, in some areas, southwest as shown in figure 19. Water from the two sources converges and mixes along the northeast canyon wall of Spanish Valley and west of the canyon wall.

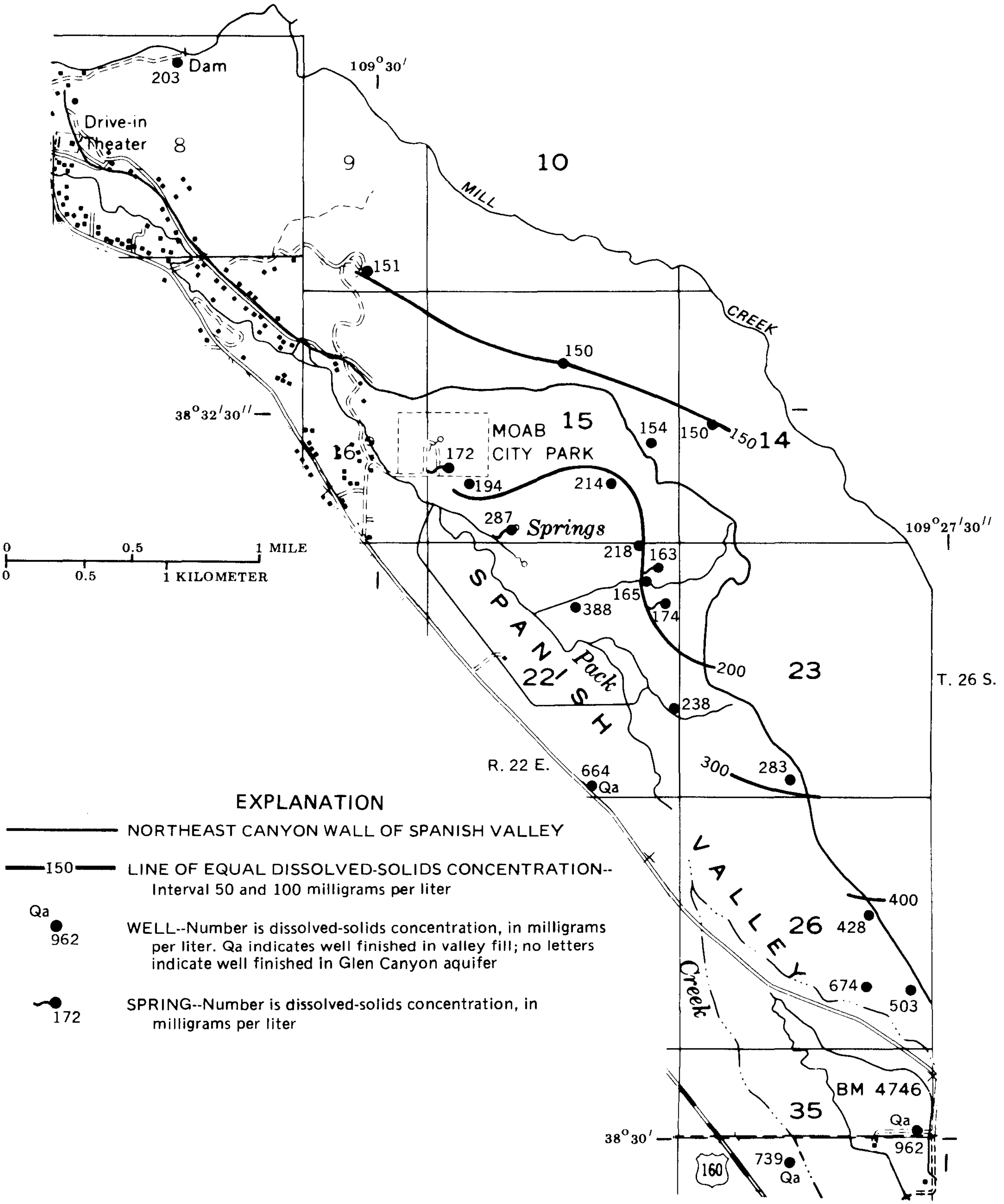


Figure 23.--Concentration of dissolved solids in water from the Glen Canyon aquifer and from overlying valley fill in the Mill Creek-Pack Creek area.

