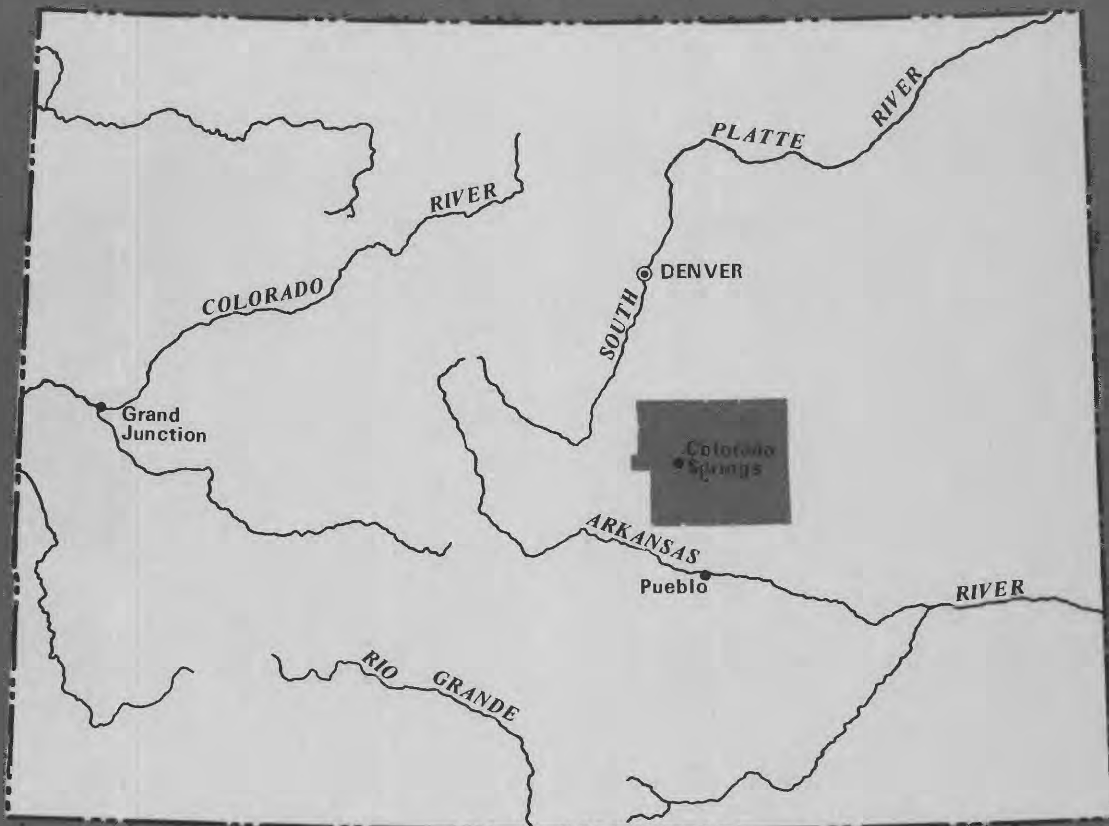
ARTIFICIAL-RECHARGE TESTS IN UPPER BLACK SQUIRREL CREEK BASIN, JIMMY CAMP VALLEY, AND FOUNTAIN VALLEY, EL PASO COUNTY, COLORADO

U. S. GEOLOGICAL SURVEY



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Prepared in cooperation with the
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July 1977

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METRIC CONVERSION

Multiply English unit	*By*	*To obtain metric unit*
acres	0.4047	hectares (ha)
acre-feet (acre-ft)	1,233	cubic meters (m^3)
acre-feet per year (acre-ft/yr)	1,233	cubic meters per year (m^3/yr)
cubic feet (ft^3)	.0283	cubic meters (m^3)
inches (in.)	25.40	millimeters (mm)
feet (ft)	.3048	meters (m)
feet per day (ft/d)	.3048	meters per day (m/d)
square feet (ft^2)	.0929	square meters (m^2)
miles (mi)	1.609	kilometers (km)
miles per year (mi/yr)	1.609	kilometers per year (km/yr)
square miles (mi^2)	2.590	square kilometers (km^2)

