REGIONAL HYDROLOGY OF THE BLANDING-DURANGO AREA, SOUTHERN PARADOX BASIN, UTAH AND COLORADO

By M. S. Whitfield, Jr., William Thordarson, W. J. Oatfield,
E. A. Zimmerman, and B. F. Rueger

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CONVERSION TABLE

For those readers who prefer to use inch-pound units of measurement, the following conversion table is provided:

Multiply metric unit	by	To obtain inch-pound unit
millimeter (mm)	0.03937	inch (in.)
millimeter per annum (mm/a)	0.03937	inch per year (in./yr)
meter (m)	3.281	foot (ft)
meter per day (m/d)	3.281	foot per day (ft/d)
meter per hour per meter [(m/h)/m]	1.0	foot per hour per foot [(ft/h)/ft]
meter per meter (m/m)	1.0	foot per foot (ft/ft)
kilometer (km)	0.6214	mile (mi)
meter squared per day (m^2/d)	10.76	square feet per day (ft^2/d)
square kilometer (km^2)	0.3861	square mile (mi^2)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	0.0008107	acre foot (acre-ft)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per day (m^3/d)	35.31	cubic foot per day (ft^3/d)
cubic meter per annum (m^3/a)	35.31	cubic foot per year (ft^3/yr)
liter (L)	0.2642	gallon
liter per second (L/s)	15.85	gallon per minute (gal/min)
millidarcy (md)	.002725	foot per day (ft/d)
microgram per liter (µg/L)	1.0[1/]	part per billion (ppb)
milligram per liter (mg/L)	1.0[1/]	part per million (ppm)
degree Celsius (°C)	(°F = 9/5°C + 32)	degree Fahrenheit (°F)

[1/] For concentrations less than about 7,000 mg/L.

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

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ABSTRACT

Regional hydrologic studies have been conducted in the Paradox basin in Utah and Colorado by the U.S. Geological Survey for the U.S. Department of Energy, as part of a national program to evaluate the suitability for storing radioactive wastes in bedded salt deposits. The Blanding-Durango area is one of five areas that comprise the Paradox basin, in which the U.S. Geological Survey is making studies. This area encompasses approximately 12,000 square kilometers, or about 40 percent of the basin. A thick sequence of salt beds underlies most of this structural basin.

Rock units that underlie the area have been grouped into hydrogeologic units based on their hydraulic interconnection and water-transmitting properties. An evaporite confining bed that consists primarily of halite separates an upper ground-water system from a lower ground-water system. In the study area, the lower ground-water system is not hydrologically connected with the upper ground-water system or to surface water, except locally; some interconnection occurs near the Abajo Mountains, where intense fracturing and faulting exist.

Aquifers in the study area generally are isolated from the salt beds by bounding confining beds; as a result, ground water in the Blanding-Durango area has little or no contact with salt beds. No brines in this study area were observed to flow to the biosphere.

The upper aquifer, principally the Mesozoic sandstone aquifer, probably is the most permeable hydrogeologic unit in this study area. Hydraulic-head data from oil, gas, and water wells indicate a regional flow direction southwestward toward the San Juan River. Potential for recharge to the upper ground-water system increases toward higher altitudes, where precipitation is greater and temperature is cooler. A large part of potential recharge water is lost through evaporation and transpiration by phreatophytes. In the principal recharge areas, an estimated 2 percent of average annual precipitation reaches the zone of saturation. The principal element of ground-water discharge is through evapotranspiration from phreatophyte areas. Phreatophytes cover approximately 56 square kilometers, of which 29.5 square kilometers are on the flood plains of the San Juan and Mancos Rivers; here, ground water is at shallow depths and is readily available to phreatophytes. An estimated total of 33×10^6 cubic meters of ground-water discharge is evapotranspired per year from phreatophyte areas in the Blanding-Durango area.

The lower ground-water system does not have recharge or discharge areas within the study area. Recharge areas occur primarily north and northeast of

the study area. The regional hydraulic-head gradient is southwestward toward discharge sites along the Colorado River in the Grand Canyon area.

General water quality from more permeable zones in the upper ground-water system is acceptable for domestic, industrial, and municipal use. Water from the lower ground-water system generally is saline to briny as a result of local natural downward flow from the Paradox Member of the Hermosa Formation across relatively impermeable strata that have been structurally breached. The lower ground-water system also probably has been contaminated by drilling through salt beds, using drilling muds containing large concentrations of chloride.

INTRODUCTION

The U.S. Geological Survey has conducted a series of geohydrologic investigations, funded by the U.S. Department of Energy under Interagency Agreement DE-AI97-79ET 44611, related to the potential isolation of high-level radioactive wastes in the Paradox basin, Utah, and Colorado. The Paradox basin was chosen for exploration because the salt beds of the basin are believed to be sufficiently thick and to have physical, chemical, and mechanical properties desirable as a storage environment. As part of the investigations, this report presents geohydrologic information for the southern part of the Paradox basin of Utah and Colorado, the Blanding-Durango area. Various geological, geophysical, and hydrological studies were made to evaluate selected bedded salt structures and their regional environment.

Purpose and Scope

The purpose of this report is to describe the regional hydrogeologic systems in the Blanding-Durango area and to establish their relationship to the geologic and hydrologic conditions associated with bedded salt in order to help assess salt as an effective storage medium for radioactive wastes. Interpretations are based principally on existing data; however, well inventories, phreatophyte mapping and stream-flow measurements were made during 1978, 1979, and 1980.

Location and Extent of the Study Area

The regional geographic setting of the Paradox basin relative to other areas in the conterminous United States underlain by salt is shown in figure 1. The areal extent of the Paradox basin in southeastern Utah and southwestern Colorado, and the Blanding-Durango study area described in this report, is shown in figure 2. The study area encompasses about 12,000 km^2, or about 40 percent of the Paradox basin. Approximately 60 percent of the area described in this report is in Utah, and the remaining 40 percent is in Colorado. The southern and western boundaries of the study area are approximately the same as the edge of the Paradox basin, and the northern and eastern boundaries coincide with the drainage divides. The largest community in the study area, Durango, Colorado, is in the southeastern part of the area. Blanding and Monticello, Utah, and Cortez, Colorado are other large towns in the study area.

Previous Work

Many reports describe the geology and regional correlation of stratigraphic units of southeastern Utah. Baker (1936, p. 17) compiled an extensive bibliography of such literature. This list is not repeated here; however, several papers are cited that describe early geologic investigations of the study area.

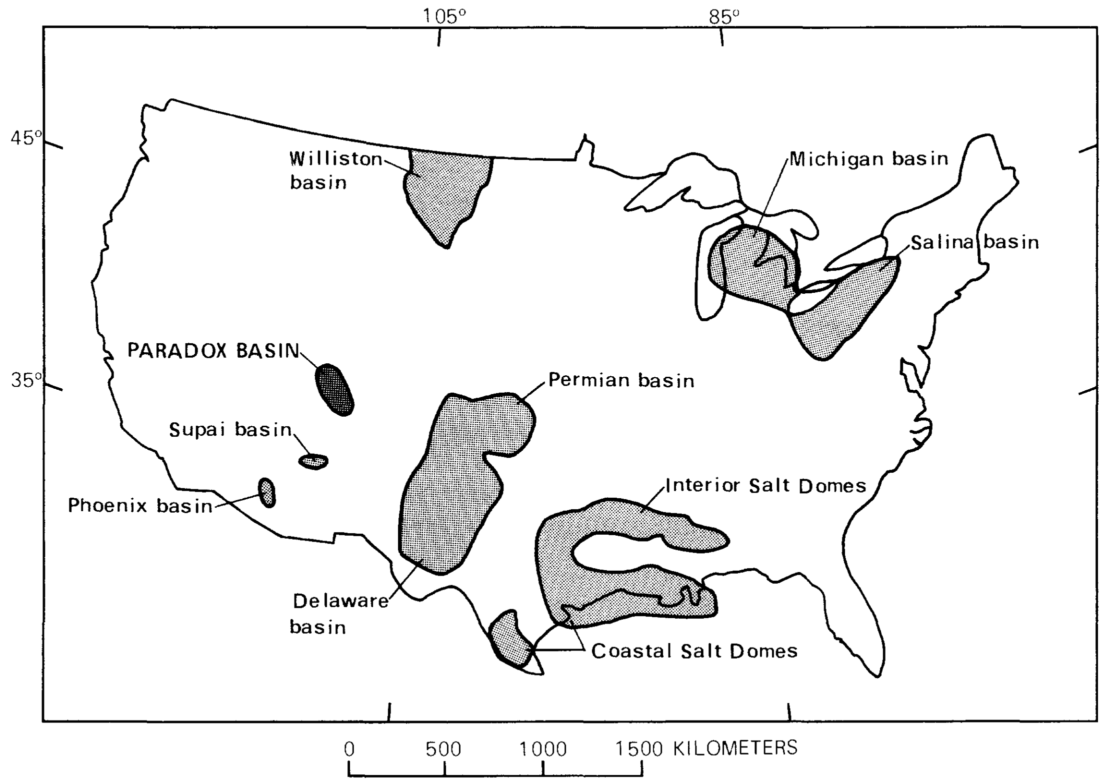


Figure 1.--Location of the Paradox basin and other areas underlain by salt in the conterminous United States.

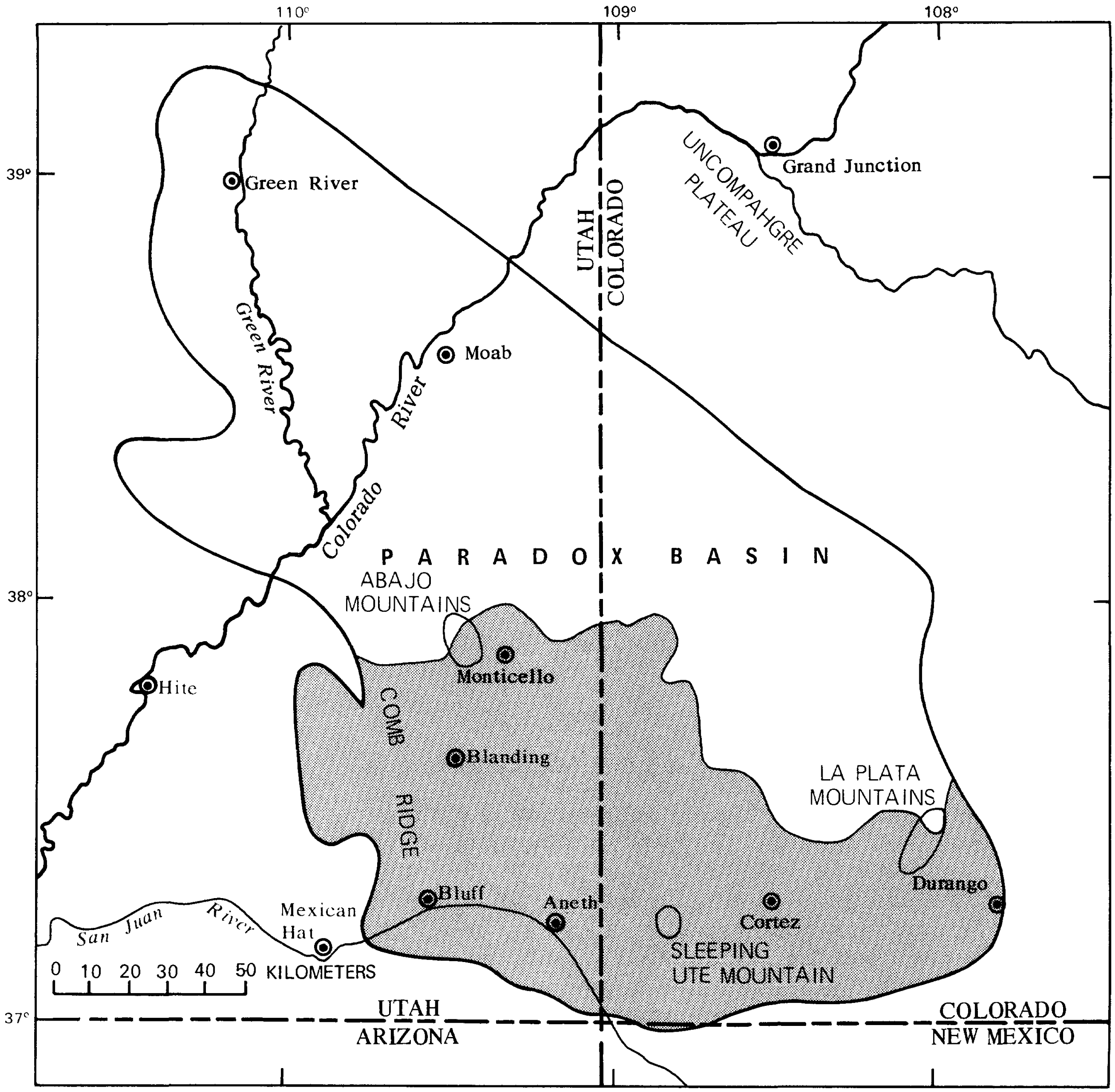


Figure 2.--Location of the Blanding-Durango area in the Paradox basin of southeastern Utah and southwestern Colorado.

Witkind (1964) described stratigraphic units in the Abajo Mountains (Utah) near Monticello. Ekren and Houser (1965) described geology, petrology, and stratigraphic characteristics of geologic units in the Sleeping Ute Mountain (Colorado) area, and briefly discussed water resources in that area. Iorns, Hembree, and Oakland (1965), in a regional study of the Upper Colorado River Basin, presented basic data and summarized hydrology of a large area that includes the study area. Baars' (1966) discussion of pre-Pennsylvanian paleotectonics includes some hydrologic characteristics of the stratigraphic units involved. Feltis (1966), in his reconnaissance of regional ground-water data, described the occurrence and quality of water in aquifers of eastern Utah. A regional report by Hanshaw and Hill (1969) includes potentiometric maps, hydrologic interpretations, and chemical analyses of water from aquifers ranging in age from Mississippian to Permian. Haynes, Vogel, and Wyant's (1972) geologic and structural map of the Cortez quadrangle aided considerably to understanding the geology of the area. Reports published to provide geologic and hydrologic information in the Paradox basin for determining the suitability of salt deposits for waste storage include those by Hite and Lohman (1973), Hite (1977), Rush and others (1980), and Wollitz and others (1982). The first three reports describe the geology of salt anticlinal areas and contain references to many of the geologic reports published concerning the Paradox basin.

Interstitial hydraulic conductivity and transmissivity of sandstones of Permian and Mesozoic age in the Colorado Plateau have been described by Jobin (1962). A discussion of the relationship between permeability of Mesozoic sandstones to uranium ore deposits is given in Johnson and Thordarson (1966). Ground-water circulation in the western Paradox basin has been described by Thackston and others (1981).

Numbering System for Hydrologic Sites

Location numbers for hydrologic sites in this report are based on the rectangular subdivision of the public lands, referenced to the Salt Lake base line and meridian in Utah and the New Mexico base line and meridian in Colorado. The location number consists of three units: the first is the township either north (Colorado) or south (Utah) of the base lines; the second unit, separated from the first by a slant, is the range east (Utah) or west (Colorado) of the meridian; the third unit, separated from the second by a dash, designates the section number. The section number is followed by as many as three letters that indicate quarter section, quarter-quarter section, and quarter-quarter-quarter section. The letter "a" designates the northeast quarter of each subdivision; the letter "b" designates the northwest quarter; the letter "c" designates the southwest quarter and the letter "d" designates the southeast quarter. For example, the well in Utah with location number 41/25-17cbd is in the SE¼NW¼SW¼ of sec. 17, T. 41 S., R. 25 E., Salt Lake base line and meridian. If the location of a hydrologic site is not accurately known, only part of the location number or letter designation is given. The location of sites shown on plates 1 and 2 is identified only by township, range, and section, unless the letters are needed to distinguish among sites.

HYDROLOGIC ENVIRONMENT

Physiography and Drainage

The Blanding-Durango area is the southern part of the Paradox basin. The Paradox basin is a major subdivision of the Colorado Plateau Province (as defined by Fenneman, 1946). The Paradox basin, according to Hite and Lohman (1973, p. 4), is not a definable physiographic feature, but rather is defined as the area of the Colorado Plateau Province that is underlain by a sequence of evaporites, mostly halite (salt) beds, of Pennsylvanian age.

Despite the existence of localized high topographic relief, gently dipping sedimentary units characterize much of the area. Steeply dipping units occur adjacent to igneous intrusives, such as the Abajo Mountains and Sleeping Ute Mountain, as well as along an eroded monocline, Comb Ridge in Utah (pl. 1). The top of Sleeping Ute Mountain is 1,200 m above the surrounding area, which ranges in altitude from about 1,500 m in McElmo Creek (Utah-Colorado) to 1,800 m on mesas north of McElmo Creek. Altitudes generally exceed 1,500 m in the southernmost part of the study area and increase to more than 2,000 m northward. Near the town of Durango and near the Abajo and the San Juan Mountains, the altitude is about 3,000 m above sea level. In the southwestern part of the study area near the San Juan River (Utah), altitude decreases to about 1,300 m.

The major river in the study area is the San Juan River, a perennial stream and a tributary to the Colorado River. It acts as the drain for two major tributaries: the La Plata River and the Mancos River in Colorado. McElmo Creek and Cottonwood Wash in Utah are tributaries that are intermittent in flow in all or part of their reach. These tributary drainages flow south and southwest to the San Juan River, which discharges from the southwestern part of the study area (fig. 3). The San Juan River has eroded increasingly older rock units as it flows westward across the southern end of the report area. Just outside the study area at the Goosenecks (pl. 1) of the San Juan River in Utah, it flows on the Hermosa Formation, the oldest geologic unit exposed near the study area. The La Plata and Mancos Rivers and McElmo Creek are important for irrigation of croplands. These streams head in the San Juan Mountains in Colorado and have segments of minor perennial flow. All other flow is short-term response to snowmelt and infrequent storm runoff. Springs are abundant in the mountains; some of them flow throughout the year.

June and July are generally the months of maximum flow, resulting from spring snowmelt mostly upstream from the report area. During most of the remainder of the year, the streams have much lower flow with minimum flow generally occurring during September and October. Perennial streams are maintained mostly by ground-water contributions, irrigation runoff, and discharge from surface-water reservoirs during these low-flow periods.

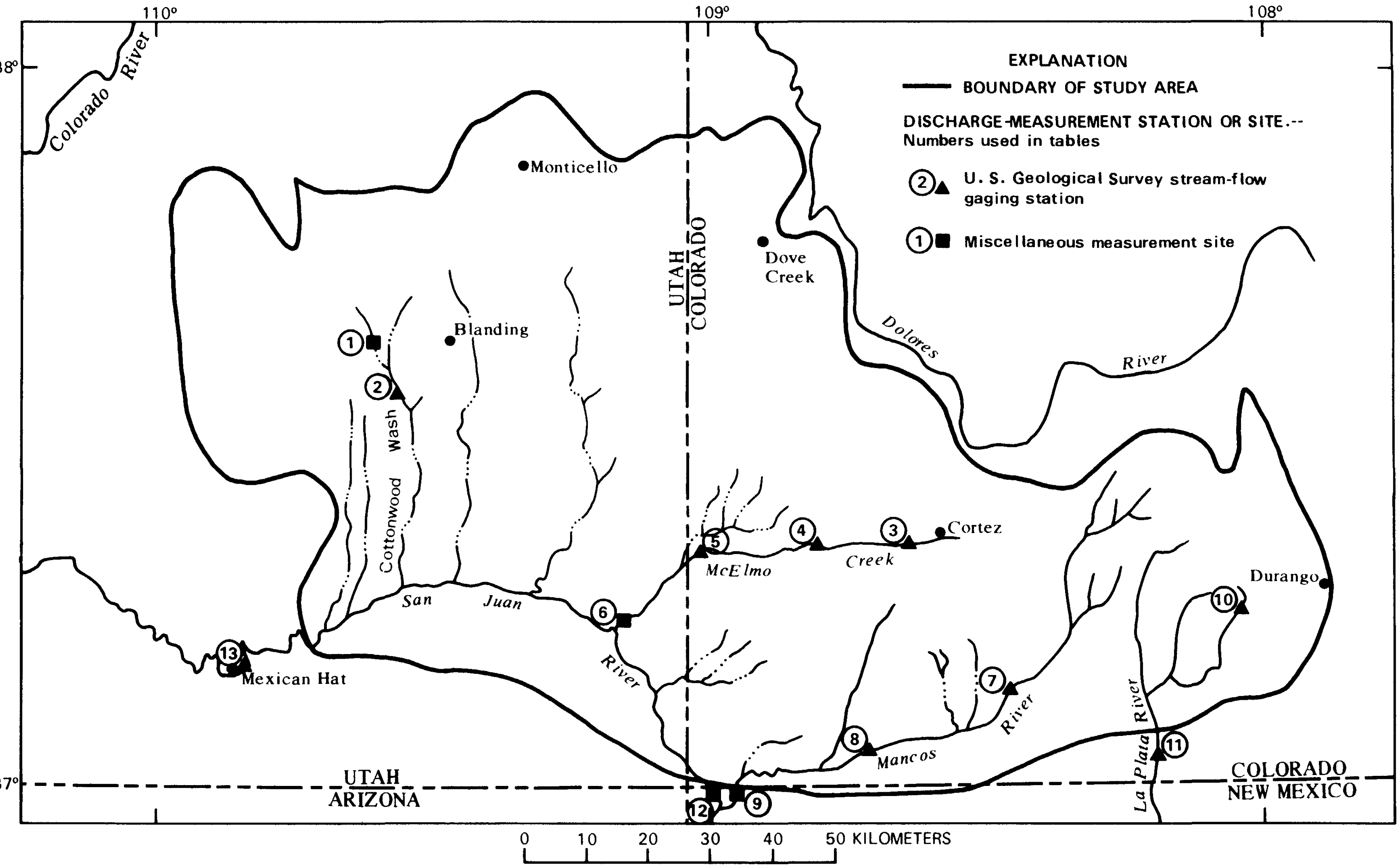


Figure 3.--Location of principal streams and discharge-measurement stations and sites in and near the Blanding-Durango area.

Precipitation

Precipitation for the study area was first measured and recorded at Mancos in 1898, Durango in 1900, and at Monticello in 1902. Since then, abundant precipitation data have been collected, as summarized in several tables and illustrations in this section of the report.

A summary of average annual precipitation at weather stations in and near the study area is given in table 1. Location of the stations are shown on figure 4. Because some of the periods of record for precipitation are short in relation to the records at Monticello and Durango, all short-term station averages were adjusted to the longer-term means (table 1). These values were then plotted on a graph (fig. 5) to determine the general relation of precipitation to altitude in the area. As shown, average precipitation systematically increases with altitude from about 170 mm/a at an altitude of 1,300 m to 900 mm/a or more at altitudes of 3,000 m. These precipitation values approximate the entire precipitation range for the study area.

Areal distribution of precipitation in the study area is shown in figure 4. Average annual precipitation on the mesas and flatlands ranges from about 150 to 500 mm. Potential average annual evaporation is estimated to be 1,000 to 1,250 mm (Iorns and others, 1965, plate 8). Therefore, mesas and flatlands are arid to semiarid. At higher altitudes, in the Abajo Mountains, Sleeping Ute Mountain, and San Juan Mountains, precipitation exceeds 600 mm/a; the climate is subhumid to humid, because the quantity of precipitation is similar to the quantity of potential evaporation.

The Blanding-Durango area, according to Pyke (1972, fig. 36), is in a precipitation zone characterized by maximum precipitation in August. Monthly distribution of precipitation is shown in figure 6 for Monticello and Durango. Both stations have similar distribution patterns: (1) A dry period from November through June; and (2) a wetter period from July through October. Precipitation patterns in the lower, more arid southwestern part of the study area are somewhat more erratic because of fewer storms.

