RECONNAISSANCE OF THE GEOHYDROLOGY OF THE MOAB-MONTICELLO AREA, WESTERN PARADOX BASIN, GRAND AND SAN JUAN COUNTIES, UTAH

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CONVERSION FACTORS

For use of those readers who may prefer to use inch-pound units rather than metric units, the conversion factors for the terms used in this report are listed below:

Metric unit	Multiply by	To obtain inch-pound unit
millimeter (mm)	3.937×10^{-2}	inch (in.)
millimeter per day (mm/d)	3.937×10^{-2}	inch per day (in./d)
millimeter per year (mm/yr)	3.937×10^{-2}	inch per year (in./yr)
kilometer (km)	6.214×10^{-1}	mile (mi)
square kilometer (km^2)	3.861×10^{-1}	square mile (m^2)
meter (m)	3.281	foot (ft)
cubic meter per second (m^3/s)	3.531	cubic foot per second (f^3/s)
cubic meter per minute (m^3/min)	3.531	cubic foot per minute (f^3/min)
cubic meter (m^3)	3.531	cubic foot (f^3)
cubic meter per year (m^3/yr)	3.351	cubic foot per year (f^3/yr)
degree Celsius (°C)	1.8°C + 32	degree Fahrenheit (°F)
meter per hour per meter [(m/h)/m]	1.076 x 10	foot per hour per foot [(f/h)/f]
meter per year (m/yr)	3.281	foot per year (f/yr)
milligram per liter (mg/L)	1/ 1.0	part per million (ppm)
microsiemens (μS) per centimeter at 25° Celsius	1.0	micromho per centimeter at 25° Celsius
microgram per liter (μg/L)	1/ 1.0	part per billion (ppb)
liter per second (L/s)	1.586×10^{1}	gallon per minute (gal/min)
liter per minute (L/min)	9.516×10^{2}	gallon per minute (gal/min)

1/ Approximate.

Classification of Natural Water[1/]

Class	Dissolved solids (parts per million - milligrams per liter)	Specific conductance (micromhos per square centimeter at 25° Celsius)
Fresh	0 to 1,000	0 to 1,400
Slightly saline	1,000 to 3,000	1,400 to 4,000
Moderately saline	3,000 to 10,000	4,000 to 14,000
Very saline	10,000 to 35,000	14,000 to 50,000
Briny	More than 35,000	More than 50,000

[1/] From Feltis (1966, p. 8) and Robinove, Langford, and Brookhart (1958, p. 3).

NGVD

The base datum used in this report is the National Geodetic Vertical Datum of 1929 (NGVD of 1929). This is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada. This datum was formerly called mean sea level, and is referred to as sea level in this report.

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ABSTRACT

Study of the geohydrology of the Moab-Monticello area in Grand and San Juan Counties, Utah, is one of five reconnaissance investigations of the Paradox basin. These studies are part of a program designed to evaluate possible storage of radioactive waste in salt deposits. The work was done by the U.S. Geological Survey under the auspices of the U.S. Department of Energy. The area, approximately 4,900 square kilometers in size, is in the western part of the Paradox basin and includes the west slope of the La Sal Mountains and the north slope of the Abajo Mountains.

The study area is more humid than most of the surrounding Colorado Plateau region. Precipitation generally ranges from about 200 millimeters per year to about 750 millimeters per year; the estimated volume of water falling on the area is 1,600 x 10^6 cubic meters per year. Of this total, approximately 265 x 10^6 cubic meters per year (17 percent) is runoff, 150 x 10^6 cubic meters per year (9 percent) recharges upper-system aquifers and an estimated 42 x 10^6 cubic meters (3 percent) returns to the atmosphere via evapotranspiration from stream valleys. The rest is evaporated rapidly at or near the place where it falls.

Rocks ranging in age from Proterozoic to Holocene occur in the area. Most of the rock formations that are Paleozoic in age or older are mainly sedimentary and occur only in the subsurface. Sedimentary strata comprise the great preponderance of the geologic section. Permeable sandstones, limestones, and salt (halitic) deposits with little permeability are the most important, as far as ground-water hydrology is concerned. The hydrogeologic units selected for reconnaissance evaluation, in descending order of estimated hydraulic conductivity, are: (1) The lower Paleozoic aquifer; (2) the alluvial aquifer; (3) the Mesozoic sandstone aquifer; (4) Tertiary aquifer; (5) the Mesozoic-upper Paleozoic confining beds; (6) the Cretaceous confining beds; (7) Upper Paleozoic confining beds; (8) the lower Paleozoic and Proterozoic confining unit; and (9) the salt confining beds, consisting of the salt deposits of the Paradox Member of the Hermosa Formation. The salt confining beds divide upper and lower ground-water systems.

Structurally, the area consists of dominantly northwest-trending salt anticlines and contiguous faults paralleled by synclines. The intrusive masses that form the La Sal and Abajo Mountains are laccoliths, with bysmaliths and complex other intrusive forms comprising, in gross form, moderately faulted

domal structures. The geologic structures significantly modify ground-water flow patterns in the upper ground-water system, but have no obvious effect on the flow regime in the lower ground-water system.

The general quality of water in the upper ground-water system is suitable for most uses. The quality of water of the lower ground-water system is slightly saline to briny. Water quality of the Colorado River is suitable for most uses, based on dissolved chemical constituents; some of the small tributaries of the river are saline.

INTRODUCTION

The U.S. Geological Survey has conducted a series of investigations, funded by the U.S. Department of Energy under Interagency Agreement DE-AI97-79ET44611, related to the potential isolation of high-level radioactive wastes in the Paradox basin, Utah and Colorado. These investigations included geologic, geophysical, and hydrologic studies to identify suitable environments for waste storage and to develop new techniques for site exploration and evaluation. As part of the investigations, this report presents general geohydrologic information on the Moab-Monticello area in the western part of the Paradox basin in Utah.

The purpose of this report is to define surface-water and ground-water hydrology of the Moab-Monitcello area in sufficient detail to be part of the data base to determine the feasibility of storing nuclear waste in salt deposits associated with salt anticlines. The investigation primarily used existing data and reports, with minor supplementation from reconnaissance inventories and measurements.

Location and Extent of the Area

The part of the Paradox basin described in this report is shown in figure 1. The area adjoins the Colorado River to the northwest between the mouth of the Dolores River at the northernmost part and a point approximately 22 km downstream from the mouth of the Green River. The eastern boundary is the drainage divide between the Dolores and Colorado Rivers for about 90 km in a southerly direction through the La Sal Mountains (pl. 1). The southern boundary follows the drainage divide between the Colorado and San Juan Rivers for about 65 km, in a generally westerly direction across the Abajo Mountains (pl. 1). The southwest boundary of the area is a 56-km span that coincides with the approximate limit of the Paradox basin evaporites (defined by Hite and Lohman, 1973, fig. 1).

The Moab-Monticello area is about 120 km long in a north-south direction and ranges from about 15 km wide near the northern end to about 65 km wide at the southern end. It includes about 4,900 km^2, or about 16 percent of the Paradox basin. Approximately 60 percent of the Paradox basin is in south-eastern Utah and about 40 percent is in Colorado. Virtually all of the Moab-Monticello is in Utah (pl. 1 and fig. 1).

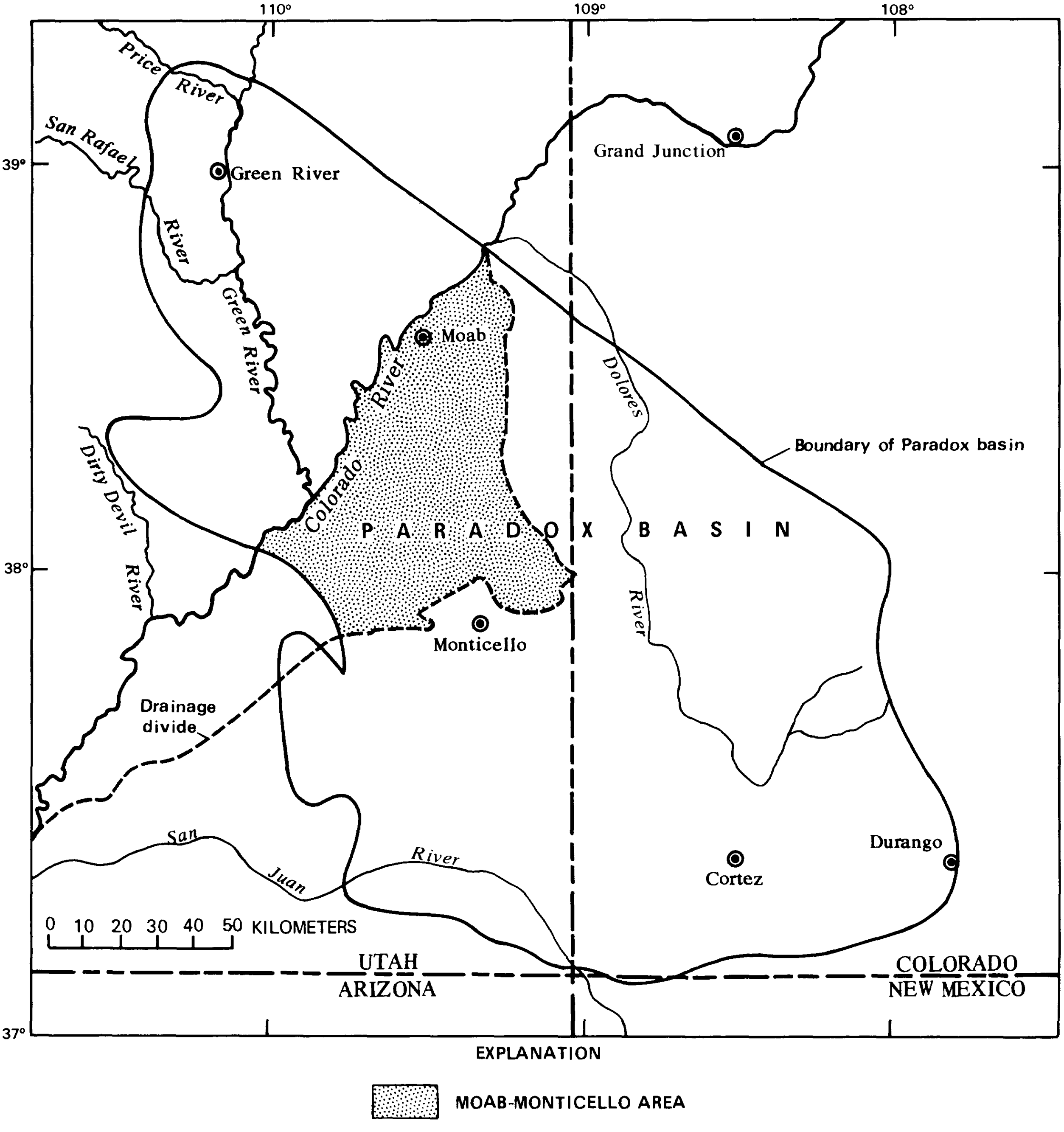


Figure 1.--Location of the Moab-Monticello area in the Paradox basin of southeastern Utah.

Previous Work

Baker (1933) described the general geology and possibilities of oil occurrence in parts of the Moab-Monticello area, including some references to water resources. Hunt (1958) described the structural and igneous geology of the La Sal Mountains in detail and briefly noted some of the water resources. Hunt's report includes much of the northeastern part of the Moab-Monticello area. Richmond (1962) described the Quaternary stratigraphy and physiographic development of the La Sal Mountains. Iorns, Hembree, and Oakland (1965), in a regional study of the upper part of the Colorado River basin, presented geohydrologic data and summarized the hydrology of a region that includes the Moab-Monticello area. Baars' (1966) analysis of the pre-Pennsylvanian paleotectonics includes some of the hydrologic characteristics of the stratigraphic units involved. Feltis (1966), in a regional reconnaissance, described the occurrence and quality of water in bedrock aquifers of eastern Utah. Sumsion (1971) described the water resources of the Spanish Valley area, with primary emphasis on the alluvial aquifer and flow in the creeks. Sumsion and Bolke (1972) completed an investigation of parts of Canyonlands National Park and ground-water occurrences, partly included in the Moab-Monticello area. Hite and Lohman (1973) described the general characteristics of the salt anticlines in the Paradox basin and their relationship to possible waste-disposal sites. Huntoon (1979) described the occurrence of ground water in Permian age rocks and Thackston and others (1981) described ground-water circulation in western Paradox basin. Rush and others (1982) described the hydrology of the Green River-Moab area, adjacent to this study area and on the west side of the Colorado River. Most of the authors cited above used some data from exploratory drilling done by oil and mining companies.

Numbering System for Hydrologic Sites

Location numbers for wells, springs, and other places where data were obtained for this report are based on the rectangular land subdivisions of the U.S. Government in Utah, referenced to the Salt Lake base line and meridian. The number describes the position of a data point within the land net. All of the Moab-Monticello area is south of the base line and east of the meridian. A location number consists of three segments: the first designates the township south of the base line; the second segment, separated from the first by a slanted line, designates the range east of the meridian; and the third segment, separated from the second by a dash, is the section number. If the site could be located precisely, following the section number are two or three letters indicating the quarter section, quarter-quarter section, and quarter-quarter-quarter section; the letter "a" indicates the northeast quarter of each subdivision; "b" indicates the northwest quarter; "c" indicates the southwest quarter, and "d" indicates the southeast quarter. Thus, 25/22-1 acb designates the location of a hydrologic site located in the NW¼ SW¼ NE¼ sec. 1, T. 25 S., R. 22 E.

HYDROLOGIC ENVIRONMENT

Climate

The region in and around the Moab-Monticello area has a diverse climate. Differences in altitude and the effect of mountains on the movement of air masses and storms have more effect on the climate than the small range of geographic latitude. Pacific air masses and storms dominate the regional weather during October through April; warm, moisture-laden air masses from the Gulf of Mexico may traverse the region in summer. Summer weather produces less frequent but more intense storms. The higher parts of the La Sal and Abajo Mountains are comparatively wet and cool; their slopes and adjacent plateaus are drier, and subject to large variations in diurnal and seasonal temperature. The semiarid and arid canyons and valleys at low altitudes have hot summers and cold winters.

In the hydrologic regimen of the Moab-Monticello area, evaporation constitutes the bulk of consumptive use (water loss). Consumptive use includes water loss through transpiration by all types of vegetation (not only phreatophytes, described separately in this report) and evaporation from land, vegetation, and water surfaces. Potential evapotranspiration is defined by Thornthwaite and Mather (1955) as the water loss that will occur if there is no deficiency of soil water. A weighted mean annual potential evapotranspiration for the Moab-Monticello area is about 1,000 mm. Potential evapotranspiration (total evaporational loss) ranges from about 1,400 mm in the lower altitudes (below 1,500 m) to about 600 mm near the summits of the La Sal Mountains along the eastern boundary of the area and the Abajo Mountains along the southern boundary of the area (above 3,300 m). These values for potential water loss are, of course, much greater than actual water loss, because soil moisture is nearly continuously deficient in this arid environment.

Physiography and Drainage

The Moab-Monticello area is in the western part of the Paradox basin, a major subdivision of the Colorado Plateaus province (as defined by Fenneman, 1946). Thornbury (1965) defined the Colorado Plateaus province as an area encompassing approximately 240,000 km^2 in parts of Arizona, New Mexico, Utah, and Colorado; about 90 percent of the province is drained by the Colorado River and its tributaries.

Despite the existence locally of significant structural relief, gently dipping sedimentary rocks characterize much of the province. Altitudes exceed 1,500 m throughout most of the Colorado Plateaus province. Deep canyons are more common here than in any other part of the United States. Differential erosion of hard and soft rocks has produced innumerable escarpments and benches; these benches generally follow or parallel structural features (pl. 1). The great relief is largely the result of deep canyons eroded into moderately flat terrain.

Altitudes range from about 1,100 m at the area's southern boundary at the Colorado River to more than 3,800 m on the highest peak of the La Sal Mountains. Steplike structural benches, usually called mesas, are common between the river and the two mountain ranges.

Hite and Lohman (1973, p. 4) noted that the Paradox basin is not a definable physiographic feature. The basin boundaries are determined by the extent of a thick sequence of Pennsylvanian evaporites, called the Paradox Member of the Hermosa Formation; therefore, the basin is depositional rather than structural.

The surface drainage system of the Moab-Monticello area is tributary to the Colorado River. Snowmelt and springs of the higher mountains and mesas provide water to a few small perennial and intermittent streams tributary to the Colorado River.

Castle Creek (25/23) originates on the northwestern slope of the La Sal Mountains. Pack Creek and its largest tributary, Mill Creek, originate on the west slope of the La Sal Mountains and flow through Spanish Valley (27/23), reaching the Colorado River near Moab, Utah. Kane Springs Creek (27/21) and its chief tributary, Hatch Wash (29/22), drain much of the mesa country between the La Sal and Abajo Mountains; this drainage system is perennial near the Colorado River. The flow of Indian Creek and Salt Creek reaches the Colorado River from the north slope of the Abajo Mountains only during spring and early summer periods of larger runoff. The headwaters of Indian Creek largely are diverted south out of the area by an aqueduct to Blanding, Utah, where they are used for public water supply; most of the remaining flow is appropriate for irrigation on ranches in the Indian Creek drainage system. Total surface-water inflow to the Colorado River from the Moab-Monticello area is very small in comparison to the average flow of the river through this area (pl. 2).

Hydrogeologic Units

Because of the general paucity of ground-water data available for the Moab-Monticello area, and in order to maintain the reconnaissance scope of this report, a simple three-fold designation of major hydrogeologic units has been chosen (table 1, column 7), consisting of a lower and an upper ground-water system separated by a salt confining unit. The lower ground-water system includes the stratigraphic units from the granitic basement upward to the base of the salt-bearing beds of the Paradox Member of the Hermosa Formation. The principal confining unit is the Paradox Member. The upper ground-water system contains predominantly freshwater and consists of all stratigraphic units from the top of the Paradox Member to the land surface; locally, it includes Quaternary alluvium.

The lower ground-water system contains saline water and, locally, some oil and gas. The equivalent of the Leadville Limestone, called Leadville equivalent in this report, is the most permeable unit in the lower ground-water system. The equivalent of the McCracken Sandstone Member of the Elbert

Formation locally yields saline water, oil, and gas to some of the boreholes that have penetrated it. The remaining five stratigraphic units in the lower ground-water system probably have little permeability.