ARTIFICIAL-RECHARGE TESTS IN UPPER BLACK SQUIRREL CREEK BASIN, JIMMY CAMP VALLEY, AND FOUNTAIN VALLEY, EL PASO COUNTY, COLORADO

By Patrick J. Emmons

ABSTRACT

Artificial-recharge tests were conducted in the alluvium in upper Black Squirrel Creek basin, the alluvium in Jimmy Camp Valley, and in the alluvium overlying the Widefield aquifer which is located in an ancestral channel in Fountain Valley. Nine artificial-recharge pits with areas of approximately 9,200 square feet (850 square meters) each were excavated in the unsaturated zones above the three aquifers. Each artificial-recharge site was instrumented to measure inflow, stage fluctuations, and water-table fluctuations. Artificial-recharge tests of approximately 10 days' duration were conducted at each of the nine artificial-recharge sites and one extended test of approximately 30 days' duration was conducted in each of the three study areas. Periphyton growth, present in most of the artificial-recharge ponds, was insufficient to cause noticeable decline in the rate of infiltration.

Artificial-recharge tests conducted in upper Black Squirrel Creek basin indicated that the average adjusted rates of infiltration, adjusted for a pond stage of 2.5 feet (0.8 meter), for the three sites ranged from 1.6 to 2.4 feet (0.5 to 0.7 meter) per day. Based on an average adjusted rate of infiltration of 1.8 feet (0.5 meter) per day and 122 days of operation, each acre of artificial-recharge pond could recharge approximately 220 acre-feet (270,000 cubic meters) per year.

Artificial-recharge tests conducted in Jimmy Camp Valley indicated that the average adjusted rates of infiltration for the two sites ranged from 3.8 to 24.7 feet (1.2 to 7.5 meters) per day. Based on an average adjusted rate of infiltration of 9.4 feet (2.9 meters) per day and 122 days of operation, each acre of artificial-recharge pond could recharge approximately 1,200 acre-feet (1.5 million cubic meters) per year.

Artificial-recharge tests conducted on the Widefield aquifer indicated that the average adjusted rate of infiltration for the four sites ranged from 2.3 to 12.9 feet (0.7 to 3.9 meters) per day. Based on an average adjusted rate of infiltration of 9.5 feet (2.9 meters) per day and 122 days of operation, each artificial-recharge pond could recharge approximately 1,200 acre-feet (1.5 million cubic meters) per year.

INTRODUCTION

El Paso County (fig. 1), which is located along the Front Range in central Colorado, has experienced one of the most rapid population increases in the United States. In the 20-year period between 1950 and 1970, the population of El Paso County increased from approximately 74,500 to approximately 236,000, an increase of greater than 300 percent. Between the years 1970 and 2000, the county population is anticipated to double (Pikes Peak Area Council of Governments, 1974). With the population increase, a resulting like demand for municipal and industrial water supplies has occurred.

The alluvial aquifers in upper Black Squirrel Creek basin (fig. 2), Jimmy Camp Valley, and Fountain Valley, which includes the Widefield aquifer (alluvium in an ancestral channel of Fountain Valley) are the principal alluvial aquifers in El Paso County (fig. 3). The aquifers have been used extensively to help meet the increasing demand for water. As a result, the water level in the alluvial aquifer in upper Black Squirrel Creek basin has declined as much as 46 ft (14 m) between 1964 and 1974. For this period, the ground-water storage has decreased about 50,000 acre-ft (6.2×10^7 m^3). The water levels in the alluvial aquifer in Jimmy Camp Valley and the Widefield aquifer in Fountain Valley have not changed significantly since 1955 (Livingston and others, 1976a).

The principal users of the water from the three aquifers are concerned with the proper management and assurance of adequate water supplies for the future. To meet these demands, Security Water and Sanitation District, Cherokee Water District, Widefield Homes Water Co., Stratmoor Hills Water District, and the city of Fountain formed the El Paso County Water Association in 1973. The association hopes to obtain better utilization of ground water by artificially recharging the aquifers when a surplus of water is available.

Purpose

The El Paso County Water Association entered into a cooperative agreement with the U.S. Geological Survey in 1974 to conduct an artificial-recharge study of the alluvial aquifers in upper Black Squirrel Creek basin, Jimmy Camp Valley, and the Widefield aquifer in Fountain Valley. The purpose of the investigation was to determine the artificial-recharge potential for selected sites in the unsaturated alluvium overlying the aquifers. The artificial-recharge tests also will aid in the evaluation of the suitability of the aquifers for storage of surplus water.