To evaluate the long-term hydrologic character of the area, short-term measurements have to be put into a long-term perspective; information is presented in figures 7 and 8 to show that perspective. As seen in figure 7, for the period of recorded precipitation, dry conditions prevailed during 1900-04, 1930-39, and 1942-78. Moist conditions are noted during 1905-29 and 1940-41. These modern short-term variations in precipitation are typical of the short-term cycles occurring since 1130, based on tree-ring chronologies in figure 8. Prior to that time, climatic conditions probably were more moist.

In conclusion: (1) Recent precipitation probably reflects a continuation of the general trend since 1130, with no long-term increases or decreases in overall climatic dryness; (2) more moist and more dry periods, similar to those recorded since that date, will probably occur in the future; (3) moist conditions similar to those for 700-1130 are possible sometime again in the undetermined future.

Table 1.--*Average annual precipitation at weather stations in and near the Blanding-Durango area*[1]

Map number (fig. 4)	Station name	Altitude above sea level (meters)	Period of record[2]	Average annual precipitation (millimeters)	
				Average	Adjusted to long term[3]
1	Elk Ridge Kigalia, Utah	2,591	1968-76	602	(a) 668
2	Buckboard Flats, Utah	2,743	1968-74	838	(a) 920
3	Monticello, Utah	2,079	1902-78	392	393
4	Northdale, Colo.	1,978	1930-78	332	(a) 369
5	Mexican Hat, Utah	1,295	1946-78	152	(a) 169
6	Bluff, Utah	1,325	1919-78	197	(a) 209
7	Hovenweep National Monument, Utah	2,154	1958-78	265	(a) 296
8	Yellow Jacket, Colo.	2,089	1960-78	385	(b) 406
9	Dolores, Colo.	2,118	1916-78	443	(b) 461
10	Cortez, Colo.	1,883	1929-78	331	(b) 344
11	Mesa Verde National Park, Colo.	2,121	1922-78	456	(b) 477
12	Mancos, Colo.	2,114	1898-1978	404	(b) 421
13	Fort Lewis, Colo.	2,320	1914-78	472	(b) 474
14	Durango, Colo.	1,996	1900-78	480	480

[1]Based on data from U.S. Weather Bureau, National Weather Service.

[2]Precipitation data not continuous through period of record, 1898-1978.

[3]Adjustment to long term, based on cumulative departure at Monticello, Utah (a), and Durango, Colorado (b).

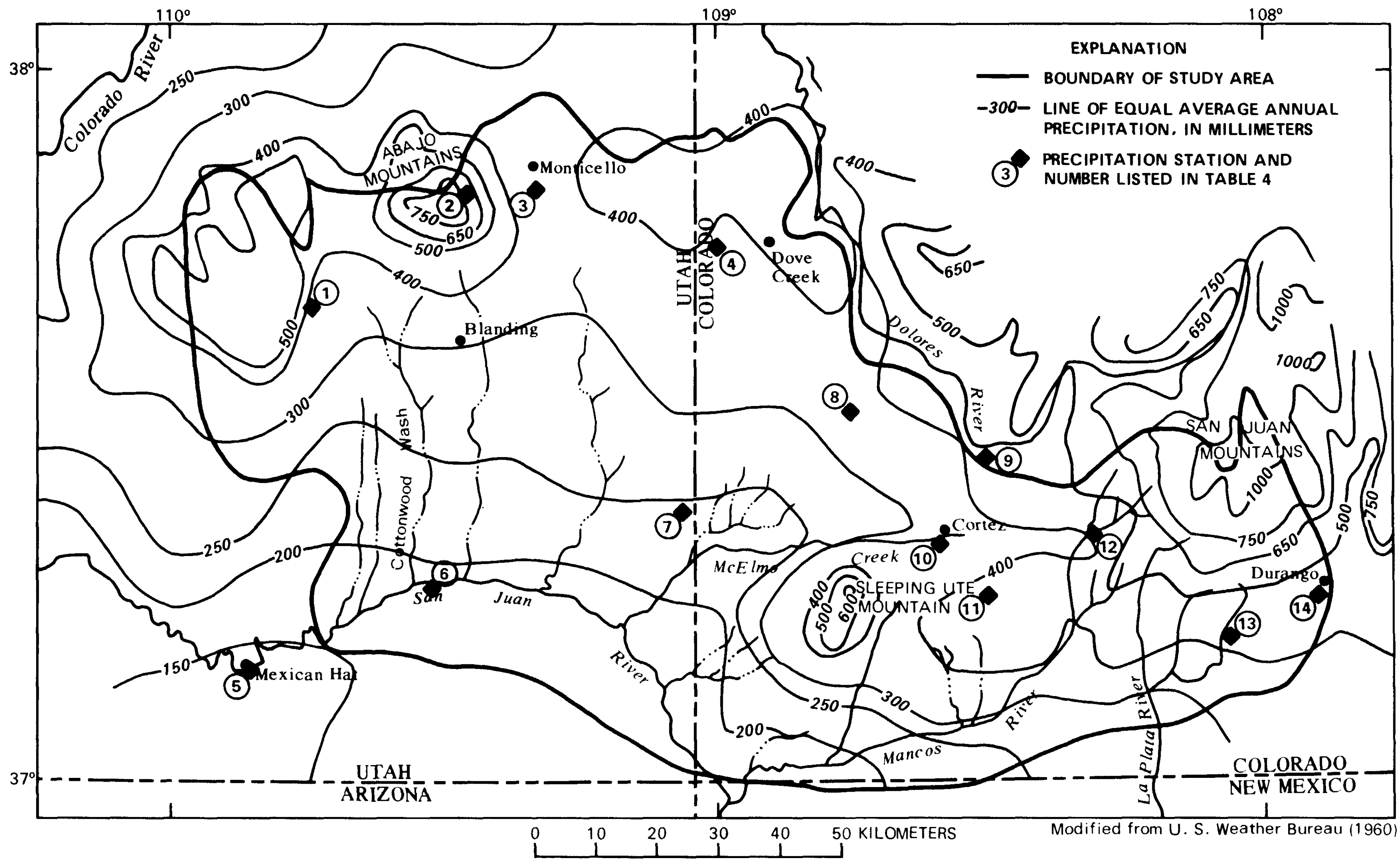


Figure 4.--Average annual precipitation and location of precipitation stations in and near the Blanding-Durango area (U.S. Weather Bureau, 1960).

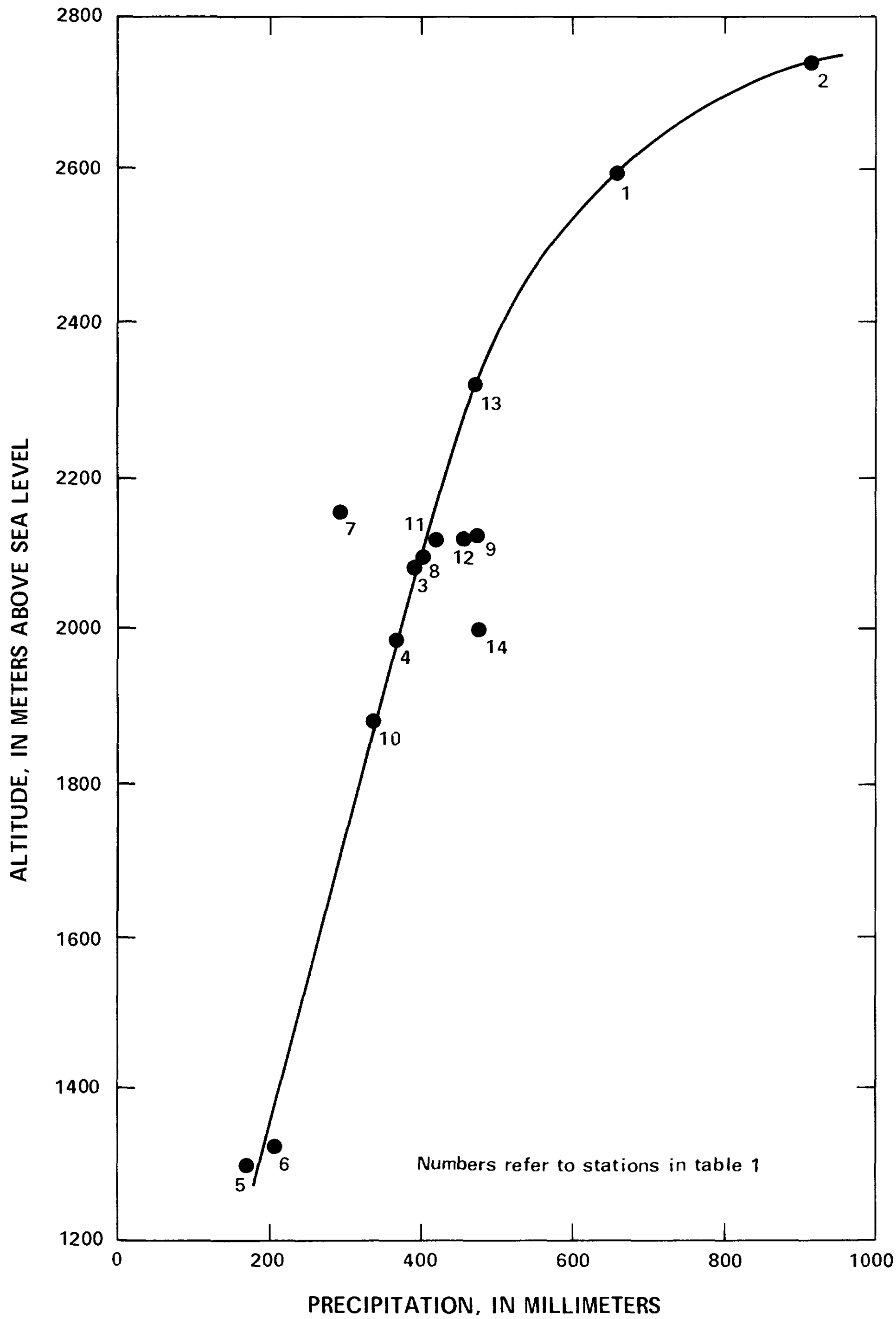


Figure 5.--General relationship between precipitation and altitude in and near the Blanding-Durango area. Based on data from National Weather Service.

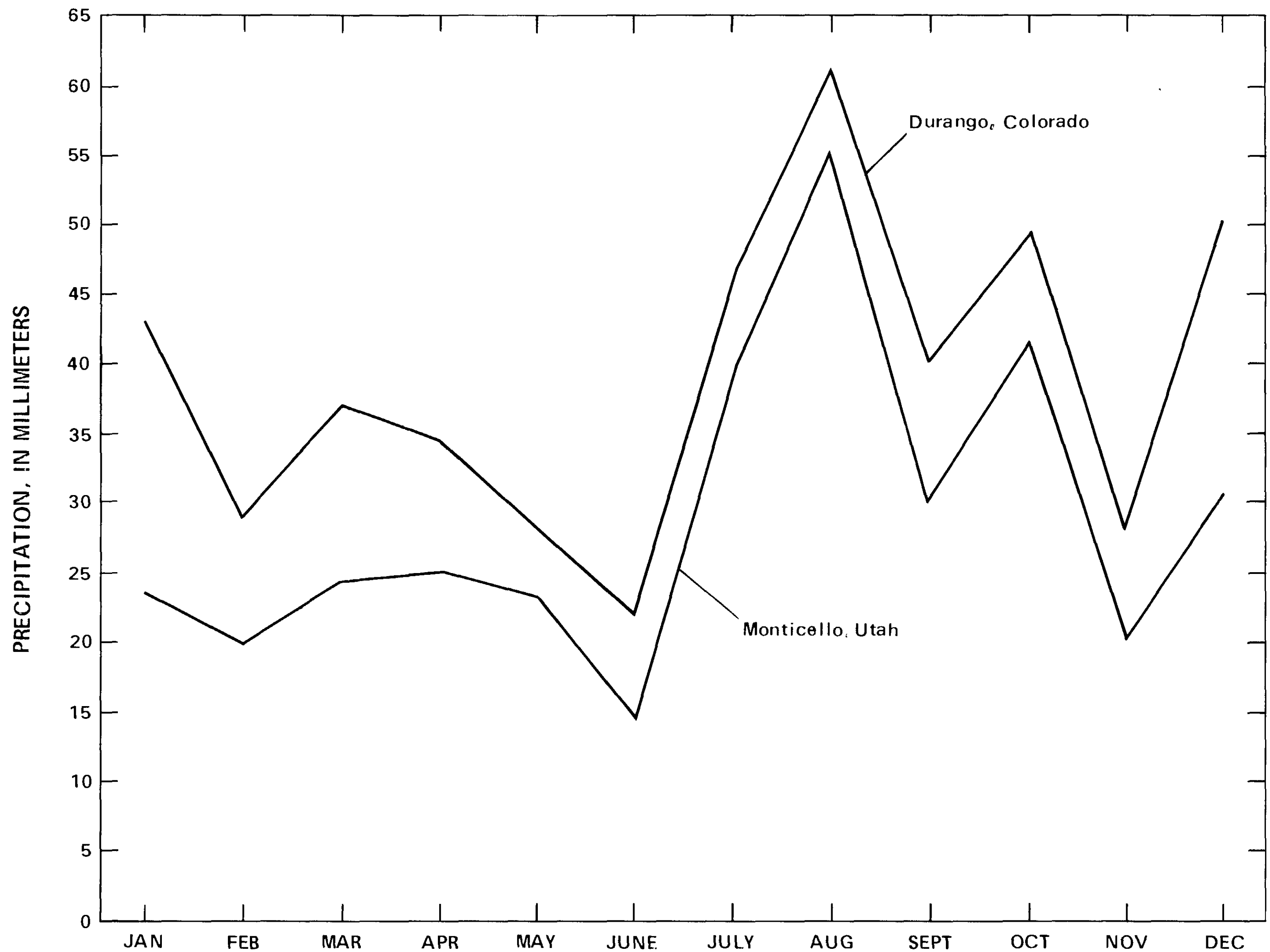


Figure 6.--Monthly distribution of average annual precipitation at Durango, Colorado, and Monticello, Utah. Based on data from National Weather Service, 1941-78.

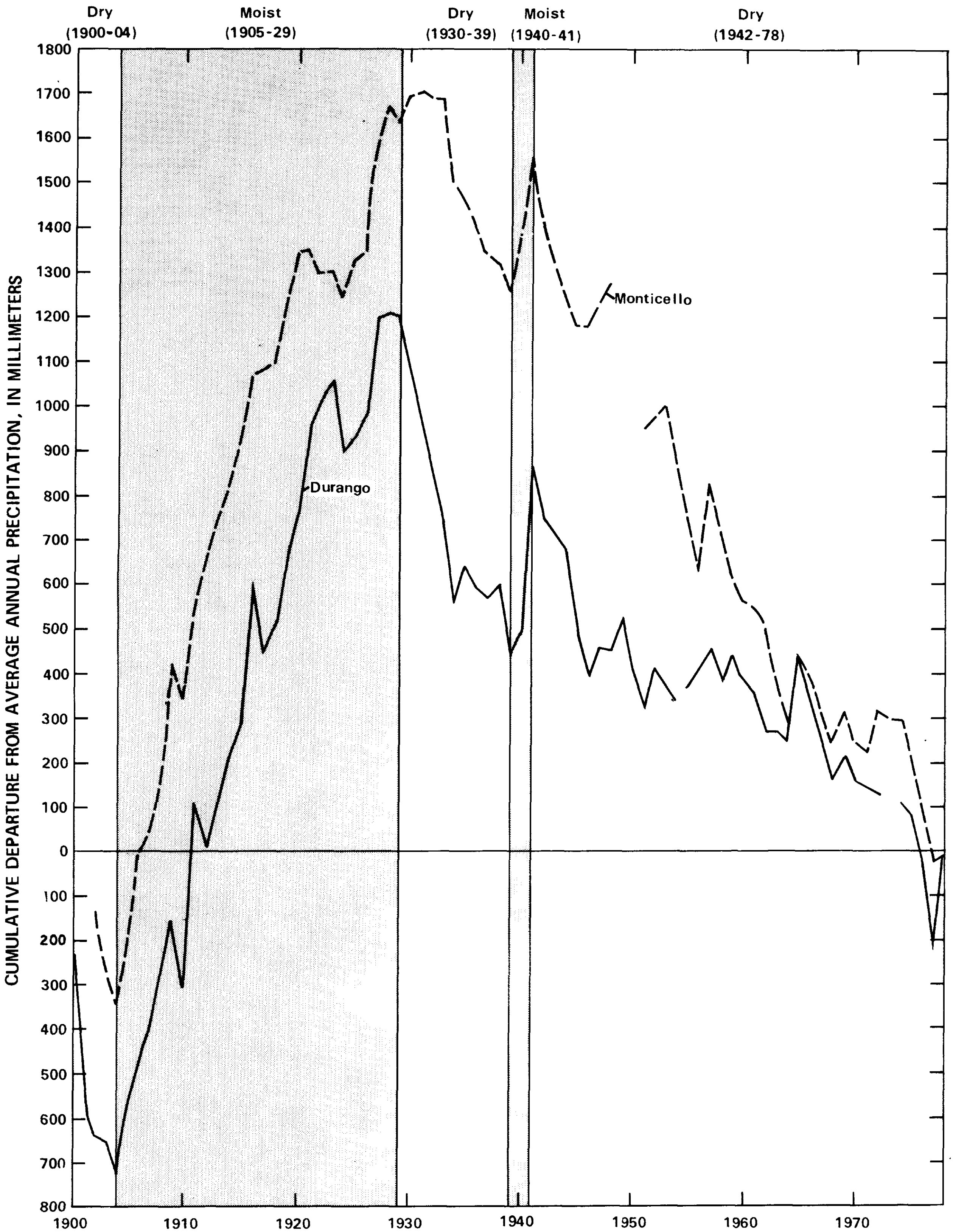


Figure 7.--Cumulative departure from average annual precipitation, based on measured precipitation at Durango, Colorado, and Monticello, Utah. Based on data from National Weather Service.

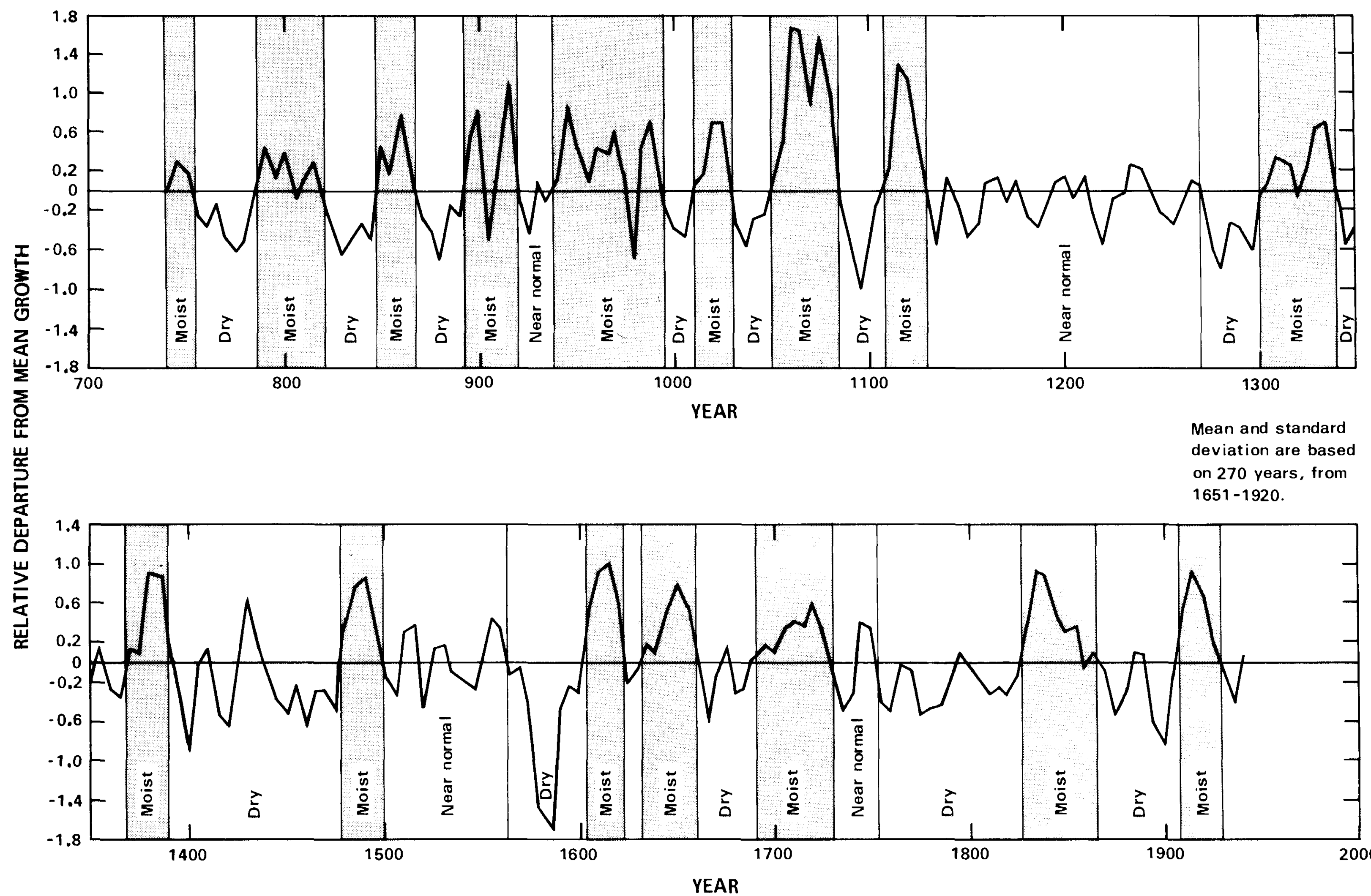


Figure 8.--Long-term precipitation variation at Mesa Verde National Park, Colorado, based on tree-ring chronologies. Based on data from Fritts, 1965.

Estimated volume of average annual precipitation is about $4,400 \times 10^6\ m^3$ within the study area (table 2). These estimates are based on the altitude-precipitation relation shown in figure 5.

Runoff

Three potential sources of runoff exist in the study area: (1) Melting mountain snow during the spring; (2) infrequent summer and early fall showers; (3) surplus water from trans-basin diversion from the Dolores River northeast of the study area for irrigation.

Most of the study area has an average annual rate of runoff less than 10 mm. North of Durango, at higher altitudes, the rate of average annual runoff increases rapidly to a maximum value of about 250 mm/a (fig. 9). Streams draining the high mountains usually are perennial, with small flood peaks, caused by slow snowmelt. Flow in streams at lower altitudes is sporadic. Storms in the study area generally are short-duration, high-intensity summer thunderstorms that cause local flooding. At all other times, streamflow is nonexistent, unless it is sustained by ground-water discharge or surplus water from irrigation.

Imported water in addition to normal streamflow is used to irrigate approximately $59.5\ km^2$ of farmland near the headwaters of the Mancos River, La Plata River, and McElmo Creek between May and October (fig. 10). As much as $91.5 \times 10^6\ m^3$ of water per annum is used for irrigation. A large part of the irrigation water is transpired and evaporated from soil; the remainder percolates downward to the saturated zone of the upper ground-water system. Locally, water from the recharged upper ground-water system may move laterally to discharge into streams.

Trans-basin diversion from the Dolores River is about $158.5 \times 10^6\ m^3/a$. This diversion, coupled with flow regulation by reservoirs, probably is responsible for maintaining flow in the upstream reach of McElmo Creek during the drier parts of the year.

Hydrogeologic Units and Structural Features

The 50 stratigraphic units that underlie the study area are summarized in table 3 (in pocket); they have been grouped into 10 hydrogeologic units according to their hydraulic interconnection and water-transmitting properties, which is related to their general lithology. The six hydrogeologic units above the evaporite hydrogeologic units comprise the upper ground-water system, and the three hydrogeologic units below the evaporite comprise the lower ground-water system.