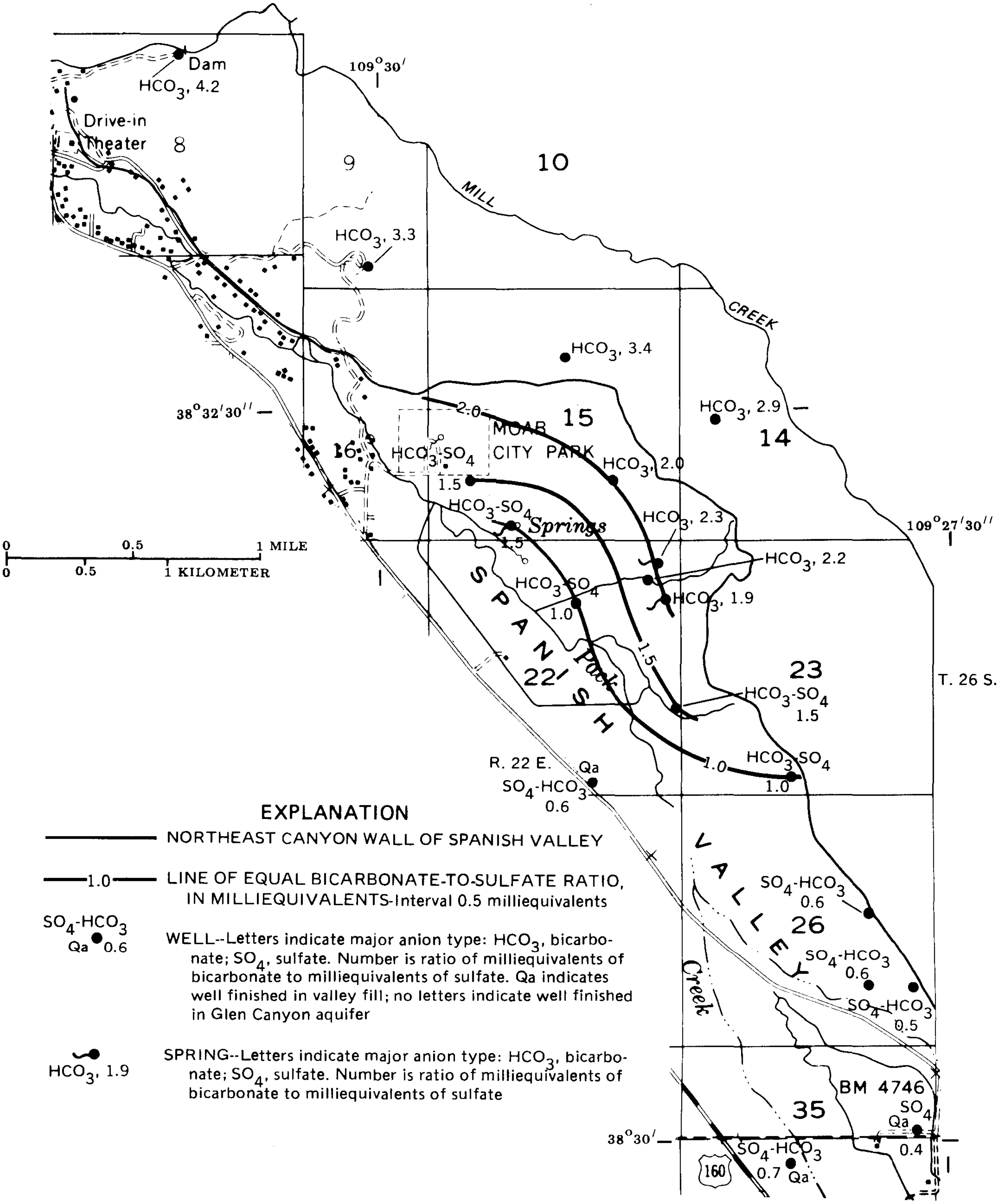


Figure 24--Anion chemistry of water from the Glen Canyon aquifer and from overlying valley fill in the Mill Creek-Pack Creek area.