Scope

The scope of this investigation included the determination of the continuous infiltration rates in nine spreading ponds located in the alluvial aquifers in upper Black Squirrel Creek basin, Jimmy Camp Valley, and the Widefield aquifer in Fountain Valley. The artificial-recharge tests provided information on the temporal and spatial variations in infiltration rates for the

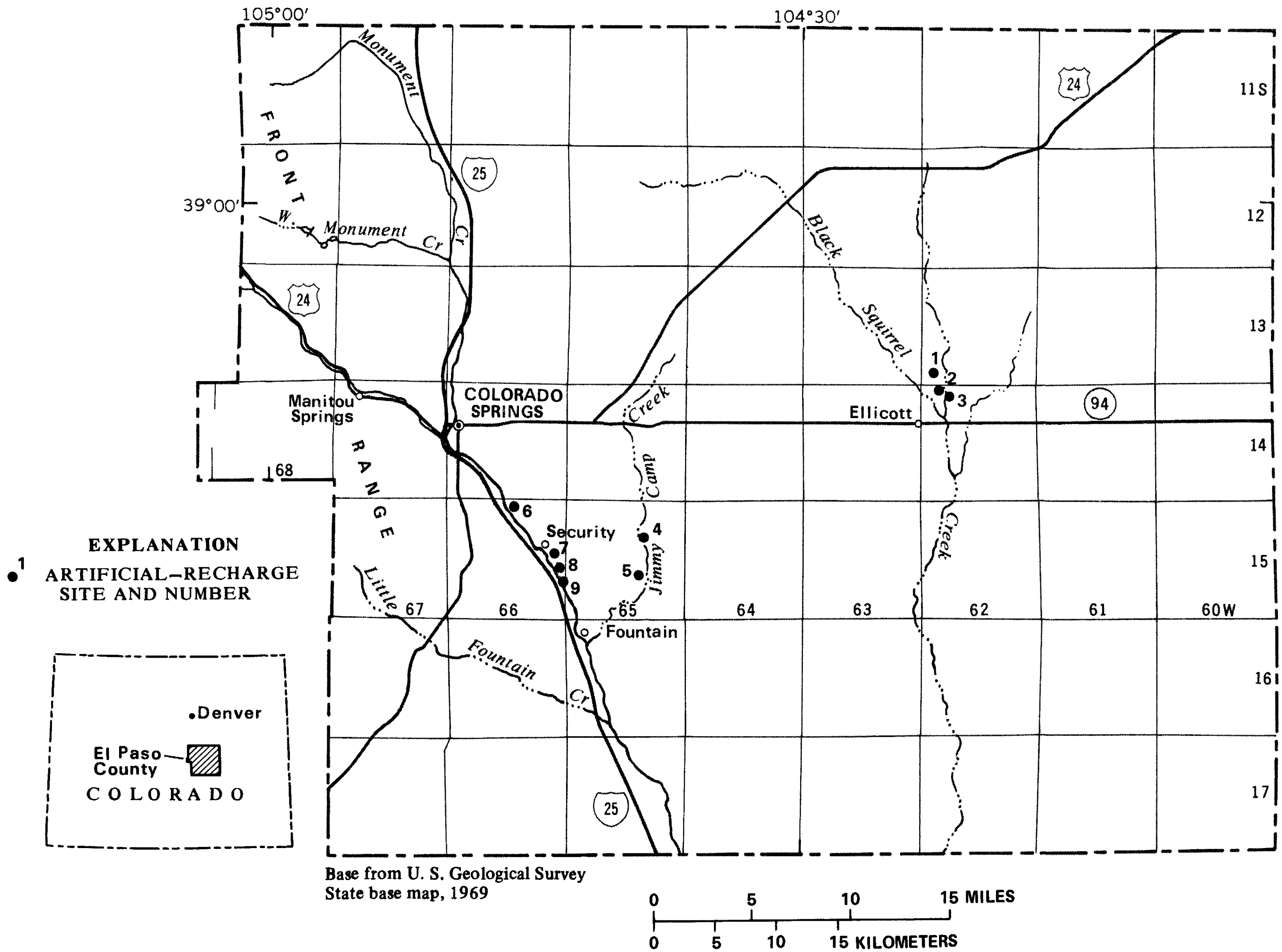


Figure 1.--Location of study area.