The lithology of rocks underlying the study area is diverse. Siltstone, mudstone, shale, and intrusive rocks generally have low hydraulic conductivities and, therefore, transmit little water. Sandstone, conglomerate, gravel, dolomite, and limestone have a wide range of hydraulic conductivity; however, they generally are more transmissive than the

Table 2.--*Estimated long-term average annual precipitation*

Precipitation zone (from U.S. Geological Survey topographic maps[1]		Area (square kilometers) (1)	Estimated precipitation		
(feet)	(meters)		Range (from fig. 6) (millimeters)	Average (meters) (2)	Average ($\times 10^6$ cubic meters) [(1) X (2) = (3)]
>9,000	>2,743	367	>900	1.0	370
8,000-9,000	2,438-2,743	580	550-900	.72	420
7,000-8,000	2,134-2,438	1,900	400-550	.47	890
6,000-7,000	1,829-2,134	4,340	300-400	.35	1,500
5,000-6,000	1,524-1,829	2,980	250-300	.27	800
<5,000	<1,524	1,910	<250	.20	380
Total (rounded)		12,000			4,400

[1]Scale: Utah, 1:62,500; Colorado, 1:24,000.

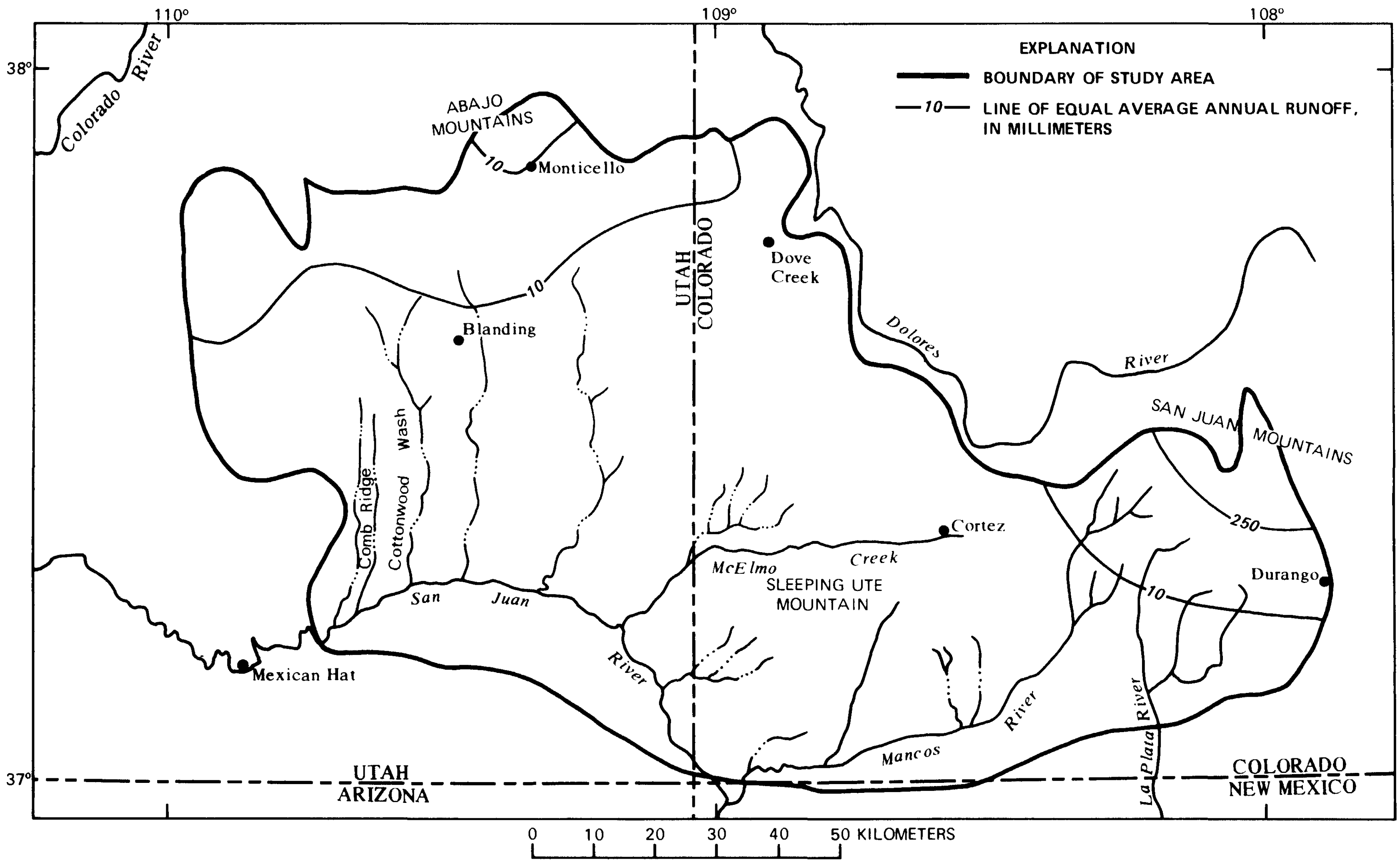


Figure 9.--Distribution of average annual runoff.
(Adapted from Hedlund and others, 1971.)

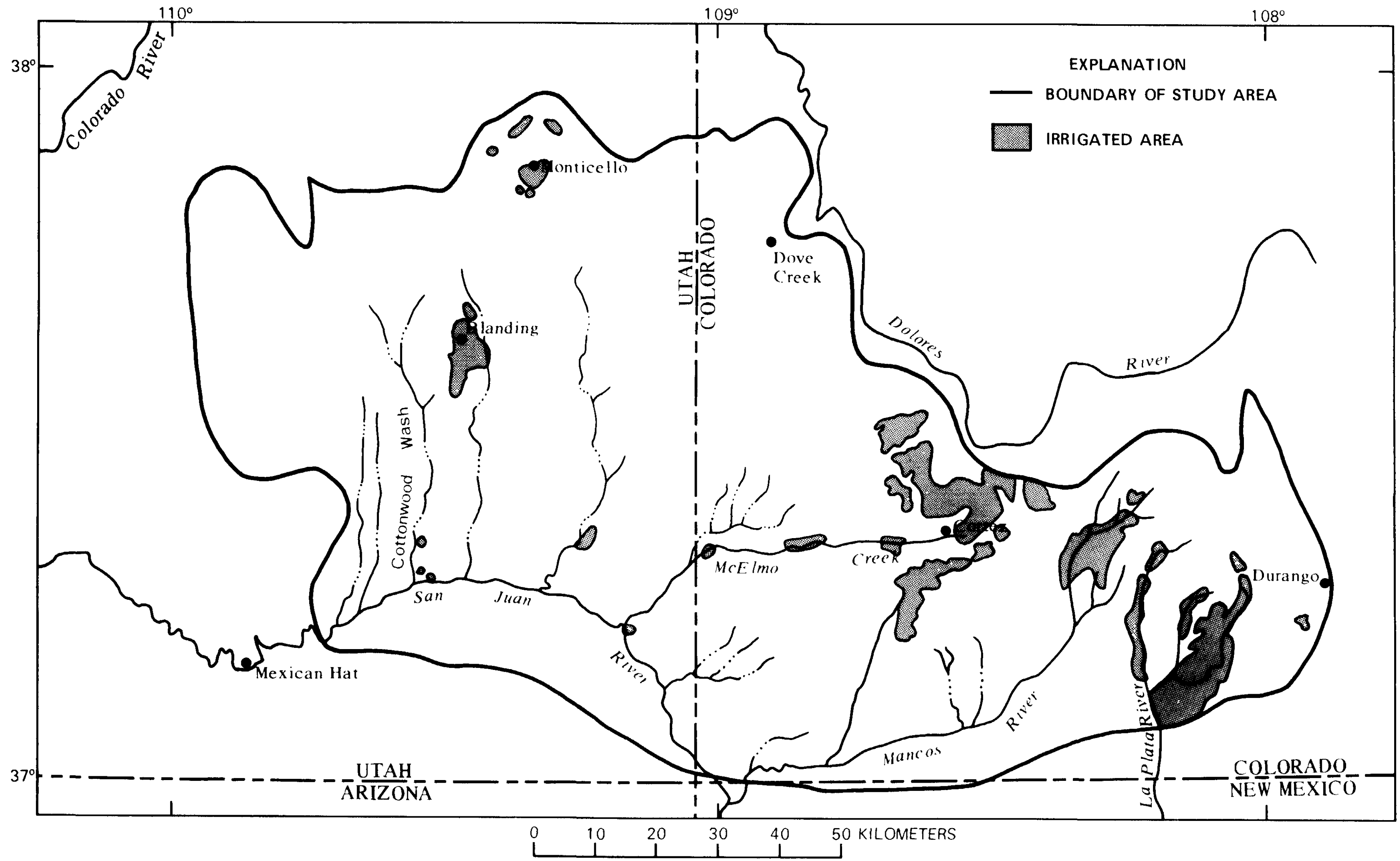


Figure 10.--Location of irrigated areas. From Iorns and others, 1965.

siltstone, mudstone, shale, and intrusive rocks. Sandstone and conglomerate may have both primary and secondary permeability; in carbonate rocks, particularly dolomite, characteristically secondary permeability dominates. Salt and gypsum at great depths below land surface have a plastic character and are commonly self-sealing when fractured; as a result, they transmit even less, if any, ground water. Although alluvial deposits commonly have very significant hydraulic conductivities; in the study area, they are relatively thin and generally unsaturated. However, along the upstream reaches of the San Juan River and along the Mancos River, alluvial deposits are thicker and are generally saturated (pl. 1).

Excluding the alluvium (table 3), two aquifers comprise the upper ground-water system and are referred to as the Cutler aquifer and the Mesozoic sandstone aquifer. In the northern part of the Paradox basin, the Cutler aquifer was not considered a major aquifer (Rush and others, 1981). Because of an increase in permeable strata from intertonguing of thick sandstone units of the Cutler Formation in the study area, it was appropriate to treat this unit as an aquifer.

Lower Paleozoic Aquifer

The lower Paleozoic aquifer includes mostly limestone and dolomite, which are generally porous and permeable. The Leadville Limestone of Mississippian age or equivalents are the principal water-yielding units in the lower ground-water system. The formation consists of a lower dolomitic unit and an upper limestone unit. The dolomite generally has greater porosity and permeability than the limestone (Hanshaw and Hill, 1969, p. 271; Hood and Danielson, 1979, p. 14). This predominantly limestone formation occurs only in the subsurface in the Blanding-Durango area. The unit is exposed a short distance north of Durango, Colorado, but pinches out in the subsurface along the Uncompahgre Plateau north of these exposures. Transmissivity values for the Leadville obtained from drill-stem tests in the western Paradox basin range from less than 1.4×10^{-3} to more than 5.4 m^2/d (Thackston and others, 1981, p. 215). According to Neff and Brown (1958, p. 108), some of the Devonian rocks are permeable and transmit water as part of the lower Paleozoic aquifer.

Cutler Aquifer

The Cutler aquifer principally is composed of the Cutler Formation and is dominantly sandstone, with some mudstone, siltstone, and limestone present in lower members. Thin sandstone beds that overlie the Cutler Formation also are included in this aquifer. These beds comprise the Hoskinnini Member of the Moenkopi Formation (table 3). During Permian time, uplift and erosion occurred in the Uncompahgre Plateau, and a large volume of coarse sediments accumulated in the Paradox basin, which was near the source area. Finer sediments were carried farther westward and deposited as the Halgaito and Organ Rock Tongues of the Cutler Formation. These two tongues are intercalated with two eolian sandstone units, the Cedar Mesa Sandstone and

DeChelly Sandstone Members. The two fine-grained tongues are relatively impermeable layers above and below the Cedar Mesa Sandstone Member, from which significant spring-flow occurs (Witkind, 1964, p. 81).

Mesozoic Sandstone Aquifer

The Mesozoic sandstone aquifer in the study area consists of a sequence of 15 rock units, predominantly sandstone, that thickens to the northwest (table 3). Most of the volume of this aquifer is unsaturated throughout most of the study area; however, perched water bodies are common and yield small supplies to wells and springs. The principal water-yielding units are the Wingate, Navajo, Bluff, and Dakota Sandstones, the Slick Rock Member of the Entrada Sandstone, and the Morrison and Burro Canyon Formations (Hite and Lohman, 1973, p. 9; Huntoon, 1977, p. 5; Hood and Danielson, 1979, p. 14). Thin permeable units occur within Mesozoic confining beds.

Springs commonly occur at the base of the more permeable units, such as sandstones in the Bluff, Navajo, and Wingate Sandstones. Springs are discussed in more detail in a later section of this report.

Evaporite Confining Beds

Evaporite confining beds of the Paradox Member of the Hermosa Formation that separate the upper and lower ground-water systems are nearly impermeable (Rush, 1980, p. 15); they generally form a hydraulic boundary between the two systems, except perhaps locally in the grabens near the Abajo Mountains (pl. 1). Here, some recharge from precipitation may be infiltrating to the lower ground-water system. The presence of sodium chloride water in equivalents to Leadville strata, which lie below the saline facies of the Paradox Member, was suggested by Hanshaw and Hill (1969) as being the result of downward cross-formational flow of saline water from the Paradox Member. They believed that cross-formational flow could only occur in areas where the normal stratigraphic sequence has been disrupted. Locally, the conduits of these flows might be caused by faulting or folding in areas such as the Verdure graben, or by diapirism-induced pinchouts of the salt adjacent to salt anticlines. These structurally related pathways, if permeable, would allow water to flow past and dissolve the Paradox salt, then flow downward into the Leadville equivalent carbonates. Gaping surficial cracks filled with alluvium are common in the graben area (Biggar and others, 1981), which serve as recharge areas during intense rains.

Stratigraphic units that transmit little water occur immediately above and below the evaporite confining beds. These confining beds, in addition to providing a hydraulic barrier between aquifer systems, also provide a barrier between the salt and overlying and underlying aquifers. Lower and Middle Pennsylvanian confining beds contain a large percentage of shale that provides separation between the bottom of the evaporite confining beds and the underlying lower Paleozoic aquifer. Overlying the evaporite confining beds are shale and mudstone that separate the evaporite confining beds from the Cutler aquifer (table 3).

Outcrop Patterns

The outcrop pattern of the hydrogeologic units in the study area is shown on plate 1. The most widely outcropping units are those of the upper ground-water system. The oldest rocks crop out just outside the southwestern part of the study area, near Mexican Hat, where the San Juan River has incised beds of the upper member of the Hermosa Formation. The principal mapped faults (Hintze and Stokes, 1964; Andrews and Hunt, 1956) also are shown on plate 1. Numerous faults and associated fractures in the northwestern and southeastern part of the study area locally may control the lateral and vertical direction and rate of ground-water flow.

Drill-Stem Tests

Formation-fluid recovery rates during drill-stem tests of petroleum-exploration wells are related in part to permeability of the tested zones. Results of 242 tests are summarized in table 4. This table is based on results of drill-stem tests that are summarized in tables 14 and 15 in the Supplemental Data section at the end of this report. Tabulation of fluid-recovery rates shows that the Cutler Formation has the fastest recovery rate; thus, it probably has a relatively appreciable effective permeability. Some bias probably is introduced, however, because several of the hydrogeologic units have too few tests to constitute an adequate number of samples, and many of the tests are for wells in established oil fields, where permeability is known to be favorable for production. The Hermosa Formation, in addition to containing evaporites, also includes some marine shelf facies, as in the Aneth area (Utah), where porosity and permeability are much more than in the formation as a whole. These are especially favorable as oil or gas reservoirs; therefore, they have been intensively explored and tested by drill-stem tests.

Values of transmissivity and hydraulic conductivity for all the individual hydrogeologic units generally are not known. Based on the lithology, grain size, and drill-stem tests of the strata that comprise these units (table 3), relative permeability ranking, not including the alluvial aquifer, probably is as follows:

Rank	Unit
Most permeable ↑	Mesozoic sandstone aquifer
	Cutler aquifer
	Lower Paleozoic aquifer
	Tertiary and Cretaceous confining beds
	Mesozoic confining beds
	Upper and Middle Pennsylvanian confining beds
	Middle and Lower Pennsylvanian confining beds
	Lower Paleozoic and Precambrian confining beds
Least permeable ↓	Evaporite confining beds

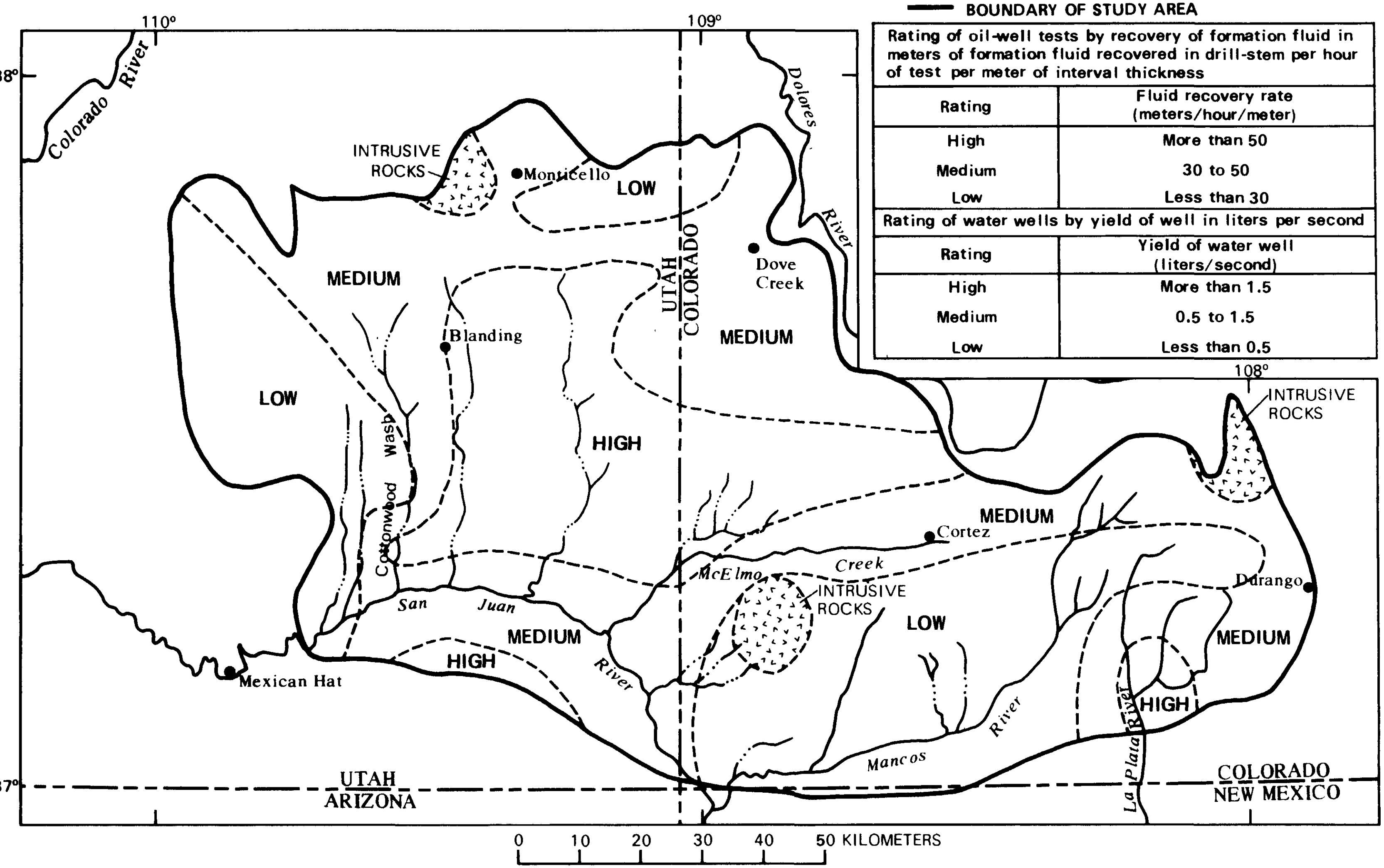
A map of the relative potential of the upper ground-water system to yield formation fluid (fig. 11) serves as an approximate index of permeability distribution in the study area. This map is based partly on rates of fluid

Table 4.--*Summary of formation-fluid recovery rate during drill-stem tests*

[Based on data in tables 14 and 15; rock unit, only units that were tested are listed; (m/h)/m, meters of formation fluid recovered in drill stem per hour of test per meter of test-interval thickness; N, no recovery rate; s, slow recovery rate]

Rock unit (from table 3)	Number of tests	Fluid-recovery rate [(m/h)/m]		Hydrogeologic unit (from table 3)	Number of tests	Fluid-recovery rate [(m/h)/m]	
		Range	Mean			Range	Mean
Fruitland Formation	1	-----	1	Tertiary and Cretaceous confining beds	[1]5	0-2	1
Mancos Shale	4	0-2	1				
Dakota Sandstone	7	0-6	1	Mesozoic sandstone aquifer	[1]10	0-6	1
Morrison Formation	1	-----	4				
Salt Wash Member	1	-----	N				
Entrada Sandstone	1	-----	N				
Chinle Formation, Shinarump Member	1	-----	N	Mesozoic confining beds	[1]1	-----	N
Cutler Formation	8	15-213	63	Cutler aquifer	[1]11	15-213	.61
DeChelly Sandstone Member	3	22-71	54				
Hermosa Formation, upper member	2	s-1	1	Middle and upper Pennsylvanian confining beds	[2]131	0-437	27
Hermosa Formation (undivided)	129	0-437	27				
Hermosa Formation, Paradox Member	50	0-152	15	Evaporite confining beds	50	0-152	15
Hermosa Formation, lower member	1	-----	s	Lower and Middle Pennsylvanian confining beds	[1]4	s-25	5
Hermosa Formation, lower member, and Molas Formation	2	2-25	13				
Molas Formation	1	-----	5				
Leadville Limestone	26	s-127	15	Lower Paleozoic aquifer	30	s-127	14
Devonian (undivided)	2	9-26	17				
Elbert Formation (undivided)	1	-----	6				
McCracken Sandstone Member	1	-----	s				

[1]Sample too small to be representative of hydrogeologic unit.
[2]Some evaporite confining beds may be included in tests.



EXPLANATION

— BOUNDARY OF STUDY AREA

Rating of oil-well tests by recovery of formation fluid in meters of formation fluid recovered in drill-stem per hour of test per meter of interval thickness

Rating	Fluid recovery rate (meters/hour/meter)
High	More than 50
Medium	30 to 50
Low	Less than 30

Rating of water wells by yield of well in liters per second

Rating	Yield of water well (liters/second)
High	More than 1.5
Medium	0.5 to 1.5
Low	Less than 0.5

Figure 11.--Relative potential of the upper ground-water system to yield formation fluid during drill-stem tests.

recovery and partly on reported yields of water wells; however, data do not show an orientation of permeability patterns that easily can be related to geologic framework of the study area.

Permeability and porosity have been determined for cores of Cretaceous and Pennsylvanian rocks from oil-test wells in areas thought to have hydrocarbons; these date are presented in table 5. Values of permeability obtained from a limited number of cores may not be representative of the average permeability of the aquifer. Laboratory permeameter results may be quite different from those obtained by means of pumping tests conducted in the field. Because undisturbed samples of unconsolidated rock are virtually impossible to obtain, one has to be aware that the core samples may have undergone some degree of change in porosity, packing, and grain orientation, which alters the permeability of the rock. Core-laboratory analyses define the permeability of pieces of a core, usually in 0.3-m increments. These values were averaged for the entire length of the core and reported as "average permeability." Interstitial permeabilities of core samples to nitrogen gas for sandstone of Mesozoic and Permian age were measured by Jobin (1962, table 31); these permeability values are given in table 6.

Ground-Water Occurrence

Water in the rocks of the study area occurs as: (1) Water in the unsaturated part of the upper ground-water system that originates as recharge from local precipitation and is percolating downward toward the underlying zone of saturation; (2) percolating water trapped by an impervious stratum in the unsaturated part of the ground-water system and perched above the zone of saturation; and (3) water in the saturated part of the upper regional ground-water system, and in the saturated lower regional ground-water system. In the lower ground-water system, the principal component of flow is in a horizontal direction. Water enters and leaves the study area from beyond its boundaries and is part of a large, regional flow system (Hanshaw and Hill, 1969, p. 271).