To evaluate the water yielding character of the lower ground-water system, 82 drill-stem tests for the system were examined; one drill-stem test (29½/24-32 aa DST 1) was available for the upper ground-water system. A summary of these tests is compiled in table 2. Detailed data for all 83 drill-stem tests are compiled in table 3. The Leadville equivalent in the lower ground-water system was tested most frequently, and the Paradox Member of the Hermosa Formation was tested second most frequently. Based on comparative rates of fluid recovery during testing, the Leadville equivalent, Ouray, and Elbert Formations are the most permeable stratigraphic units tested. Two-thirds of the tests of the Paradox Member of the Hermosa Formation primarily recovered drilling mud, indicating little permeability; therefore, the calculated mean fluid recovery rate [19 (m/h)/m of tested interval] probably is deceptively large and indicative of permeability where nonsaliferous interbeds are thickest and shattered by faulting and folding.

The salt confining unit consists of 70 to 80 percent halite and some associated potash salts that are practically impervious to fluid flow. Black shale, dolomite, and anhydrite interbedded with the salt are fractured and yield from traces to commercially productive accumulations of oil and gas. "Oil and petroleum gases, primarily methane, are found in the Paradox Member by almost every well drilled in the Paradox basin" (Hite and Lohman, 1973, p. 42). Generally, pressure in these hydrocarbon deposits dissipates within a few hours or days, indicating that they are localized reservoirs sealed in by salt layers. The salt deposits constitute an effective barrier to fluid flow. Underlying and overlying strata with very little permeability (parts of two confining units) augment the confining functions of the salt-bearing beds.

Sandstone beds of the upper ground-water system yield varying quantities of freshwater to wells and springs, where saturated. Some of the sandstones yield some water from interstices, but most of them yield moderate quantities of water from fractures. Not all beds in this thick section are sandstone; some are shale, mudstone, limestone, or conglomerate; where these beds are intensely fractured, they also transmit some water.

In addition to lithified-rock (mainly sandstone) aquifers in the upper system, Quaternary alluvium (table 1) yields water to wells and springs in a few valleys where it is thickest and saturated. One notable example is Spanish Valley, where numerous wells on the valley floor produce water from alluvial deposits (Sumsion, 1971, p. 14).

The Entrada, Navajo, and Wingate Sandstones are the most important aquifers throughout much of the Moab-Monticello area, because these aquifers yield water that is chemically suitable for most uses. In a few places, yields from water wells completed in the Navajo Sandstone are large; for example, well 26/22-15 dca, a part of the Moab water supply, yields 9,255 L/min. In the

Table 2.--*Summary of formation-fluid recovery rates during drill-stem tests*

[(m/h)/m, meters per hour per meter; M, minor recovery rate]

Rock unit (table 1)	Number of tests	Fluid recovery rate [(m/h)/m]		Remarks
		Range	Mean	
Cutler (Rico?) Formation	1	---	---	Recovered 704 meters of freshwater in unspecified length of time.
Hermosa Formation	1	---	---	Gas to surface in 7 minutes.
Upper member	4	---	---	Recovered only drilling mud.
Paradox member	[1]22	M-42	19	----
Lower member	1	---	3	----
Molas Formation	3	---	---	Recovered only drilling mud.
Leadville equivalent	38	M-136	49	----
Ouray and Elbert Formations	6	M-26	20	----
Elbert Formation	7	M-25	---	Five of the tests recovered only drilling mud.
Equivalent of McCracken Sandstone member				

[1]Majority of these tests recovered mud or water- and gas-cut mud. Mean fluid-recovery rate calculated from results of seven tests.

Table 3.--*Results of drill-stem tests*

[Depth and test interval in meters below land surface; approximate altitude and hydraulic head in meters above sea level; m, meters; depth, total drilled depth of well; fluid-recovery rate is formation fluid recovered per hour of testing of testing per meter of tested interval; min, minutes; (m/h)/m, meters per hour per meter; *, minor recovery rate]

Location	Approximate altitude (m)	Depth (m)	Test number	Stratigraphic unit (table 1)	Tested interval (m)	Hydraulic head (m)	Fluid recovery: Type	Fluid recovery: Length (m)	Fluid recovery: Duration (min)	Fluid recovery: Rate [(m/h)/m]
24/23-13cd	1,392	4,362	1	"Leadville"	3,947-4,008	1,221	Water cushion	1,524	20	---
							Drilling mud	6	---	---
27/21-1db	1,665	2,042	1	"Leadville"	1,862-1,937	1,468	Drilling mud	168	---	---
							Salty sulphur water.	1,372	45	24
			2	Ouray and Elbert.	2,015-2,042	-334	Drilling mud	3	30	---
27/21-3cd	1,302	1,937	1	Paradox Member	391-611	-----	Sulfur water	449	120	1
27/22-15ad	1,772	2,457	2	"Leadville"	2,246-2,457	-----	Saltwater-cut mud	55	---	*
27/22-17dd	1,612	2,400	1	Paradox Member	1,963-2,004	2,166	Muddy saltwater	355	---	---
							Gas-cut mud	2,166	120	---
							Gas- and mud-cut distillate.	37	---	---
			2	"Leadville"	2,141-2,159	1,299	Black salty sulfur water.	1,445	120	40
			3	"McCracken" Member.	2,310-2,326	-663	Drilling mud	-----	120	---
27/22-27ba	1,674	2,409	1	Paradox Member	1,969-1,991	-----	Slightly gas-cut drilling mud.	61	60	---
27/22-32aa	1,674	2,389	1	"Leadville"	2,214-2,237	1,345	Drilling mud	1,115	60	26
							Black saltwater	603	---	---
			2	"Leadville"	2,198-2,209	1,358	Mud-cut water	142 }	75	117
							Black saltwater	1,468 }		
28/20-22bb	1,380	1,885	2	"Leadville"	1,561-1,591	-----	Water-cut mud	192	120	*
							Brackish water	1,207	---	20
			3	Ouray and Elbert.	1,809-1,826	-----	Muddy water	375 }	210	26
							Black salty water	1,193 }		
28/20-23ddd	1,398	1,716	1	Paradox Member	705-722	774	Gas-cut mud	3	60	---
			2	"Leadville"	1,426-1,436	1,176	Mud-cut salty water	366 }	90	69
							Salty sulfur water	671 }		
			3	Ouray and Elbert.	1,661-1,711	1,291	Mud-cut salty sulfur water.	305 }	150	14
							Salty sulfur water	1,058 }		
28/21-22cdd	1,828	2,596	1	Paradox Member	1,406-1,453	634	Drilling mud	31	64	---
			2	Paradox Member	2,234-2,251	-308	Drilling mud	27	72	---
			3	"Leadville"	2,355-2,374	1,379	Drilling mud	61	60	---
							Muddy saltwater	938 }	---	101
							Black sulfur water	988 }		
			4	"McCracken" Member.	2,563-2,596	1,056	Drilling mud	6	66	---

Table 3.--*Results of drill-stem tests*--Continued

Location	Approximate altitude (m)	Depth (m)	Test number	Stratigraphic unit (table 1)	Tested interval (m)	Hydraulic head (m)	Fluid recovery Type	Length (m)	Duration (min)	Rate [(m/h)/m]
28/21-31db	1,327	1,617	1	"Leadville"	1,078-1,094	1,236	Water-cut drilling mud.	105	90	*
			2	"Leadville"	1,094-1,132	1,184	Mud-cut black water	137	240	3
							Black water	296		
			3	"Leadville"	1,265-1,278	1,262	Mud-cut water	21	180	28
							Salty sulfur water	1,067		
			4	Ouray and Elbert.	1,294-1,320	1,218	Mud-cut water	61	180	14
							Black sulfur water	1,036		
28/21-33ac	1,791	2,441	1	Paradox Member	1,320-1,338	533	Drilling mud	15	45	---
			2	Paradox Member	1,920-1,978	147	Oil-cut mud	27	70	---
							Gas-cut mud	75	---	---
			3	Paradox Member	2,188-2,257	1,405	Oil-cut mud	104	5	---
							Gas- and water-cut mud.	21	---	*
			4	"Leadville"	2,310-2,356	1,368	Sulfur water-cut mud.	69	30	*
							Black salty sulfur water.	1,693	---	74
28/22-10ddb	1,593	2,393	1	"Leadville"	2,164-2,197	1,394	Drilling mud	140	30	---
							Black saltwater	1,692	---	103
28/23-2bba	2,087	3,205	1	Hermosa	1/ 2,437-2,442					
28/23-10bba	1,951	3,162	1	"Leadville"	2,932-2,946	1,336	Water cushion	601	---	---
							Saltwater	853	---	---
			3	Paradox Member	2,807-2,856	1,292	Water cushion	462	---	---
							Gas-cut mud	85	---	---
28/23-17cd	1,752	2,578	1	"Leadville"	2,515-2,556	1,329	Gas-cut mud	110	60	---
			2	"Leadville"	2,551-2,576	1,339	Sulfur water	1,865	---	75
29/20-4cd	1,413	1,547	1	"Leadville"	1,279-1,292	1,234	Water-cut mud	73	120	*
			2	"Leadville"	1,321-1,324	1,287	Black sulfur water	1,137	240	95
			3	Ouray and Elbert.	1,495-1,547	1,265	Water-cut mud	61	120	*
			4	"Leadville"	1,280-1,311	1,072	Water-cut mud	70	70	*
29/20-15bbb	1,403	1,528	1	"Leadville"	1,514-1,528	1,303	Mud-cut saltwater	435	120	38
							Black sulfur water	626		
29/21-15bcc	1,915	2,566	1	Paradox Member	1,372-1,429	571	Drilling mud	27	60	---
			2	"Leadville"	2,283-2,339	1,222	Gas-cut mud	138	127	---
							Slightly muddy water	128	---	1
			3	"Leadville"	2,337-2,369	1,266	Drilling mud	55	180	---
							Gas-and water-cut mud.	18	---	*
			4	"McCracken" Member.	2,504-2,566	1,246	Water-cut mud	330	120	*
			5	"Leadville"	2,370-2,398	1,239	Water-cut mud	113	240	*
							Gas-cut water	292	---	3

Table 3.--*Results of drill-stem tests*--Continued

Location	Approximate altitude (m)	Depth (m)	Test number	Stratigraphic unit (table 1)	Tested interval (m)	Hydraulic head (m)	Fluid recovery: Type	Length (m)	Duration (min)	Rate [(m/h)/m]
29/21-18cb	1,890	2,212	1	Molas	1,938-1,957	1,281	Drilling mud	9	30	---
			2	"Leadville"	1,957-1,993	1,336	Drilling mud	18	45	---
							Black saltwater	1,219	---	45
			3	"McCracken" Member.	2,174-2,212	792	Drilling mud	29	60	---
29/23-24ac	1,988	3,034	1	Hermosa[2/]	1,553-1,576	566	Drilling mud	61	120	---
			2	Hermosa	2,763-2,812	1,332	Drilling mud	290	150	---
							Gas-cut brackish water.	351	---	3
			3	"McCracken" Member.	2,990-3,034	1,373	Gas-cut salty sulfur water.	2,225	120	25
29/24-19ab	1,986	1,981	1	Paradox Member	1,832-1,852	453	Gas-cut saltwater and drilling mud.	107	135	2
			2	Paradox Member	2,161-2,181	1,041	Water and gas-cut drilling mud.	229	60	*
			3	Paradox Member	2,944-2,970	1,331	Water cushion	244	60	---
							Saltwater	503	---	19
29/24-28aca	2,058	3,069	1	Paradox Member	1,111-1,129	1,129	Muddy saltwater Saltwater	91 341 }	45	32
			2	"Leadville"	2,973-3,010	-817	-----	-----	30	---
			3	"Leadville"	3,010-3,033	1,305	Saltwater	2,070	60	90
29/24-29ddc	2,070	3,046	1	Paradox Member	2,048-2,472	2,130	Water cushion	914	320	---
							Black sulfur saltwater.	610	---	2
			3	"Leadville"	2,944-2,987	-48	Water cushion	610	30	---
							Drilling mud	9	---	---
			4	"Leadville"	3,001-3,044	1,364	Water cushion	457	75	---
							Black salty sulfur water.	1,517	---	28
29½/24-32aa	1,919	3,242	1	Cutler (Rico?)	857-868	1,854	Drilling mud	58	---	---
							Freshwater	704	---	---
			2	Hermosa	973-933	1,039	Drilling mud	5	---	---
			4	Paradox Member	1,522-1,528	425	Drilling mud	4	---	---
			5	Paradox Member	2,645-2,663	2,945	Gas-cut saltwater	1,922	---	---
			7	"Leadville"	3,004-3,021	1,283	Muddy saltwater	220	---	---
30/20-19cd	1,528	1,523	1	Paradox Member	1,141-1,160	454	Drilling mud	5	60	---
			2	"Leadville"	1,251-1,272	337	Drilling mud	3	60	---
			3	"Leadville"	1,350-1,380	966	Salty sulfur water	341	120	6
			4	"McCracken" Member.	1,545-1,590	996	Drilling mud	6	60	---

Table 3.--*Results of drill-stem tests*--Continued

Location	Approximate altitude (m)	Depth (m)	Test number	Stratigraphic unit (table 1)	Tested interval (m)	Hydraulic head (m)	Fluid recovery Type	Length (m)	Duration (min)	Rate [(m/h)/m]
30/24-2ca	2,003	3,176	1	Molas	2,913-2,940	-843	Drilling mud	9	60	---
			2	Molas	2,944-2,994	-799	Drilling mud	9	30	---
			3	"Leadville"	2,993-3,026	-941	Drilling mud	6	30	---
			4	"Leadville"	3,024-3,051	-877	Drilling mud	6	30	---
			5	Ouray and Elbert.	3,051-3,122	1,062	Drilling mud	91	60	---
							Water-cut filtrate water.	9	---	*
			6	"McCracken" Member.	3,148-3,176	191	Drilling mud	6	30	---
30/24-4ac	1,965	2,748	1	"Leadville"	2,733-2,748	1,173	Gas-cut black sulfur water.	1,524	45	136
31/23-26bd	1,876	2,528	1	Hermosa[3/]	1,385-1,390	512	Drilling mud	18	120	---
			2	Paradox Member	1,529-1,537	1,662	Muddy saltwater	1,006	180	42
			3	"Leadville"	2,548-2,573	1,367	Water cushion	305	120	---
							Saltwater	1,591	---	32
32/19-18dc	1,977	862	2	"Leadville"	945-977	1,074	Drilling mud	2	90	---
33/18-36cc	2,422	1,232	1	Hermosa	754-769	1,710	Drilling mud	2	90	---
			2	Paradox Member	790-804	1,653	Drilling mud	2	90	---
			3	"Leadville"	1,151-1,166	-----	Drilling mud	2	40	---
33/21-5cad	1,842	1,337	1	Paradox Member	728-824	1,915	Sulfur water	1,915	32	37

1/ Gas to surface in 7 minutes.

2/ Upper part of Paradox (?) Member and lower member of Hermosa Formation.

3/ Upper member of Hermosa.

southern part of the Moab-Monticello area, mainly in The Needles area and in Beef Basin, the Cedar Mesa Sandstone Member of the Cutler Formation is an important aquifer. Along the upper slopes of the La Sal and Abajo Mountains and on Elk Ridge, the Burro Canyon Formation is an important aquifer.

Ground-water information is not abundant for all stratigraphic units in the Moab-Monticello area. More precise details of how water is transmitted through various rocks and their fractures probably will result from future development and more intense investigation.

Structure

Within the Paradox basin, the principal structural features are the salt anticlines, most of which are elongated wrinkles trending predominantly northwest. Synclines parallel the salt anticlines. Faults and fracturing associated with and contiguous to folding affect lateral migration of water in the upper ground-water system almost everywhere.

The salt anticlinal structures resulted from both regional compressive stresses and plastic flowage of the Paradox Member of the Hermosa Formation (Hite and Lohman, 1973, p. 68). Fisher Valley, Castle Valley, Moab-Spanish Valley in addition to parts of Pine Ridge, Cane Spring, Lockhart, and Meander anticlines, plus Rustler and Gibson domes, are all associated with or are anticlines within the Moab-Monticello area (Hite and Lohman, 1973, fig. 1, p. 5).

Intrusive rocks of Tertiary age form the cores of La Sal and Abajo Mountains. These rocks are stocks, laccoliths, sills, dikes, and bysmaliths that are broadly domal in structural aspect. Broad structural benches on the flanks of the mountains are underlain by sandstones of the upper ground-water system (pl. 1; fig. 2).

Ground-Water Occurrence

The principal aquifers of the upper ground-water system consist of alluvium of Quaternary age and the Dakota Sandstone, Burro Canyon Formation, and Entrada, Navajo, and Wingate Sandstones of Mesozoic age, all of which crop out in the study area. The upper ground-water system is confined locally by strata with negligible permeability, but in most places it is unconfined because confining units have been removed by erosion. Underlying these aquifers and overlying the salt confining beds is the Mesozoic-upper Paleozoic confining bed (table 1), which is dominantly mudstone, siltstone, shale, and limestone interbedded with calcareous sandstone and conglomerate, all with little permeability. Stratigraphically, the confining unit includes all rocks from the salt deposits up to the top of the Chinle Formation.