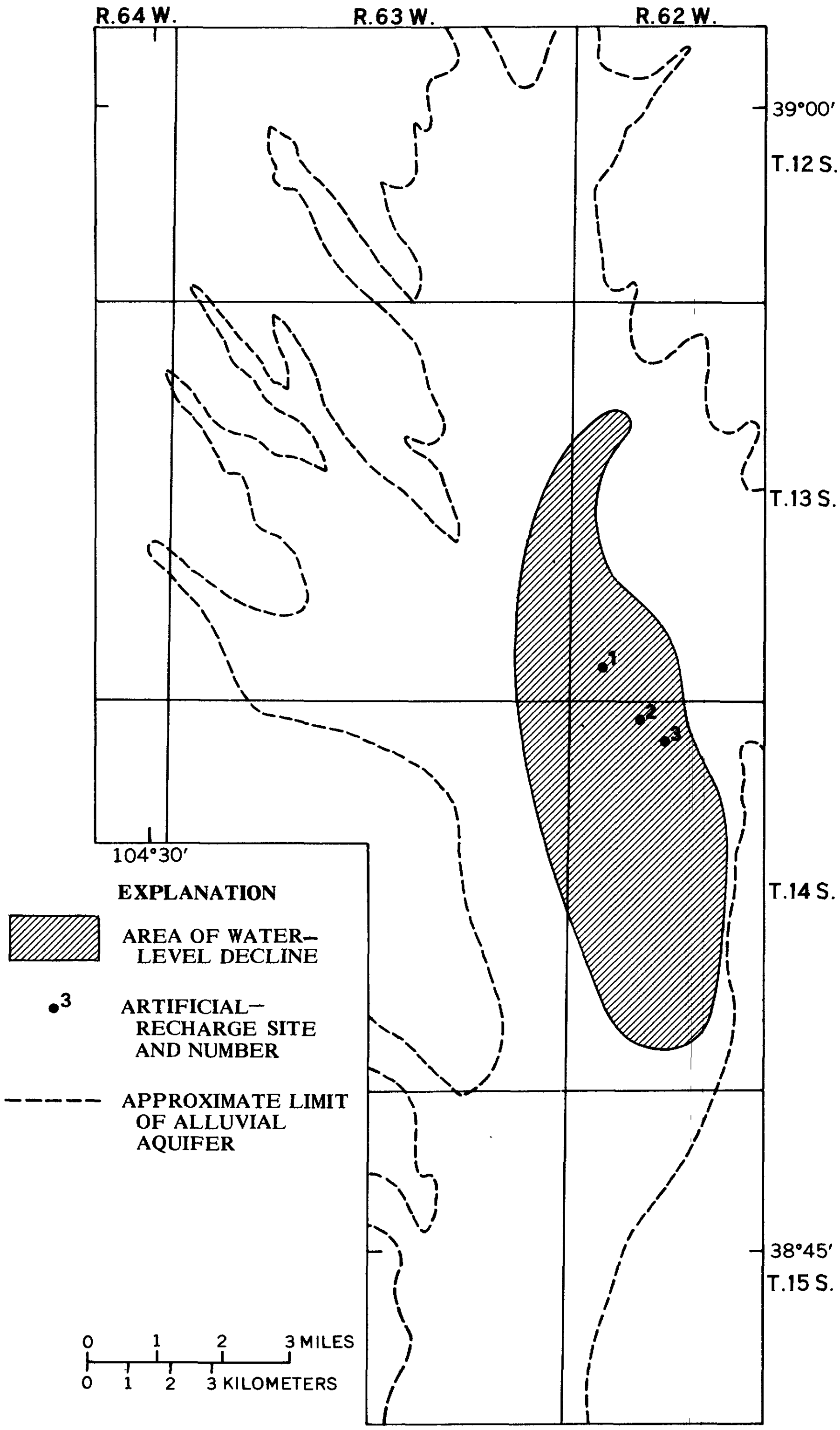


Figure 2.--Alluvial aquifer in upper Black Squirrel Creek basin.