The potential for water to recharge the saturated zone of the upper ground-water system indirectly increases with increasing precipitation. In the study area, precipitation generally increases toward the north, and it may be assumed that the potential for ground-water recharge has a similar pattern. Where ground-water recharge occurs, water commonly percolates vertically through as much as several hundred meters before reaching the zone of saturation and becoming a part of the upper regional flow system. Part of the perched water may be discharged from shallow depths by evaporation, transpiration of phreatophytes, and springs, thereby not reaching the saturated zone.

In the vicinity of the San Juan River, all permeable strata below the altitude of the river are saturated with water, except where oil and gas occur. In general, depth to the saturated zone increases with distance from the river, because of increase in altitude of the land surface. Depth to the saturated zone may exceed several hundred meters beneath highlands in the

Table 5.--*Hydrologic properties determined by core analyses*

Well location	Rock unit	Depth interval (meters)	Average length of core (meters)	Average permeability (millidarcies)		Average porosity (percent)	Source
				Horizontal	Vertical		
			COLORADO				
32/17-8cb	Mancos	271-277	6	155	--	12	Core Laboratories, Inc.
32/17-9bb	Mancos	316-317.5	2	25.6	--	11.25	Core Laboratories, Inc.
32/17-22cb	Mancos	385-390	4.4	275	99	16	Core Laboratories, Inc.
33/18-14bb	Mancos	111-115	3	66	--	16	Core Laboratories, Inc.
33/18-15a	Mancos	109-115	5	22.8	--	10	Core Laboratories, Inc.
33/20-4dd	Hermosa	1,830-1,834	4	13.9	--	9.4	Not Known
33½/20-21da	Hermosa	1,756.9-1,764.8	7.9	28	27	9.2	Core Laboratories, Inc.
------------	Hermosa	1,750-1,752.3	2.3	22	21	13.5	Core Laboratories, Inc.
34/12-29db	Hermosa	2,341-2,348	5.5	7.2	--	16.5	Core Laboratories, Inc.
35/20-15dc	Hermosa	1,772.5-1,774.6	2.1	1.4	.8	10.4	Core Laboratories, Inc.
------------	Hermosa	1,787-1,792	5	3.2	2.2	13.1	Core Laboratories, Inc.
33½/20-22bc	Paradox	1,743-1,746	3	13	3.4	7.1	Core Laboratories, Inc.

Table 6.--*Interstitial permeability of Mesozoic and Permian sandstones*
[From table 31 of Jobin (1962)]

Formation	Location	Number of samples	Mean interstitial permeability[1] to nitrogen gas (millidarcies)
Mesaverde Group	Mesa Verde National Park, Colo.	26	162
Dakota Sandstone and Burro Canyon Formation	McElmo Canyon, southwest of Cortez, Colo.	4	186
	Comb Ridge, west of Blanding, Utah	4	813
Morrison Formation, Brushy Basin Member	McElmo Canyon, southwest of Cortez, Colo.	2	10
Morrison Formation, Salt Wash Member	McElmo Canyon, southwest of Cortes, Colo.	10	263
Morrison Formation, Westwater Canyon Member	McElmo Canyon, southwest of Cortez, Colo.	7	589
Morrison Formation	Comb Ridge, northwest of Blanding, Utah	10	813
Bluff Sandstone	McElmo Canyon, southwest of Cortez, Colo.	4	3,240
	Bluff, Utah	11	1,100
Entrada Sandstone	McElmo Canyon, southwest of Cortez, Colo.	9	1,440
	Comb Ridge, west of Blanding, Utah	10	138
	Comb Ridge, west of Bluff, Utah	5	26.3
Carmel Formation	McElmo Canyon, southwest of Cortez, Colo.	2	.00
	Comb Ridge, west of Blanding, Utah	2	21.4
	White Canyon, east of Hite, Utah	3	53.7
Navajo Sandstone	McElmo Canyon, southwest of Cortez, Colo.	8	178
	Comb Ridge, west of Bluff, Utah	13	398
	Comb Ridge, west of Blanding, Utah	5	525
Kayenta Formation	Comb Ridge, northwest of Blanding Utah	9	138
	Comb Ridge, west of Bluff, Utah	6	282
Wingate Sandstone	Comb Ridge, west of Bluff, Utah	5	63.1
	Comb Ridge, west of Blanding, Utah	6	115
Chinle Formation, Shinarump Member	Deer Flat, east of Hite, Utah	10	282
Chinle Formation, Moss Back Member	Deer Flat, east of Hite, Utah	7	891
Chinle Formation	Comb Ridge, west of Bluff, Utah	3	1.10
Dolores Formation	Dolores River Canyon, northeast of Cortez, Colo.	5	.00
Cutler Formation	White Canyon, east of Hite, Utah	5	195
	Dolores River Canyon, northeast of Cortez, Colo.	3	56.2

[1]Represents an average of horizontal and vertical permeability.

northeastern and northwestern parts of the study area; depth to the saturated zone in the southern part of the study area may be as shallow as 30 m near the San Juan River.

Because there were no large regional declines in hydraulic heads caused by pumping reported within the study area, it is assumed that the volume of ground water in storage only has been affected locally. The long-term production of oil from the equivalent of the Leadville Limestone, near Aneth has not created a noticeable cone of depression in the potentiometric surface of the lower ground-water system (fig. 12). The lower ground-water system probably is totally confined by overlying evaporites and confining beds with negligible hydraulic conductivity. Locally, mounds occur in the upper ground-water system under areas of extensive irrigation, indicating local recharge by downward percolation from fields and canals. The location of the area irrigated in the Blanding-Durango area is shown in figure 10.

GROUND-WATER FLOW

Inflow to the Ground-Water Systems

Potential sources of inflow to the upper ground-water system include recharge from precipitation, local infiltration in sandy channels of tributaries of the San Juan River, and subsurface inflow to the study area from adjoining areas.

Inflow to the lower ground-water system is by lateral ground-water flow from outside the report area. Evaporite-confining beds prevent vertical flow between the upper and lower ground-water systems, except in the area west of Comb Ridge, where evaporite confining beds thin to a thickness of 17 m or less, and possibly near the Abajo Mountains, where confining beds are faulted. Hydraulic-head data indicate that the two aquifer systems generally function independently within the study area. In addition, no indisputable evidence of natural mixing of the two different waters occurs near the contact of these two aquifers and their confining beds. Occurrences of oil and gas below depths of 52 m in a well drilled into the lower member of the Hermosa Formation in the San Juan Canyon in 41/19-27, indicates that the lower member is a confining bed in this locality (Baker, 1936, p. 89). Here, interbedded shales prevent appreciable vertical flow of water.

Recharge from Precipitation

A part of the precipitation that falls in the study area infiltrates to the ground-water reservoir. In this section of the report, only a minimal estimate is made of annual quantity. An empirical method of estimating average annual ground-water recharge from precipitation in desert regions was developed by Eakin and others (1951, p. 79-81). Recharge was estimated as a percentage of the average annual precipitation within an area. Geographic zones in which average precipitation ranges between specified limits were delineated on a map, and a percentage of precipitation was assigned to each zone; this percentage represented assumed average recharge from average annual

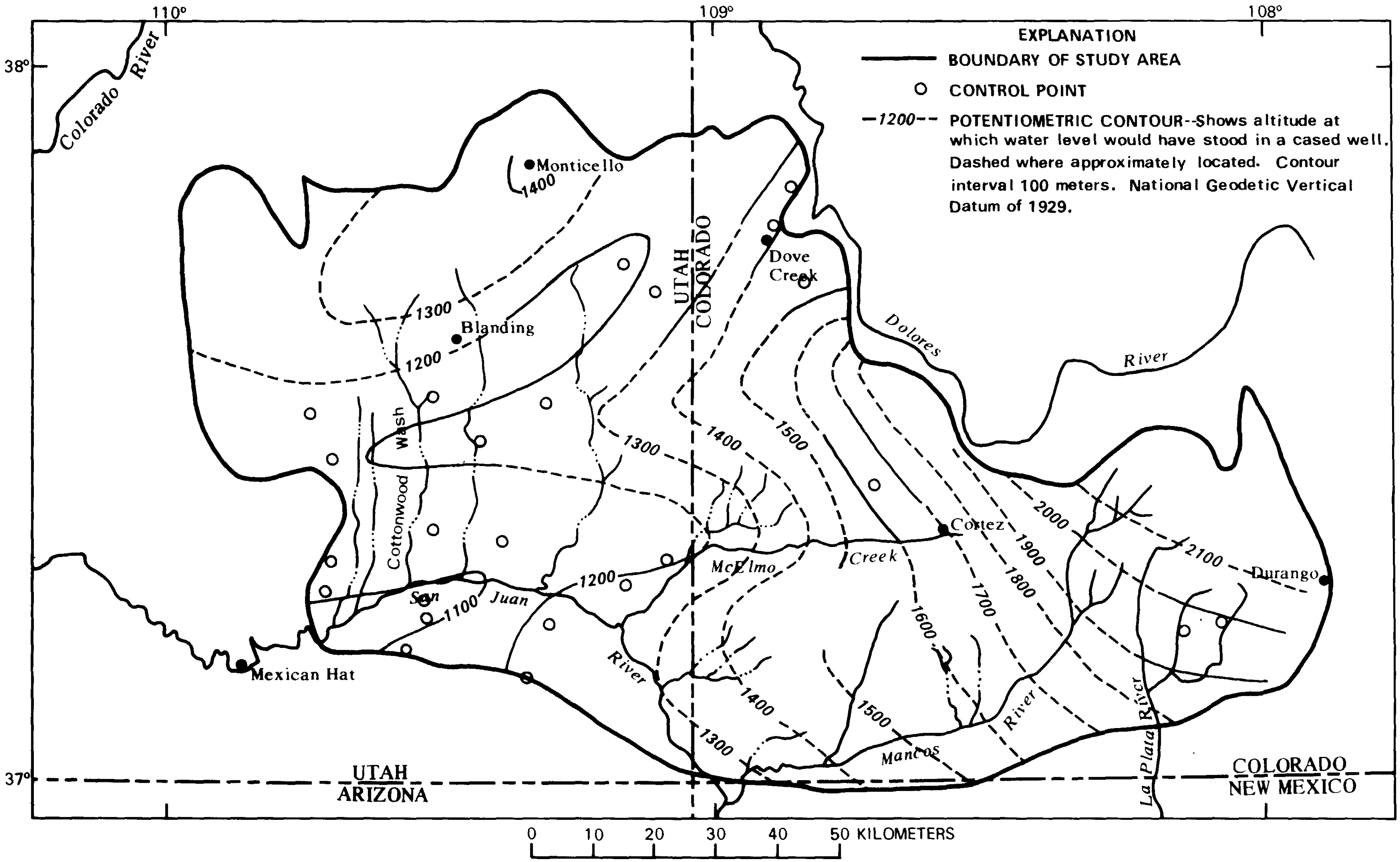


Figure 12.--Generalized potentiometric surface of the lower ground-water system.

precipitation in that zone. Such an estimate was calculated for the northwestern part of the Paradox basin (Rush, Whitfield, and Hart, 1981), where very little, if any, runoff reaches regional streams and flows from the area. In the Blanding-Durango area, potential for such surface-water outflow is much larger because of greater precipitation and runoff rates; under these conditions, the estimation method of Eakin and others (1951) is not valid. However, if a recharge rate of only 2 percent is assumed for the areas receiving the most precipitation (areas above 2,100 m in altitude), a minimum approximation of annual recharge would be about 33×10^6 m^3.

Most water in the upper ground-water system originates as recharge from precipitation in higher parts of the study area--around the Abajo Mountains, Sleeping Ute Mountain, La Plata Mountains, Mesa Verde National Park, and topographic ridges between adjacent drainage basins. These recharge areas are similar to recharge areas on the Navajo Indian Reservation, where altitude is predominantly above 1,981 m, and where annual precipitation is more than 356 mm (Cooley and others, 1969, p. A41).

Recharge to the Lower Ground-Water System

Recharge to the lower ground-water system occurs mainly east and northeast of the study area, as indicated by potentiometric contours in figure 12. These contours are based mainly on data from drill-stem tests of oil and gas exploration wells. Drill-stem test data for both the upper and lower ground-water systems were evaluated by techniques described by Bredehoeft (1965) and Hackbarth (1978). Selected drill-stem data are included in tables 14 and 15 in the Supplemental Data section at the end of the report.

Where the lower ground-water system crops out beyond the study area and boundaries of the Paradox Basin, it receives recharge from precipitation and from streams that cross the outcrops. Water in the lower ground-water system generally flows southwestward beneath the study area. Vertical flows may occur near the Abajo Mountains where overlying confining beds either are breached by the intrusion of magmatic rock or are faulted.

Outflow from the Ground-Water Systems

Outflow from the upper ground-water system includes evapotranspiration, springflow, discharge to the San Juan River, subsurface outflow, and discharge by wells. Of these, only subsurface outflow occurs from the lower ground-water system.

Evapotranspiration

Ground water is discharged by transpiration of phreatophytes and evaporation from soil where the water table is shallow. These areas primarily are the flood plains of the San Juan and Mancos Rivers, and along ephemeral streams such as Montezuma Creek. Along ephemeral streams, discharge is principally drainage from perched zones of saturation and short-term runoff resulting from storms and snowmelt.

The area covered by phreatophytes is approximately 56 km^2, of which about 29.5 km^2 are on the flood plains of the two perennial streams, the San Juan and the Mancos Rivers (pl. 2). Generally, where stands of salt cedar, willow, cottonwood, and salt grass grow, the water table is less than 6 m below the land surface. Greasewood, salt bush, and rabbit brush can be supported, where the water table is 3 to 15 m below land surface. A dense growth of phreatophytes occurs along the San Juan River downstream from its confluence with the Mancos River to Mexican Hat. The density and size of salt cedar and greasewood plants are greater in that area than anywhere else in the Paradox basin. Using pan-evaporation data from a hydrologic station at Mexican Hat, 0.46 m^3/s of river water was calculated to have been lost along this same reach by evaporation from the river surface. Evaporation losses from the moist sand surfaces adjacent to the San Juan River were not included in this calculation. In addition, for this same reach of the river, a total of 0.41 m^3/s of ground water was calculated to be discharged through evapotranspiration from phreatophyte areas. Thus, the San Juan River and its tributaries serve as major discharge areas of ground water through evapotranspiration.

Total transpiration by phreatophytes in the Blanding-Durango study area is about 33 x 10^6 m^3/a. This estimate is based on an estimated average annual rate of transpiration of about 1.0 m by salt cedar, cottonwood, and willow, and about 0.1 m by greasewood, salt bush, rabbit brush, and salt grass. These rates are based on research done by Lee (1912), White (1932), Young and Blaney (1942), Houston (1950), Robinson (1965), and Harr and Price (1972) in other areas. In the study area, about 30 km^2 are covered by salt cedar, cottonwood, and willow, and about 26 km^2 are covered by greasewood, salt bush, rabbit brush, and salt grass.

Discharge to Streams

Location of water in streams during a low-flow period, as determined by aerial observation, is shown in figure 13. Reaches of tributaries to the San Juan River, in which water flowed during low flow in October 1979, are shown. Low-flow stream measurements along selected reaches of major tributaries in the study area indicate that they are not receiving large quantities of ground-water discharge from the upper ground-water system. The lower ground-water system probably is not hydrologically connected with the upper ground-water system, or to sources of surface water in the study area, except perhaps in the Abajo Mountains.

Water discharges from the upper ground-water system into the San Juan River, as well as to reaches of Cottonwood Wash, McElmo Creek, the Mancos River, and the La Plata River. This observation is supported by the following data: (1) Instantaneous measurements of streamflow (as listed in table 7); (2) distribution of potentiometric contours for the upper ground-water system (pl. 2); and (3) evapotranspiration survey (as shown on pl. 2). The location

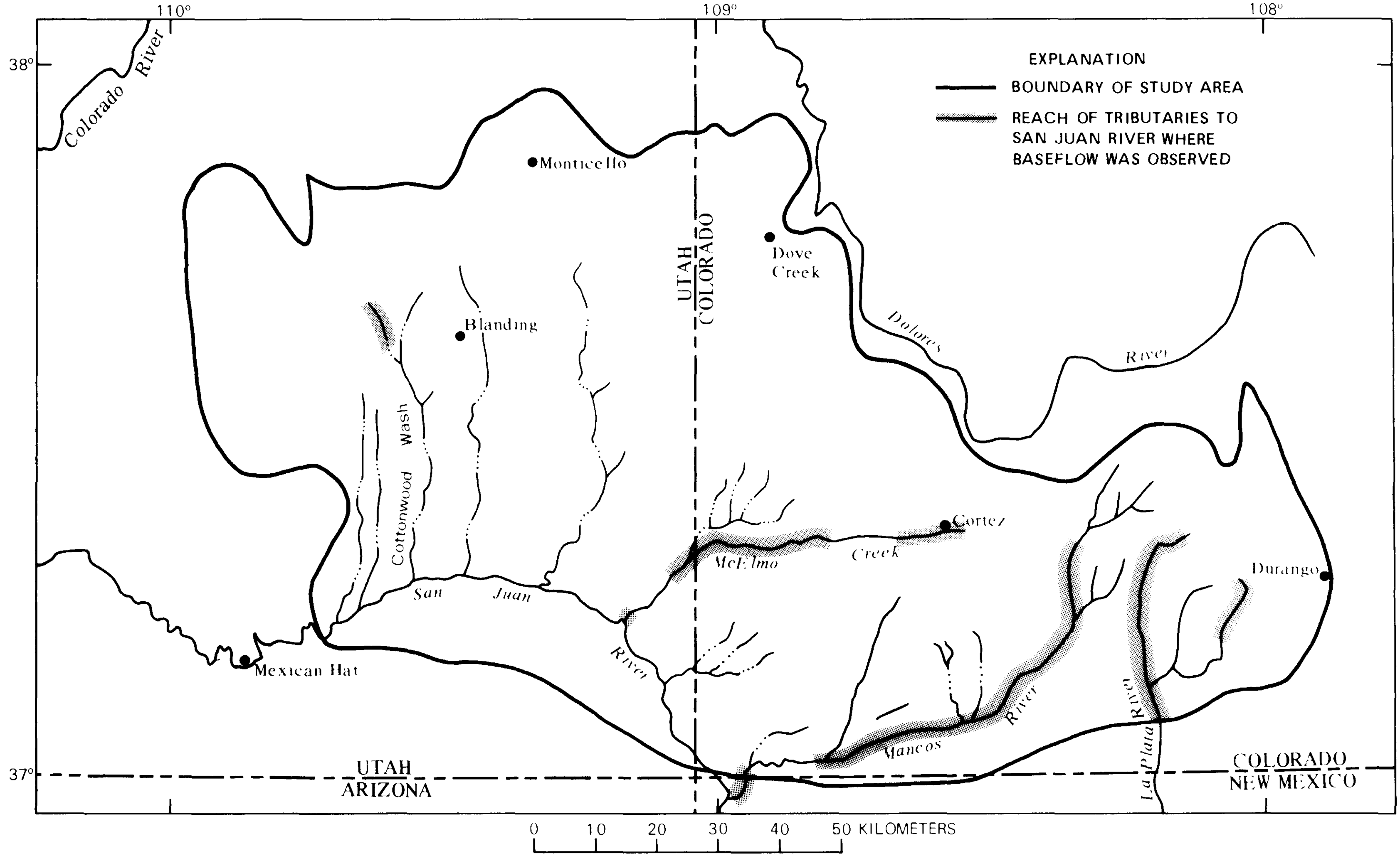


Figure 13.--Aerial observations of low flow in tributaries to the San Juan River, October 1979.

Table 7.--*Stream-discharges for Cottonwood Wash, McElmo Creek, Mancos River, La Plata River, and San Juan River, showing average annual, and low-flow measurements*
[All discharges expressed in cubic meters per second; see figure 3 for site and station locations]

Cottonwood Wash

Data point	Site 1	Station 2
Average annual discharge	--	2.1×10^{-1}
Period of record	--	1964-78
Low flow	2.2×10^{-2}	dry
Date of measurement	10-19-79	10-19-79

McElmo Creek

Data point	Station 3	Station 4	Station 5	Site 6
Average annual discharge	6.8×10^{-1}	10.5×10^{-1}	12.7×10^{-1}	--
Period of record	1972-77	1972-77	1951-77	--
Low flow	5.1×10^{-1}	1.8×10^{-1}	6.2×10^{-1}	4.8×10^{-1}
Date of measurement	10-19-79	10-19-79	10-19-79	10-19-79

Mancos River

Data point	Station 7	Station 8	Site 9
Average annual discharge	1.9×10^{-1}	1.4	--
Period of record	1977 only	1920-43, 1951-77	--
Average annual discharge	1.9×10^{-1}	1.8×10^{-1}	--
1977 only	1977 only	1977 only	--
Low flow	2.8×10^{-1}	0.09×10^{-1}	1.6×10^{-1}
Date of measurement	10-19-79	10-19-79	10-19-79

La Plata River

Data point	Station 10	Station 11
Average annual discharge	12.5×10^{-1}	9.4×10^{-1}
Period of record	1917-77	1920-77
Low flow	6.6	2.4
Date of measurement	10-19-79	10-19-79

San Juan River

Data point	Site 12	Station 13
Average annual discharge	--	7.1×10^{1}
Period of record	--	1914-78
Low flow	2.0×10^{1}	2.1×10^{1}
Date of measurement	10-20-79	10-20-79

of discharge-measurement stations and sites that will be discussed in this section of the report are shown in figure 3. Ground-water flow to Cottonwood Wash in October sustained streamflow at site 1, but not at station 2. Measured flow at site 1 was 2.2×10^{-2} m^3/s (as listed in table 7). Farther downstream, at station 2, no flow was observed; however, ground-water flow toward the wash was being discharged by phreatophytes (pl. 2). Between station 2 and the San Juan River, phreatophyte distribution was intermittent. At the time of the low-flow measurements, no streamflow in Cottonwood Wash was reaching the San Juan River (fig. 13). All the observed low flow either was evaporated or had reentered the upper ground-water system beneath the wash.

At station 3, on the headwaters of McElmo Creek, a low-flow rate of 5.1×10^{-1} m^3/s was measured (table 7). Discharge from the upper ground-water system occurs here, as shown by the potentiometric contours on plate 2. Regulation by reservoirs affects streamflow at this station, following periods when return flow from irrigation flows back into surface streams. Therefore, discharge from the upper ground-water system for this station cannot be determined quantitatively.

Streamflow at station 4 is less than would be expected (table 7), probably because of significant transpiration by salt cedar and cottonwoods. Hydraulic-head distribution near station 4 is not well known. Relatively large flows occur in the reach of McElmo Creek upstream from station 5 during low-flow periods (table 7). No importation and regulation of water occurs in this area, and discharge from the upper ground-water system is inferred. Potentiometric contours (pl. 2) support this assumption.

Discharge from the upper ground-water system occurs along the Mancos River (as shown by potentiometric contours on plate 2). Flow at station 8 is considerably less than at station 7 and site 9 during low-flow periods (table 7).

Discharge for the La Plata River at station 10 was 6.6 m^3/s on October 19, 1979. On this same date, farther downstream at station 11, the discharge had decreased to 2.4 m^3/s. Extensive irrigation in the upstream reach of the La Plata River is shown in figure 10. Diversion and regulation are not important considerations here, and water availability is limited to ground water and infrequent summer rainfall. Lack of water at station 11 results from evapotranspiration.

Low-flow measurements at site 12, site 6, and station 13 indicate that water is lost at a rate of 1.88×10^{-1} m^3/s between site 12 and station 13. However, potentiometric contours indicate that water is discharging from the upper ground-water system along the San Juan River. A rapid rate of evapotranspiration adjacent to the San Juan River is presumed to be the major cause of water loss during low flow.