The principal aquifer of the lower ground-water system consists of the Leadville equivalent, Ouray, and Elbert Formations; the equivalent of the

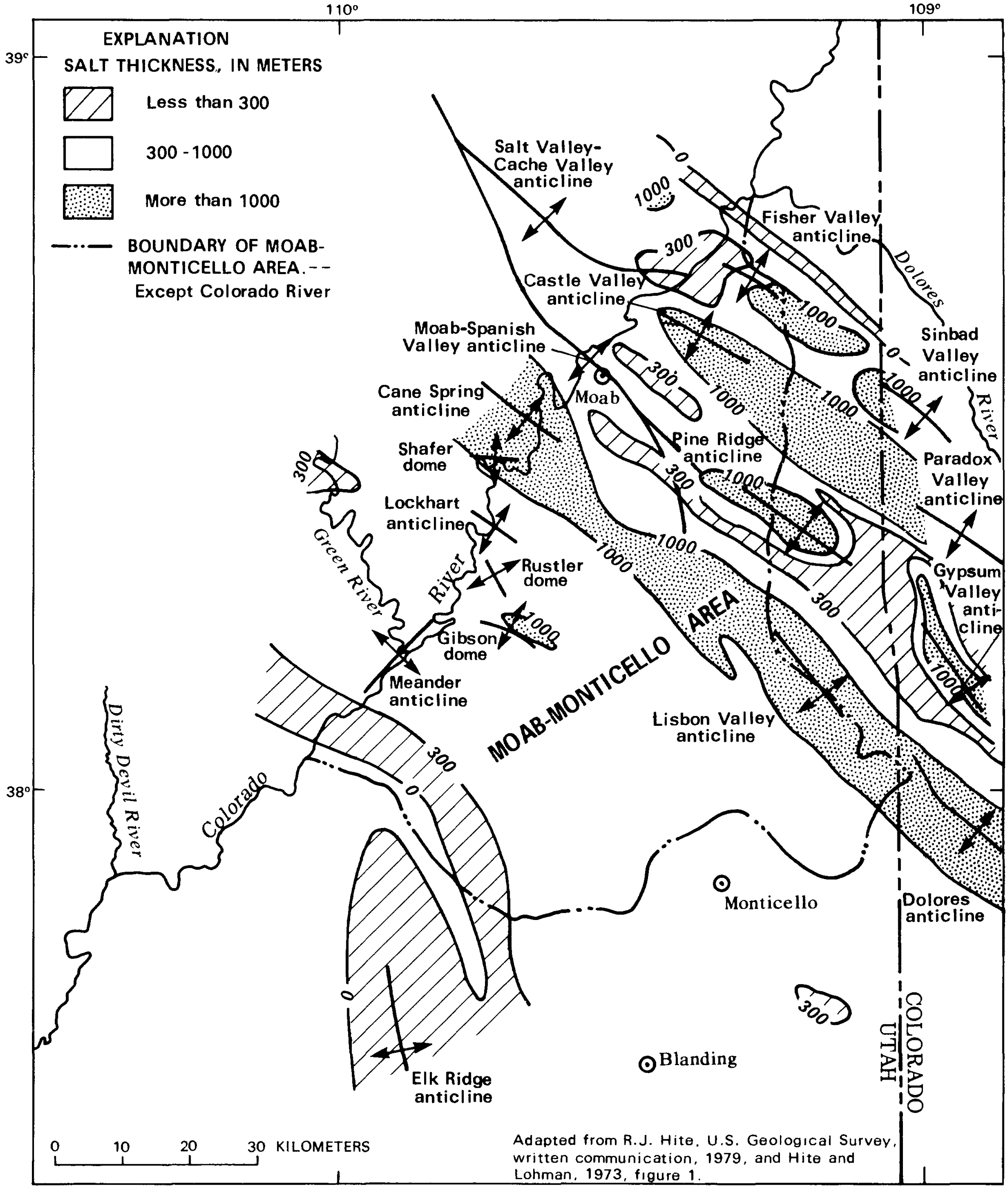


Figure 2.--Generalized salt thickness and major structural trends in and near the Moab-Monticello area.

McCracken Standstone Member of the Elbert Formation; and possibly the Lynch Dolomite (see table 1), all of Paleozoic age; none of these units crop out in the study area. The lower ground-water system receives its recharge in areas of outcrop outside the boundaries of the study area, mostly beyond the Paradox basin. The system probably is confined by the overlying Molas Formation and lower member of the Hermosa Formation, which are all effective confining units. Because of salt flowage, the Paradox Member is absent or thin in a few localities (pl. 1).

The table below lists the hydrogeologic units selected for reconnaissance evaluation in order of decreasing estimated hydraulic conductivity:

Hydrogeologic unit (Decreasing hydraulic conductivity ↓)	Lithologic characteristics
Lower Paleozoic aquifer	Fractured and dolomitized carbonates and buried karst zones.
Alluvial aquifer	Unconsolidated clastic deposits.
Mesozoic sandstone aquifer	Dominantly sandstone; includes some fine-grained strata.
Tertiary aquifer	Locally fractured intrusive rocks.
Mesozoic-upper Paleozoic confining beds.	Dominantly siltstone, shale, and mudstone.
Cretaceous confining beds	The Mancos Shale is thin to absent and not a very important confining unit in the study area.
Upper Paleozoic confining beds.	Mostly siltstone, shale, and anhydrite.
Lower Paleozoic and Proterozoic confining unit.	Mainly granite and quartzite of the basement complex.
Salt confining beds	Halitic deposits.

Ground-water flow is principally lateral. Such stratigraphic units as the Brushy Basin Member of the Morrison Formation, and the Summerville, Chinle, and Moenkopi Formations restrict vertical migration of fluids in the upper ground-water system, although these units might transmit some water where they underlie or are between more permeable units that are saturated. The Paradox Member and lower member of the Hermosa Formation and the Molas Formation comprise a very effective confining unit, restricting vertical migration of fluid between the upper and lower ground-water systems. Where the Paradox Member has not been thinned or removed by salt flowage, it is an extremely effective confining unit. Extensive faulting and fracturing occur in some areas of very thin salt. In these areas, minor vertical interchange of water could potentially occur between the two ground-water systems; however, no such interchange was identified during this study.

In some localities, ground water is withdrawn from shallow depths by phreatophytes before it reaches the main zone of saturation. Springs and a few wells discharge some of the ground water after it reaches the main zone of saturation. Except along the Colorado River, much of the water discharged by springs, phreatophytes, and wells probably comes from permeable beds overlying less permeable beds.

All permeable strata below river level near the Colorado River are saturated. The top of the saturated zone, an irregular surface, slopes upward away from the river (pl. 2). Some saturated beds would not yield water freely to a borehole because of the very small permeability of these units.

Precipitation

The Moab-Monticello area, according to Pyke (1972, fig. 3b) is in a transition-precipitation zone of multiple monthly maxima, between areas to the south, east, and west characterized by maximum precipitation in August, and secondary precipitation in February, May, and December.

Precipitation for the Moab-Monticello area was first measured and recorded at Moab during 1890. Abundant precipitation data collected since that time are summarized in several tables and illustrations in this section of the report.

Average annual precipitation at weather stations in and near the study area is summarized in table 4. Location of the stations is shown in figure 3. Because some of the periods of record for precipitation are short in relation to the records of Moab, La Sal, and Monticello, all short-period station averages were adjusted to the longer-term means (table 4). These values were plotted on a graph (fig. 4) to determine the general relation of precipitation to altitude in the area. As shown, average precipitation systematically increases with altitude from a minimum of about 200 mm/yr or less at an altitude of 1,120 m to more than 1,000 mm/yr at an altitude of 3,760 m, which are the approximate minimum and maximum altitudes for the study area.

Areal distribution of precipitation in the report area is shown in figure 3. Average annual precipitation on the mesas and flatlands ranges from about 200 to 250 mm. Average annual potential lake evaporation is estimated to be 1,050 to 1,200 mm (Kohler and others, 1959, pl. 2), or about 5 times greater than precipitation. Therefore, mesas and flatlands are arid to semiarid. In the higher areas of the La Sal and Abajo Mountains, precipitation is 750 mm/yr or more; the climate is subhumid to humid where the quantity of precipitation approximates potential evaporation.

The estimated volume of long-term average annual precipitation (table 5) is computed to be about 1.6×10^9 m^3, or equal to an average of about 200 mm throughout the study area. These estimates are based on the altitude-precipitation relations shown in figure 4, weighted for areal distribution (fig. 3).

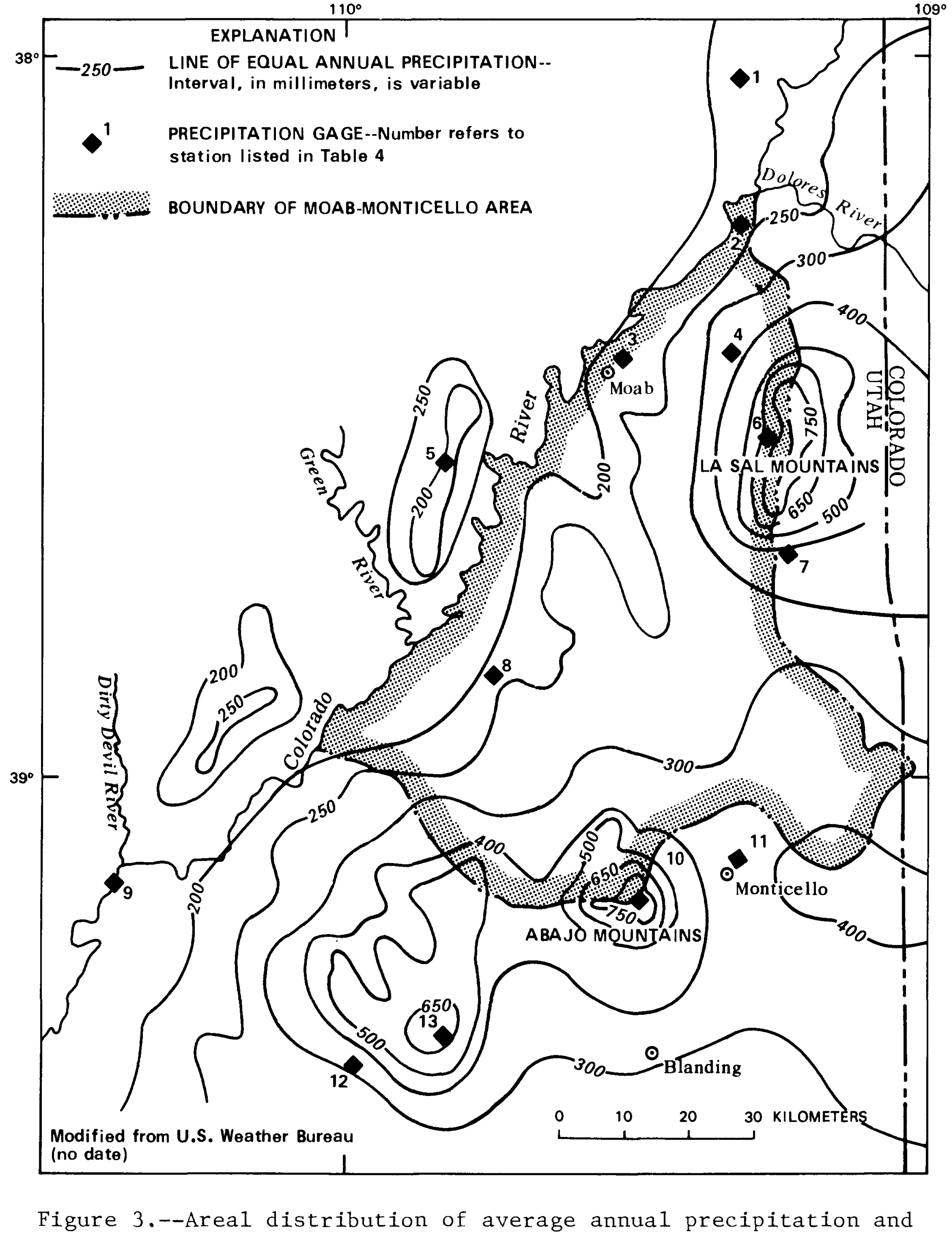


Figure 3.--Areal distribution of average annual precipitation and location of precipitation gages in and near the Moab-Monticello area.

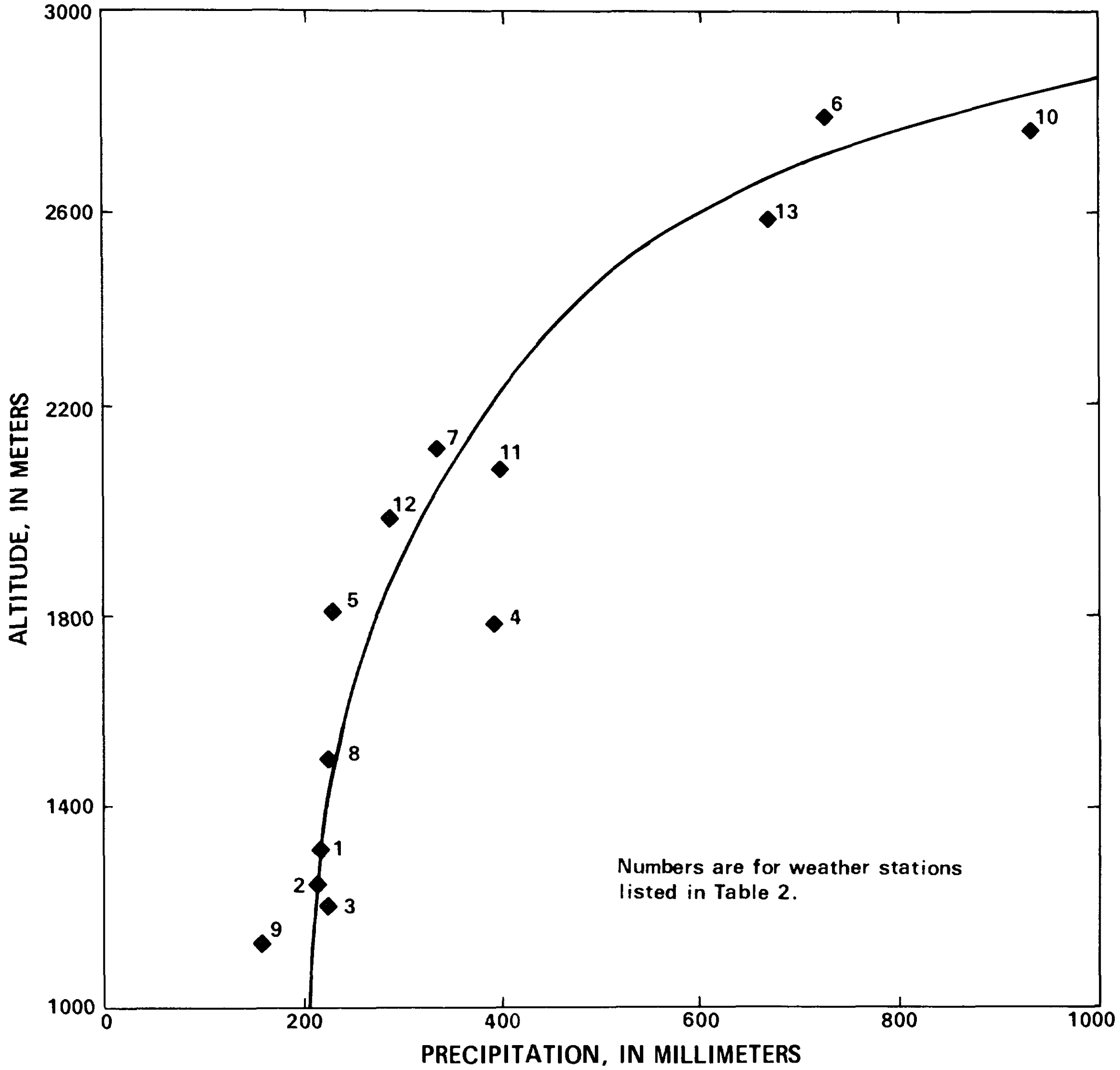


Figure 4.--Approximate relationship of precipitation to altitude.

Table 4.--*Average annual precipitation at weather stations in and near the Moab-Monticello area**

[Map No. is the number used to identify stations on figures 3 and 4; Adjustment to long term mean is based on cumulative departure at Moab (a), La Sal (b), and Monticello (c); m, meters; mm, millimeters]

Map No.	Station name	Altitude above sea level (m)	Period of record	Average annual precipitation	
				Average (mm)	Adjusted (mm)
1	Cisco	1,320	1953-66	188.5	a219
2	Dewey	1,256	1968-77	199.6	a216
3	Moab	1,209	1890-77	224.5	225
4	Castleton	1,780	1963-77	351.8	a393
5	Canyonlands-Neck	1,798	1966-77	206.8	a299
6	La Sal Mountain Upper	2,865	1959-74	709.2	b731
7	La Sal	2,128	1901-77	324.9	325
8	Canyonland-Needles	1,536	1966-77	204.7	b209
9	Hite Marina	1,125	1968-77	146.9	a159
10	Buckboard Flats	2,743	1968-74	837.6	c920
11	Monticello	2,079	1902-77	392.5	393
12	Natural Bridges National Monument.	1,981	1965-77	287.5	c306
13	Elk Ridge Kigalia	2,591	1968-76	601.9	c668

*Based on data from the National Weather Service, 1947-1974 and 1974-1977.

Table 5.--*Estimated long-term average annual precipitation and ground-water recharge to the upper ground-water system*

[m, meters; km^2, square kilometers; mm, millimeters; m^3, cubic meters; m^3/yr, cubic meters per year]

Altitude of precipitation Zone (from topographic maps) (m)	Area (km^2)	Estimated precipitation (based on figure 4)			Estimated recharge	
		Range (mm)	Median (m)	Average (10^6 m^3)	Percentage of precipitation	(10^6 m^3/yr)
>2,743	145	>800	0.9	130 }		
2,438-2,743	156	500-800	.65	100 }	25	60
2,134-2,743	568	350-500	.42	240	15	40
1,829-2,134	1,670	300-350	.32	530	7	40
1,524-1,829	1,480	230-300	.26	380	3	10
<1,524	865	<230	.2	170	Minor	Minor
Total (rounded)	4,900			1,600		150*

*Estimate considered a maximum value; see discussion in text.

Monthly distribution of precipitation for Moab and Monticello is shown in figure 5. Both stations have the same general distribution pattern: (1) A dry period from November through June and (2) a moister period from July through October.

To evaluate the long-term climatological character of the area, modern field observations are given in a long-term perspective; that relationship is shown in figures 6 and 7. Dry conditions prevailed during 1942-77 at Moab and Monticello; a series of moist and dry periods occurred prior to 1942 (fig. 6). Long-term climatic trends (fig. 7) can be identified from interpretations of tree-ring chronologies (Fritts, 1965). Beginning approximately 1200, no long-term systematic change in precipitation has been identified in the report area. Modern short-term variations in precipitation (fig. 6) appear typical of the short-term cycles occurring since 1200. Additionally, archeological study (Hunt, 1953) indicates a general trend toward a quantity of precipitation adequate to support human existence in the region as far back as 8000 B.C.

The following conclusions are made from the precipitation data: (1) Modern precipitation cycles probably are a continuation of the general trend with no long-term increases or decreases in overall climatic dryness; (2) moist and dry periods probably will occur in the future, similar to those recorded in the past, and (3) conditions under which this reconnaissance was made probably were dryer than normal.