The proportion of water from the two sources dictates the water-quality characteristics of water being pumped in sections 15 and 22, in the eastern part of Spanish Valley. Water withdrawn in the north half of section 15 has water-quality characteristics similar to those of water in the Glen Canyon aquifer to the east. Water withdrawn in section 22, just to the south of section 15, has water-quality characteristics similar to water from the valley fill aquifer to the southeast (fig. 23). The gradual decrease in the bicarbonate-to-sulfate ratio from 3.0 or greater in sections 8, 9, 14, and the northern half of 15, to less than 1.0 in sections 26, 35, and the western half of 22 (fig. 24) also show this gradual mixing of the two different water types.

A change in water quality with time was observed at City of Moab well number 6. From 1978 to 1986, average annual discharge from the well was about 500 acre-ft/yr. Specific conductance was 268 µS/cm (microsiemens per centimeter at 25 degrees Celsius) in March 1969 and 360 µS/cm in August 1985 (table 4); however, specific conductance decreased from 360 to 290 µS/cm from August 1985 to January 1986.

Specific conductance was measured in well number 6 during January and February 1986 when the well was being pumped as part of an aquifer test. During the aquifer test, specific conductance was 290 µS/cm after 20 minutes of pumping at about 1,670 gal/min, and increased to 345 µS/cm after about 2 1/2 days of pumping at about the same rate. This increase is about 60 percent of the increase observed between March 1969 and August 1985.

The small difference in specific conductance between March 1969 (268 µS/cm) and January 1986 (290 µS/cm) indicates that long-term changes in water quality at the well site are minimal. The March 1969 sample was collected at the beginning of or possibly prior to the pumping season, and the August 1985 sample was collected during the pumping season. The differences between 1969 and 1985 samples are probably attributable to seasonal pumping. Seasonal pumping may change the proportion of water entering the well from the Glen Canyon aquifer and from ground water moving down Spanish Valley.

SUMMARY AND CONCLUSIONS

The Grand County area is located in southeastern Utah, and includes about 3,980 square miles in Grand County, the Mill Creek and Pack Creek drainages in San Juan County, and the area between the Colorado and Green Rivers in San Juan County. The principal consolidated-rock aquifers in the Grand County area are the Entrada, Navajo, and Wingate aquifers in the Entrada Sandstone, the Navajo Sandstone, and the Wingate Sandstone. The Glen Canyon aquifer in the Glen Canyon Group is the principal consolidated-rock aquifer in the Mill Creek-Spanish Valley area. The Glen Canyon Group is comprised of the Navajo Sandstone, the Kayenta Formation, and the Wingate Sandstone. The Glen Canyon aquifer is used only in the Mill Creek-Spanish Valley area. Elsewhere in the study area, the separate Navajo and Wingate aquifers are used. Other consolidated-rock units known to yield water in the Grand County area are the Parachute Creek Member of the Green River Formation, the Wasatch Formation, the Cedar Mountain Formation, the Brushy Basin Shale and Salt Wash Sandstone Members of the Morrison Formation, the White Rim Sandstone Member of the Cutler Formation, and the undifferentiated Cutler Formation.

Springs discharge from the Parachute Creek Member of the Green River Formation and from the Wasatch Formation in outcrop areas north of the Book Cliffs, in the northern part of the Grand County area. The springs discharge at rates ranging from less than 1 to about 20 gal/min, and the water is fresh; concentrations of dissolved solids are about 600 mg/L or less.

Water from springs and flowing wells discharges from the Cedar Mountain Formation and the Brushy Basin Shale and Salt Wash Sandstone Members of the Morrison Formation in an outcrop band south of the Book Cliffs, and water from one spring discharges from the Salt Wash Member of the Morrison Formation on the lower flanks of the La Sal Mountains. Discharge rates typically are less than 1 gal/min. The water is slightly saline; concentrations of dissolved solids range from about 1,000 to 1,500 mg/L.