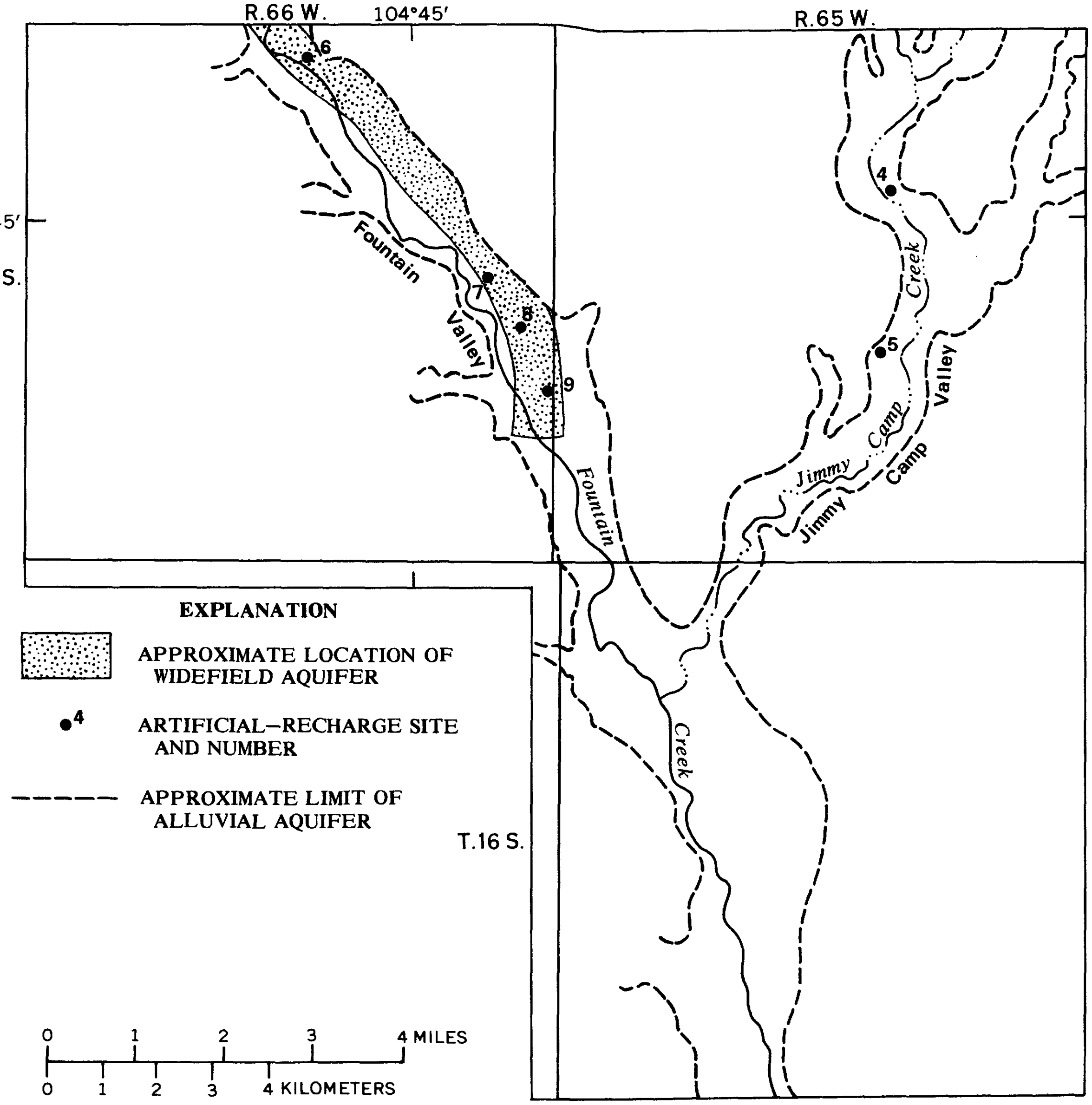


Figure 3.--Alluvial aquifer in Jimmy Camp Valley and Widefield aquifer in Fountain Valley.

three aquifers. Two observation wells were drilled at each site to monitor the effects of artificial recharge on the aquifers. Two bottom-sediment samples were collected from each pit to determine grain-size distribution and to determine possible relationships between grain size and infiltration rates. Periphyton, micro-organisms including algae, that are attached to or live upon submerged solid surfaces, were collected from each pond to evaluate their possible effects on infiltration rates.