Runoff

Runoff in the drainage network occurs in response to snowmelt from higher altitudes in the spring and early summer and also as a result of summer and autumn rainstorms, sometimes intense and usually limited in areal extent. Runoff in the perennial streams is augmented by base flow, or that part of streamflow resulting from ground-water discharge into the channels. Several tributaries of the Colorado River in the Moab-Monticello area are perennial (table 6), such as Pack and Mill Creeks (26-28/21-24). Some reaches of Onion, Professor, Castle, Indian, and Salt Creeks, and the Hatch Wash-Kane Springs Creeks system of drainage also are perennial (pl. 2).

Average annual runoff for the upper Colorado River region is 63.5 mm/yr (Price and Arnow, 1974, pl. 1); most of the Moab-Monticello area, about 4,250 km^2, has less runoff than the average (fig. 8). The total water yield occurring as runoff from the report area is estimated to be 265 x 10^6 m^3/yr, using a mean value of 53 mm/yr for that part of the area that is less than the regional average, and 182 mm/yr for the subhumid, high country that is greater than the regional average. The La Sal and Abajo Mountains yield 150 x 10^6 m^3/yr and the remaining part of the area yields 115 m^3/yr. Runoff is about 17 percent of total precipitation.

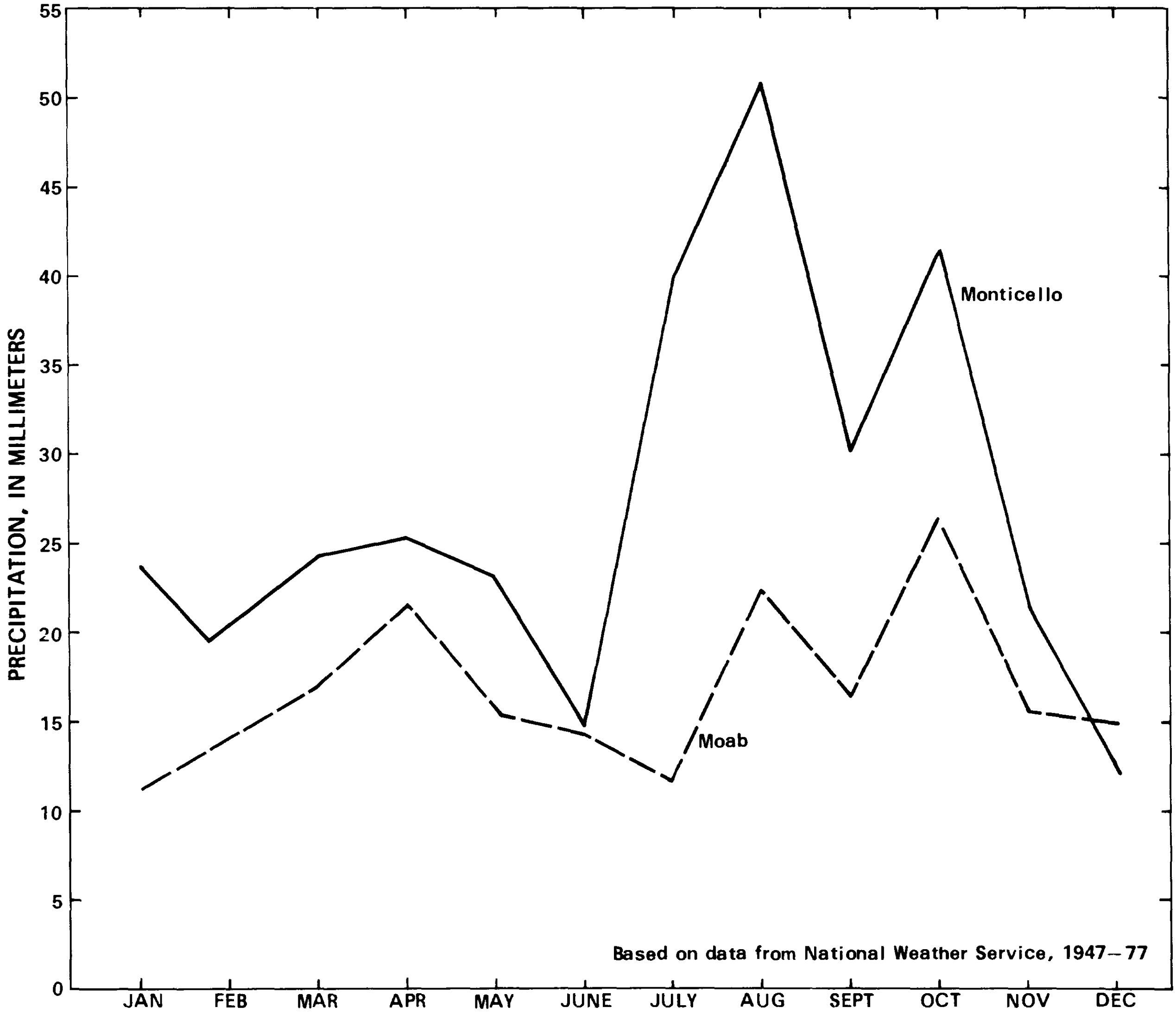


Figure 5.--Average monthly distribution of precipitation.

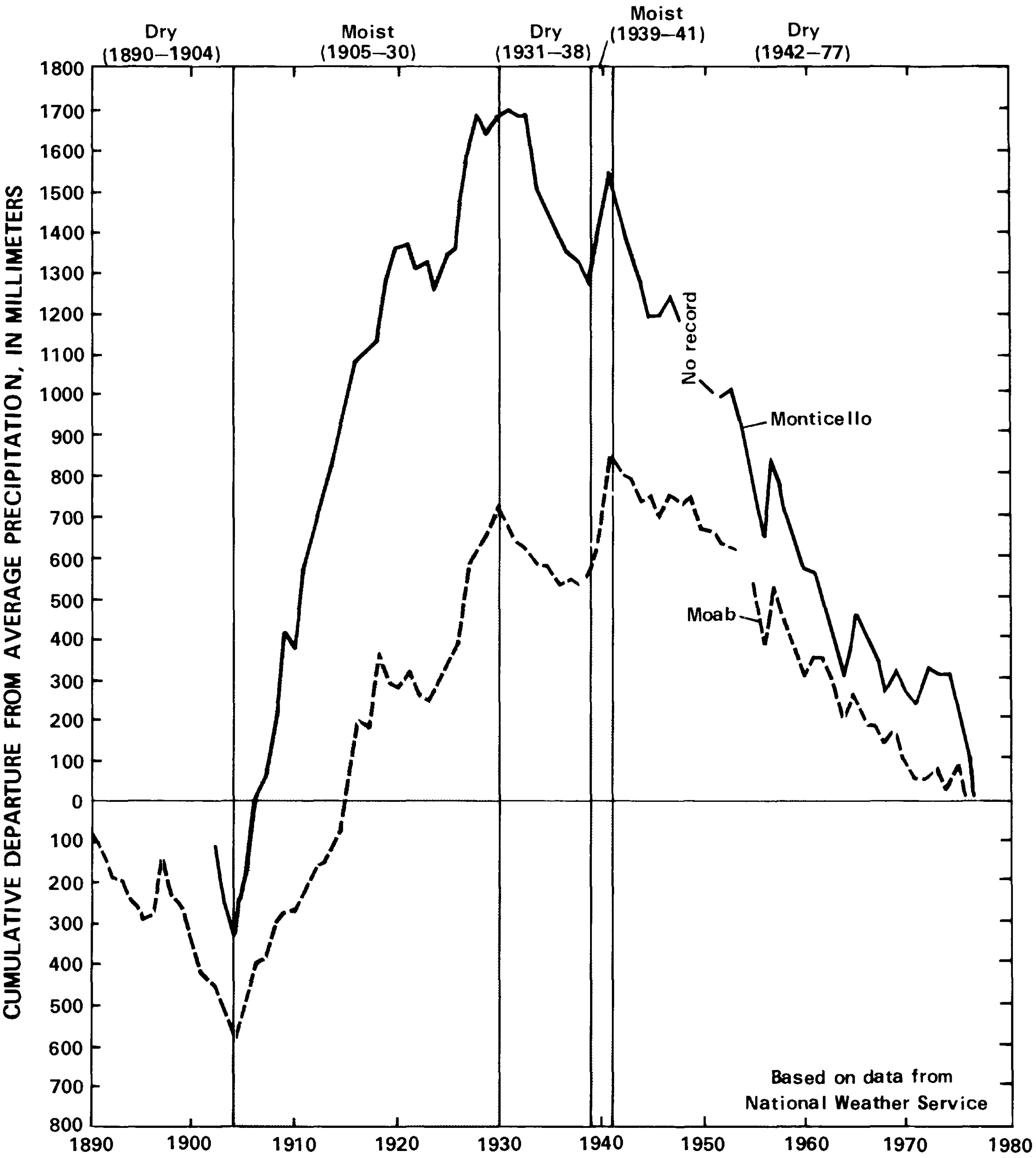
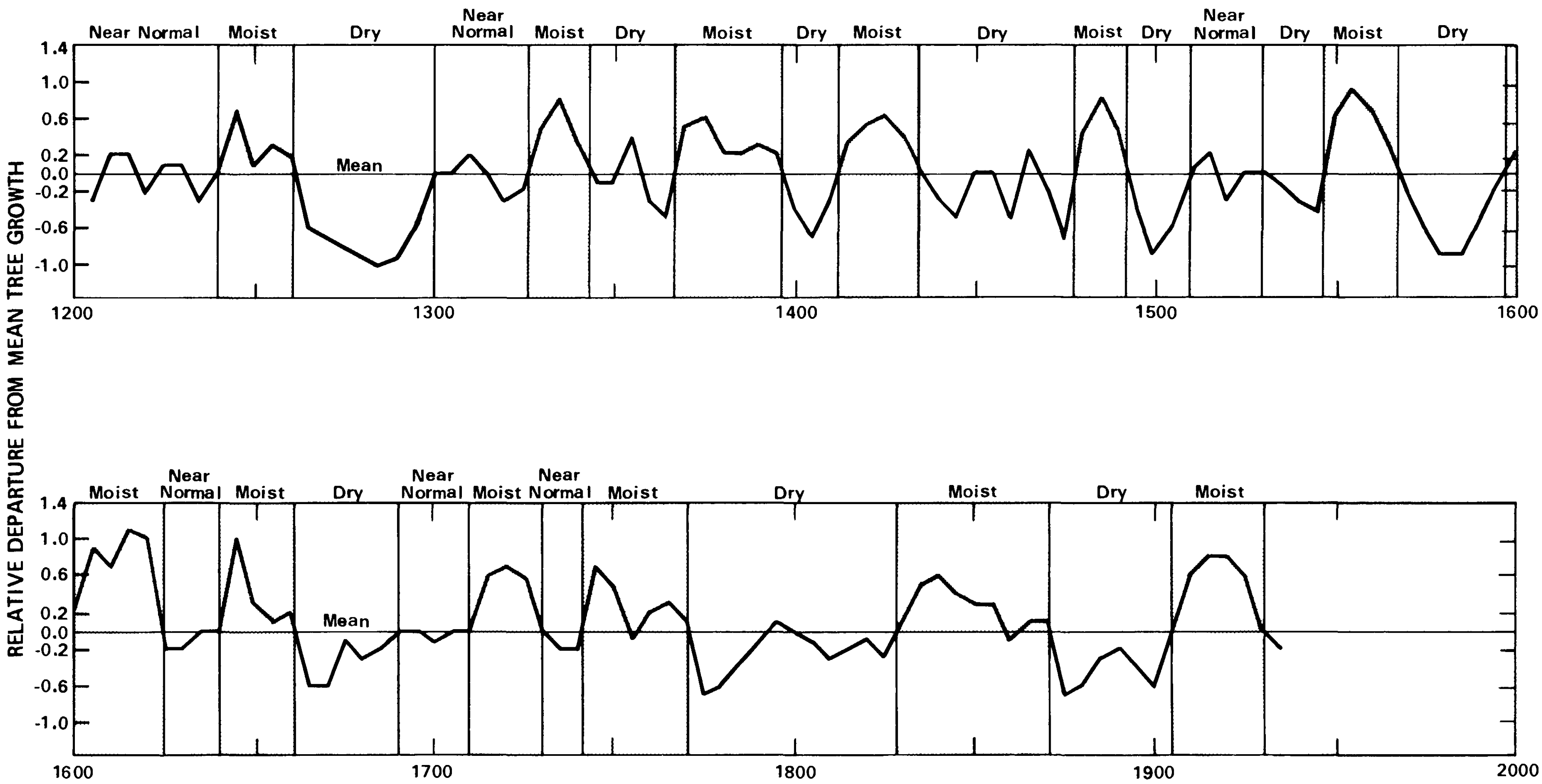


Figure 6.--Cumulative departure from average annual precipitation, based on measured precipitation at Moab and Monticello.



Mean and standard deviation are based on 270 years (1651-1920).

Based on data from Fritts, 1965.

Figure 7.--Long-term precipitation variation in the northwestern part of the Paradox basin, based on tree-ring chronologies.

Table 6.--*Hydrologic data from selected perennial streams*

[Discharge: (M), measured, all others are estimated; m^3/min, cubic meters per minute; °C, degrees Celsius; µS, microsiemens per centimeter at 25° Celsius]

Location	Name of location	Date determined	Discharge (m^3/min)	Temperature (°C)	Specific conductance (µS)
24/22-35aca	Castle Creek at White Ranch.	9-12-78	2.0	16.5	3,050
24/23-11cbd	Onion Creek	9-12-78	1.36 (M)	22	3,850
24/23-27abd	Professor Creek	9-15-78	4.25 (M)	25	480
24/23-35cbb	Professor Creek	9-15-78	4	24	420
24/24-21add	Onion Creek	9-14-78	1.53 (M)	15	2,800
24/24-22bcc	Onion Creek	9-14-78	1.5	15	1,300
24/24-26cca	Onion Creek	9-15-78	1.70 (M)	15	800
24/25-16dda	Professor Creek	9-12-78	1.36 (M)	20.5	3,340
25/22-1bda	Castle Creek Narrows.	9-16-78	17.40 (M)	16	3,100
25/23-6cbb	Castle Creek Entrance.	9-16-78	1.19 (M)	12.5	850
25/23-14dcc	Castle Creek Weir	9-16-78	2.80 (M)	20.5	835
25/24-33aab	Upper Castle Creek	9-16-78	2.5	10	220
25/25-6bb	Fisher Creek	9-14-78	1	17.5	240
28/23-22cc	Muleshoe Canyon	9-19-78	3	10	1,430
32/21-15bcb	North Cottonwood Creek.	9-22-78	2.5	21.5	602
32/22-21bdb	Indian Creek	9-22-78	2	9	545

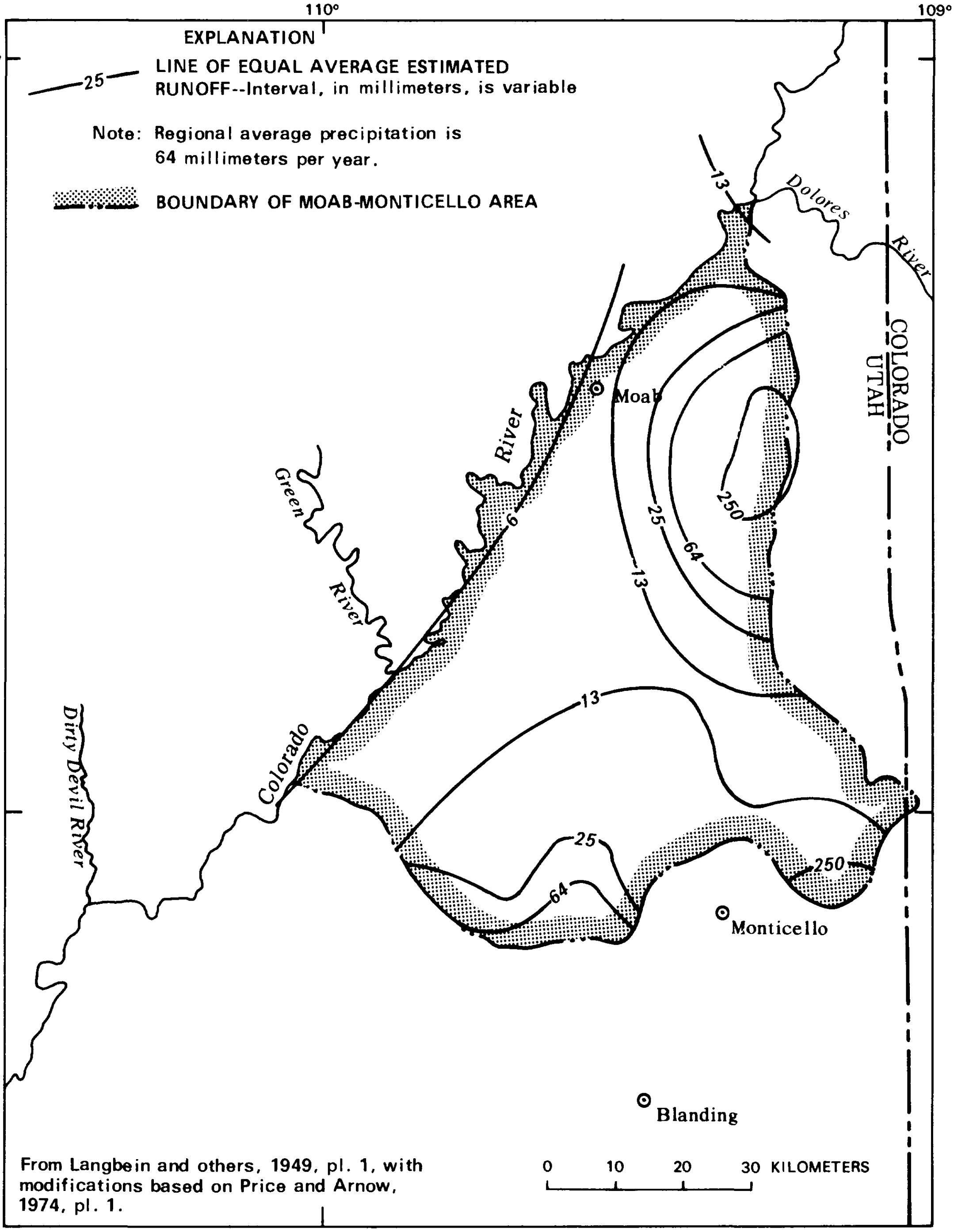


Figure 8.--Average annual runoff.