Wells are completed in and springs and seeps discharge from the White Rim Sandstone Member of the Cutler Formation in and north of Canyonlands National Park. Water from wells typically is slightly saline, and water from springs and seeps is fresh.

About 30 wells are completed in the undifferentiated Cutler Formation along the west side of Castle Valley. Measured specific capacity of the wells ranged from less than 0.01 to 4.0 (gal/min)/ft of drawdown. Five wells produced from 20 to 40 gal/min for 2 hours without measurable drawdown. Water in three sampled wells was slightly saline to saline; concentrations of dissolved solids ranged from 1,420 to 3,450 mg/L. Water from the wells also had concentrations of selenium that exceeded the State of Utah primary drinking-water standard of 10 μg/L.

The Entrada Sandstone, the Navajo Sandstone, and the Wingate Sandstone crop out extensively in the southern one-third of the Grand County area; however, few wells have been completed in these aquifers. Characteristics typical of springs in the Entrada, Navajo, and Wingate aquifers are: (1) Discharge is less than 5 gal/min, (2) concentrations of dissolved solids in the water are less than 200 mg/L, (3) the water type is calcium bicarbonate or calcium magnesium bicarbonate, and (4) the water is moderately hard to hard. Springs with larger discharge rates are present near the intersection of the Colorado River and Moab Valley.

In the Mill Creek-Spanish Valley area, the Navajo Sandstone, the Wingate Sandstone, and the intervening Kayenta Formation, which comprise the Glen Canyon Group, combine to form the Glen Canyon aquifer. Most of the recharge to the Glen Canyon aquifer in the area occurs in the outcrop area of the Glen Canyon Group east of Spanish Valley. Movement of ground water generally is westward and southwestward toward Spanish Valley, and much of the water moves toward the City of Moab well field.

The principal area of discharge from the Glen Canyon aquifer in the Mill Creek-Spanish Valley area occurs in and near the City of Moab well field, along the northeast canyon wall of Spanish Valley. Near the well field, average annual discharge from municipal wells and springs between 1978 and 1986 was about 2,000 acre-ft/yr. Several wells in the area have discharge rates that exceed 1,000 gal/min, and two springs in the area have discharge rates that exceed 300 gal/min.

Water levels in the Mill Creek-Pack Creek area declined between the early 1960's and about 1979, and then rose as much as 39.5 feet from 1979 through 1987. Precipitation was consistently above normal from 1977 through 1986, and it appears that the larger-than-normal quantity of precipitation is a contributing factor to the rise in water levels. Water levels fluctuate seasonally in response to pumping in the City of Moab well field. Between August 1986 and January 1987, recovery from seasonal pumping ranged from about 2.9 to 7.3 feet.

Water-quality characteristics typical of water in the Glen Canyon aquifer are: (1) Concentrations of dissolved solids are between 150 and 220 mg/L, (2) the water type is calcium magnesium bicarbonate, and (3) the water is hard. West and south of the City of Moab well field, concentrations of dissolved solids and sulfate increase because an increasingly larger proportion of the ground water is derived from valley-fill deposits to the southeast, in Spanish Valley, and a smaller proportion is derived from the Glen Canyon aquifer.