Spring Discharge

A total of 259 springs were found on 7.5-minute and 15-minute topographic quadrangles of the Blanding-Durango area. The actual number of springs is probably greater, as many very small intermittent springs probably went unnoticed or unreported, because of negligible flow or remoteness of location. Many springs that flow in spring and early summer are dry by fall and become intermittent. The number of perennial springs is estimated to be 36. A summary of the number and type of springs associated with the various rock units is provided in table 8.

In the study area, springs occur as contact, artesian, or fracture springs. Most are contact springs; they occur in all the stratigraphic units except the Mancos Shale. Contact springs generally are concentrated along canyon walls, where a less permeable unit is overlain by a more permeable unit. Artesian and fracture springs occur in areas adjacent to igneous intrusives, where surrounding sedimentary rocks have been fractured and domed upward. Major water-movement controls in the Wingate Sandstone are vertical joints and bedding planes. Cross-bedding is the control in the Navajo Sandstone. Seepage springs are numerous and occur along stream channels and in mountains.

Alluvial and eolian sandstones in the Morrison, Cutler, and Dakota-Burro Canyon Formations have most of the spring discharge. The Navajo, Wingate, and Bluff Sandstones, as well as the Mesaverde Group and the Tertiary volcanic rocks also have a significant number of springs, but these springs have smaller yields than those in the preceding group (table 8). The greatest concentrations of springs occur along Comb Ridge, in the extreme western part of the area. There, the greatest density of springs is located in 42/20 and 43/20, along the contact between the Navajo Sandstone and the underlying Kayenta Formation (pl. 1). Springs in the north-eastern part of the area are associated with younger rocks; springs in the southwestern part are associated with older rocks of the region, reflecting the general outcrop pattern.

Published data on rate of flow of springs are sparse. Measurements were made for three springs during October 1978. Two of these springs were issuing from the Moss Back Member of the Chinle Formation: Notch Spring (35/20-6) and Crystal Spring (33/19-27). Notch Spring was flowing 0.13 L/s and Crystal Spring was flowing 0.19 L/s. Sweet Alice Spring (33/18-34), issuing from the Cedar Mesa Sandstone Member of the Cutler Formation, was flowing 0.16 L/s. These rates probably are representative of spring flows of the area, based on recharge, runoff, and precipitation data.

Well Discharge

One hundred thirty-seven water wells were selected from the Utah and Colorado State Engineer's application forms to provide representative ground-water data for the Blanding-Durango area. Two wells were picked per township in order to provide regional coverage; these selected wells are listed in table 9. An attempt was made to field-check all these wells for water level,

Table 8.--*Summary of springs*

Hydrologic unit and rock unit	Number of springs	Areal distribution	Type of spring
<u>Quaternary alluvial aquifer</u>:			
Alluvial and eolian deposits	40	Alluvium along river courses, eolian deposits scattered throughout area	Contact, seepage
Alluvial gravel deposits	3	Scattered throughout area, primarily along stream creek courses or at the foot of elevated areas	Contact, artesian
Colluvial deposits	6	Sleeping Ute Mountain, Abajo Mountains, and Bluff Bench (Utah)	Contact, seepage
Glacial deposits	1	East of Durango	Contact
<u>Tertiary and Cretaceous confining beds</u>:			
Volcanic (Tertiary and Cretaceous)	13	Abajo and Sleeping Ute volcanic centers	Contact, fracture, seepage
Animas Formation	2	Near Sawmill Canyon, south of Durango	Contact
Kirtland Shale	2	Along Iron Springs Gulch, southeast of Mesa Verde National Park	Contact
Fruitland Formation	4	Along Iron Springs Gulch, southeast of Mesa Verde National Park	Contact
Pictured Cliffs Sandstone	1	Along Iron Springs Gulch, southeast of Mesa Verde National Park	Contact
Lewis Shale	1	Along Iron Springs Gulch, southeast of Mesa Verde National Park	Contact
Mesaverde Group	11	Mesa Verde National Park area	Contact
Mancos Shale	5	Scattered throughout outcrop area	Seepage, artesian

Table 8.--*Summary of springs*--Continued

Hydrologic unit and rock unit	Number of springs	Areal distribution	Type of spring
Mesozoic sandstone aquifer:			
Undifferentiated Dakota Sandstone-Burro Canyon Formation	29	Scattered throughout outcrop area	Contact, seepage, artesian, fracture
Morrison Formation	39	Scattered throughout the area with most concentrated near San Juan River	Contact, seepage
Bluff Sandstone	11	Scattered throughout the outcrop area with concentration near Bluff, Utah	Contact, seepage
San Rafael Group (excluding Bluff Sandstone)	4	Concentrated where the San Juan River dissects Comb Ridge	Contact
Navajo Sandstone	15	Concentrated along Comb Ridge	Contact, seepage, fracture
Kayenta Formation	9	Concentrated on western flank of Comb Ridge	Contact, seepage, fracture
Wingate Sandstone	11	Concentrated on western flank of Comb Ridge	Contact, fracture
Mesozoic confining beds:			
Chinle Formation	9	Concentrated along Comb Wash	Contact, seepage, fracture
Moenkopi Formation	2	Both located in Navajo Indian Reservation, west of Comb Ridge	Contact
Cutler aquifer:			
Cutler Formation (primarily Cedar Mesa Sandstone Member)	36	Scattered throughout outcrop area west of Comb Ridge	Contact, seepage

Table 8.--*Summary of springs*--Continued

Hydrologic unit and rock unit	Number of springs	Areal distribution	Type of spring
Rico Formation	3	Located in Navajo Indian Reservation west of Comb Ridge	Contact
<u>Upper and Middle Pennsylvanian confining beds</u>:			
Hermosa Formation, upper member	2	Located in river canyons west of Comb Ridge	Contact
Total number of springs	259		

Table 9.--*Records of selected water wells*

[Altitude, above mean sea level; m, meters; mm, millimeters; L/s, liters per second; µS/cm at 25°C, microsiemens per centimeter at 25° Celsius. Stratigraphic units: Qal, alluvium of Quaternary age; Kmv, Mesaverde Group of Cretaceous age; Kdb, Dakota Sandstone and Burro Canyon Formation undifferentiated; Kd, Dakota Sandstone of Cretaceous age; Kbc, Burro Canyon Formation of Cretaceous age; Jms, Morrison (Salt Wash Member) of Jurassic age; Jm, Morrison Formation of Jurassic age; Jb, Bluff Sandstone of Jurassic age; Je, Entrada Sandstone of Jurassic age; JTrn, Navajo Sandstone of Jurassic and Triassic(?) age.]

Owner	Location	Altitude (m)	Well depth (m)	Diameter of well (mm)	Perforated interval (m)	Water source (strati-graphic unit)	Yield (L/s)	Specific conductance (µS/cm at at 25°C)	Depth to water (m)	Date of measurement	Use
UTAH:											
K. S. Bartow	34/23-36ba	2,073	43	130	---	Kbc	---	---	--	----	Domestic
										05-22-80	Stock
Unknown	34/26-19ccd	2,085	22	150	---	Kd	---	---	5	01-01-74	Domestic
									3	05-22-80	
Harold Keown	35/23-9bab	2,205	55	100	Open	Kdb	---	---	44	07-17-75	Domestic
									40	05-22-80	
Porter Webb	36/22-15dbb	1,949	69	110	Open	Kdb	.63	---	42	10-01-76	Domestic
									36	05-22-80	
Energy Fuels	37/22-22ccb	---	---	---	---	JTrn	6.3	---	--	----	Industrial
Do.	37/22-28cad	---	---	---	---	JTrn	13.9	---	--	----	Industrial
Do.	37/22-28dbb	---	---	---	---	JTrn	11.0	---	--	----	Industrial
Do.	37/22-28dcb	---	---	---	---	JTrn	14.2	---	--	----	Industrial
Do.	37/22-28dcd	---	---	---	---	JTrn	12.6	---	--	----	Industrial
Do.	37/22-33dda	---	---	---	---	JTrn	---	---	--	----	Industrial
Bureau of Land Management	38/23-5aa	1,634	94	150	---	Jm	1.3	---	40	04- -35	Stock
									29	05-22-80	
Do.	39/22-22bcd	1,469	145	150	Open	Jb	.90	---	87	03- -35	Stock
									64	05-22-80	
Do.	40/21-10aba	1,460	85	150	Open	Jb	.11	---	64	1960	Stock
									53	05-21-80	
State of Utah	40/22-20acd	1,402	73	150	Open	Je	.06	---	34	1960	Unused
									32	05-21-80	
C. E. Clagston	40/24-32dcb	1,356	79	150	---	Jb	.63	---	5	1967	Domestic
									3	05-21-80	
Superior Oil	41/25-17cbd	1,360	219	330	Open	JTrn & Jb	9.90	---	+55 (flowing)	1964	Industrial
									37	05-21-80	
COLORADO:											
Lois Stinson	33/13-1bad	2,006	81	---	---	Kmv	3.2	---	11	01- -76	Domestic
									15	05-07-80	
Paul Martin	33/20-25cdc	1,494	76	---	---	Kdb	---	---	17	01-01-31	Stock
									13	05-21-80	
Bryan T. Conner	34/11-16cd	2,249	20	150	Open	Kmv	.25	---	--	----	Domestic
									8	05-07-80	

Table 9.--*Records of selected water wells*--Continued

Owner	Location	Altitude (m)	Well depth (m)	Diameter of well (mm)	Perforated interval (m)	Water source (strati-graphic unit)	Yield (L/s)	Specific conductance (µS/cm at at 25°C)	Depth to water (m)	Date of measurement	Use
COLORADO--Continued:											
Fred Kelly	35/16-20ad	1,847	212	180	---	Kdb	---	---	18	08- -62	Domestic
									61	05-09-80	
Robert Schuster	35/19-3cab	1,573	75	180	---	Kd	.38	---	46	02-17-71	Domestic
									35	05-21-80	
Earl Thompson	36/11-28ba	2,731	35	---	---	Qal	.95	2,100	23	05-01-74	Domestic
									18	05-07-80	
Eugene Possen	36/15-11ac	2,051	37	---	---	Kdb	.25	3,200	12	10-20-77	Domestic
									9	05-08-80	
Troy Oliver	36/17-8bbb	2,096	20	---	---	Kd	.50	---	12	10-12-74	Domestic
									10	05-21-80	
L. E. Gawith	36/17-17ba	2,097	72	---	---	Kbc	.32	---	18	unknown	Domestic
									13	05-21-80	Stock
Charles Porter	36/18-29dd	1,652	98	150	Open	JTrn	.44	---	34	10-15-70	Domestic
									27	05-21-80	Stock
Unknown	36/18-36dac	1,716	55	---	---	JTrn	---	---	30	03-29-79	Domestic
									23	05-22-80	
U.S. Forest Service	37/12-17bd	2,725	37	150	Open	Jms	0.19	---	35	08-21-63	Domestic
									4	05-07-80	
Fredrick Prowse	37/16-10cd	2,042	61	130	49-55	Kd	.32	---	15	12-02-72	Domestic
									4	05-07-80	
Norlen Sorensen	38/16-31ac	2,067	21	100	---	Qal	.06	11,000	5	08-01-77	Domestic
									2	05-06-80	
J. R. Lanier	39/18-31aaa	2,057	26	170	18-26	Qal	.25	---	5	07-17-70	Domestic
									13	05-06-80	
Leonard Legg	39/19-16ccc	2,010	9	---	---	Qal	.06	15,000	2	09-15-63	Stock
									2	05-09-80	
Glen Hudgeons	40/18-4ca	2,167	14	180	7-9	Kd	.63	19,000	9	04-21-69	Domestic
									0	05-09-80	
Lloyd Baze	41/19-5ad	2,067	31	100	---	Kd	1.26	8,000	10	07-23-64	Domestic
									22	05-09-80	
Paul Martin	41/19-11bc	2,128	63	180	46-53	Kd	.25	11,000	25	09-10-63	Stock
									17	05-09-80	Irrigation

specific conductance of water, yield, and use, but all such data were collected at only a few wells. Water readily is available at shallow depths from stratigraphic units in the upper ground-water system. The only wells inventoried that penetrated the lower aquifer system were oil wells; these are discussed as drill-stem tests in the sections, Subsurface Inflow and Subsurface Outflow, of this report.

Of the 35 wells inventoried, most were small-diameter, small-yield wells primarily used for rural domestic and livestock purposes. Water wells also are used for municipal, industrial, and irrigation water supplies. Some of these wells are entirely cased, and the casing penetrating the water-transmitting unit is either screened or perforated. Yields range from 0.06 to 14.2 L/s. The Navajo Sandstone is the major unit yielding water to shallow wells.

Total annual outflow from the upper ground-water system by means of pumpage for rural domestic, livestock, municipal, and industrial uses in the study area was estimated to be 413 x 10^6 L. The sparse population and scarcity of industrial and agricultural pursuits in this area mean that demand for large quantities of water is small; thus, pumpage remains a minor part of the outflow budget.

Rural domestic

Withdrawals of ground water by rural populations were estimated, based on census figures. Consumption figures for homes with indoor plumbing and for homes without plumbing were applied, based on local economic conditions and local depths to water. Human consumption of ground water was estimated to be 185.6 x 10^6 L for 1980.

Livestock

Ground-water consumption by livestock was estimated by multiplying the species population by a consumption figure obtained from the U.S. Bureau of Land Management. Animal populations were obtained from the Utah and Colorado State Agricultural Statistics Reports (1981). These animal census figures are based on January counts; populations may vary widely during the marketing year. Consumption figures were adjusted in areas having surface-water supplies. Livestock ground-water consumption during 1980 is estimated to have been 178.6 x 10^6 L.

Municipal

The town of Bluff in San Juan County, Utah, pumped 43 x 10^6 L of water during 1980 from three wells open to sandstones of the Glen Canyon Group. The town of Monticello drilled 13 wells during the 1977 drought, but has relied on its historical spring supply and surface-water runoff sources from pediment gravels in the wetter years since then. These wells completed in the Dakota and Burro Canyon Formations probably were used during the dry 1981 season.

Thirty-two kilometers south of Monticello, the town of Blanding also uses its normal surface-runoff sources and diversion from Indian Creek for its water supply. Water from the headwaters of Indian Creek is diverted by an aqueduct southward to Blanding. Considerable runoff from the north slope of the Abajo Mountains occurs in Indian Creek during the spring and early summer. The town has plans to set pumps in three old wells of varying depths, that are completed in the Navajo and Dakota Sandstones and some intervening formations, to meet its municipal demands. The town of Dove Creek, Colorado, pumped 17.1×10^6 L of water during 1980 from two wells screened in the Dolores River alluvium; these wells are located about 10 km northeast of Dove Creek in 41/18-14.

Industrial

The largest single consumer of ground water in the study area is the Energy Fuels uranium mill on White Mesa, about 10.5 km south of Blanding in 37/22. Four wells are located in section 28, and one well in the southwestern corner of section 22. They are completed in the Navajo Sandstone and are capable of producing a total of 45.4 L/s of water. Pumpage from these four wells was about 6.0×10^6 L during 1980. A sixth and new well located in the southeastern corner of section 33 is completed through the Navajo into the Wingate and is capable of producing 12.6 L/s of water. No water supplies have been developed from the lower ground-water system in the study area.

Baseflow

Potentiometric contours for the upper ground-water system on plate 2 show that ground water has a general flow direction to the southwest, where it discharges into the San Juan River and its tributaries; along the western boundary of the study area, flow is westward toward the Colorado River (pl. 2).

The potentiometric contours of hydraulic-head data obtained from drill-stem tests of oil and gas wells for the lower ground-water system (fig. 12) shows that water in this system has a regional flow direction also toward the southwest, where it probably discharges ultimately into the Colorado River in southern Utah and northern Arizona. In the Grand Canyon, and in the Canyon of the Little Colorado River, the Mississippian strata that are herein referred to as the lower ground-water system are equivalent for the most part to the Redwall Limestone. Large springs discharge from this unit on the north wall of the Grand Canyon. These springs provide freshwater to the park headquarters located on the South Rim and may be from a flow system that flows west of the Paradox basin from the recharge area in the Uinta Mountains. Cooley (1976) observed springs discharging into the Canyon of the Little Colorado River containing dissolved solids ranging from 2,320 to 3,970 mg/L.

An estimate of baseflow to the San Juan River was made during a very low water period in July 1959, before the Navajo Dam was built. Baseflow in this report is defined as ground water contributed to a stream. Total estimated baseflow in the San Juan River between the gaging stations at Shiprock, New Mexico, and Bluff, Utah (this station is actually at Mexican Hat, Utah), was 0.81 m^3/s (table 10) as calculated from surface-water data of the U.S. Geological Survey (1959). The river gain per kilometer of river length, 163 km, was 5.0 L/s. A river gain similar to this was determined on October 20, 1979, during a time when the Navajo Dam on the San Juan River near Navajo City, New Mexico, was releasing surface water (table 11). Low-flow streamflow measurements from downstream from the confluence of the Mancos and San Juan Rivers and the gaging station at Mexican Hat (a distance of 124.7 km) indicate a baseflow of about 0.51 m^3/s, after subtracting inflow from McElmo Creek, the only tributary flowing into the San Juan River, and also subtracting the release of water from Navajo Dam during this low-flow period (fig. 3). The gain per kilometer of river length, 124.7 km, was 4.1 L/s. This baseflow is considered to be from the upper ground-water system.

Estimated total baseflow to the San Juan River of 0.51 m^3/s between the Mancos River and Mexican Hat, Utah, and 0.81 m^3/s between Shiprock, New Mexico, and Mexican Hat, Utah, are small values of ground-water inflow. However, no large ground-water contributions from springs occur, and baseflow must be from percolation through the rocks, so baseflow is expected to be small. During very dry seasons, the San Juan River ceases flowing, and no large springs in the river bed were observed, further indicating little ground-water baseflow. An example of the San Juan River ceasing to flow occurred at Mexican Hat from August 24 through 27, and on August 29, 1939; during this same month from August 24 through 25, a low flow of 0.23 m^3/s was measured at Shiprock, New Mexico (U.S. Geological Survey, 1959).

Another approach is to estimate ground-water baseflow using estimated average interstitial hydraulic conductivity of 0.33 m/d (400 md), from table 6; total thickness of sandstones in the upper ground-water system of 427 m; average river flood-plain width of 1,130 m; and an average gradient of 0.012 m/m from plate 2; and substituting into the formula Q = KIA, one obtains Q = 0.022 m^3/s as follows:

$$Q = 0.33 \text{ m/d} \times 0.012 \frac{\text{m}}{\text{m}} \times 427 \text{ m} \times 1{,}130 \text{ m}$$

$$= 1{,}910 \text{ m}^3/\text{d} = 0.022 \text{ m}^3/\text{s} ,$$

where

Q = baseflow, in cubic meters per second;
K = hydraulic conductivity, in meters per day;
I = hydraulic gradient, in meters per meter; and
A = cross-sectional area, in square meters.

This estimated baseflow, Q, probably would be much larger if the hydraulic conductivity through faults and fractures could have been used, but the total baseflow rate probably would be 1 m^3/s or less. Another indication that total baseflow to the San Juan River is small is that more than 0.2 m^3/s is estimated to be maintaining the flow in the perennial reaches of tributaries flowing into the Colorado River in Glen Canyon and into the San Juan River (Cooley and others, 1969).

Table 10.--*Estimated baseflow to the San Juan River between gaging stations at Shiprock, New Mexico, and near Bluff, Utah, July 24-30, 1959*

Stream inflow	Cubic meters per second
San Juan River at Shiprock, New Mexico	0.38
McElmo Creek	.0056
Mancos River	.00
Total (rounded)	.39
Stream outflow	
San Juan River near Bluff, Utah	.61
Evapotranspiration[1]	.59
Total	1.20
Baseflow: Stream outflow minus stream inflow	.81

[1]Based on a transpiration rate of 2.1 millimeters per day, water-surface area of 1.1 square kilometers, and a vegetated flood plain of 22.7 square kilometers.

Table 11.--*Estimated baseflow to the San Juan River between the mouth of the Mancos River and the gaging station near Bluff, Utah, October 19-20, 1979*

Stream inflow	Cubic meters per second
San Juan River below mouth of Mancos River (Station 12)	20.34
McElmo Creek (Station 6)	.52
Total	20.86
Stream outflow	
San Juan River near Bluff, Utah (Station 13)	20.50
Evapotranspiration[1]	.87
Total	21.37
Baseflow: Stream outflow minus stream inflow	0.51

[1]Based on a transpiration rate of 2.1 millimeters per day, water-surface area of 11.37 square kilometers, and a vegetated flood plain of 16.7 square kilometers.

Water may seep from the San Juan River into the Lower and Middle Pennsylvanian confining beds of the lower member of the Hermosa Formation, at the top of the lower ground-water system in the San Juan Canyon west of Comb Ridge (O'Sullivan, 1965). The San Juan River at an altitude of 1,256 m is 156 m above the 1,100-m potentiometric contour shown for the lower ground-water system in this area (fig. 12). Therefore, the San Juan River is a potential losing stream in the San Juan River Canyon; however, the confining beds may prevent appreciable losses from the river, if these beds do not have open vertical fractures.

INFLOW-OUTFLOW BALANCE

During the long term, most natural ground-water systems approach dynamic equilibrium; that is, inflow equals outflow and water in ground-water storage remains nearly constant. A water budget for the Blanding-Durango area is shown in table 12. Although the budget is very approximate and incomplete, some useful conclusions can be obtained from it on the basis of relative volumes of water for each of the inflow and outflow elements. Conclusions for the upper ground-water systems are: (1) The principal element of ground-water loss is through transpiration by phreatophytes; (2) all other elements of outflow are relatively small; (3) estimated average annual outflow from the system is about 33 x 10^6 m^3; (4) both the rates of recharge from subsurface inflow and runoff inflow are unknown; however, subsurface inflow is probably several times larger than recharge from runoff; and (5) based on the information in table 2, average annual precipitation totals about 4,400 x 10^6 m^3. Using a recharge rate of only 2 percent, the estimated annual recharge in the study area would be approximately 33 x 10^6 m^3.

For the lower ground-water system, conclusions are: (1) Total inflow and outflow are about equal because water lost by leakage, if any, is small, compared to water discharged from the study area; (2) because the evaporite geohydrologic unit virtually is an impervious confining bed, almost all inflow to and outflow from the system is subsurface ground-water flow; (3) the volume of water moving through the system is unknown, but probably represents a nearly constant large volume of water. Southwest of the study area, the Redwall Limestone (Leadville Limestone equivalent) yields large quantities of water to Blue Spring in the canyon of the Little Colorado River (Cooley and others, 1969, p. A-9). These conclusions are based on the assumption that no interchange of water occurs between the upper and lower ground-water systems. However, some recharge to the lower system may occur near the Abajo Mountains.

GENERAL CHEMICAL CHARACTER OF WATER

Data for ground-water chemistry in the Blanding-Durango area are presented in table 13. This table summarizes data contained in reports by Feltis (1966) and Hutchinson and Brogden (1976) and data obtained from the Petroleum Information data bank and the U.S. Geological Survey's water-quality WATSTORE system. Some of these sources commonly express concentrations in parts per million (ppm) rather than milligrams per liter (mg/L); the two units

Table 12.--*Water budget for the ground-water systems*

Budget element	Estimated average annual amount (million cubic meters)
Upper ground-water system	
Inflow	
Recharge from precipitation	33
Recharge from runoff originating from precipitation falling outside the report area	<0.1
Recharge from infiltration of regional streamflow	<0.1
Subsurface inflow	<0.1
Total inflow (rounded)	[1]33
Outflow	
Evapotranspiration	33
Springflow	<0.1
Discharge to streams	<0.1
Subsurface outflow to San Juan River	<0.3
Wells	0.4
Total outflow (rounded)	33.9
Lower ground-water system	
Subsurface inflow	Unknown
Subsurface outflow	Unknown; probably about equal to inflow.

[1]Assumed to be about equal to total outflow.