GROUND-WATER FLOW

Inflow to the Ground-Water Systems

Potential sources of inflow to the ground-water flow systems include recharge from precipitation, possible infiltration locally from the Colorado River, and subsurface inflow across the area boundary from adjoining areas. Evaporites generally prevent vertical flow between the upper and lower ground-water systems, as discussed previously. Therefore, probably the only inflow to the lower system is by lateral ground-water flow from beyond the study area boundary.

Recharge from Precipitation

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 value represented assumed average recharge from average annual precipitation on that zone. The degree of reliability of the estimate so obtained is related to the degree to which the values approximate actual precipitation, and the degree to which the assumed percentage represents actual percentage of recharge. Neither of these factors is known precisely enough to assume a significant degree of reliability for any area. However, this method has proved useful for reconnaissance estimates, and experience in using the method throughout Nevada and the desert areas of western Utah indicates that in many areas in these desert regions, estimates probably are near the actual long-term average annual recharge.

Recharge from precipitation probably is greatest near the La Sal and Abajo Mountains, where precipitation quantities are relatively large and along both ephemeral and perennial channels, where deep infiltration is most likely. Maximum annual recharge to the upper ground-water system from precipitation is estimated to be 150×10^6 m^3 (table 5). This is about 9 percent of estimated average annual precipitation. This numerical recharge-precipitation ratio is large compared to the Colorado River basin average of 4 percent (Price and Arnow, 1974, p. 69), but not greatly inconsistent with similar areas of Nevada and western Utah.

Possible Recharge from the Colorado River

Potentiometric contours (pl. 2) show that water moves in the upper ground-water system toward the Colorado River, indicating that no net recharge occurs from the river. The river generally is a gaining stream (Rush and others, 1982) throughout the reach bounding the Moab-Monticello area. By hydrologic inference, it similarly is evident that the river does not recharge the lower ground-water system.

Subsurface Inflow

Potentiometric contours for equivalent freshwater heads (fig. 9) indicate that ground water flows into the lower ground-water system from adjacent areas. Inflow is primarily from the north, southeast, and east. The main movement of water through the lower ground-water system is lateral beneath and adjacent to the Paradox basin.

Potentiometric contours (pl. 2) for the upper ground-water system indicate little if any subsurface inflow from adjacent areas. The southeastern part of the Moab-Monticello area might receive minor inflow from adjacent areas, but data are extremely sparse in this part of the study area. Similarly, in all boundary areas where control is lacking, no definite interpretation as to minor inflow is possible.

Outflow from the Ground-Water Systems

The various elements of ground-water outflow include evapotranspiration, springflow, discharge to the Colorado River, subsurface outflow, and discharge by wells. Significant subsurface outflow is likely only for the lower ground-water system.

Evapotranspiration

Shallow ground water is discharged by transpiration by phreatophytes and evaporation from soil. Shallow ground water occurs beneath the flood plain of the Colorado River and beneath the principal perennial and ephemeral stream channels (pl. 1).

The area covered by phreatophytes is estimated to be about 60 km^2, of which about 2 km^2 is river flood plain. In general, the shallower depth-to-water areas, mainly along the Colorado River, have stands of saltcedar, cottonwood, willow, and saltgrass. Areas with a greater depth-to-water (as much as 15 m) support greasewood, saltbush, and rabbitbrush.

The total average annual discharge by phreatophytes probably is about 42×10^6 m^3. This total is based on an estimated average annual rate of about 1 m/yr for saltcedar, cottonwood, and willow, and about 0.1 m/yr for greasewood saltbush, rabbitbrush, and saltgrass. These unit quantities of evapotranspirative losses were chosen from research done by Lee (1912), White (1932), Young and Blaney (1942), Houston (1950), Robinson (1965), and Harr and Price (1972) in other areas. About 40 km^2 in the Moab-Monticello area are covered by saltcedar and other trees, including cropland, and 20 km^2 by bushes and saltgrass.

Sumsion (1971, p. 24) estimated evapotranspiration from an area of 9 km^2 in Spanish Valley, in the central northwestern part of the Moab-Monticello area, to be 6×10^6 m^3/yr. Our estimate of the area in Spanish Valley where

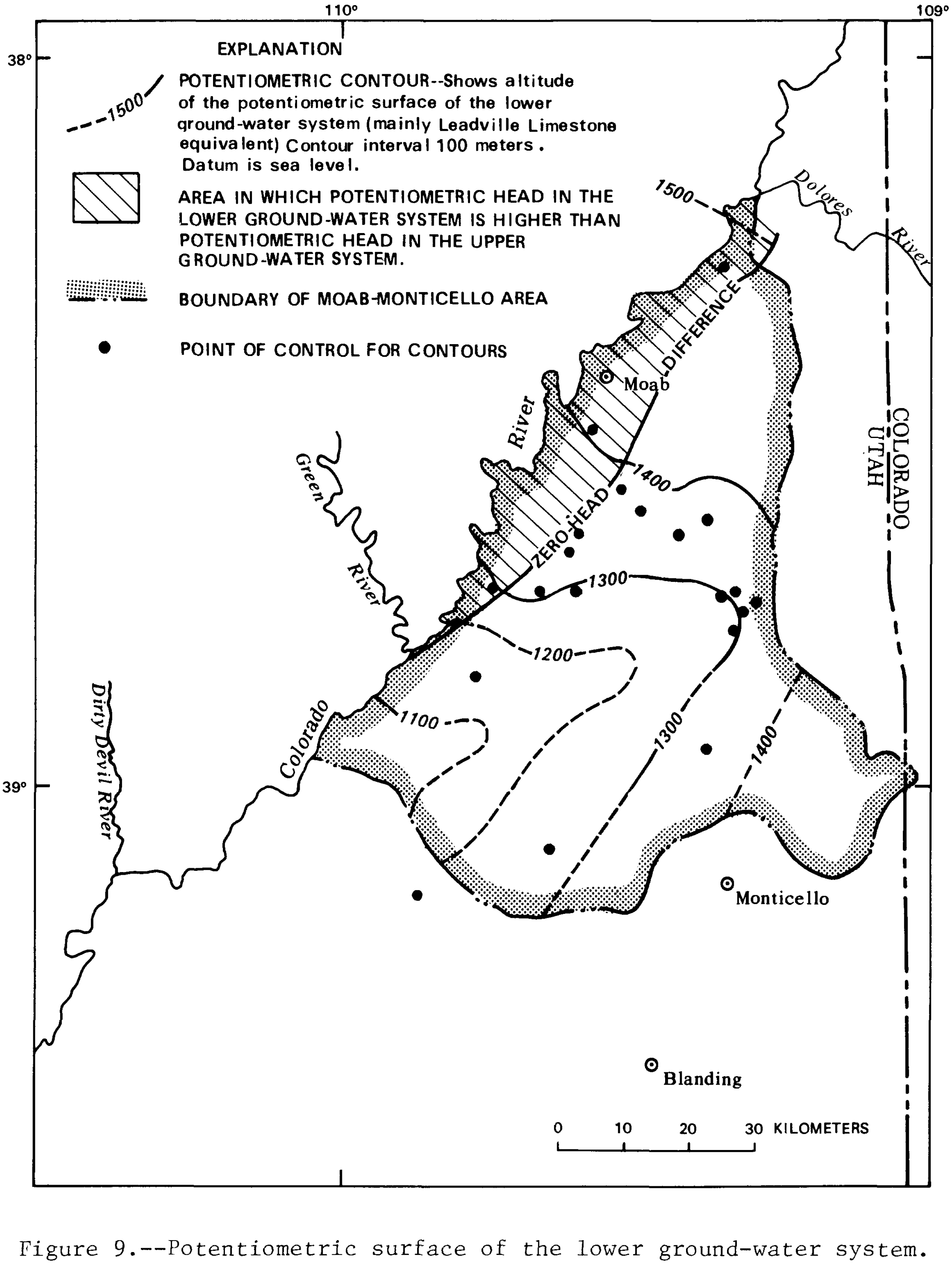


Figure 9.--Potentiometric surface of the lower ground-water system.

phreatophytes grow is 20 km^2, or more than twice that estimated by Sumsion; our estimate of the quantity of water evapotranspired in Spanish Valley is 16 x 10^6 m^3/yr, almost three times the quantity estimated by Sumsion. Major differences lie in the mapped areas that have phreatophytes. Sumsion did not identify considerable areas of phreatophyte growth in tributary canyons of the valley, and our estimate probably is more representative of actual evapotranspirational losses in the Spanish Valley area.

Springflow

Known springs in the Moab-Monticello area number at least 90, as determined from a count of those springs on the 15-minute topographic quadrangle maps, plus a few additional springs located during the reconnaissance. The actual number of springs, both perennial and ephemeral, probably is much greater, as many are small ephemeral springs in remote areas; some of the ephemeral springs may not have been detected during the mapping or were unreported. Data were obtained from 66 springs within or adjacent to the area (table 7). The number of perennial springs in the area is estimated to be about 55. Spring discharge in the area is considerably greater than in the Green River-Moab area (Rush and others, 1982) to the northwest. Most springs have only small discharges and occur high on the flanks of the La Sal and Abajo Mountains. The estimated total spring discharge for the area is about 9,000 L/min, or about 5 x 10^6 m^3/yr. Most of the springs have a source in perched water bodies.

Many of the springs occur along canyon walls at formation contacts, usually where more permeable rocks overlie beds with little permeability. Fractures in the more competent sandstone units are a major control for the point of discharge from the units. Discharges of recorded springs (table 7) range from a seep to 1,261 L/min; most are less than 50 L/min. Many springs that flow in the spring and early summer cease flowing by late July or August. This condition is especially true for many of the springs at lower altitudes in the southwest part of the area.

Many springs discharge from the Dakota Sandstone and Burro Canyon Formation. These are at higher altitudes along the flanks of the La Sal and Abajo Mountains and, for the most part, are perennial springs with an average discharge of about 70 L/min and a probably large variation in flow during the year. The quality of water generally is suitable for most uses, with an average specific conductance of 534 μS. These high-altitude springs discharge from more permeable beds overlying less-permeable beds. The underlying stratigraphic units are the Brushy Basin Member of the Morrison Formation, composed mostly of bentonitic mudstone and siltstone, and the Summerville Formation composed of sandstone, shale, and mudstone. These strata are relatively impervious and plastic; even where they have been extensively fractured, they retard water flow because the fractures have been resealed by plastic flowage.

Table 7.--*Hydrologic data from selected springs in and near the Moab-Monticello area*

[Stratigraphic units: J̄Kn, Navajo Sandstone; Pc, Cutler Formation; Qal, Quaternary Alluvium; K̄w, Wingate Sandstone; K̄K, Kayenta Formation; Kb, Burro Canyon Formation; Je, Entrada Sandstone; Pccm, Cedar Mesa Sandstone Member of the Cutler Formation; Kd, Dakota Sandstone; K̄c, Chinle Formation; L/min, liters per minute; °C, degrees Celsius; μS, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter]

Spring number	Location	Location or name	Date	Strati-graphic unit	Discharge[1/] (L/min)	Temper-ature (°C)	Specific conduc-tance (μS)	Dissolved-solids concentration (mg/L)	Remarks
1	23/24-16cbc	Waring Canyon	09-14-78	J̄Kn	---	---	---	---	No visable flow, dense willow growth.
2	23/24-27cca	Cowskin Spring	09-14-78	J̄Kn	---	---	---	---	No flow, vegetative growth.
3	24/24-21cca	Stinking Spring	09-12-78	Pc	0.8	25	150,000	---	Flow from fractures near collapsed area.
4	24/24-26cbb	Onion Creek	09-15-78	Qal	---	---	---	---	Wide zone of seepage.
5	24/24-26acb	Onion Creek	09-15-78	Qal	11	13.5	1,360	---	Near base of Qal.
6	24/24-27bac	Onion Creek	09-15-78	Qal	700	14	1,020	---	-----
7	24/24-27baa	Onion Creek	09-15-78	Qal	300	11	1,500	---	-----
8	24/25-20ada	Cottonwood Canyon	09-14-78	J̄Kn	---	---	---	---	No flow, moist ground.
9	24/25-32cdb	Hideout Canyon	09-14-78	J̄Kn	2	14	810	---	-----
10	[2/]25/21-26bdd	Matrimony Spring	10-09-58	K̄w	18.9 M	16.7	---	186	-----
11	[3/]25/21-35aaa	Skakel Spring (D. Parriot).	10-19-67	K̄w	900	14	---	168	-----
12	[2/]25/21-36dcc	M. R. Fish	10-27-33	K̄w	5.7 M	---	---	202	Spring developed by 35-meter-long tunnel dug into sandstone.
13	25/22-1acb	Lower Homestead	09-16-78	Qal	300	14.5	1,530	---	-----
14	25/22-1acc	Upper Homestead	09-16-78	Qal	200	16	2,520	---	-----
15	25/22-1acd	South Homestead	09-16-78	Qal	19	15	3,400	---	-----
16	25/23-6add	Castle Creek Spring	09-16-78	Qal	8	16	501	---	-----
17	25/23-7aac	McGinty Spring	09-16-78	Qal	1,135 M	18	2,000	---	-----
18	25/23-25ada	Castleton Site	09-16-78	Qal	11	13.5	700	---	-----
19	26/21-27cbc	Hunter's Canyon	09-13-78	K̄K	25	17	490	---	-----
20	[3/]26/22-7cca	Jackson Reservoir	03-07-68	K̄w	90.1 M	16	---	117	-----
21	[3/]26/22-14acc	Deep Cut Spring	11-19-68	J̄Kn	340 M	16	---	171	-----
22	[3/]26/22-15cbb	Birch Spring	10-19-67	K̄w	340.2 M	14	---	172	-----
23	[3/]26/22-15abc	Moab Spring 1	03- -69	J̄Kn	189.1 M	14	---	---	-----
24	[3/]26/22-22aaa	Moab Spring 2	03- -69	J̄Kn	1,136 M	14	---	---	-----
25	[3/]26/22-22aaa1	Moab Spring 3	03- -69	J̄Kn	1,261 M	14	---	---	-----
26	[3/]26/23-3ccc	Sand Pot Spring	11- -68	J̄Kn	45	16	---	---	-----
27	[3/]26/24-28aba	Warner Lake Spring	07-08-69	Kb	755	7	---	101	-----
28	27/21-20cbb	Dripping Spring	06-06-79	Qal	8	26	1,920	---	Perched water table of Qal in Cutler Formation.
29	27/21-26dbc	Trough Spring	06-05-79	K̄w	30	24	590	---	Several springs grouped to form one discharging to the stream.
30	[3/]27/23-24dcc	Pack Creek Spring	04-30-68	Qal	755	13	---	995	-----
31	[3/]27/23-30bbc	Barber Spring	04-30-68	Qal	115	14	---	1,040	-----
32	28/20-27aab	Lockhart Spring	06-07-79	Pc	10	20	6,500	---	Several fractures in Cutler Formation.
33	28/22-1ca	Kane Springs	09-19-78	Je	75	16	660	---	Several springs in Slick Rock Member.
34	28/23-3aa	Yellow Circle Mine	09-20-78	Kb	1	9	630	---	-----
35	28/23-23dcc	Brown Hole #1	09-19-78	Kb	40	12.5	540	---	-----
36	28/23-23ddb	Brown Hole #2	09-19-78	Kb	8	14	490	---	-----

Table 7.--*Hydrologic data from selected springs in and near the Moab-Monticello area*--Continued

Spring number	Location	Location or name	Date	Strati-graphic unit	Discharge[1/] (L/min)	Temper-ature (°C)	Specific conduc-tance (µS)	Dissolved-solids concentration (mg/L)	Remarks
37	28/23-23acc	Cottonwood Canyon	09-19-78	Kb	10	18	675	---	-----
38	28/23-25bbd	Buck Hollow	09-19-78	Kb	75	14	610	---	-----
39	28/23-36dba	West Coyote Creek	09-19-78	Kb	20	13.5	830	---	-----
40	29/23-31dbc	Joe Wilson Canyon	06-06-79	JK̄n	3	23	1,100	---	-----
41	29½/22-31cbd	Hart's Draw	06-07-79	K̄w	---	21	2,500	---	No flow, small brackish seep.
42	30/19-25cdc	Squaw Spring	06-08-79	Pccm	---	---	---	---	May not flow, possibly due to pumping from wells drilled upgradient.
43	30/19-27cdc	Soda Spring	06-08-79	Pccm	---	---	---	---	Do.
44	30/19-28acd	Elephant Canyon	06-08-79	Pccm	---	---	---	---	Do.
45	30/19-30aca	Cyclone Canyon	06-08-79	Pccm	---	---	---	---	Do.
46	30/20-20cdd	Cave Spring	06-08-79	Pccm	---	---	---	---	Do.
47	31/20-6ada	Peekaboo Spring	06-08-79	Pccm	2	16	745	---	-----
48	31/22-1dad	Hart's Spring Draw	06-07-79	JKn	---	---	---	---	No flow, small brackish pond.
49	31/23-31aaa	The Seeps	06-07-79	JK̄n	---	---	---	---	New well drilled just upgradient from seep area.
50	32/18-32da	Homewater Spring	08-07-79	Pccm	4	15.5	670	---	Located just outside the study area.
51	32/18-36aaa	Stanley Spring	08-07-79	Pccm	3	20.5	730	---	Do.
52	32/18-36cd	Calf Wash Springs	08-07-79	Pccm	40	---	---	---	Do.
53	[2/] 32/23-24ccc	Peters Spring	10-28-33	Kb	---	---	---	324	-----
54	33/18-24acc	Sweet Alice Spring	08-08-79	Pccm	9.5 M	11.5	720	---	Located just outside the study area. Discharge from near top of the Cedar Mesa Sandstone Member.
55	33/18-27abd	Crystal Spring	08-08-79	K̄c	11.4 M	8.5	480	---	Located just outside study area.
56	33/21-17bbb	North Cottonwood	09-22-79	K̄c	6	14.5	1,310	---	-----
57	33/21-17bcd	North Cottonwood	09-22-79	K̄c	1	12.5	1,265	---	-----
58	33/22-2dad	Jackson Spring	09-21-78	Kd	8	8	340	---	-----
59	33/22-11abb	Upper Jackson Spring	09-21-79	Kd	8	7	540	---	-----
60	33/22-20bba	Indian Creek	09-21-78	Kd	6	9.5	360	---	-----
61	33/22-22baa	Hart's Draw Reservoir Spring.	09-21-78	Kd	4	7.5	560	---	-----
62	[4/] 33/22-23dac	Spring Creek Lake	09-20-78	Kd	10	9.5	295	---	-----
63	[4/] 33/22-25add	Taylor Spring Point	09-20-78	K̄c	20 M	15	---	120	-----
64	[4/] 33/22-25cca	Lower Taylor Spring	09-20-78	K̄c	20 M	5.8	---	120	-----
65	[4/] 33/23-30dca	Dalton Spring	09-20-78	Kd	20 M	16.7	---	137	-----
66	[4/] 33/23-30dda	Dalton Spring	09-20-78	Kd	20 M	6	---	120	-----

[1/] All discharges are estimated except those marked M, measured.