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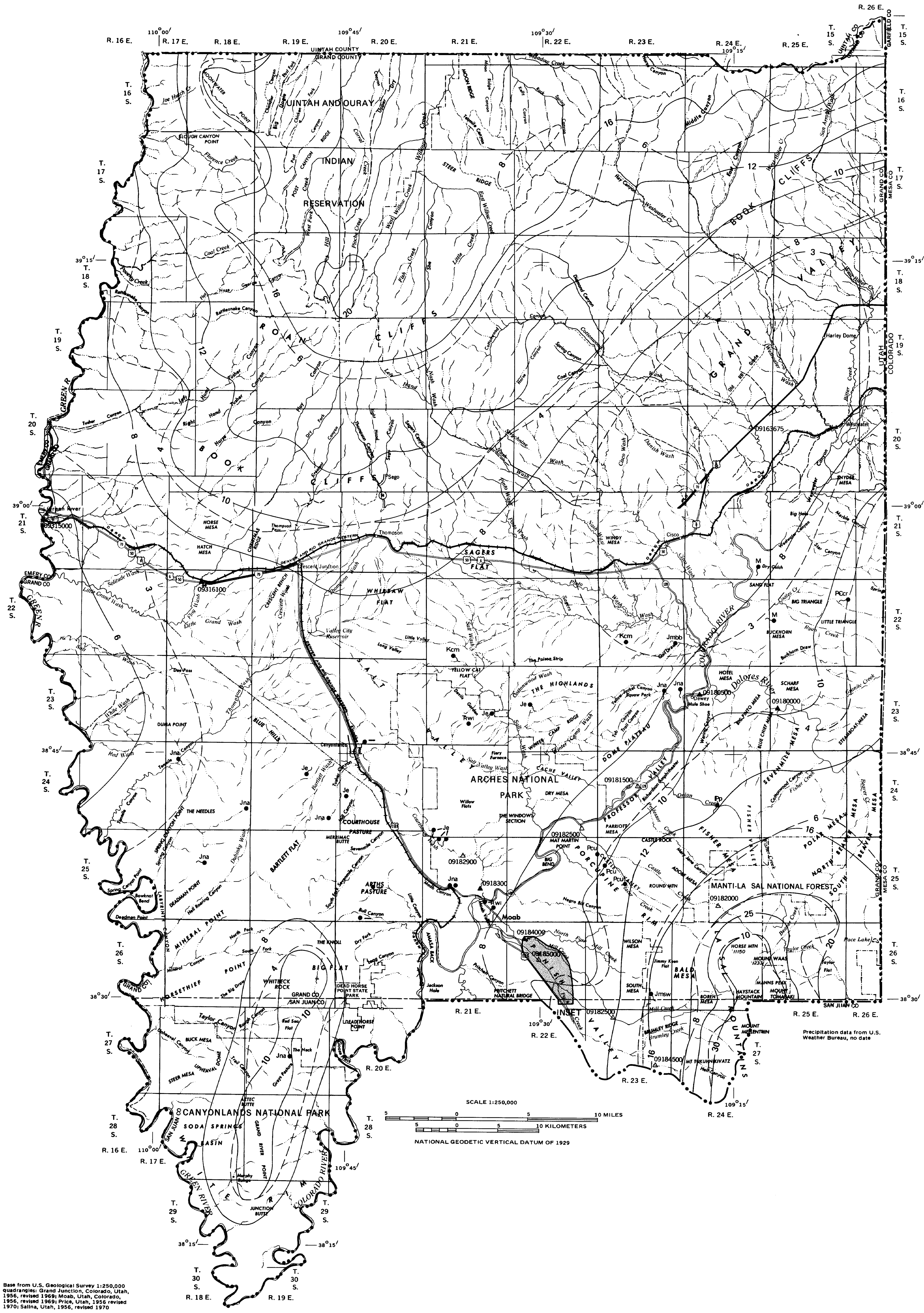
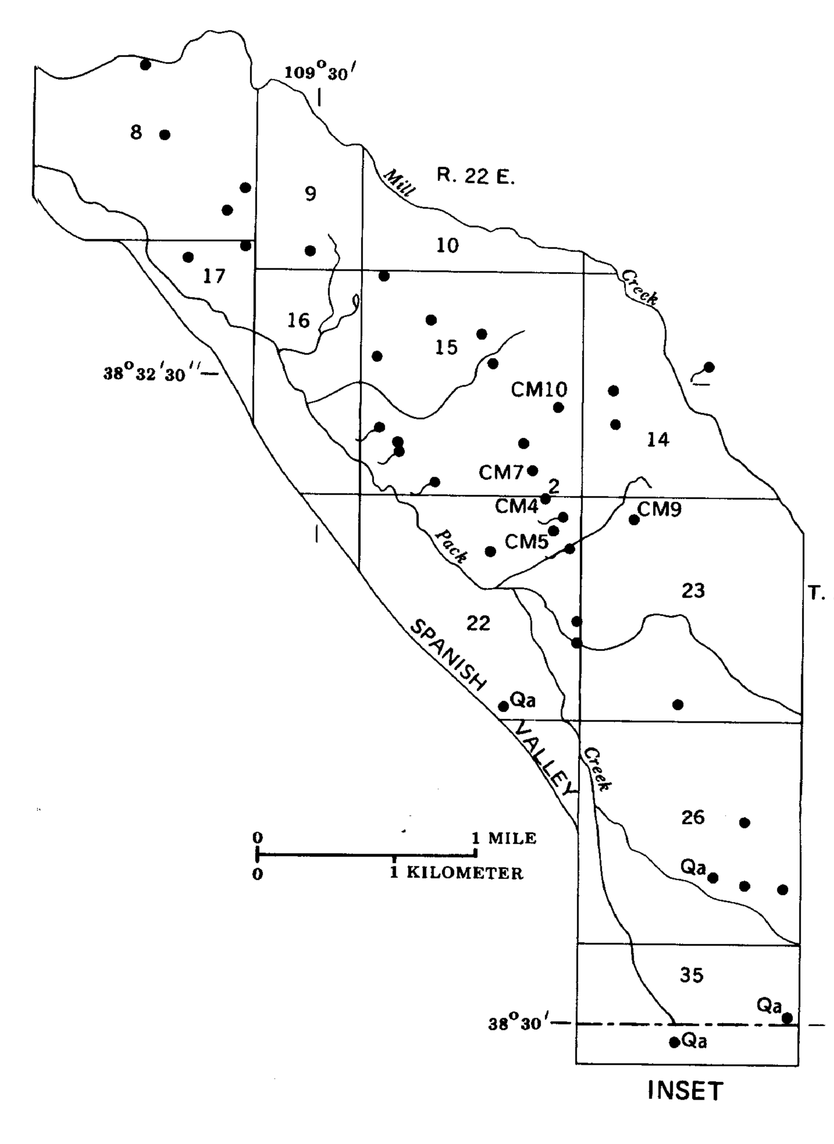
DEPARTMENT OF NATURAL RESOURCES