Table 13.--*Summary of water chemistry for hydrogeologic units*

[Dissolved solids, chloride, and sulfate in mg/L (milligrams per liter) for values equal to or less than 7,000; and in ppm (parts per million) for values greater than 7,000; specific conductance in μS/cm at 25°C (microsiemens per centimeter at 25° Celsius; type of site: S, springs; GW, wells less than 150 meters deep; W, wells greater than 150 meters deep]

Hydrogeologic unit and stratigraphic unit	Type[1] of site	Number of samples	Dissolved solids (mg/L or ppm)		Specific conductance (μS/cm at 25°C)		Chloride (Cl) (mg/L or ppm)		Sulfate (SO_4) (mg/L or ppm)		pH
			Range	Average	Range	Average	Range	Average	Range	Average	Range
Quaternary alluvial aquifer:											
Flood-plain deposits[1]	S	1	-----------	762	-----------	1,080	-----------	22	-----------	345	---------
	GW	3	209-700	486	348-1,100	800	1.8-56	22	19-160	110	6.9-7.3
Terrace deposits[1]	S	3	362-508	413	588-950	738	7.0-18	34	28-75	55	7.2-8.3
	GW	23	293-870	418	320-1,350	686	3.5-249	42	20-302	62	5.7-8.7
Tertiary and Cretaceous confining beds:											
San Jose Formation[1]	S	1	-----------	194	-----------	350	------------	3.2	----------	11	---------
	GW	2	1,360-1,857	1,610	1,940-2,700	2,320	120-123	122	710-927	818	7.6-8.2
Annimas Formation[1]	GW	18	302-3,490	776	535-4,920	1,200	12-1,400	169	5.9-567	172	6.5-9.3
Kirtland Shale	S	2	1,120-3,118	2,119	1,810-3,700	2,760	21-54	38	8.6-927	468	6.9-7.4
	GW	3	2,710-4,450	3,430	3,920-6,530	5,020	13-21	16	35-45	40	7.0-7.6
Pictured Cliffs Sandstone	GW	1	-----------	1,274	-----------	1,980	------------	60	----------	102	---------
Lewis Shale	S	1	-----------	1,929	-----------	2,100	------------	337	----------	1,065	---------
	GW	3	662-2,255	1,410	950-2,450	1,800	14-275	113	30-1,201	505	6.2-7.6
Cliff House Sandstone	S	2	402-810	606	640-1,125	882	8.8-25	17	95-313	204	6.9-7.4
	GW	16	181-2,179	1,026	330-3,780	1,629	1.5-115	27	4.3-2,100	352	5.1-8.6
Menefee Formation	S	1	-----------	4,050	-----------	7,169	------------	124	----------	4,053	---------
	GW	7	210-3,350	1,720	133-3,400	1,490	5.5-93	48	2.9-2,000	418	6.5-8.2
Mancos Shale	S	1	-----------	598	-----------	890	------------	21	----------	220	---------
	GW	3	207-4,110	1,960	460-6,400	3,050	2.2-1,700	611	36-190	112	7.9-8.2
Mesozoic sandstone aquifer:											
Dakota Sandstone and	S	3	1,220-2,890	1,960	1,650-3,930	2,690	20-54	39	572-1,670	972	---------
Burro Canyon Formation	GW	13	290-1,860	590	462-2,630	913	4-390	51	33-740	179	7.0-8.4
Morrison Formation	S	8	216-712	390	354-1,030	613	6-33	15	16-361	103	---------
	GW	5	217-1,460	890	370-2,230	1,330	1.8-91	34	43-631	299	7.3-7.7
Bluff Sandstone[2]	S	2	139-241	190	225-388	306	4-7	6	17-20	18	---------
	GW	3	438-7,350	3,320	728-10,400	4,770	8.5-2,110	732	41-2,330	1,070	---------
Entrada Sandstone[2]	S	1	-----------	287	-----------	467	------------	19	----------	65	---------
	GW	6	360-2,180	767	620-3,180	1,190	7.5-78	24	51-841	198	8.0-8.8
Navajo Sandstone	S	2	143-236	190	220-384	302	10-13	12	12-48	30	---------
	GW	4	171-500	270	273-846	439	5-21	10	12-52	31	7.5-9.0
	W	10	210-7,250	3,060	329-11,500	4,920	9-2,960	888	46-2,550	682	7.5-8.6
Wingate Sandstone	S	3	133-279	206	206-491	308	5-8	6	9-42	26	---------
	W	1	-----------	404	-----------	662	------------	5	----------	9.5	---------

Table 13.--*Summary of water chemistry for hydrogeologic units*--Continued

Hydrogeologic unit and stratigraphic unit	Type[1] of site	Number of samples	Dissolved solids (mg/L or ppm)		Specific conductance (μS/cm at 25°C)		Chloride (Cl) (mg/L or ppm)		Sulfate (SO_4) (mg/L or ppm)		pH
			Range	Average	Range	Average	Range	Average	Range	Average	Range
Glen Canyon Group[3]	GW	2	1,735-8,640	5,190	3,115-12,000	7,560	415-3,490	1,950	214-1,640	927	7.8-7.9
	W	10	239-6,851	1,860	378-1,630	760	1.8-1,378	290	44-2,550	490	6.0-8.7
Mesozoic confining beds:											
Shinarump Member of Chinle Formation	W	2	387-477	432	591-740	666	10-17	14	53-55	54	8.0-8.2
Cutler aquifer:											
Cutler Formation	W ?	2	2,370-4,020	3,195	-----------	------	317-390	353	22-1,770	896	---------
DeChelly Sandstone Member	W	3	17,262-52,187	31,003	-----------	------	9,646-31,700	18,050	446-892	729	---------
Cutler Formation	S	4	341-2,550	1,010	584-2,640	1,260	10-55	28	50-1,520	482	7.6-8.0
Upper and Middle Pennsylvanian confining beds:											
Rico Formation	S	2	719-3,070	1,890	1,020-3,280	2,150	16-72	44	349-1,910	1,130	7.0-7.9
Evaporite confining beds:											
Paradox Member	W	23	6,730-381,436	202,700	-----------	-----	3,660-238,680	125,980	145-4,601	1,190	5.0-8.3
Lower Paleozoic aquifer:											
Leadville Limestone	W	10	5,560-239,459	83,640	-----------	-----	90-140,740	47,170	1,013-6,412	2,780	6.0-8.3
Devonian rocks	W	6	33,665-158,882	87,110	-----------	-----	14,597-95,000	49,600	963-5,580	3,320	5.8-7.5
Lower Paleozoic confining beds:											
Cambrian rocks	W	1	------------	182,246	-----------	-----	-----------	107,000	-----------	4,385	---------

[1]Includes a few wells or springs just outside area.
[2]Some wells may include some water from adjacent sandstones.
[3]Contains two or more of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone.

are equivalent at dissolved-solids concentrations less than about 7,000 mg/L. For this study, in table 13, units of measure are milligrams per liter for values equal to or less than 7,000 mg/L, and parts per million for values more than 7,000 mg/L.

Springs commonly occur in recharge areas; water from these springs typically has smaller concentrations of dissolved solids than ground water that has travelled long distances through rock. Dissolved solids generally are greater in deeper parts of structural basins, such as in deeper parts of the San Juan basin (Berry, 1959, p. 131), and in the Paradox basin. In general, predominant ions are calcium and bicarbonate in water from springs in sandstone, or in water from wells completed in sandstones near recharge areas.

Predominant ions in water from shale are sodium and bicarbonate; sulfate and chloride ions are also abundant. As noted by Hanshaw and Hill (1969, p. 285), sulfate becomes the increasingly dominant anion as dissolved solids decrease. Large differences in water chemistry in a single aquifer in the study area may indicate either local differences in recharge sources, presence of structural barriers, or major lithologic changes.

Quaternary Alluvial Aquifer

Water in flood-plain and terrace deposits of the Quaternary alluvial aquifer had dissolved-solids concentrations ranging from 209 to 870 mg/L, based on the results from 30 samples from the Southern Ute Indian Reservation in southwestern Colorado (Hutchinson and Brogden, 1976). The average dissolved-solids concentration in water from wells completed in flood-plain deposits was 486 mg/L, and in water from wells completed in terrace deposits, it was 418 mg/L. Water in the aquifer generally contained large concentrations of calcium, sodium, bicarbonate, sulfate, and chloride. Water in 6 of the 26 wells sampled contained more than 500 mg/L of dissolved solids.

Tertiary and Cretaceous Confining Beds

Analyses of water samples from the San Jose and Animas Formations in the southeast corner of the study area (pl. 1) indicate that water in these units contains large concentrations of dissolved solids. Average dissolved-solids concentration was 1,610 mg/L for the San Jose Formation and 776 mg/L for the Animas Formation. Water from these units generally contained large concentrations of sodium, calcium, bicarbonate, sulfate, and chloride.

Analyses of water samples from the rocks of Cretaceous age, namely, Kirtland Shale, Pictured Cliffs Sandstone, Lewis Shale, Cliff House Sandstone, Menefee Formation, and Mancos Shale, indicate that ground water in these units is also high in dissolved solids. Chemical analyses from these rocks are predominantly from 31 wells and 6 springs in the Southern Ute Indian Reservation, in southwestern Colorado (Hutchinson and Brogden, 1976). Water from the springs had a dissolved-solids concentration that ranged from 402 to

3,118 mg/L. Water from the wells has dissolved-solids concentration ranging from 181 to 4,450 mg/L. Dissolved-solids concentrations in water from 33 of the 37 wells and springs exceeded 500 mg/L (Brogden, Hutchinson, and Hillier, 1979). Water in these units contained large concentrations of sodium, calcium, bicarbonate, sulfate, and chloride.

Mesozoic Sandstone Aquifer

Predominant ions in water discharging from springs in the Mesozoic sandstone aquifer generally are calcium and bicarbonate. Sodium, bicarbonate, and sulfate were predominant ions in spring water from the Dakota Sandstone and Burro Canyon Formation, probably because of ground-water contact with adjacent shale beds. In general, dissolved-solids concentrations in water from springs did not exceed 500 mg/L, whereas in water from wells, this concentration generally was exceeded.

Sodium, bicarbonate, and sulfate generally were predominant ions in water from wells. Calcium and chloride also were predominant in water from a few wells. A summary of water-chemistry data from individual sandstone units is presented in table 13.

Mesozoic Confining Beds

Predominant ions in water from the Mesozoic confining beds are calcium, sodium, bicarbonate, and sulfate in both wells and springs. In some wells and springs, chloride is an additional predominant ion. Dissolved-solids concentrations in water from the wells and springs generally exceeded 500 mg/L.

The Sonsela Sandstone Bed of the Petrified Forest Member of the Chinle Formation does not crop out in the study area; in the subsurface it may yield minor quantities of water, as it does in the Navajo Reservation to the south (Cooley and others, 1969, p. 7 and 52). Dissolved-solids concentration in water from wells in the Navajo Reservation ranged from 353 to 1,810 mg/L.

Analyses of two samples from the same well in the southwestern part of the study area show that the Shinarump Member of the Chinle Formation contains a sodium bicarbonate water. Dissolved-solids concentrations were 387 and 477 mg/L for these samples. No water-chemistry data from wells were obtained for the Moenkopi Formation.

Cutler Aquifer

Five analyses are available from the DeChelly Sandstone Member of the Cutler Formation and the correlative Coconino Sandstone, all from the southwestern part of the area. Three samples indicate a sodium potassium chloride water. Another analysis is from a sodium potassium sulfate sample, and the last is from a mixed water, with sodium and potassium the dominant cations and with chloride concentration slightly greater than that of sulfate. Dissolved-solids concentrations ranged from 2,370 mg/L to 52,187 ppm.

Upper and Middle Pennsylvanian Confining Beds

Samples from 2 springs in the Rico Formation had dissolved-solids concentrations of 719 and 3,070 mg/L. Sulfate is the dominant anion.

Evaporite Confining Beds

Because of extensive exploration for oil and gas in the Paradox Member of the Hermosa Formation, water-chemistry data from drill-stem tests are plentiful from the permeable interbeds found within this evaporite sequence, which as a whole are a confining bed. Approximately 80 percent of the water samples are a sodium potassium chloride type. The other samples represent mixed brines, with calcium usually the predominant cation and with significant concentrations of sodium, potassium, and magnesium. Chloride is always the dominant anion. Dissolved-solids concentrations ranged from 6,730 mg/L to 381,436 ppm, and averaged 202,700 ppm, based on analyses of 23 samples from wells. Dissolved-solid concentration is greatest toward the east, decreasing toward the western limit of evaporite deposition near Bluff (Mayhew and Heylmun, 1965, p. 24).

Middle and Lower Pennsylvanian Confining Beds

Other chemical analyses are available from the Hermosa Formation, but the member from which the samples were taken is not known; therefore, these analyses are not included. No chemical analyses were obtained in the study area for the Molas Formation.

Lower Paleozoic Aquifer

A total of 16 chemical analyses were obtained from 14 drill-stem tests and 1 swab test of the lower Paleozoic aquifer, penetrated by 14 wells in the Blanding-Durango area. Because most of these analyses were analyzed in the 1950's, sodium-plus-potassium values obtained were mostly computed. This older method of obtaining sodium-plus-potassium values precludes effective checks on analytical accuracy. Analyses have been accepted as valid after inspection and some general comparisons. Areal distribution of these samples limits the scope of the conclusions that can be made on the basis of these analyses, because wells penetrating this aquifer form an arc from the northern end of Comb Ridge, along the San Juan River, to the Colorado border. No analyses of water samples from this unit are available from the Colorado part of the study area.

The Leadville Limestone is the uppermost unit below the evaporite confining beds for which data are available. Ten analyses of samples from this formation are available. Nine of these analyses indicate sodium potassium chloride water, with dissolved-solid concentrations that ranged from 31,600 to 239,459 ppm. A tenth sample, obtained from a well at 35/20-18, was a sodium potassium sulfate water, with 5,560 mg/L of dissolved solids.

The Leadville Limestone probably has been contaminated by chloride drilling muds or by drilling through overlying salt beds in quest of hydrocarbons. Therefore, representative water analyses may be impossible. Drillers' logs commonly indicate a loss of circulation involving the disappearance of thousands of gallons of mud into fractured limestone and dolomite of this unit. Additionally, comparison of chloride concentrations from wells located near and away from oil fields supports this possibility. The water-quality data available for the Leadville Limestone do not provide adequate regional coverage and do not provide a comparative historical base. From the Canyon Mesa area of San Juan County, Utah, to the west and to the southwest of the study area, chloride concentrations increase downgradient from oil fields. This trend occurs despite progressive thinning of overlying salt beds in this direction, as they near the boundary of the Paradox basin.

Structural features (pl. 1) in the northwestern part of the study area probably control the flow of water in the Leadville Limestone and affect water chemistry. A series of east- and northeast-trending grabens near Monticello provide a means for local recharge, or act as a barrier to general southwestern flow of water in the upper ground-water system. These structural features probably explain the anomalous chloride to sulfate ratios in the northwestern part of the study area in the lower Paleozoic aquifer.

Two analyses of water from wells near the edge of the Paradox basin in the northwest corner of the study area have greater concentrations of sulfate relative to chloride. One of these wells produced a sample of sodium potassium sulfate water. This well, located in 35/20-18, is in a narrow neck where salt is not present, but where it exists on all sides, except to the northwest. The other well is at 36/18-36. In this salient, thin salt beds extend westward from the Paradox basin. Both wells are west of a series of grabens (pl. 1) that trend north and northeast of their intersection with Elk Ridge (Utah). The wells are also northwest of the Comb Ridge monocline, which is parallel to Comb Ridge (pl. 1), and which may be faulted at depth. Both structures may serve as potential paths for recharge of the Paleozoic strata, or both may act as barriers separating two different flow patterns in the southwestern part of the study area.

Water-chemistry data for six samples from five wells were obtained for Devonian strata. All six samples represent sodium potassium chloride waters with dissolved-solids concentrations that ranged from 33,665 to 158,882 ppm. The sample from a well at 38/20-22 is on the edge of the salt-bed salient on the west side of the study area, west of Comb Ridge. This sample has the smallest dissolved-solids concentration and the greatest sulfate concentration relative to chloride of all waters obtained from Devonian strata. This well is in a narrow neck, trending northward, where evaporite beds are thin or nonexistent above the Devonian. The Cutler aquifer crops out in this area, providing the opportunity for recharge to other Paleozoic units.

Lower Paleozoic and Precambrian Confining Beds

Only one analysis is available of water from Cambrian rocks and no water analyses are available from Precambrian rocks. The sample from Cambrian rocks was collected from a well in 39/23-32, and represents a sodium potassium chloride water with 182,246 ppm of dissolved solids. The sulfate concentration in this sample was similar to that in water from other formations in the vicinity.

Regional Streams

Surface water in the Blanding-Durango study area generally contains dissolved-solids concentrations ranging from 250 to 3,200 mg/L. Dissolved-solids concentrations in the primary stream in the area, the San Juan River, range from about 250 to about 1,200 mg/L, with specific conductance ranging from about 400 to about 1,600 microsiemens per centimeter[1]. Discharge and water-chemistry changes occur primarily in response to the release of water from the Navajo Reservoir. These releases mask the normal seasonal discharge and water-chemistry values. For example, the greatest specific-conductance measurement during 1977, at the San Juan River near Bluff gaging station, was measured in July. In contrast, a measurement in July 1979 was the least for that particular year. Generally, water in this river can be characterized as a mixed type, with calcium, magnesium, and sodium the major cations, and with sulfate the dominant anion. Calcium is nearly always the major cation, with sodium usually second.

The Mancos River, a major tributary to the San Juan River, is a perennial stream throughout most of its course. Water-chemistry data are available from a gaging station (33/15-15) located approximately at the mid-point along the river's course from the La Plata Mountains to the San Juan River. These analyses indicate a mixed magnesium-calcium-sulfate type water. Dissolved-solids concentrations range from about 1,600 to about 3,200 mg/L; discharge usually is less than 1.0 m^3/s. Sulfate always is the dominant anion, with a concentration three to seven times that in the San Juan River. Bicarbonate is 15 to 20 percent as concentrated as sulfate in the Mancos River and is only slightly more concentrated than bicarbonate in the San Juan River. Magnesium and calcium are the important cations, with magnesium usually slightly more concentrated. Magnesium in the Mancos River is approximately five times as concentrated as it is in the San Juan River. Water-quality data from upstream and downstream from the confluence of the Mancos and San Juan Rivers indicate that the Mancos River, despite its small discharge, probably is responsible for significant concentrations of the sulfate and magnesium in the downstream reach of the San Juan River. The large sulfate concentrations in the Mancos River are derived from leaching of Mancos Shale outcrops in the drainage

[1]Equivalent to micromhos per centimeter at 25° Celsius.

basin. The San Juan River also flows through a large area of Mancos Shale outcrops, but its flood plain is underlain by thicker alluvial deposits that insulate it from the shale. Large magnesium concentrations in the Mancos River probably are derived from erosion of the La Plata Mountains' igneous center. This feature, at the headwaters of the river, is a Tertiary and Cretaceous system of stocks, sills, laccoliths, and dikes, with large quantities of magnesium enriched pyroxenes and amphiboles.

RELATIONSHIP OF THE GROUND-WATER FLOW SYSTEMS AND SALT BEDS

In the Blanding-Durango area, ground-water circulation primarily is through three major aquifers (table 3). These aquifers generally are isolated from evaporite beds by bounding confining beds. As a result, very little circulating ground water has contact with salt beds of the Paradox Member of the Hermosa Formation. In the confining beds, brines have been encountered during drilling, but they probably have very slow rates of circulation. As a result, salt solution and removal probably is very slow in the study area, as opposed to other areas of the Paradox basin where salt occurs near or at land surface (Konikow and Bedinger, 1978, p. 4).

Salt solution, where it occurs, probably involves circulation of water along bedded surfaces of the salt sequence rather than vertically through the sequence, because the impermeable nature of the salt beds probably prevents water movement through the unit. Fracture zones, perhaps associated with faulting and folding, would be the most favorable avenues of circulation for dissolution of the salt beds from the bounding units.

Brines have been identified in the subsurface, but have not been identified as ground-water outflow to the land surface. Dissolution of salt beds, as would be evidenced by the existence of brine springs or ground-water discharges to regional streams, is not known to occur in the Blanding-Durango area.

CONCLUSIONS

Storage of radioactive waste in salt deposits of the paradox basin has been considered for several years (Hite and Lohman, 1973). Principal findings of this study that are pertinent to an assessment of suitability of the hydrogeologic systems to store and contain radioactive waste in salt anticlines of adjacent areas are:

1. Water in the upper ground-water flow system discharges to the San Juan River--a major tributary of the Colorado River. Discharge of water from the upper aquifer system to streambed channels of the San Juan River and its tributaries during low-flow periods primarily is through evapotranspiration from areas on flood plains and maintenance of streamflow.
2. The lower ground-water system does not have known recharge or discharge areas within the study area; subsurface inflow to this system comes from recharge areas located north and northeast of the study area.

3. The upper and lower ground-water systems are separated regionally by thick salt deposits in the Blanding-Durango study area of the Paradox basin.
4. Potential exists in mountainous areas for downward leakage between the upper and lower ground-water systems, where salt deposits are thin, absent, or faulted.
5. No brines were found in this study area with outflow to the biosphere.
6. Water in the upper ground-water system generally is fresh. Water in the lower ground-water system generally is brackish or saline.
7. Ground-water flow disruptions by contiguous faults probably are common in the upper ground-water system. These disruptions of flow are not apparent in the lower ground-water system, perhaps because available hydrologic data for the lower ground-water system are scarce.

The above major findings do not preclude the potential for waste storage in salt; however, they do not allow the prediction of detailed ground-water flow rates and directions through this area.