[2/] Information from Feltis, 1966, table 3.

[3/] Information from Sumsion, 1971, table 10.

[4/] Information from U.S. Forest Service, unpublished reports, Monticello field office.

Springs also discharge from the Entrada, Navajo, and Wingate Sandstones, and Cedar Mesa Sandstone Member (table 7). A substantial number of these springs are intermittent. The main recharge areas for these formations are at lower altitudes than the Dakota Sandstone and Burro Canyon Formation, and they occur in areas of less precipitation. The Dewey Bridge Member of the Entrada Sandstone (Carmel Formation in older reports) is a very fine-grained sandstone and siltstone that has negligible permeability, enabling bodies of perched water to form in the upper units of the Entrada Sandstone.

The Kayenta Formation consists of lenticular channel sandstones and floodplain deposits of siltstone and mudstone. Besides the one spring in the Kayenta area, at least one more spring is just outside the area (26/20-24abb). Because the Kayenta Formation transmits fluids (largely where it is fractured), the Navajo Sandstone above it and the Wingate Sandstone below it are hydraulically connected, at least to a limited extent where fractures have remained open. The Chinle and Moenkopi Formations, below the Wingate Sandstone, are composed of siltstone and mudstone, and therefore are efficient confining beds. The Cedar Mesa Sandstone Member of the Cutler Formation is extensively exposed in the southern part of the area. Where the exposures are high on the flanks of the Abajo Mountains and along northern Elk Ridge (southwest of the report area), the springs issuing from the Cedar Mesa are perennial; where the exposures are at lower altitudes, north and west in The Needles area (31/19), the springs are ephemeral.

In Fisher and Castle Valleys, several springs discharge from the alluvium. Both valleys are underlain by extensive alluvial fill. Recharge probably is derived mostly from perennial stream runoff at the eastern end of the valleys; springs have developed at the western ends of these valleys. The recharge from perennial streams is supplemented by local infiltration of precipitation. Spanish Valley also is extensively alluviated. There, the alluvium receives recharge mainly from inflow via bedrock along the sides of the valleys. Recharge is greater in the southeastern part of Spanish Valley because of greater abundance of rainfall and runoff. The outflow to the river from alluvium in Spanish Valley was estimated to be approximately 10×10^6 m^3/yr (Sumsion, 1971, p. 24).

Generally, springs discharging from younger rocks occur in the eastern and southeastern parts of the study area, along the La Sal and Abajo Mountains; those springs issuing from older rocks are farther southwest and reflect the distribution of the exposed formations (pl. 1).

Discharge to the Colorado River

An analysis was made of ground-water inflow to the Colorado River (Rush and others, 1982, p. 54 to 66), as part of the reconnaissance investigation of the Green River-Moab area, which borders the Moab-Monticello area on the northwest. Applicable parts of that analysis are presented here.

Rush and others (1982) concluded that ground-water discharges from the upper ground-water system into the Colorado River. This conclusion was based on: (1) Surface-water data for the Colorado River and its tributaries in 1948; (2) surface-water data for the river and its principal tributaries from September 1949 through 1958; and (3) potentiometric contours for the upper ground-water system for that area (pl. 2). Separate discussions follow for each of the three sets of data, insofar as they apply to the inflow of water from the eastern side of the river.

During 1946 through 1948, three reconnaissance trips by the U.S. Geological Survey were made by boat down the Utah reach of the Colorado River to determine flow of the river at numerous sites not included in the U.S. Geological Survey gaging-station network (Thomas, 1952, p. 2). The trips were made in September and October, when flows were expected to be at or near minimum for the year. However, in 1946 and 1947, at Lees Ferry, Arizona, and Hite, Utah, both downstream from the study reach, flows during the reconnaissance periods were 1.4 to 2.0 times as large as those measured during the reconnaissance in 1948. Because small contributions of ground water to river flow are detected more precisely during minimum flows, the 1946 and 1947 data are not used. The 1948 data were considered by Thomas (1952, p. 2 and 4) to be especially favorable for estimating ground-water gains and losses, because the flow of the river was lower than at any time since 1940, and very little storm runoff occurred during or immediately preceding the reconnaissance.

Ground-water inflow data for several reaches of the Colorado River are presented in tables 8, 9, and 10; these results are summarized in figure 10. Ground-water inflow to the Colorado River upstream from the mouth of the Green River is about 90 L/s per kilometer of aquifer length. The area southeast of this reach of the river contains the La Sal Mountains, which receive more than 700 mm of precipitation annually (fig. 3); as a result, they produce much more runoff and ground-water discharge than the tributary area northwest of the same river reach. Estimated ground-water discharge from the upper ground-water system to the river was determined for the study area by multiplying the discharge estimate of the segments by the aquifer lengths. The Colorado River crosses about 112 km of aquifer; estimated inflow to the river from the study area is therefore about 0.8×10^4 L/s. Annual inflow rates were determined from transmissivity, which was constant, and hydraulic gradient, which, over such a large area, was assumed to be almost constant; therefore, the estimated average annual discharge to the Colorado River is about 250×10^6 m^3. Southwest of the study area and the Paradox basin, estimated ground-water discharge to the river per kilometer of aquifer is about 40 L/s, based on estimates for that reach.

Streamflow data and computations of river gain downstream from the Cisco gage to Hite for each September from 1949 through 1958 are presented in table 11. Gains in flow are recorded for 8 of the 10 years; on the average, a total computed gain to the river from ground-water sources is about 10,000 L/s, or about 40 L/s per kilometer of aquifer length.

Table 8.--*Estimated ground-water inflow to the Colorado River between Cisco, Utah, and the mouth of the Green River, September 28-29, 1948*

[Based mostly on unpublished data by H. W. Chase, U.S. Geological Survey, Salt Lake City, Utah]

Inflow	Cubic meters per second
River at Cisco gage (September 28)	67.1
Tributaries	1/ .3
Total (1)	67.4
Outflow	
River upstream from mouth of Green River (September 29)	74.5
Evapotranspiration	2/ 1.4
Total (2)	75.9
Ground-water inflow [(2)-(1)]	8.5
River gain per kilometer of aquifer (rounded)	3/ 90 liters per second

1/ Included flow in Onion, Rock, Castle, Negro Bill, Mill, and Indian Creeks, Salt Wash, Lockhart Canyon, and a spring.

2/ Based on evapotranspiration rate of 5 millimeters per day, water-surface area of 20 square kilometers, and vegetated flood plain of 3.8 square kilometers.

3/ Based on an aquifer distance of 90 kilometers.

Table 9.--*Estimated ground-water inflow to the Colorado River between the mouth of the Green River and Hite, Utah, September 29-October 4, 1948*

[Based on unpublished data by H. W. Chase, U.S. Geological Survey, Salt Lake City, Utah]

Inflow	Cubic meters per second
Colorado River	74.5
Green River	26.8
Tributaries	.9
Total (1)	102.2
Outflow	
Colorado River	104.5
Evapotranspiration	[1]/.4
Total (2)	104.9
Ground-water inflow [(2)-(1)]	2.7
River gain per kilometer of aquifer (rounded)	[2]/40 liters per second

[1]/Based on an estimated evapotranspiration rate of 5 millimeters per day, water-surface area of 6.5 square kilometers, and vegetated flood plain of 0.67 square kilometer.

[2]/Based on an aquifer distance of 70 kilometers.

Table 10.--*Estimated ground-water inflow to the Colorado River between Hite, Utah, and Lees Ferry, Arizona, October 4-7, 1948*

[Based mostly on unpublished data by H. W. Chase, U.S. Geological Survey, Salt Lake City, Utah; data predated Lake Powell]

Inflow		Cubic meters per second
Colorado River		104.5
Tributaries		26.7
Total (1)		131.2
Outflow		
Colorado River		133.9
Evapotranspiration		1/ 2.7
Total (2)		136.6
Ground-water inflow	[(2)-(1)]	5.4
River gain per kilometer of aquifer (rounded)		2/ 40 liters per second

1/ Based on an estimated evapotranspiration rate of 5 millimeters per day, water-surface area of 39 square kilometers, and vegetated flood plain of 6.2 square kilometers.

2/ Based on an aquifer distance of 150 kilometers.

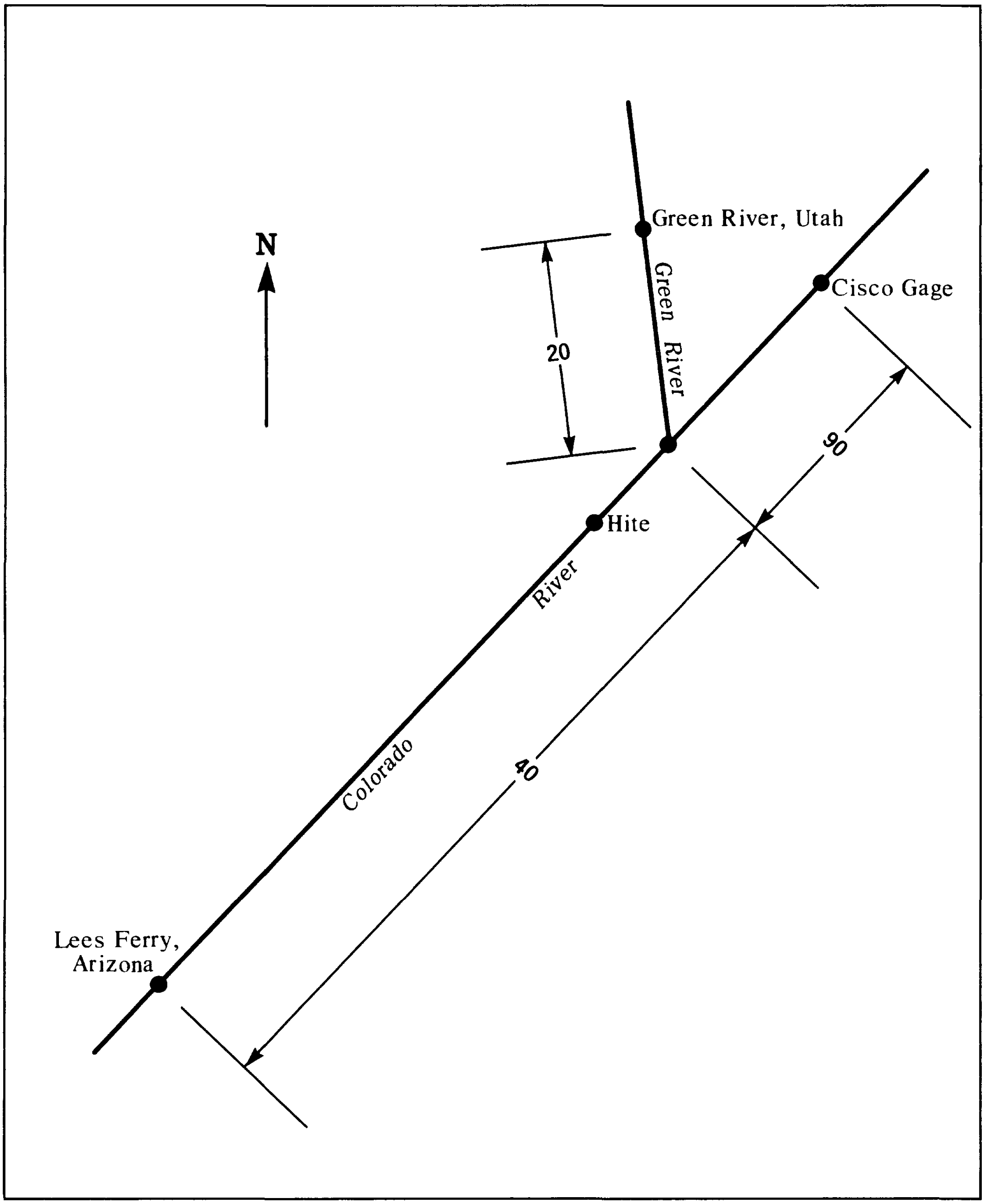


Figure 10.--Summary diagram of estimated ground-water inflow to the Colorado and Green Rivers (in liters per second per kilometer of underlying aquifer. Adapted from Rush and others, 1982).

Table 11.--*Computation of streamflow gains or losses in the Paradox basin for each September, 1949 through 1958*

[Flow rate in cubic meters per second, based on U.S. Geological Survey records]

Stream	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	Average
Colorado River near Cisco.	75.4	65.5	62.1	102	60.8	81.5	51.3	38.8	149	72.9	75.9
Onion Creek	---	.028	.009	.013	.016	.043	.009	---	---	---	.020
Professor Creek	---	---	.017	.006	.013	---	---	---	---	---	.012
Castle Creek	---	---	.063	.069	.020	1/ .18	.038	---	.029	.13	.076
Courthouse Wash	---	.30	.003	.008	.002	.090	.004	---	.003	---	.059
Mill Creek	---	.28	.22	.40	.28	.35	.22	.18	.38	.46	.308
Pack Creek	---	---	---	---	---	---	.051	.044	.074	.053	.056
Indian Creek	---	.041	.003	.030	.010	.25	.001	.001	.030	---	.046
Green River at Green River, Utah.	53.0	70.9	84.6	87.7	41.6	63.8	33.6	34.5	96.0	45.6	61.1
Saleratus Wash	.15	.017	.043	.060	.012	.54	.001	---	---	.040	.108
Browns Wash	---	0	0	.028	0	.087	.001	0	.010	.029	.017
San Rafael River	1.21	.49	.56	2.3	.73	1.8	.021	.003	2.0	2.0	1.11
Dirty Devil River.	2.25	1.4	.93	6.2	.78	2.9	.25	.11	2.3	2.0	1.91
North Wash	---	---	.002	.007	0	.043	0	0	.001	.013	.008
White Canyon	---	---	0	.11	0	.39	0	0	.012	.13	.080
Total (1) (rounded)	132.0	139.0	148.6	198.9	104.3	152.0	85.5	73.6	249.8	123.4	140.8
Colorado River at Hite (2)	140.7	142.9	163.1	214.9	112.5	146.0	91.5	76.3	279.2	116.7	148.4
Gain(2)-(1)	+8.7	+3.9	+14.5	+16.0	+8.2	2/ -6.0	+6.0	+2.7	+29.4	3/ -6.7	+7.6

1/ Discharge estimated on basis of seven discharge measurements, weather records, and records for nearby stations.

2/ Possible explanation of 1954 loss is that some water from upstream stations that had peaks late in September did not arrive at Hite before the end of the month, especially a September 27 peak on the Green River at Green River, Utah.

3/ Cannot explain 1958 loss: rainfall departures are greater than normal; also possible that some peaks at gages on wash-type streams measured water that never arrived in major streams.

Total ground-water inflow to the Colorado River, as estimated by Rush and others (1982) and shown in figure 10 is: (1) Reach (90 km) upstream from mouth of Green River is 90 L/s per kilometer; and (2) reach (22 km) downstream from mouth of Green River is 40 L/s per kilometer. Thus, estimated ground-water inflow to the river from the eastern side can be obtained by subtracting 10 L/s per kilometer, selected by Rush and others (1982) for inflow from the drier, western side. Therefore: (1) 90 km x 80 L/s per kilometer = 7,200 L/s; (2) 22 km x 30 L/s per kilometer = 660 L/s; and (3) the total is 7,860 L/s which, when converted to an annual total and rounded to the nearest even 10 m^3/yr, is 250 m^3/yr.

Wells

Only a few large-yield, large-diameter wells are known in the study area. These selected water wells are listed in table 12. Discharge from wells is a small part of the water budget of the systems and is unimportant except in the three principal alluviated valleys: Spanish Valley, Castle Valley, and Fisher Valley.

Moab, Utah, the only sizable community in the study area, obtains its public water supply from two wells and five springs in Spanish Valley (Sumsion, 1971, p. 25). The two wells (26/22-15 dca and 22 aab) are used mainly during the summer to supplement water supplies from the springs. These five springs (26/22-14 acc, 15 ccb, 15 abc, 22 aaa, and 22 aaa1) flow a total of 3,826 L/min (table 8).

In Spanish Valley, ground water is pumped from wells for domestic use throughout most of the northwestern part of the valley; irrigation and public-supply wells, that withdraw the greatest volumes of water, are in the central part of the valley (Sumsion, 1971, table 9). Withdrawals from all wells are greatest during the growing season, from April to October, to supplement supplies from springs.

In Castle Valley, wells supply very little of the irrigation water. The McGinty Ranch (25/23-7) obtains most of its water by impounding spring water and using well water only as a supplemental supply. The farms of the Seventh Day Adventist Church (25/23-8), the other large user of irrigation water, obtain most of their water from Castle Creek, a perennial stream that flows the length of the valley. The remaining wells in Castle Valley are used primarily for domestic purposes. All the wells in Castle Valley are withdrawing water from the alluvium. As in Spanish Valley, the largest consumptive use of water occurs during April to October.

In Fisher Valley, there are two producing wells. The well used for irrigation (25/23-8 baa), is capable of producing 757 L/min, and a smaller well (25/23-8) is used for domestic supply. The irrigation well is used to supplement flow diverted from Fisher Creek.