Acknowledgments

The author wishes to thank the members of the El Paso County Water Association for their assistance in selecting the artificial-recharge sites and for supplying water at six of the sites; Mrs. Vera Ceresa, the J. H. W. Investment Co., The Cer Don Co., Cimarron Corp., Mr. Leo Ververs, and Continental Materials Corp. for allowing artificial-recharge tests to be conducted on their property; and Mr. E. F. Gobatti for making equipment available and for providing assistance with the artificial-recharge tests. Special thanks are extended to Mr. Richard Janitell for allowing artificial-recharge tests to be conducted on his property and for making equipment available, including a bulldozer.

GEOHYDROLOGY AFFECTING ARTIFICIAL RECHARGE

The feasibility of artificially recharging an aquifer, using the technique of water spreading, is dependent on both the geologic and hydraulic characteristics of the aquifer and of the sediments overlying the aquifer through which the recharge water must percolate. The geohydrology of upper Black Squirrel Creek basin has been reported by McGovern and Jenkins (1966), Erker and Romero (1967), Goeke (1970), and Bingham and Klein (1973b). Previous investigations of the geology and hydrology of Jimmy Camp Valley and the Widefield aquifer in Fountain Valley include Jenkins (1964), Bingham and Klein (1973a), Scott and Wobus (1973), and Klein and Bingham (1975).

A summary of the aquifer characteristics relating to artificial recharge is given in table 1. The hydraulic conductivity of the aquifer is the rate at which water is transmitted through a unit area of an aquifer under a unit hydraulic gradient. The specific yield is the ratio of the volume of water drained by gravity from an unconfined aquifer to its own volume.

Upper Black Squirrel Creek Basin

The Colorado Ground Water Commission has declared the Black Squirrel area to be a "Designated Ground Water Basin" as defined in the "Colorado Ground Water Management Act," chapter 148-18, revised 1965. Ground water which is within the geographic boundaries of a designated ground-water basin is that ground water which, in its natural course, would not be available to and required for the fulfillment of decreed surface-water rights, or ground water in areas not adjacent to a continuously flowing natural stream wherein ground-

Table 1.--*Summary of alluvial aquifer characteristics*

Aquifer location	Area (square) miles)	Average depth to water below land surface in spring 1974 (feet)	Hydraulic conductivity (feet per day)	Specific yield	Dissolved-solids concentration (milligrams per liter)
Upper Black Squirrel Creek basin-----------	101.3	29	127	0.20	<400
Jimmy Camp Valley-------	13.5	20	135	.1	[1]500-3,000
Fountain Valley (Widefield aquifer)---	3.3	33	757	.25	500

[1]Dissolved-solids concentration increases from about 500 mg/L (milligrams per liter) approximately 2 mi northeast of artificial-recharge site 5, to about 3,000 mg/L near the confluence with Fountain Valley.

water withdrawals have constituted the principal water usage. The boundaries of the designated basin correspond to the natural limits of the surface-water drainage basin except for the southern boundary. The southern boundary is set as the south line of township 15 south even though the alluvial aquifer extends farther south.

The alluvial aquifer covers approximately 100 mi^2 (260 km^2) of the 350-mi^2 (910-km^2) upper Black Squirrel Creek basin. Some of the characteristics of the aquifer in upper Black Squirrel Creek basin in table 1 were estimated. The average depth to water of 19 ft (5.8 m) below land surface was extrapolated from water-level data contained almost exclusively in T. 14 S., R. 62 W. (fig. 2). Erker and Romero (1967) estimated the hydraulic conductivity of the aquifer from three aquifer tests which they felt may not be representative of the entire aquifer.

According to Erker and Romero (1967) and Goeke (1970), the alluvium in which the aquifer is located consists generally of light-yellowish-gray to grayish-orange gravelly sand with silt and clay and minor amounts of reworked shale which are generally in thin beds. The presence of thin, discontinuous beds of clay and silt can affect significantly the artificial-recharge potential of the area as evidenced at artificial-recharge site 2. Well logs for observation wells SC14-62- 5BBC1 and SC14-62- 5BBC2 (see section on Supplemental Information), located 23 and 52 ft (7.0 and 15.8 m), respectively, south of the artificial-recharge pit, do not indicate the presence of a clay layer. Nevertheless, part of the pit was excavated in a very hard, dark-gray clay which significantly reduced the artificial recharge at the site.