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SUPPLEMENTAL DATA

Table 14.--*Results of selected drill-stem tests in Utah*

[Tests were drill-stem tests unless otherwise indicated under Remarks; Altitude, approximate altitude of land surface above sea level; Depth, total depth drilled below land surface; Rock unit tested, see table 1 for full name and rank of each rock unit; Test interval, depth below land surface; Freshwater head, above sea level unless number is preceded by minus sign; Fluid-recovery rate, meters of formation fluid recovery in drill stem per hour of test per meter of test interval thickness; N/A, not applicable; *, minor recovery rate; °C, degrees Celsius; ppm, parts per million; %, percent; mg/L, milligrams per liter; CO_2, carbon dioxide; NaCl, sodium chloride; H_2S, hydrogen sulfide]

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Freshwater head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
33/25-26ca	2,092	1,805	Upper member of Hermosa	1,475-1,484	90	1,912	Gas-cut mud Gas- and mud-cut water	43 18	N/A 1	-----
33/25-26ca	2,092	1,805	Hermosa	1,740-1,771	210	1,897	Mud	34	N/A	-----
33/26-32cc	2,082	1,762	Hermosa	1,694-1,741	120	1,921	Gas-cut mud	82	N/A	-----
34/25-7da	2,084	853	Chinle-Shinarump	808-812	30	1,625	Mud	2	N/A	-----
34/26-16ca	2,070	1,844	Hermosa	1,758-1,777	210	1,731	Gas-cut mud	94	N/A	-----
35/20-18dc	2,629	1,326	Mississippian	1,295-1,325	120	1,804	Water-cut mud Muddy water	91 373	N/A 6	Temperature: 27°C. Average permeability: 66.5 millidarcys.
35/22-1db	2,077	1,964	Paradox	1,852-1,864	320	1,955	Gas-cut mud Very gas-cut oil-mud emulsion Water oil Oily saltwater Clean oil	18 82 27 81 9	N/A N/A * 1 *	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
35/22-21bc	2,128	1,785	Hermosa	1,696-1,719	191	1,720	Mud Muddy saltwater	85 27	N/A *	-----
35/23-32aa	2,028	2,071	Hermosa	1,962-1,995	90	-----	Mud	94	N/A	Temperature: 49°C.
35/25-9ad	1,973	2,366	Molas	2,144-2,179	120	1,244	Drilling mud Muddy water Black sulfur water, salty	15 29 357	N/A * 5	-----
35/26-20ad	2,071	2,574	Leadville	2,281-2,312	150	1,566	Gas Mud, gas-cut, sulfur odor	--- 101	N/A N/A	-----
35/26-31dd	2,038	1,970	Cutler	1,416-1,428	150	1,800	Saltwater	369	12	-----
36/21-22bd	1,784	1,790	Hermosa-Paradox	1,684-1,705	180	1,772	Mud-cut saltwater Saltwater	23 549	* 9	Temperature: 48°C.
36/21-25bb	1,888	1,936	Hermosa	1,844-1,853	120	1,756	Gas- and oil-cut mud Saltwater	44 160	N/A 9	Temperature: 46°C.
36/25-13ac	1,861	1,803	Hermosa	1,773-1,795	120	2,577	----	---	---	Temperature: 62°C.
37/20-32aa	1,841	1,341	Leadville	1,326-1,341	120	1,142	Water	518	17	-----
37/21-22cd	1,694	1,920	Hermosa	1,850-1,856	170	1,274	Very slightly gas-cut mud with trace of oil	6	N/A	Temperature: 59.4°C.
37/22-17ca	1,677	2,601	Leadville	2,351-2,356	240	1,144	Saltwater with trace of oil	313	16	Water tested, 145,000 ppm salt.
37/22-17ca	1,677	2,601	McCracken	2,554-2,601	180	1,765	Water cushion Mud Saltwater	305 27 55	N/A N/A *	-----
37/23-22ba	1,772	1,976	Hermosa	1,944-1,949	735	1,862	Gas-cut oil Black saltwater Gas	731 3 ---	12 * N/A	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
37/24-20ab	1,771	2,699	Leadville	2,463-2,500	240	1,218	Gas-cut mud Heavily gas- and water-cut mud Heavily gas- and mud-cut water	46 18 75	N/A N/A 1	Temperature: 66°C.
38/19-22bb	1,881	-----	Paradox	684-697	60	1,210	Drilling mud	5	N/A	-----
38/20-22bb	1,808	1,475	Elbert	1,197-1,212	210	1,161	Saltwater	293	6	-----
38/21-16cb	1,596	2,341	Leadville	2,337-2,341	60	1,257	Mud Salty sulfur water	863 509	N/A 127	-----
38/22-28bb	1,535	1,868	Hermosa	1,803-1,810	240	1,186	Saltwater	214	8	-----
38/22-32aa	1,452	1,811	Upper member of Hermosa	1,726-1,742	155	1,231	Oil- and gas-cut mud Heavily oil- and gas-cut mud Free oil, muddy	27 84 9	N/A N/A *	-----
38/23-6dd	1,624	2,525	Leadville	2,299-2,333	65	1,247	Gas (non-flamable)	164	N/A	Temperature: 62°C.
38/24-19aa	1,602	1,900	Hermosa	1,795-1,808	180	1,370	Oil-cut mud	229	N/A	-----
38/25-5da	1,570	1,676	Hermosa	1,632-1,644	420	1,682	Oil	251	3	-----
38/25-5da	1,570	1,676	Hermosa	1,644-1,662	150	1,516	Gas-cut mud Water	128 341	N/A 8	-----
38/25-15bd	1,606	1,808	Hermosa	1,700-1,737	30	1,453	Water-cut drilling mud	199	N/A	Temperature 49°C.
38/25-36aa	1,498	1,733	Hermosa	1,699-1,733	150	-----	Mud	96	N/A	-----
38/26-16ba	1,763	1,888	Hermosa	1,568-1,605	75	1,808	Mud Mud-cut saltwater	19 324	N/A 7	-----
39/20-10bb	1,552	-----	Hermosa	596-610	60	1,143	Water with a strong sulfur odor	137	10	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
39/21-11cc	1,466	1,798	Hermosa	1,747-1,765	105	1,198	Slightly oil- and gas-cut mud Heavily oil- and gas-cut mud	24 30	N/A N/A	-----
39/21-11dd	1,495	1,855	Hermosa	1,779-1,797	180	1,250	Oil and gas Very heavily oil- and gas-cut mud Oil- and gas-cut saltwater	439 128 9	8 N/A *	-----
39/21-11dd	1,495	1,855	Hermosa	1,796-1,806	120	1,205	Slightly muddy saltwater Clear saltwater	29 52	1 3	------
39/21-13da	1,436	1,793	Hermosa	1,722-1,740	90	1,212	Heavily oil and gas-cut drilling mud Oil Saltwater	18 137 959	N/A 5 36	-----
39/21-15cdb	1,479	1,821	Hermosa	1,722-1,753	60	1,220	Mud-cut saltwater	70	2	-----
39/22-14cb	1,460	1,838	Hermosa	1,716-1,735	151	-----	Mud	238	N/A	-----
39/22-14cb	1,460	1,838	Hermosa	1,749-1,768	1,298	931	Oil	-----	17	Recovered 49,300 liters of oil
39/22-14cb	1,460	1,838	Paradox	1,810-1,827	150	1,026	Mud Saltwater	85 82	N/A 2	-----
39/22-14cd	1,463	-----	Hermosa	1,747-1,786	405	1,111	Oil Water	716 506	3 2	-----
39/22-15ad	1,476	1,848	Hermosa	1,744-1,762	210	1,171	Slightly gas-cut mud Gas-cut mud Gas-cut water	58 46 9	N/A N/A *	-----
39/22-15ad	1,476	1,848	Hermosa	1,762-1,780	210	1,174	Gas-cut mud Gas-cut water	104 9	N/A *	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
39/22-15db	1,549	1,908	Hermosa	1,873-1,890	300	1,079	Mud Slightly gas-cut mud Saltwater	37 30 55	N/A N/A 1	-----
39/22-19bb	1,416	1,779	Hermosa	1,704-1,736	210	1,259	Oil and condensate Oil- and gas-cut saltwater Saltwater, clear	376 499 487	3 4 4	-----
39/22-23bb	1,457	1,771	Hermosa	1,712-1,771	110	818	Slightly oil-cut and medium gas-cut mud	183	N/A	Temperature: 64°C.
39/22-29cd	1,479	2,383	Leadville	2,308-2,321	240	1,149	Gas-cut mud Saltwater	131 1,250	N/A 24	-----
39/23-6ad	1,496	1,905	Hermosa	1,844-1,864	123	1,237	Mud Slightly gassy, muddy saltwater	58 183	N/A 4	-----
39/23-29ac	1,621	1,875	Hermosa	1,804-1,822	60	1,297	Oil-cut mud Green oil	30 308	N/A 17	-----
39/23-30ac	1,434	2,195	Missis-sippian	2,120-2,155	---	1,136	Highly gas-cut mud Gas-cut saltwater	64 549	N/A 16	-----
39/24-31cc	1,537	1,910	Paradox	1,846-1,856	240	1,083	Heavily gas-cut drilling fluid Heavily gas-cut saltwater	15 396	N/A 10	-----
39/24-31cc	1,537	1,910	Paradox	1,855-1,877	180	1,163	Heavily water and gas-cut drilling fluid Heavily gas-cut saltwater with a rainbow of oil	50 1,311	N/A 20	-----
40/20-9cc	1,534	1,083	Upper Hermosa	504-511	90	1,181	Muddy water with a sulfur odor	55	5	-----
40/20-9cc	1,534	1,083	Lower member of Hermosa	725-738	60	1,408	Gas-cut mud	55	N/A	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
40/20-28cc	1,581	1,023	Leadville	794-811	120	1,115	Freshwater	108	3	-----
40/21-12ddb	1,416	1,753	Upper Hermosa	1,592-1,673	120	1,269	Free oil Highly oil- and gas-cut mud Gassy saltwater	76 128 88	* N/A 1	-----
40/21-19aa	1,875	2,846	Cutler	2,472-2,481	88	1,089	Muddy water Mud	238 27	18 N/A	-----
40/21-36adb	1,438	2,067	Lower Hermosa-Molas	1,877-1,945	240	1,411	Heavily gas and mud-cut saltwater	1,680	6	Water contains 115,000 ppm salt.
40/21-36adb	1,438	2,067	Leadville	2,044-2,067	240	1,094	Heavily gas-cut mud Oil with 5% mud and 10% saltwater Saltwater	55 302 201	N/A 3 2	-----
40/22-4cd	1,495	1,853	Paradox	1,809-1,853	120	994	Mud Mud-cut water Water	37 11 18	N/A * *	-----
40/22-5ad	1,469	1,829	Paradox	1,781-1,811	90	1,070	Drilling mud Saltwater	95 46	N/A 1	-----
40/22-8ba	1,445	1,769	Hermosa	1,716-1,729	90	1,225	Very heavily oil- and gas-cut mud Heavily gas-cut mud Free oil Muddy water	55 9 110 9	N/A N/A 6 *	-----
40/22-11bd	1,425	1,780	Paradox	1,740-1,779	90	1,363	Drilling mud Muddy water Saltwater	73 37 146	N/A 1 2	-----
40/22-21ab	1,414	1,755	Hermosa	1,664-1,684	180	1,236	Very highly gas- and oil-cut mud Gas- and oil-cut saltwater Gas-cut and slightly oil-cut saltwater	32 82 770	N/A 1 13	-----
40/22-21ab	1,414	1,755	Hermosa	1,708-1,740	150	1,215	Mud Saltwater	15 299	N/A 4	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
40/22-24db	1,385	1,740	Hermosa	1,662-1,690	130	1,214	80% saltwater and 20% oil Saltwater	1,690 1,036	28 17	-----
40/22-24db	1,385	1,740	Hermosa	1,670-1,680	180	1,217	15% oil and 85% saltwater Oil Heavily oil-cut saltwater Slightly oil-cut saltwater Saltwater	49-69 27 46 61 1,390	2 1 2 2 46	-----
40/23-1cd	1,605	1,953	Paradox	1,893-1,910	240	1,278	Drilling mud Saltwater	91 61	N/A 1	-----
40/24-3cd	1,394	1,748	Paradox	1,689-1,695	60	-----	Gas-cut watery mud Saltwater	37 212	N/A 35	Water sample 125,000 ppm.
40/24-3cd	1,394	1,747	Paradox	1,711-1,714	---	1,248	Oil-cut water	92	N/A	-----
40/24-11dc	1,434	1,749	Paradox	1,676-1,693	40	1,281	Oil	514	45	-----
40/24-13bc	1,504	1,816	Paradox	1,731-1,750	120	1,227	Highly gas-cut and slightly oil-cut mud	244	N/A	-----
40/24-16aa	1,479	1,795	Paradox	1,766-1,786	120	-----	Saltwater-cut mud	1,463	N/A	-----
40/24-16ba	1,413	1,728	Hermosa	1,620-1,667	150	1,165	Heavily gas-cut and slightly oil-cut mud Heavily gas- and oil-cut mud Heavily gas- and oil-cut mud	45 61 61	N/A N/A 1	-----
40/24-16ca	1,388	1,699	Paradox	1,636-1,654	120	1,214	Oil Heavily oil- and gas-cut mud Dry Gassy oil-cut mud	174 27 55 137	5 N/A 0 N/A	Temperature: 53°C.
40/24-27ad	1,479	1,798	Paradox	1,769-1,783	60	1,168	Saltwater, slightly oil- and gas-cut	1,036	74	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
40/24-27ddd	1,436	1,775	Paradox	1,730-1,738	60	1,116	Muddy saltwater Saltwater	40 91	5 11	-----
40/24-31dd	1,448	1,754	Paradox	1,721-1,737	15	1,226	Oil Heavily oil and gas-cut mud	610 110	152 N/A	-----
40/25-5cd	1,565	1,887	Hermosa	1,849-1,887	60	1,218	Saltwater-cut mud Mud-cut saltwater	137 165	N/A 4	-----
40/25-9bb	1,596	1,899	Hermosa	1,798-1,843	60	1,298	Gas Heavily gas-cut oil	N/A 1,707	N/A 38	-----
40/25-14cc	1,533	2,309	Leadville	2,219-2,271	90	1,217	Slightly mud-cut heavily gas-cut water	1,481	19	-----
40/25-15aa	1,615	1,898	Hermosa	1,835-1,843	120	1,269	Gas-cut mud Saltwater	25 396	N/A 25	-----
40/25-17db	1,509	1,818	Hermosa	1,783-1,791	120	1,066	Mud Muddy saltwater	9 183	N/A 11	-----
40/25-22ac	1,566	1,856	Hermosa	1,794-1,802	---	1,276	Gas Mud- and gas-cut oil Mud- and gas-cut saltwater	N/A 244 518	N/A N/A N/A	-----
40/25-23cb	1,588	1,876	Hermosa	1,808-1,815	---	1,365	Slightly oil- and mud-cut gassy saltwater	---	---	-----
40/25-23da	1,535	1,804	Hermosa	1,718-1,740	100	1,253	Gas Gas-cut mud Mud- and gas-cut water Saltwater	61 82 137 942	N/A N/A 4 26	-----
40/25-23da	1,535	1,804	Hermosa	1,740-1,751	70	-----	Mud Saltwater	137 907	N/A 71	-----
40/25-25ca	1,517	1,784	Hermosa	1,717-1,737	75	1,405	Mud Water-cut mud Mud-cut saltwater	55 55 138	N/A N/A 6	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
40/25-26bb	1,588	1,880	Upper Hermosa	1,814-1,827	60	1,119	Gas-cut muddy saltwater	320	25	-----
40/25-35bd	1,506	1,768	Hermosa	1,737-1,744	100	1,224	Heavily gas- and oil-cut mud	52	N/A	-----
							Gas-cut muddy saltwater	55	5	
							Gas-cut saltwater	488	42	
40/26-5dc	1,569	2,420	Leadville	2,274-2,295	125	1,150	Slightly muddy CO_2-cut saltwater (salinity 104,000 ppm)	274	6	-----
							CO_2-cut saltwater (salinity 28,000 ppm)	993	21	
40/26-27ba	1,630	1,851	Hermosa	1,791-1,805	90	1,353	Oil	1,150	55	Temperature: 46°C.
40/26-27ca	1,519	1,744	Hermosa	1,707-1,719	60	1,340	Drilling mud	21	N/A	Temperature: 55°C.
							Oil, clean	192	16	
40/26-29caa	1,434	1,692	Hermosa	1,637-1,642	15	1,227	Highly gas-cut oil	1,633	1,306	Temperature: 57°C.
							Mud- and oil-cut water	9	7	
40/26-30aca	1,489	1,716	Hermosa	1,701-1,716	30	1,058	Saltwater	433	58	135,068 ppm dissolved solids.
40/26-31ac	1,425	1,710	Hermosa	1,645-1,659	100	1,197	Oil	840	36	-----
							Heavily gas-cut saltwater	437	19	
							Heavily oil- and gas-cut mud	57	N/A	
							Heavily gas-cut drilling mud	27	N/A	
40/26-32aa	1,472	1,746	Hermosa	1,666-1,692	150	1,299	Drilling mud	30	N/A	-----
							Saltwater	1,067	16	
41/21-35da	1,433	1,802	Hermosa	1,535-1,553	60	1,157	Oil	1,219	68	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Amount (meters)	Rate (meters per hour per meter)	Remarks
41/21-35dc	1,425	1,934	Missis-sippian	1,910-1,934	120	1,179	Water-cut mud Slightly muddy water Water, (salinity 78,400 ppm)	137 137 396	N/A 3 8	-----
41/22-7bb	1,523	2,164	Leadville	2,119-2,164	120	1,051	Heavily gas-cut mud Muddy saltwater	121 232	N/A 3	-----
41/23-1cd	1,412	1,724	Hermosa	1,647-1,667	130	1,304	Oil	24,288	560	-----
41/23-2dd	1,353	1,646	Hermosa	1,612-1,646	120	-----	Oil Gas	869 N/A	13 N/A	-----
41/23-12cb	1,393	1,681	Paradox	1,670-1,673	28	1,179	-----	---	---	-----
41/24-5dc	1,379	1,707	Paradox	1,670-1,676	120	-----	Mud-, gas-, and slightly oil-cut saltwater Clear saltwater	56 393	5 33	-----
41/24-6cc	1,436	1,757	Paradox	1,677-1,691	120	1,266	Oil Heavily oil- and gas-cut mud	183 110	7 N/A	-----
41/24-7ca	1,444	1,749	Paradox	1,714-1,744	35	1,293	Oil Mud-cut oil	453 37	26 2	-----
41/25-17dd	1,365	1,675	Cutler	711-763	60	1,509	Very slightly salty water	---	---	-----
41/25-17dd	1,365	1,675	Paradox	1,601-1,625	120	1,301	Slightly oil- and gas-cut mud Saltwater-cut mud Saltwater	49 82 369	N/A N/A 8	-----
41/25-19bb	1,389	1,691	Paradox	1,609-1,673	200	1,599	Oil Gas	736 N/A	3 N/A	-----
41/25-21cc	1,367	1,660	Hermosa	1,625-1,658	174	1,247	Oil Gas	1,191 N/A	12 N/A	-----
41/25-26cc	1,407	1,704	Hermosa	1,635-1,644	120	1,270	Slightly gas-cut drilling mud Brackish saltwater	91 1,341	N/A 75	52,500 ppm salt.

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
41/25-31db	1,547	1,815	Paradox	1,744-1,779	---	1,222	Oil	628	N/A	-----
							Thin, watery drilling mud	27	N/A	
							Flared oil at surface	N/A	N/A	
41/26-5bc	1,476	1,734	Hermosa	1,706-1,709	100	1,086	Heavily gas-cut mud	18	N/A	-----
							Heavily gas- and slightly oil-cut mud	12	N/A	
							Saltwater	1,108	221	
41/26-9dd	1,461	1,732	Hermosa	1,708-1,723	120	1,258	Heavily gas- and heavily oil-cut muddy saltwater	494	16	
							Heavily gas- and medium oil-cut muddy saltwater	658	22	
							Heavily gas- and medium oil-cut saltwater	82	3	-----
							Slightly gas- and very slightly oil-cut saltwater	165	6	-----
							Slightly gas- and very slightly oil-cut saltwater	30	1	
41/26-10ca	1,446	1,737	Hermosa	1,676-1,706	130	1,207	Slightly gas-cut mud	21	N/A	-----
							Heavily gas- and slightly oil-cut mud	24	N/A	
							Heavily gas- and heavily oil-cut mud	15	N/A	
							Heavily gas- and slightly oil-cut mud	12	N/A	
							Slightly gas-cut muddy saltwater	79	1	
							Saltwater	122	2	
41/26-15db	1,541	1,816	Hermosa	1,782-1,787	110	1,208	Slightly gas-cut mud	82	N/A	-----
							Gas-cut muddy water	119	13	
							Saltwater	192	21	

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
41/26-19dd	1,566	1,881	Paradox	1,812-1,834	120	1,328	Heavily oil- and gas-cut mud Gassy, slightly muddy oil Saltwater	134 55 250	N/A 1 6	-----
41/26-33ba	1,484	1,817	Hermosa	1,741-1,757	63	1,266	Oil (60%), water (40%) Flowed	1,371 192	82 11	-----
42/20-9da	1,442	1,737	Paradox	1,643-1,689	60	1,129	Water-cut drilling mud Saltwater	188 486	N/A 11	Temperature: 44°C.
42/20-34cc	1,503	1,694	Hermosa	1,473-1,492	120	1,214	Oil-, gas-, and mud-cut sulfur water	1,158	30	Salinity 28,000 ppm.
42/21-2ba	1,410	1,809	Paradox	1,738-1,809	120	1,101	Slightly oil- and gas-cut mud Slightly gas-cut saltwater	30 579	N/A 4	-----
42/22-7bc	1,468	1,859	Paradox	1,579-1,637	150	-----	Mud Slightly gas-cut mud Heavily oil- and gas-cut mud	119 18 55	N/A N/A N/A	-----
42/22-16bd	1,500	1,806	Paradox	1,692-1,722	120	1,193	Watery mud Saltwater, slightly muddy, slightly gassy	55 465	N/A 8	Maximum salinity 65,000 ppm NaCl.
42/22-28bd	1,512	1,703	Paradox	1,427-1,451	152	1,171	Gas- and very slightly oil-cut mud Very slightly gas-cut water Slightly gas-cut water	27 302 652	N/A 5 11	Maximum salinity 77,500 ppm.

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
42/22-33ba	1,530	1,688	Hermosa	1,434-1,441	120	1,150	Oil	170	12	-----
							Saltwater	501	36	
42/22-34bc	1,548	1,630	Hermosa	1,457-1,466	100	1,128	Heavily gas-cut mud	18	N/A	-----
							Gas-cut saltwater	1,049	70	
							Gas	N/A	N/A	
42/23-2bdc	1,470	2,041	Leadville	1,785-1,826	150	1,228	Gas-cut saltwater	1,469	14	-----
42/23-28bb	1,465	1,820	Hermosa	1,761-1,774	185	1,348	Oil, mud and water mixed	46	1	134,000 ppm.
							Oil, clean, high-gravity brown	137	3	
							Water, very salty	1,372	34	
42/23 -30ca	1,546	1,894	Paradox	1,827-1,893	90	1,185	Sulfur water	1,387	14	-----
42/26-5cb	1,479	1,825	Hermosa	1,758-1,768	120	1,262	Heavily oil- and gas-cut water	33	2	-----
							Heavily gas- and water-cut mud	29	N/A	
							Heavily gas- and mud-cut saltwater	57	3	
							Heavily gas-cut saltwater	381	19	
42/26-9ad	1,442	1,795	Hermosa	1,735-1,749	160	1,311	Mud-cut oil	114	3	-----
							Saltwater	610	16	
42/26-15bb	1,506	1,872	Hermosa	1,794-1,804	255	1,294	Salt, water - 2% oil	1,460	34	-----
42/26-19ba	1,380	1,744	Hermosa	1,684-1,711	75	1,212	Slightly gas-cut mud	30	N/A	-----
							Slightly gas- and oil-cut saltwater	61	2	
							Saltwater	440	13	
42/26-21bb	1,445	1,816	Hermosa	1,748-1,759	95	1,311	Mud	27	N/A	-----
							Mud, slightly oil- and gas-cut	110	N/A	
							Oil- and gas-cut muddy water	192	11	
							Gassy, muddy water cleaving to clean water downward	1,125	65	

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
42/26-32dd	1,491	1,853	Hermosa	1,809-1,853	100	1,217	Oil- and gas-cut mud	732	10	Temperature: 52°C.
							Gas-cut water	549	7	
							Saltwater	274	4	
43/21-23cc	1,597	1,946	Paradox	1,645-1,661	60	1,151	Water-cut mud	27	N/A	Temperature: 59°C.
							Black, sulfur water	311	19	
43/22-2dc	1,553	1,591	Hermosa	1,422-1,436	60	1,178	Gas-cut, muddy water	82	6	-----
							Water, sulfur, gas-cut	878	63	
43/22-15cc	1,513	396	Cutler	354-359	60	1,496	Slightly oil-cut water	5	1	-----
							Freshwater	287	57	
43/22-16dc	1,508	1,464	Cutler	347-351	65	1,521	Oil	227	52	-----
							Oily mud	9	N/A	
43/22-16dc	1,519	1,464	Paradox	1,318-1,326	155	1,086	Gas-cut mud	'73	N/A	-----
							Gas-cut black, sulfur, brackish water	728	35	
43/22-19ad	1,526	1,676	Cutler	567-569	60	1,513	Freshwater	427	213	-----
43/22-19ad	1,526	1,676	Hermosa	1,477-1,482	235	1,160	Oil	143	7	-----
							Water, black, salty, with sulfur odor	372	19	
							Gas	---	N/A	
43/22-19ad	1,526	1,676	Paradox	1,565-1,569	65	-----	Slightly gas-cut mud, very slight trace of oil.	137	N/A	-----
43/22-21ad	1,627	495	Cutler	422-447	60	1,503	Clean oil	123	25	-----
							Mud-cut oil	61	12	
							Slightly oil-cut muddy water	91	18	
43/22-21daa	1,610	469	Cutler	430-438	60	1,506	Water	347	43	-----
43/22-24dd	1,550	486	DeChelly	444-456	30	1,516	Freshwater	427	71	-----
43/22-25da	1,560	471	DeChelly	424-427	60	1,524	-----	---	---	----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
43/23-25cc	1,638	1,835	Hermosa	1,469-1,498	212	1,218	Very slightly muddy, gassy water	227	2	-----
43/23-25cc	1,638	1,835	Paradox	1,537-1,589	160	1,307	Slightly oily and muddy gas-cut water	491	4	Salinity 103,500 ppm $H_2S \rightarrow 0.04\%$.
43/23-25cc	1,638	1,835	Lower Hermosa	1,640-1,676	90	1,265	Water-cut mud Slightly muddy water Slightly oil-cut muddy sulfur water Slightly muddy black sulfur water	18 155 91 165	N/A 3 2 3	-----
43/23-32ac	1,641	544	DeChelly	523-526	65	1,543	Freshwater	228	70	-----
43/23-32ac	1,641	544	DeChelly	527-544	65	1,547	Freshwater	398	22	-----
43/23-4dd	1,622	1,940	Upper Hermosa-Paradox	1,684-1,696	120	1,552	Saltwater-cut mud Muddy saltwater	122 9	N/A *	Water salinity 52,000 ppm.
43/24-4dd	1,622	1,940	Paradox	1,804-1,840	120	1,314	Heavily gas-cut mud Heavily gas-cut saltwater Gas-cut oily saltwater	98 28 12	N/A * *	-----
43/24-6bb	1,679	2,111	Leadville	2,073-2,111	75	1,248	Muddy water Saltwater	64 1,212	1 26	-----
43/24-13aa	1,568	2,015	Hermosa	1,616-1,636	15	1,354	Clean oil	567	113	-----
43/24-27cc	1,561	1,768	Paradox	1,622-1,635	95	1,186	Slightly oil- and gas-cut mud Heavily oil- and gas-cut mud Slightly oil- and gas-cut muddy water Black salty sulfur water	14 27 27 202	N/A N/A 1 10	-----