Table 12.--*Hydrologic data from selected water wells*

[m, meters; L/min, liters per minute; µS, microsiemens per centimeter at 25° Celsius; °C, degrees Celsius; Stratigraphic units: Qal, Quaternary Alluvium; Pc, Cutler Formation; JKn, Navajo Sandstone; KK, Kayenta Formation; Kb, Burro Canyon Formation; Kw, Wingate Sandstone; Kd, Dakota Sandstone; Je, Entrada Sandstone; and Pccm, Cedar Mesa Sandstone Member of the Cutler Formation]

Well number on plate 2	Well name or owner	Location	Land-surface altitude (m)	Well depth (m)	Strati-graphic unit	Yield (L/min)	Specific conduct-tance (µS)	Temper-ature (°C)	Depth to water (m)	Date sampled	Remarks
1	Titus Ranch	24/23-15bbb	1,244	15.5	Qal	8	---	--	---	----	Domestic
2		24/23-20dbc	1,231	11.3	Qal	8	---	--	7.3	----	Irrigation
3	Richardson	24/23-22cbb	1,289	18.9	Qal	114	---	--	8.5	----	Domestic
4	Bates Wilson	24/23-27abc	1,314	30.5	Qal	57	1,460	21	---	9-15-78	Domestic
5	Suburban Gas Company.	25/21-26dcc	1,216	16.8	Qal	95	440	16	---	9-05-68	Domestic
6	Utex Exploration Company.	25/21-36cdc	1,218	27.4	Qal	265	---	--	5.2	10- -67	Domestic
7		25/23-1ddd	1,561	30.5	Pc	151	---	--	11.0	----	-----
8	A. Sorten	25/23-8baa	1,426	86.9	Pc	757	1,400	--	Flows	2-26-55	-----
9	Seventh Day Adventest School.	25/33-8bab	1,426	----	Qal	19	1,120	16	---	9-16-78	Domestic
10		25/33-17bad	1,439	61.6	Qal	303	---	14	25.9	----	-----
11		25/23-20aba	1,494	53.3	Qal	76	---	13	36.9	----	-----
12	Castleton	25/23-25add	1,817	45.7	Qal	19	535	26	24.4	9-16-78	Domestic
13	Taylor Ranch (Irrigation).	25/24E-1aab	1,817	93.9	Qal	757	500	14	48.8	9-12-78	Irrigation
14	Taylor Ranch (Domestic).	25/24-1add	1,804	51.8	Qal	49	450	14	---	9-12-78	Domestic
15	Desert Lodge	26/21-1dcc	1,233	15.2	Qal	79	286	15	5.5	7-08-69	Commercial
16	D. Provonsha	26/22-6cbc	1,242	25.9	Qal	57	---	--	3.0	4- -56	Domestic
17	City of Moab	26/22-15dca	1,402	56.4	JKn	9,255	268	15	16.5	3-06-69	Public Supply
18	Garrett Freight Lines Company.	26/22-17dbc	1,356	46.6	Qal	53	961	16	23.5	7-09-68	Domestic
19	City of Moab	26/22-22aab	1,399	32.3	JKn	3,785	273	13	9.4	11-19-68	Public Supply
20	L. W. Bull	26/22-35ada	1,445	56.4	Qal	26	1,230	14	46.9	7-08-69	Domestic
21	F. Shields	26/23-10ccb	2,097	135.6	JKn	2	---	--	125.0	8- -53	Irrigation
22	J. W. Corbin	26/23-12cca	2,274	335.3	Qal	---	---	--	259.1	1- -66	Irrigation
23	U.S. Bureau of Land Management.	27/22-2dbd	1,506	96.0	Qal	34	---	--	86.6	11- -38	Unused stock well
24	U.S. Bureau of Land Management.	27/23-6dad	1,542	138.7	Qal	57	---	--	118.9	11- -41	Unused stock well
25	U.S. Bureau of Land Management.	27/23-9cac	1,609	29.3	JKn	---	---	--	23.5	11- -67	Unused stock well
26	D. H. Brownell	27/23-23cab	1,841	25.6	Qal	379	1,240	13	8.8	4-30-68	Domestic
27	U.S. Bureau of Land Management.	28/21-16bba	1,786	213.4	JKn	38	210	27	---	6-06-79	Hatch camp ground
28	Unknown	28/22-1cda	1,536	30.5	JKn	151	---	--	7.3	----	-----
29	Unknown	28/23-4bcb	1,774	131.1	KK	341	---	--	85.3	----	-----
30	Unknown	28/23-19dcc	1,732	137.2	KK	38	---	--	91.4	----	-----

Table 12.--*Hydrologic data from selected water wells*--Continued

Well number on plate 2	Well name or owner	Location	Land-surface altitude (m)	Well depth (m)	Strati-graphic unit	Yield (L/min)	Specific conduct-tance (μS)	Temper-ature (°C)	Depth to water (m)	Date sampled	Remarks
31	Unknown	28/23-25cba	1,938	43.3	Kb	19	---	4	24.4	----	-----
32	Unknown	28/23-31bbc	1,829	259.1	Kw	26		14	149.4	----	-----
33	Unknown	29/24-4cba	2,039	83.8	Kb	76	---	12	40.2	----	-----
34	Unknown	29/24-9abb	2,042	38.7	Kb	30	---	--	12.2	----	-----
35	Joe R. Derioux	29/24-10bbc	2,054	51.2	Kd	---	---	--	15.2	----	Domestic
36	Unknown	29/24-23aab	2,039	743.4	Je	---	---	--	137.2	----	-----
37	Big Indian Mine	29/24-34abc	1,841	73.2	Kb	189	---	--	27.4	----	-----
38	Unknown	29½/23-33aca	1,695	40.5	JKn	53	---	7	12.2	----	-----
39	Canyonlands National Park.	30/20-20dad	1,527	19.8	Pccm	125	---	44	6.4	6-08-79	-----
40	Canyonlands National Park.	30/20-30cbd	1,530	15.8	Pccm	15	550	15	5.5	6-08-79	-----
41	U.S. Bureau of Land Management.	30/21-25bcc	1,957	61.0	Kw	11	---	7	12.2	----	Stock well
42	U.S. Bureau of Land Management.	30/22-13bda	1,829	----	JKn	38	410	24	---	6-06-79	Wind Whistle camp ground.
43	Unknown	30/22-18cab	1,884	113.7	JKn	57	---	--	---	----	-----
44	Dugout Ranch	30/23-8dad	1,792	91.4	JKn	11	---	--	---	6-09-79	-----
45	Dugout Ranch	30/23-17cab	1,768	114.3	JKn	26	---	--	82.3	6-09-79	-----
46	Dugout Ranch	30/23-20bbb	1,859	94.5	JKn	26	510	17	---	6-09-79	-----
47	Dugout Ranch	30/23-22bcc	1,777	91.4	JKn	30	---	--	45.7	6-09-79	-----
48	Unknown	30/24-22caa	1,829	152.4	Kw	235	---	7	24.4	----	-----
49	Unknown	31/23-1dbb	1,829	84.1	JKn	34	---	--	41.1	----	-----
50	Unknown	31/23-9ddd	1,884	109.7	JKn	38	---	--	48.8	----	-----
51	Unknown	31/23-27acd	1,884	99.1	JKn	11	490	15	80.8	6-09-69	-----
52	Photograph Gap •	31/23-28cab	1,957	----	Je	---	360	15	---	9-21-78	-----
53	Unknown	31/23-29cca	1,871	470.9	K	---	---	--	123.7	----	-----
54	Unknown	32/23-1acd	1,865	85.3	Je	151	---	--	48.8	----	-----
55	Unknown	32/23-26aaa	2,042	21.3	Kd	8	---	--	4.6	----	-----
56	Monticello Airport.	33/23-1cad	2,109	----	Kd	114	1,060	14	---	9-20-78	-----

The study area contains many stock and domestic wells and a few public-supply wells; water from only a few was tested. Most of these wells, particularly the stock wells, are in use only part of the year; they are not used at all some years. None of these wells produces large quantities of water; production usually is only about 15-100 L/min when the wells are operating (table 12).

Most wells along the west and south flanks of the La Sal Mountains and along the north and east flanks of the Abajo Mountains produce from the Dakota Sandstone and Burro Canyon Formation. Wells on the high mesas, southwest of the La Sal Mountains between Moab and Monticello, such as Hatch Point and Harts Point, produce from the Entrada, Navajo, and Wingate Sandstones. Further to the southwest, three wells in The Needles area of Canyonlands National Park (pl. 1) produce small quantities of water (10-45 L/min) from the Cedar Mesa Sandstone Member of the Cutler Formation.

Sumsion (1971, p. 26) estimated that 4.19×10^6 m^3/yr of ground water was used in Spanish Valley for public supply and irrigation. Possibly one-half that quantity is used elsewhere throughout the Moab-Monticello area, for an estimated total of about 6×10^6 m^3/yr of water pumped from wells in the area.

Inflow-Outflow Balance

During a multiyear period, most natural hydrologic systems approach dynamic equilibrium; that is, inflow equals outflow, and the volume of ground-water in storage remains nearly constant. A preliminary water budget for the Moab-Monticello area is shown in table 13. Though the budget is incomplete, some useful conclusions can be drawn from it on the relative volumes of water for each of the inflow and outflow elements:

1. For the upper ground-water system:

(A) Subsurface inflow of ground water is probably minor in volume; the principal inflow is recharge from precipitation, approximately 150×10^6 m^3/yr;

(B) The principal element of ground-water outflow is discharge to the Colorado River;

(C) All other elements of outflow are relatively small; and

(D) The estimated total outflow from the system is about 300×10^6 m^3/yr.

2. For the lower ground-water system:

(A) Total inflow and outflow are about equal;

(B) Because the evaporite confining bed is nearly impermeable, all inflow to and outflow from the system is subsurface ground-water flow; and

(C) The volume of water moving through the system is unknown, but probably is nearly constant.

The calculated imbalance of the budget for the upper ground-water system is approximately 150×10^6 m^3/yr. The reason inflow and outflow quantities are so different warrants discussion. The outflow estimate for the budget

Table 13.--*Water budgets for the ground-water systems*

Budget element	Average annual estimate (10^6 cubic meters)
Upper Ground-Water System	
Inflow	
Recharge from precipitation and runoff (table 4).	150
Recharge from Colorado River (p. 51).	0
Subsurface inflow (p. 52 and 68)	Unknown; probably minor but possibly significant if lower ground-water system leaks upward.
Total (rounded)	150
Outflow	
Evapotranspiration (p. 54)	40
Springflow (p. 55)	5
Discharge to Colorado River (p. 61)	250
Subsurface outflow (p. 54)	Probably small.
Wells (p. 71)	6
Total (rounded)	300
Lower Ground-Water System	
Subsurface inflow (p. 52)	Unknown: virtually all recharge is from precipitation on outcrops outside the study area.
Subsurface outflow (p. 54)	Unknown, but probably identical to inflow.

probably is the most accurate of the two parts; therefore, we reasonably deduce that inflow probably is too small. Recharge, the principal element of inflow having a significant consequence to the estimate, presumably, should be larger. If the curve (fig. 4) relating precipitation to altitude, from which volume of recharge was estimated, were drawn as a straight line that plotted largely to the right of the curved version presented, the precipitation would be larger for a given altitude zone (table 4), and estimated recharge would be proportionately greater. Unknown subsurface inflow laterally from outside the study area is properly designated as minor in quantity; however, if the lower ground-water system leaks upward, which is suggested as a possibility in the section on summary of flow system, the resultant inflow might be significant to the budget for the upper system.

Summary of Flow Systems

All large hydrologic systems include recharge areas, areas of lateral movement (such as the Paradox basin), and discharge areas. Recharge areas for the lower ground-water system are remote (east and north) from the study area; likewise, conspicuous discharge areas are outside the study area. Marble and Grand Canyons, southwest of Paradox basin, comprise two such discharge areas for the lower ground-water system or its regional equivalent. In these canyons, ground water discharges from the Redwall Limestone, which is approximately the same age as the Leadville Limestone equivalent. However, not all water recharging the lower Paleozoic aquifer in the region is discharged from the Redwall Limestone into the Colorado River. Areas undoubtedly exist along the regional flow paths where water can migrate upward into younger rocks from the aquifer and its equivalent strata. Hydraulic potential for upward leakage exists almost everywhere in the area. Hydraulic heads are sufficient to raise fluid at least as high as lower saturated, permeable units of the upper ground-water system. Virtually all rocks can transmit some water, although the thick salt deposits of the Paradox depositional basin probably come as close to zero hydraulic conductivity as any natural sedimentary layers. Conceivably, the slope on the potentiometric surface of the lower ground-water system might be maintained through infinitesimally small, but widespread upward discharge; thus, the system would function without any conspicuous discharge to the surface directly from the system. Such a hypothesis would necessitate that small quantities of water from the lower Paleozoic aquifer throughout a large area enter shallower strata; some of the water interchanged vertically could contain large concentrations of sodium chloride. However, no definite occurrence of salty water in these shallower beds was observed during this reconnaissance investigation and analysis. Perhaps additional data for the deeper ground-water system could show that most of the salty water moving upward migrates through clayey membranes and is altered osmotically; that is, the freshwater fraction of the altered fluid moves upward, leaving greater salt concentrations behind in the carbonate aquifer beds.

Compared to the lower ground-water system, flow in the upper ground-water system is relatively simple. Recharge from precipitation occurs on the flanks of the La Sal and Abajo Mountains, as shown by potentiometric contours (pl. 2). Much cross-formational downward flow probably occurs within the upper system between the mountains and the Colorado River. Some spring discharge occurs locally on the mountain slopes; but, most of the discharge is to the river. Water in the permeable layers younger than the Cutler Formation probably is unconfined in most of the Moab-Monticello area, especially on the upper mountain slopes and under the high mesas. Based on water-level data, the two mountain masses form ground-water divides coinciding approximately with drainage divides, and probably no water flows into the upper ground-water system from outside the study area in the mountainous parts. The drainage divide along the southeastern boundary of the Moab-Monticello area also possibly coincides approximately with the ground-water divide; however, inflow of ground water from the adjacent Dolores River drainage area is possible. Some upward migration from the lower ground-water system, discussed earlier in this section, also is possible.

Throughout most of the Moab-Monticello area, potentiometric head in the lower ground-water system is lower than the potentiometric head in the upper ground-water system (fig. 9 and pl. 2); thus potential for some downward leakage from the upper to lower system does exist. Near the Colorado River, between its confluences with the Dolores and Green Rivers, the predominant potential is for upward leakage from the lower ground-water system (fig. 9); that is, potentiometric heads for the lower system are 100 to 200 m higher than water-level heads in the main saturated zone of the upper system. However, no direct evidence exists of any actual leakage, upward or downward, through the confining beds of salt and adjacent confining beds from these potentials. Possible upward or downward leakage depends on vertical potentiometric gradient in any specific locality.

GENERAL CHEMICAL CHARACTER OF WATER

Water-quality data for the Moab-Monticello area were obtained mostly from the work of others, mainly Feltis (1966), Sumsion (1971), and Sumsion and Bolke (1972). Water-quality data are meager or lacking in large parts of the area, and no data were obtainable for water in some of the hydrologic units.

In general, the concentration of dissolved solids in ground water depends on transit time or flow distance as the water migrates from recharge to discharge areas and on solubility of rock materials in units through which the water migrates. The water closer to recharge areas typically has smaller concentrations of dissolved solids than it does near distant discharge areas. Minerals such as gypsum and halite (salt) that are readily water soluble impart greater quantities of dissolved matter to ground water coming into contact with these rocks than do less soluble rocks such as sandstones.

The following discussion of units for which chemical analyses are available is arranged from youngest to oldest in the hydrogeologic sequence.

Alluvial Aquifer

Water in 12 samples from alluvium had dissolved-solids concentration that ranged from 167 to 1,040 mg/L and averaged 625 mg/L. Water from the alluvium is characterized as calcium sulfate or calcium bicarbonate type. Gypsum and limestone probably are the major contributors of these ions. Sodium concentration was 54 mg/L or less, and chloride was 30 mg/L or less, indicating that halite deposits have only a minor effect on the quality of water in the alluvium.

Mesozoic Sandstone Aquifer

Four samples of water from the Dakota Sandstone and the underlying Burro Canyon Formation had dissolved-solids concentrations ranging from 98 to 504 mg/L and averaging 329 mg/L. Water from these units is a calcium bicarbonate type. The freshwater in these strata can be attributed primarily to the close proximity of the sources sampled to the recharge areas.

Three samples of water from the Entrada Sandstone had 190 to 417 mg/L of dissolved solids and an average dissolved-solids concentration of 329 mg/L. Two of the samples contained mostly calcium and bicarbonate, the others contained mainly sodium, potassium, and bicarbonate.

Dissolved solids in waters from the Navajo Sandstone ranged from 163 to 505 mg/L and averaged 275 mg/L. Dominant ions in the six analyses available are calcium and bicarbonate; two of these six analyses also show moderately large concentrations of sodium, potassium, and sulfate.

Eight samples of water from the Wingate Sandstone had dissolved-solids concentrations that ranged from 164 to 684 mg/L and averaged 260 mg/L. Seven of the analyses show a predominance of calcium and bicarbonate ions; in the other analysis, calcium and sulfate ions dominated. The lone sample, from Jackson Reservoir Springs (26/22-7 cca), had greater sulfate concentration than the others and reflects local conditions near the reservoir, possibly resulting from irrigation return flows in this locality. If the analytical results of Jackson Reservoir Spring were eliminated, the average value for dissolved solids would be 199 mg/L for the seven remaining analyses, and the extremes would be 164 and 303 mg/L.

The Mesozoic sandstone aquifer yields water that is chemically suitable for most uses, as shown in the foregoing discussions of water from individual stratigraphic units. The quality of the water makes this aquifer a valuable resource.

Mesozoic-Upper Paleozoic Confining Beds

Ten water samples from the Cedar Mesa Sandstone Member of the Cutler Formation had between 228 and 931 mg/L of dissolved solids and averaged 476 mg/L. Seven of the analyses indicate that water from the Cutler Formation is a calcium bicarbonate type. Three of the analyses show that water from the Cutler is of a sodium magnesium and bicarbonate sulfate type.

Three samples of water from the Rico Formation had an average dissolved-solids concentration of 277 mg/L. Water from the Rico is a calcium bicarbonate type.

Salt Confining Beds and Lower Paleozoic Confining Unit

Drill-stem tests of the Paradox Member of the Hermosa Formation indicate the recovery of salt water or brine sometimes associated with hydrocarbons. Chemical analyses of water recovered from drill-stem testing were not made often, or results were not reported often; therefore, analytical data for the brines from interbeds in the salt deposits are scarce.

Two samples of water from the Paradox Member of the Hermosa Formation contained 152,200 and 295,000 mg/L of dissolved solids. These brines are dominantly sodium, potassium, and calcium chloride waters. Chloride concentrations were reported as 94,000 and 190,000 ppm. Such waters generally are reported as saltwater by petroleum engineers in many reports of drill-stem tests.

No chemical analysis for water from the upper Paleozoic confining beds was found during the study. Three drill-stem tests (table 2) of the Molas Formation indicated recovery of small quantities of drilling mud and no formation fluid. If the Molas were saturated with water, the minute quantity that might enter a borehole, during the 0.5 to 1 hour when the testing tool is open during a drill-stem test, would not be detectable in drilling mud.