TECHNICAL PUBLICATION NO. 100
1990 PLATE 1



EXPLANATION

- AREA SHOWN IN INSET
- BOUNDARY OF STUDY AREA
- 8 — LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION, 1931-60—Interval 2, 4, and 5 inches
- 4 — LINE OF EQUAL AVERAGE MAY-SEPTEMBER PRECIPITATION, 1931-60—Interval 1 and 2 inches
- Jna ● INVENTORIED WELL—Wells labeled with CM and number are City of Moab wells for which hydrographs are shown in figure 22
- Je INVENTORIED SPRING—Letters indicate geologic source: Kcm, Cedar Mountain Formation; Jmbb, Brushy Basin Shale Member of Morrison Formation; Jmsw, Salt Wash Sandstone Member of Morrison Formation; Je, Entrada Sandstone; Jna, Navajo Sandstone; ₮wi, Wingate Sandstone; no symbol, Glen Canyon Group; M, Mesozoic Erathem; Pcu, Cutler Formation; IPp, Paradox Member of Hermosa Formation; p€cr, undifferentiated crystalline rocks; —, Unknown
- 09180500 ▲ ACTIVE STREAMFLOW—GAGING STATION AND NUMBER
- 09182000 △ DISCONTINUED STREAMFLOW—GAGING STATION AND NUMBER



Base from U.S. Geological Survey 1:250,000 quadrangles: Grand Junction, Colorado, Utah, 1956, revised 1969; Moab, Utah, Colorado, 1956, revised 1969; Price, Utah, 1956 revised 1970; Salina, Utah, 1956, revised 1970

MAP SHOWING SELECTED HYDROLOGIC INFORMATION IN THE GRAND COUNTY AREA, UTAH