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
43/25-33ba	1,594	2,074	Hermosa	1,685-1,735	240	-----	Mud	8	N/A	-----
							Heavily gas and saltwater and slightly oil-cut mud	174	N/A	
							Heavily gas-cut saltwater	98	*	
43/25-33ba	1,592	2,074	Missis-sippian	2,036-2,073	240	1,233	Mud and saltwater	411	3	-----
							Saltwater	600	4	
							Mud	55	N/A	
							Sulfur water	91	1	
43/26-19cb	1,518	1,998	Paradox	1,875-1,896	90	1,336	Water-cut mud	27	N/A	-----
							Black salty sulfur water with a strong H_2O odor	357	11	
43/26-31bb	1,510	2,119	Missis-sippian	2,065-2,118	240	1,214	Saltwater	1,707	8	-----
43/25-1dd	1,474	1,818	Hermosa	1,742-1,762	75	1,185	Gas-cut mud	28	N/A	-----
							Heavily gas-cut oil	361	14	
							Oil- and gas-cut saltwater	101	4	
43/25-10dd	1,619	2,198	Paradox	1,840-1,855	120	1,310	Slightly gas-cut saltwater with sulfur odor	1,471	49	-----
43/25-11aa	1,491	2,011	Paradox	1,885-1,919	63	1,486	Slightly water-cut drilling fluid	171	N/A	-----
43/25-16cc	1,544	1,782	Hermosa	1,708-1,712	60	1,260	Water cushion	305	N/A	Temperature: 46°C.
							Gas- and oil-cut mud	57	N/A	
							Gas-, oil-, and mud-cut saltwater	28	7	
							Gas- and oil-cut saltwater	610	152	
							Saltwater	384	96	
43/25-21bc	1,545	1,760	Hermosa	1,678-1,684	120	1,245	Water cushion	315	N/A	Temperature: 55°C.
							Muddy, slightly salty with sulfur odor	142	12	
							Slightly salty water with sulfur odor	824	69	

Table 14.--*Results of selected drill-stem tests in Utah*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
43/25-28bb	1,561	1,756	Paradox	1,670-1,675	185	1,293	Foamy oil- and gas-cut mud	46	N/A	-----
							Gas- and slightly oil-cut mud	274	N/A	
							Water	1,074	70	
43/25-32ba	1,573	1,658	Paradox	1,573-1,658	95	1,367	Mud	9	N/A	-----
							Gas- and slightly oil-cut mud	113	N/A	

Table 15.--*Results of selected drill-stem tests in Colorado*

[Tests were drill-stem tests unless otherwise indicated under Remarks; Altitude, approximate altitude of land surface above sea level; Depth, total depth drilled below land surface; Rock unit tested, see table 1 for full name and rank of each rock unit; Test interval, depth below land surface; Freshwater head, above sea level unless number is preceded by minus sign (some freshwater-head values may be too small because equilibrium was not reached during test); Fluid-recovery rate, meters of formation fluid recovery in drill stem per hour of test per meter of test interval thickness; N/A, not applicable; *, minor recovery rate; ppm, parts per million; Cl, chloride; °C, degrees Celsius]

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
32/13½-4bb	2,111	3,041	Hermosa	2,518-2,529	75	2,046	Gas-cut mud	82	N/A	-----
32/14-2dd	2,073	1,054	Dakota	1,016-1,022	45	1,175	Slightly oil-cut mud	9	N/A	-----
32/14-11dd	2,070	2,917	Dakota	954-981	75	1,180	Drilling mud	3	N/A	-----
32/14-11dd	2,070	2,917	Dakota	999-1,003	75	1,166	Drilling mud	12	N/A	-----
32/14-11dd	2,070	2,917	Hermosa	2,636-2,681	75	1,791	Gas-cut drilling mud	191	N/A	-----
32/14-11dd	2,070	2,917	Paradox	2,833-2,862	135	899	Gas-cut mud	198	N/A	-----
32/17-1ac	1,807	2,713	Hermosa	2,396-2,430	127	852	Heavily gas-cut mud	327	N/A	-----
32/17-5cb	1,569	262	Mancos	246-259	120	1,488	Drilling mud	12	N/A	-----
32/17-7ab	1,555	240	Mancos	219-236	75	1,554	Slightly oil-, gas-, and water-cut mud	41	N/A	-----
32/17-8cb	1,569	286	Mancos	271-286	60	1,350	Oil	27	2	-----
33/14W-24dc	2,092	3,070	Lower Hermosa-Molas	2,917-3,070	75	1,785	Sulfur water Gas and water mixture (too wet to burn or gauge)	--- 610	--- 3	-----
33/18-22cd	1,629	129	Mancos	114-126	60	1,593	Gas-cut mud	27	N/A	-----
33/18-22dd	1,619	2,040	Salt Wash	383-517	125	1,616	Drilling mud	423	N/A	This well is used as a water-source well for water-flood project.
33/20-04dd	1,492	1,859	Hermosa	1,827-1,829	68	1,070	Oil-cut mud Oil	24 0.3	N/A *	-----

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Amount (meters)	Rate (meters per hour per meter)	Remarks
33½/20-09ac	1,558	1,826	Hermosa	1,760-1,815	70	1,154	Mud Saltwater	110 101	N/A 2	-----
33½/20-34bb	1,509	1,865	Paradox	1,797-1,814	128	1,620	Slightly oil-cut and heavily gas-cut mud Gas-cut saltwater	75 923	N/A 25	-----
33½/20-9bc	1,551	1,813	Hermosa	1,768-1,798	55	1,291	Oil Heavily gas-cut saltwater	30 1,539	1 56	-----
33½/20-9db	1,548	1,772	Hermosa	1,749-1,768	183	1,230	Oil- and gas-cut mud Very highly gas-cut and slightly mud-cut oil	30 581	N/A 10	-----
33½/20-10cc	1,567	1,824	Hermosa	1,763-1,793	72	1,312	Oil Oil- and gas-cut mud	91 2	3 N/A	-----
33½/20-10cd	1,567	1,827	Hermosa	1,767-1,801	100	1,296	Oil	552	10	-----
33½/20-15aa	1,553	1,846	Hermosa	1,776-1,785	240	1,332	Gas-cut mud Very heavily gas-cut with some oil Gas- and oil-cut mud Oil-cut mud	34 274 119 18	N/A N/A N/A N/A	-----
33½/20-15aa	1,553	1,846	Hermosa	1,784-1,792	240	1,299	Mud Gas- and water-cut mud Saltwater, slightly mud-cut, scum of oil at base	244 27 137	N/A N/A 4	-----
33½/20-16ac	1,565	1,830	Hermosa	1,795-1,814	110	1,281	Very slightly gas- and water-cut mud Saltwater	37 1,289	N/A 37	-----
33½/20-16bc	1,549	1,867	Hermosa	1,772-1,781	195	1,347	Oil Mud	259 9	9 N/A	-----

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Amount (meters)	Rate (meters per hour per meter)	Remarks
33½/20-16bc	1,549	1,867	Hermosa	1,781-1,787	180	1,339	Water- and oil-cut mud Saltwater (125,000 ppm, Cl)	18 174	N/A 10	-----
33½/20-16bc	1,549	1,867	Hermosa	1,795-1,804	180	1,316	Oil-, water-, and gas-cut mud Oil-cut water Saltwater	96 229 1,173	N/A 8 43	-----
33½/20-21ac	1,537	-----	Hermosa	1,809-1,814	100	1,106	Very slightly gas-cut water Very slightly gas-cut muddy water Very slightly mud-cut water	27 27 37	3 3 4	-----
33½/20-22bc	1,491	1,810	Hermosa	1,739-1,746	180	1,340	Very slightly oil-cut mud Saltwater	64 82	N/A 4	-----
33½/20-25cd	1,540	1,819	Hermosa	1,801-1,804	95	1,253	Drilling mud Saltwater	40 78	N/A 16	-----
33½/20-25cb	1,520	1,833	Hermosa	1,768-1,783	120	1,312	Mud-cut saltwater	579	19	-----
33½/20-25cb	1,520	1,833	Hermosa	1,783-1,799	120	1,343	Heavily oil-, mud-, and gas-cut water Oil and gas-cut, muddy saltwater Saltwater	91 82 841	3 3 26	-----
33½/20-26bb	1,540	1,873	Hermosa	1,774-1,782	180	1,197	Saltwater Muddy, slightly gas-cut mud Saltwater-cut gassy condensate Frothy highly oily and gassy mud Water-, oil-, and gas-cut mud	796 55 18 37 9	33 N/A 1 N/A N/A	-----
33½/20-26bb	1,540	1,873	Hermosa	1,801-1,820	120	1,358	Gassy, muddy saltwater Saltwater	73 1,417	2 37	-----

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
34/10-32bc	2,099	1,798	Fruitland	921-972	240	2,096	Gas-cut water	293	1	-----
34/12-26ac	2,144	2,888	Paradox	2,793-2,815	90	1,738	Drilling mud	134	N/A	-----
34/12-27ca	2,096	3,017	Hermosa	2,332-2,345	105	2,048	Mud Saltwater	85 1,235	N/A 54	Temperature: 103°C at 2,866 to 2,888 meters.
34/12-27ca	2,096	3,017	Leadville	2,995-3,017	75	1,898	Water cushion Saltwater	610 980	N/A 36	-----
34/12-32bb	2,110	3,024	Dakota	935-963	35	1,285	Drilling mud	12	N/A	Temperature: 60°C. Temperature: 99°C at 2,560 to 2,582 meters.
34/12-32bb	2,110	3,024	Leadville	2,993-3,024	127	1,989	Grayish, gassy freshwater Water cushion	37 393	1 N/A	Temperature: 118°C. Temperature: 99°C at 2,925 to 2,945 meters. Temperature: 98°C at 2,896 to 2,924 meters. Temperature: 97°C at 2,852 to 2,895 meters. Temperature: 99°C at 2,707 to 2,773 meters. Temperature: 98°C at 2,591 to 2,642 meters.
34/12-34ca	2,097	2,900	Middle and lower members of Hermosa	2,865-2,900	45	-----	Mud-cut oil Oil-cut mud Water cushion	27 9 482	1 N/A N/A	Temperature: 116°C.
34/13-2ca	2,364	3,083	Dakota	973-978	105	1,966	Mud-cut water (250 ppm Cl)	453	6	Temperature: 43°C.
34/13-2ca	2,364	3,095	Hermosa	2,508-2,563	105	2,509	Heavily gas-cut mud (460 ppm Cl)	---	N/A	Temperature: 81°C.
34/13-2ca	2,364	3,095	Paradox	2,729-2,762	105	-----	Salt-based drilling mud	905	N/A	Temperature: 93°C.
34/13-2ca	2,364	3,095	Paradox	2,816-2,835	105	1,967	Heavily gas-cut mud	91	N/A	Temperature: 93°C.
34/13-15cb	2,148	3,109	Dakota	942-985	105	2,258	Slightly oil-cut mud	46	N/A	Temperature: 104°C at 2,548 meters.

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
34/14-24cc	2,127	3,214	Hermosa	2,629-2,641	190	3,044	Not reported	---	---	-----
34/20-2bb	1,496	1,751	Hermosa	1,649-1,658	120	1,346	Drilling mud Heavily gas- and oil-cut mud Oil	11 98 82	N/A N/A 5	-----
34/20-2db	1,538	1,795	Lower Hermosa	1,729-1,759	190	1,321	Drilling mud Saltwater	120 78	N/A 1	Temperature: 53°C.
34/20-3ba	1,489	1,780	Paradox	1,715-1,729	120	1,277	Slightly muddy and gassy water	155	6	-----
35/12-8dc	2,241	622	Morrison	592-622	65	1,846	Muddy water	183	4	-----
35/18-8bc	2,119	394	Dakota	361-372	65	1,973	Drilling mud	55	N/A	-----
35/20-10cd	1,537	1,781	Paradox	1,732-1,748	180	-----	Slightly oil- and gas-cut mud Slightly oil- and gas-cut muddy water	28 106	N/A 2	Temperature: 56°C. Temperature: 54°C at 1,700 to 1,729 meters. Temperature: 52°C at 1,750 to 1,785 meters.
35/20-15	1,623	1,856	Hermosa	1,774-1,798	35	1,371	Mud to surface in 25 minutes Oil to surface in 28 minutes	--- 24	N/A 2	-----
35/20-15cc	1,548	1,759	Paradox	1,709-1,726	120	1,320	Highly oil- and gas-cut (reversed out)	305	9	-----
35/20-15dc	1,607	1,819	Hermosa	1,787-1,796	120	1,329	Oil Heavily oil-cut mud Heavily oil-, gas-, and water-cut mud	6 134 27	N/A N/A N/A	-----
35/20-22ac	1,593	1,806	Hermosa	1,727-1,768	62	1,366	Highly gas-cut mud Highly oil-cut mud Mud-cut distillate Muddy water	181 27 27 27	N/A N/A * *	-----

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery			Remarks
							Fluid	Amount (meters)	Rate (meters per hour per meter)	
35/20-22ba	1,601	1,804	Hermosa	1,760-1,783	60	1,305	Heavily gas-cut and slightly oil-cut mud Very highly gas-cut mud	3 119	N/A N/A	-----
35/20-22da	1,549	1,762	Hermosa	1,664-1,716	50	1,045	Highly gas-cut mud slightly oil-cut mud Highly gas- and oil-cut mud	67 55	N/A N/A	-----
36/13-8ca	2,237	1,712	Hermosa	1,632-1,702	60	2,318	Drilling mud and saltwater	1,503	21	-----
37/17-27bb	2,055	2,678	Missis-sippian	2,350-2,368	75	1,632	Gas, nonflamable Water	--- 6	N/A *	Temperature: 66°C.
38/16-6cb	2,218	2,664	Paradox	1,762-2,116	75	3,249	Mud	282	N/A	-----
38/17-17ba	2,100	1,814	Hermosa	1,449-1,471	60	1,825	Muddy saltwater Gas- and water-cut mud Saltwater	233 148 244	11 N/A 11	-----
39/19-6dd	2,020	1,940	Hermosa	1,908-1,917	180	2,500	Water-cut (mud?) Muddy water (oil- and gas-cut) Saltwater	305 36 56	N/A 1 2	-----
39/19-27cd	1,926	1,795	Entrada	156-162	120	1,833	Rat-hole mud	21	N/A	-----
39/19-29ca	2,034	1,914	Hermosa	1,495-1,501	210	1,879	Slightly gas-cut mud Slightly water-cut mud Salty water with a slight scum of dark oil	302 192 466	N/A N/A 22	-----
40/18-13dbc	2,196	2,719	Leadville	2,561-2,591	245	1,488	Water cushion Drilling mud Non-flamable gas	152 27 ---	N/A N/A N/A	Temperature: 71°C.

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Amount (meters)	Rate (meters per hour per meter)	Remarks
40/18-13dbc	2,196	2,719	Leadville	2,591-2,632	305	1,440	Non-flamable gas	---	N/A	Temperature: 82°C.
							Heavily gas and water-cut mud	247	N/A	
							Slightly gas and water-cut mud	137	N/A	
41/18-17dd	2,263	2,900	Leadville	2,775-2,824	60	1,435	Slightly salty water with numerous gas pockets	1,822	37	-----
42/18-34ba	2,402	3,072	Leadville	3,021-3,072	70	1,385	Gas-cut mud	30	N/A	Temperature: 91°C. 29,000 ppm chloride, 2,850 ppm calcium in water.
							Gas-cut saltwater	305	5	
44/16-35cd	2,024	3,309	Missis-sippian-Ouray	3,206-3,250	240	1,320	Water cushion	631	N/A	-----
							Water-cut mud	43	N/A	
44/17-8aa	2,111	3,722	Leadville	3,579-3,621	124	1,465	Gas-cut mud	368	N/A	-----
							Slightly watery mud	552	N/A	
							Slightly muddy water	1,863	21	
44/17-8aa	2,111	3,722	Leadville	3,534-3,553	---	-----	-----	762	N/A	-----
								198	N/A	
44/17-8aa	2,111	3,722	Hermosa	3,005-3,030	---	431	Muddy water	2,645	N/A	-----
44/17-14ad	2,009	2,830	Missis-sippian	2,788-2,830	105	1,582	Water cushion	549	N/A	-----
							Slightly gas-cut mud	18	N/A	
							Saltwater	1,021	14	
44/17-34dc	1,846	3,306	Missis-sippian	3,129-3,148	50	671	Freshwater cushion	1,384	N/A	-----
							Freshwater and drilling mud	1,393	88	

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
44/17-34dc	1,846	3,306	Missis-sippian	3,146-3,219	60	1,156	Gas-cut mud Water cushion Gas-cut water	37 1,189 110	N/A N/A N/A	-----
44/17-36ad	1,881	2,939	Paradox	1,882-1,930	---	660	Very slightly gas-cut mud	192	N/A	-----
44/17-36ad	1,881	2,939	McCracken	2,899-2,939	60	1,765	Watery mud and muddy water	41	N/A	-----
44/18-16bc	1,885	2,612	Elbert, McCracken, Cambrian	2,561-2,612	---	1,328	Slightly gas-cut mud Saltwater	57 224	N/A 2	-----
44/18-21	1,775	2,766	Upper member of Hermosa	1,954-1,966	60	121	Water	37	3	-----
44/18-21	1,775	2,766	Paradox	2,144-2,183	60	-255	Mud and water	140	N/A	-----
44/18-21	1,775	2,766	Lower member of Hermosa	2,552-2,570	120	-378	Mud	61	N/A	-----
44/19-5ba	1,982	3,048	Missis-sippian	2,701-2,732	---	1,265	Highly gas-cut mud	270	N/A	Temperature: 71°C.
44/19-5ba	1,982	3,048	Missis-sippian - Devonian	2,732-2,756	---	928	Heavily gas-cut mud	238	N/A	Temperature: 74°C.
44/19-5ba	1,982	3,048	Devonian	2,813-2,844	---	2,051	Water cushion Gas-cut mud Gas-cut mud	457 312 425	N/A N/A N/A	-----
44/19-16bc	2,024	2,903	Salt base of Paradox-Missis-ippian	2,709-2,744	---	180	Gas Gas-cut drilling mud	--- 82	N/A N/A	Temperature: 82°C.

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
44/19-16bc	2,024	2,903	Missis-sippian	2,744-2,771	---	1,280	Highly gas- and condensate-cut drilling mud Gas Drilling mud to surface in 75 minutes	244 --- 2,771	N/A N/A N/A	Temperature: 83°C.
44/19-16bc	2,024	2,903	Missis-sippian	2,771-2,786	155	1,238	Slightly gas-cut saltwater	527	14	-----
44/19-16bc	2,024	2,903	Missis-sippian-Ouray	2,789-2,805	60	1,256	Slightly gas-cut saltwater	274	17	Temperature: 88°C.
44/19-18ad	1,924	2,701	Aneth	2,676-2,701	---	-538	Gas-cut mud	762	N/A	Temperature: 68°C.
44/19-30ad	2,102	2,939	Missis-sippian	2,774-2,814	---	-5	Gas Gas-cut drilling mud	--- 128	N/A N/A	Inadequate data on drill-stem tests.
45/17-20bc	2,096	3,327	Upper member of Hermosa	2,938-2,976	---	522	Gas-cut mud	163	N/A	-----
45/19-26db	1,988	3,318	Upper member of Hermosa	2,668-2,688	---	539	Gas-cut mud with trace of oil Gas to surface in 50 minutes	26	N/A	-----
45/19-26db	1,988	3,318	Upper member and upper part of middle member of Hermosa	2,729-2,795	---	-510	Gas-cut mud	61	N/A	-----
45/19-26db	1,988	3,318	McCracken	3,293-3,318	180	1,428	Mud cushion Gas-cut mud Gas-cut watery mud Water	458 296 652 398	N/A N/A N/A 5	-----
45/19-26ad	1,988	3,318	Leadville	3,212-3,240	180	1,474	Water cushion Water Gas-cut water Muddy water	461 366 305 615	N/A 4 4 7	-----

Table 15.--*Results of selected drill-stem tests in Colorado*--Continued

Location	Altitude (meters)	Depth (meters)	Rock unit tested (table 3)	Test interval (meters)	Test duration (minutes)	Fresh-water head (meters)	Fluid recovery: Fluid	Fluid recovery: Amount (meters)	Fluid recovery: Rate (meters per hour per meter)	Remarks
45/19-30ad	2,082	3,095	Missis-sippian	3,030-3,063	60	1,383	Black sulfur water Drilling fluid	396 46	12 N/A	-----
45/19-31ac	2,114	3,298	Missis-sippian	3,009-3,063	---	-594	Gas-cut drilling mud	66	N/A	Temperature: 63°C.
45/19-31ac	2,114	3,298	Missis-sippian	3,096-3,150	60	1,297	Drilling mud and saltwater Saltwater	411 1,669	N/A 31	Temperature: 60°C.
46/19-6dcb	1,951	3,445	Hermosa	2,315-2,325	---	-308	Drilling fluid	27	N/A	Temperature: 56°C.
46/19-6dcb	1,951	3,445	Hermosa	2,489-2,499	---	1,325	Gas-cut drilling fluid Gas	29 ---	N/A N/A	Temperature: 61°C.
46/19-6dcb	1,951	3,445	Hermosa	2,955-2,970	---	-486	Water cushion Slightly gas-cut drilling fluid	396 9	N/A N/A	Temperature: 71°C.
46/19-6dcb	1,951	3,445	Missis-sippian	3,393-3,394	---	1,466	Saltwater	---	---	-----
46/19-30ba	1,961	3,246	Hermosa	2,535-2,574	120	2,230	Saltwater	2,469	32	-----
46/19-30ba	1,961	3,246	Missis-sippian	3,210-3,246	---	1,310	Water cushion Saltwater	457 887	N/A 11	-----
47/18-30dc	1,533	4,389	Missis-sippian	4,302-4,328	120	1,584	Water cushion Saltwater	1,265 2,036	N/A 39	Temperature: 109°C.
47/19-21dc	1,998	-----	Cutler	1,402-1,433	---	1,549	Slightly water-cut mud Mud	27 9	N/A N/A	Temperature: 33°C. More detail information available.

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