Lower Paleozoic Aquifer

Numerous drill-stem tests have been conducted in petroleum exploration holes in this aquifer. Only a few samples of water recovered during these tests were analyzed. Most of the water-quality data are for water from the Leadville equivalent, the most prolific producer in the lower Paleozoic aquifer.

Eight samples of water from the Leadville equivalent had 43,000 to 221,200 ppm of dissolved solids; the average value for dissolved solids was 121,800 ppm. This water may be characterized as a sodium potassium chloride water. The following table summarizes the results of analyses for the eight samples:

(Results in parts per million, data from Feltis, 1966, table 3)

Location	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Sulfate (SO_4)	Chloride (CL)
27/21-3 cdc	2,000	243	36,100	120	59,600
27/22-17 ddb	960	1,360	48,000	2,600	77,400
28/19-18 dc	1,840	740	14,000	4,300	21,700
28/21-22 cac	1,950	620	60,000	3,550	64,000
28/22-10 ddb	2,100	450	32,600	4,500	52,000
28/23-2 bc	1,050	390	84,400	3,700	131,000
29/20-4 cba	1,560	900	25,100	5,150	39,900
29/21-18 cb	2,870	630	75,900	3,840	120,000
Average (rounded).	1,800	670	47,000	3,500	70,700

Feltis (1966, p. 22) in discussing water from rocks of Mississippian age in the Canyonlands section (an area of greater size than Paradox basin) of the Colorado Plateau in Utah stated, "Chemical analyses of 52 water samples from the undifferentiated rocks of Mississippian age showed a range of 7,172 to 327,283 parts per million of dissolved solids ....Six of the water samples were moderately saline, 16 samples were very saline, and 30 samples were brines."

A total of 13 drill-stem tests (tables 2, 3) were conducted in Devonian rocks in the Moab-Monticello area, but no chemical analyses are available for fluids recovered from these tests. Seven of these tests were of the equivalent of the McCracken Sandstone Member of the Elbert Formation, and the other six were designated as tests of the Ouray and Elbert Formations. One-half the tests of the Elbert and Ouray recovered fluid described as "black, salty, sulfur water," and the others recovered mainly drilling mud. Tests of the McCracken equivalent recovered drilling mud, with the exception of one test that reported the recovery of "gas-cut, salty, sulfur water."

Colorado River Water

Dissolved-solids concentration in the water of the Colorado River varies nearly in inverse relation to streamflow; concentration is smallest during high flows and largest during low flows (Iorns and others, 1965, p. 20). The effect is manifest in the seasonal water-quality differences of the river water. Abundant runoff has relatively small concentrations during spring and early summer, whereas predominantly ground-water inflow has relatively larger concentrations during late summer, autumn, and winter. Long-term, weighted-average concentrations (Iorns and others, 1965, table 7, p. 20) of dissolved solids indicate 547 mg/L at the Cisco gage and 527 mg/L at the Hite gage downstream. In general, the river water is a calcium bicarbonate and sulfate type; at low flows, calcium, sodium, and sulfate become predominant ions and dissolved-solids concentration may increase to 1,850 mg/L at the Cisco gage and 1,200 mg/L at Lees Ferry, Arizona (Iorns and others, 1965, p. 26-27).

The Dolores River, whose confluence with the Colorado River is just upstream from the Cisco gage, transports water into the Colorado River that has a long-term average dissolved-solids concentration of 496 mg/L (Iorns and others, 1965, table 7, p. 20). During base-flow periods, water from the Dolores River has much larger dissolved-solids concentration. Specific-conductance measurements in the Colorado River upstream and downstream from the Dolores confluence during October 1977 (Rush and others, 1982) were 1,850 and 1,980 µS or approximately 1,240 mg/L of dissolved solids upstream, and 1,330 mg/L of dissolved solids downstream from the confluence.

Surface-water inflow to the Colorado River between the mouth of the Dolores River and the mouth of the Green River is minor in quantity. However, accretion in this reach from ground-water inflow having both larger and smaller concentrations of dissolved solids may be significant, especially during periods of low flow in the Colorado River (Rush and others, 1982).

Water from the Green River probably decreases the concentrations of dissolved solids in the Colorado River water downstream from their confluence. During October 1977, two samples collected from the Colorado River upstream and downstream from the confluence showed a change in dissolved-solids concentration from 1,260 to 933 mg/L (Rush and others, 1982). During periods of high flow in this reach of the river, changes are undoubtedly less marked. An example of this less-marked change in quality of water downstream at times of high runoff is given in the following table (Iorns and others, 1965, summarized from table 10, p. 26-27):

[L/s, liters per second; mg/L, milligrams per liter]

Colorado River near Cisco, Utah		Green River at Green River, Utah		Colorado River at Lees Ferry, Arizona	
Discharge[1/] (L/s)	Dissolved solids (mg/L)	Discharge[1/] (L/s)	Dissolved solids (mg/L)	Discharge[1/] (L/s)	Dissolved solids (mg/L)
1,763,000	238	1,796,000	222	5,047,000	250
1,686,000	239	1,598,000	222	3,888,000	253
1,578,000	240	1,457,000	222	3,461,000	256
1,358,000	241	1,182,000	225	2,874,000	262
1,079,000	248	909,000	230	2,325,000	270

[1/] Data are mean flows for water years 1914-57 adjusted to 1957 conditions.

RELATIONSHIP OF GROUND WATER AND STREAMS TO SALT BEDS

Disruptions of the ground-water flow regime are inferred (pl. 2) for the upper ground-water system because of anticlinal structures and closely related faulting that interrupt aquifer continuity. Although hydraulic-head data and other hydraulic information are not adequate everywhere to confirm these disruptions, geologic information, general hydrologic character of the strata involved in the diapir and fault structures, and indications from chemical quality of the water provided the guidelines from which water-level contours were drawn.

Shallow ground-water flow in the three main alluvial valleys in the study area is of particular interest because these valleys overlie anticlinal salt structures. All three valleys have resulted from upward plastic movement of salt and subsequent collapse above these structures, apparently from solution of the salt and later deposition of extensive alluvial deposits. Beneath the alluvium are cap rocks composed of gypsum, anhydrite, and carbonate rocks of the Paradox Member of the Hermosa Formation that were formerly interbeds in the salt sequence; in a few small areas, these cap rocks are exposed within the collapsed structures. Because of collapse after solution of halite beds, these cap rocks are chaotic. Each valley has extensive faulting visible along its margins; additional faults in the central parts of the valley are obscured by the alluvial cover. Each valley receives considerable recharge from rainfall and runoff; springs also discharge from the alluvium at the downstream ends of the three valleys. In the following paragraphs, data collected for streams, springs, and wells in each valley are discussed. Location of hydrologic sites are shown on plate 2.

Fisher Valley, the northernmost of the three valleys, trends northwest (24/25 and 25/25) (pl. 2). The valley is at the junction of the northwest-trending, collapsed, Fisher Valley anticline and the northeast-trending Cottonwood graben (pl. 2 and fig. 2). Part of the collapsed Fisher anticline is floored by the Paradox Member of the Hermosa Formation over which Onion Creek flows. Fisher Creek originates high on the northeast flank of Mount Waas (26/24), in the La Sal Mountains, and then flows the length of Fisher Valley, before flowing northeast down Cottonwood Canyon to the Dolores River. The upstream reach of Fisher Creek is the principal source of water for recharge to the alluvium in the valley, other than precipitation. The creek is used for irrigation, and its flow only reaches the Dolores River during the spring period of snowmelt and high-water runoff.

Onion Creek originates in a canyon on the west side of Fisher Valley. Flow is sustained by several small springs issuing from points near the base of the alluvium. Onion Creek flows west to the Colorado River traversing about 4.5 km of cap rock composed primarily of gypsum of the Paradox Member of the Hermosa Formation exposed in the stream valley (pl. 1).

The specific conductance of the water in the Fisher Creek at the upstream end of Fisher Valley was 240 μs during September 1978. The irrigation well that is 9.39 m deep, and probably was drilled to the base of the alluvium, yielded water with a specific conductance of 500 μS; the shallow domestic well, 5.18 m deep produced water with a specific conductance of 450 μS. Both wells are near the upstream end of the valley, where much of the recharge to alluvium is taking place. Specific conductance of the springs issuing from the alluvium into upper Onion Creek averaged 1,060 μS, measured during the same visit to the locality. Several specific-conductance measurements were made of the flow in Onion Creek. Progressing downstream, the following specific conductances were obtained: (1) 1,500 μS, at a point just before Onion Creek begins to flow across the exposed Paradox Member (pl. 1); (2) 2,800 μS at a point about midway through the reach in which the Paradox Member is exposed (24/24-20); (3) 3,200 μS at a point near the western end of the well-exposed part of the Paradox Member (24/23-24); and (4) 3,850 μS at a point near the confluence of Onion Creek and the Colorado River (24/23-11). These measurements indicate that some solution of gypsum is occurring by water as it moves through the alluvium in the upstream reach of the valley. Slightly more dissolution by Onion Creek (or its underflow) of evaporites is occurring as it flows over the exposed beds of the Paradox Member.

Castle Valley (25/23), south of Fisher Valley, overlies a diapiric salt structure. The Castle Valley structure trends northwestward, on the same lineament as the Paradox Valley structure to the southwest and the Salt Valley anticline to the northwest (fig. 2). The Castle Valley structure is separated from Paradox Valley by intrusives of the La Sal Mountains. Castle Valley separated from the Salt Valley structure by a northward bend in the Salt Valley trend that becomes the Cache Valley anticline. Outcrops of the Paradox Member occur only near the southeastern end of the valley. These are mainly small outcrops on the south side of the valley and a small exposure encircling the Round Mountain bysmalith (Hunt, 1958, p. 323).

Castle Creek originates high on the northern flank of Mount Waas and flows the length of Castle Valley to join the Colorado River. Castle Creek, the only perennial stream in Castle Valley, loses water to the alluvium in the upstream reaches (recharge area), then gains water from the alluvium via a group of springs near the downstream end. Pinhook and Placer Creeks are both ephemeral streams that originate on the west side of Mount Waas. These streams contribute to the ground water only during the high runoff season in early spring. None of the streams in this valley is in direct contact with the Paradox Member.

Specific-conductance measurements made on September 15, 1978, at selected sites along Castle Creek indicate a progressive increase in specific conductance downstream. The specific conductance of Castle Creek at the head of the valley, the southeast end, was 220 μS; approximately 7 km downstream, near Round Mountain (25/23-27), the value was 835 μS; 8 km farther downstream and near the south end of the alluvium, the value was 850 μS; and 1.5 km farther downstream, the value was 3,100 μS. The specific conductance then remained nearly the same farther downstream to the mouth of Castle Creek.

Specific conductance of the springs and well water increases northwestward down Castle Valley at about the same rate as that of the stream water. The spring at Castleton site in the upstream end of the valley had a specific conductance of 700 μS; down-valley, the wells at the Seventh Day Adventist Farms (25/23-8,17,20) had an average of 1,140 μS; McGinty Spring (25/23-7aac), a little farther downstream, had 2,000 μS; next was a spring with 501 μS. Near the downstream end of the valley (also near the downstream end of the alluvial deposits), a group of springs called Homestead Springs (25/22-1ac) had an average specific conductance of 2,438 μS. As in Fisher Valley, the increase in specific conductance may mean that there is some solution of salt or gypsum along the upper contact of the Paradox Member with the alluvium. However, one spring, 25/23-6add, in the lower valley, has an anomalously small specific conductance (501 μS).

Spanish Valley (25-27/21-23) (pl. 2) is the southernmost of the three salt-structure valleys. It is a northwest-trending anticline bounded on the southwest by the Moab fault. A very small outcrop of the Paradox Member occurs near the northwest end of the valley. Two perennial streams flow into Spanish Valley from the west flank of the La Sal Mountains. Pack Creek originates in the pass between Mount Tukuhnikivatz and South Mountain (27/24-28), and the origin of Mill Creek is to the north near Mams Peak (26/24-25). Pack Creek enters the valley at the southeast end and flows the length of the valley on alluvium. Mill Creek parallels the valley for three-fourths of its length before it joins Pack Creek (26/21-2).

Samples from streams and wells in Spanish Valley were collected and analyzed earlier for another report (Sumsion, 1971). The down-valley increase in specific conductance noted in the other two valleys does not occur in Spanish Valley. This difference may be because of the very limited contact of the alluvium with soluble parts of the Paradox Member in Spanish Valley; or, perhaps the more soluble parts of the Paradox Member have been dissolved and transported out of the valley during a much earlier period.

In the rest of the study area, three other drainage systems contribute significant quantities of water to the Colorado River. The Kane Springs-Hatch Wash system (29-32/21-25) drains a wide area east of the Colorado River between the La Sal and Abajo Mountains. The system is ephemeral throughout most of the upstream reaches. Only in the area where Hatch Wash has eroded to the base of the Entrada Sandstone and into the Navajo Sandstone, a short distance downstream from Joe Wilson Canyon and Wind Whistle Draw (29/23-32), are there enough springs for a year-round flow. Much water is lost to evapotranspiration by phreatophytes, but a sufficient discharge of water exists from seeps and springs from the Navajo and Wingate Sandstones to maintain at least a small flow in this reach throughout most of the year. In a few places, flow for short distances may occur as underflow through the alluvium. No detectable relationship causing flow disruptions was found for the ground-water regime from the diapiric structures occurring in these drainage basins.

Indian Creek and North Cottonwood Creek originate on the northern flank of the Abajo Mountains (34/21-22). These streams are both ephemeral in their downstream reaches from about the Dugout Ranch area (31/21-24) downstream. A large part of the headwaters of Indian Creek is diverted south across the Abajo Mountains divide through an aqueduct to the community of Blanding, Utah, (south of the study area) for public-water supply. The largest volume diverted occurs during the late summer and autumn when the growing-season demand is greatest, and other springs and wells that supply the town have begun to decrease in production. Most of the remaining undiverted flow in Indian Creek is appropriated for irrigation on ranches in the Indian Creek drainage system. Most of the flow of North Cottonwood Creek also is diverted for irrigation. Water reaches the Colorado River from Indian and North Cottonwood Creeks only during the spring runoff, or during infrequent, intense thundershowers.

Salt Creek, further to the west, is an ephemeral stream that contributes water to the Colorado River during the early spring, when runoff is greatest. None of the drainage system discussed above, namely Kane Springs-Hatch Wash, Indian Creek, North Cottonwood Creek, or Salt Creek, flows across areas where the Paradox Member of the Hermosa Formation is exposed. Salinity of ground water in the Lower Paleozoic aquifer probably is not affected by the salt-bearing beds, based on subsurface geology of the area (R. J. Hite, U.S. Geological Survey, oral commun. 1978). Thackston and others (1981, p. 219) described possible means whereby salt might have been dissolved from salt-bearing beds in some localities of the Paradox basin.

ADDITIONAL STUDIES

Additional studies that could be undertaken to increase understanding of the ground-water systems in the Moab-Monticello area include the following, in order of increasing importance:

1. To understand the upper ground-water system, a more complete inventory of the wells in the area and their water levels needs to be made. Only a small percentage of the wells in the study area was examined during this investigation, and almost all the static water levels were obtained from drillers' logs.

2. To understand the relationship of the evaporites to ground water in the alluvium and cap rocks within the collapsed diapiric structures, a program of drilling and testing of water quality could be undertaken. Although many wells produce water from the alluvium within these collapsed structures, they do not penetrate the underlying bedrock. A few carefully selected exploratory wells, drilled through the alluvium and into the underlying bedrock, could yield considerable information about the thickness and distribution of salt, cap rock, or other bedrock in the subsurface overlying the collapsed salt structure. Information also could be collected on any differences in water quality above the alluvium-bedrock interface.

3. To understand the movement of water in the lower ground-water system and its relationship to the Paradox Member, exploratory holes are needed in synclinal areas. Information for the lower ground-water system was obtained from deep wells drilled for oil exploration. These wells consistently have been drilled on anticlinal structures. Thus, data are only from areas where the salt is the thickest; ground-water patterns are modified significantly by these diapiric structures. Deep test wells drilled away from selected anticlinal structures would produce information about the degree of thinning and the characteristics of the salt away from areas of maximum upward salt flowage; the holes also would provide needed information on the quality and movement of ground water flowing away from these structures. This information cannot be obtained from existing well information because of the distribution of the wells.

4. To determine whether Gibson dome, currently considered a prime possibility for waste storage in salt, has favorable hydrologic attributes as a possible repository, the following work is needed:

(A) Analyze in more detail all hydraulic-head and hydraulic-conductivity data for the area to include all nearby structures, and thus produce a conceptual model of the flow pattern, with special emphasis on ground-water flow toward the Colorado River.

(B) Conduct a geophysical and conjunctive drilling exploration program for the Gibson dome area, which needs to include Rustler dome and Lockhart anticline, which would answer hydrologic questions not resolved by item A above. Lockhart basin and adjacent anticline, a major collapse feature near Gibson dome, needs to be examined in considerable detail to determine the relationship of collapse to ground-water migration and salt solution.

CONCLUSIONS

Storage of radioactive waste in salt deposits of the Paradox basin has been considered possible for several years (Hite and Lohman, 1973). The major purpose of the current reconnaissance studies of the basin is to establish a hydrologic framework as a basis for further studies to determine the feasibility of storing radioactive waste for an extended period.

Principal findings of this study that are pertinent to an assessment of the suitability of the hydrogeologic systems to store and contain radioactive waste follow:

1. Water in the upper ground-water flow system discharges to the major stream, the Colorado River.

2. Extensive, thick salt deposits and underlying and overlying confining beds effectively separate the upper and lower ground-water systems in most parts of the area.

3. Potential exists for upward leakage from the lower system into permeable units (Wingate and Navajo Sandstones) of the upper ground-water system; this would occur chiefly where salt deposits are thin.

4. Little or no recharge occurs to the lower ground-water system within the study area.

5. Active solution of evaporites, mainly gypsum, is occurring in the downstream reaches of Onion and Castle Creeks. No solution of salt in the Paradox Member has been detected elsewhere in the report area.

6. Water in the upper ground-water system generally is chemically suitable for most uses.

7. Ground-water flow disruptions by folds and contiguous faults are common in the upper system. Such geologic controls of flow are not apparent in the lower system, perhaps because available hydrologic data for lower aquifers are not sufficiently widespread.

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