Eolian deposits, referred to by Erker and Romero (1967) as "dune sand," and terrace deposits generally lie above the water table. The eolian deposits overlie much of the alluvium and bedrock in the southern and west-central parts of the basin. These deposits are 0- to 30-ft (0- to 9.1-m) thick and consist of silt and very fine to very coarse sand. The terrace deposits are located generally in the eastern part of the area. These deposits are 0- to 60-ft (0- to 18-m) thick and are approximately the same color and texture as the underlying alluvium.

The well logs of wells SC13-62-31ACC2, SC13-62-31ACC3, SC14-62- 5BBC1, and SC14-62- 5BBC2 (Supplemental Information) indicate that 5 to 10 ft (1.5 to 3.0 m) of younger alluvium(?) overlies the eolian deposits at artificial-recharge sites 1 and 2. The well logs of observation wells SC14-62- 5CAA1 and SC14-62- 5CAA2 indicate that the younger alluvium(?) and eolian deposits are not present or are not distinguishable from the alluvium at site 3.

The bedrock formations underlying the upper Black Squirrel Creek basin are the Dawson and Laramie Formations and the Fox Hills Sandstone of Tertiary and Cretaceous age. The Dawson Formation which underlies most of the basin is composed of sandstone and shale. According to Livingston, Bingham, and Klein (1975), the hydraulic conductivity of the Dawson Formation ranges from 0.03 to 4.5 ft/d (0.01 to 1.8 m/d). No aquifer-test data are available for the Laramie Formation. Erker and Romero (1967) state that the Laramie Formation, which consists of sandstone lenses usually isolated by clay or silt, is not capable of transmitting significant quantities of water. The hydraulic conductivity of the Fox Hills Sandstone in the Denver area ranges from 0.3 to 0.8 ft/d (0.1 to 0.2 m/d) and the hydraulic conductivity is believed to be similar in the upper Black Squirrel Creek basin. In contrast to the alluvial aquifer, which has a hydraulic conductivity of 127 ft/d (38.7 m/d), the hydraulic conductivites of the bedrock formations are low. Ground-water loss from the alluvial aquifer due to percolation in the bedrock was estimated as approximately 3,000 acre-ft (4.0×10^6 m^3) per year (Erker and Romero, 1967).

Jimmy Camp Valley

The alluvial aquifer in Jimmy Camp Valley covers an area of about 13.5 mi^2 (35.0 km^2). The characteristics of the aquifer are summarized in table 1. The specific yield of the aquifer was estimated by comparison of the types of alluvial deposits and the specific yields of the other aquifers.

According to Scott and Wobus (1973), nearly all of the valley fill is alluvium consisting generally of gray to brown humic-rich clayey silt and sand containing pebble lenses in the lower parts. Minor eolian deposits also are present but generally lie above the water table and are not considered as potential artificial-recharge areas. The well logs for wells SC15-65-10DCB2 and SC15-65-10DCB3, located at artificial-recharge site 4, and SC15-65-22DBA5 and SC15-65-22DBA6, located at artificial-recharge site 5 (Supplemental Information), indicate that the sites were located in sand.

Fountain Valley (Widefield Aquifer)

A summary of the hydrologic characteristics of the Widefield aquifer in Fountain Valley is contained in table 1. The Widefield aquifer is located in an ancestral, buried channel of Fountain Creek, indicated by Jenkins (1964) to be separated from the present stream course by a shale ridge. Jenkins believed the Widefield aquifer to be in hydraulic connection with Fountain Creek at the north and south ends of the aquifer. According to Livingston, Klein, and Bingham (1976a), the shale barrier is shallow and discontinuous and possibly may not exist. Gain-loss studies on Fountain Creek indicate that the stream and aquifer are in good hydraulic connection along the shale ridge, with the Widefield aquifer losing 13 ft^3 (0.37 m^3) to Fountain Creek.

The alluvium in which the Widefield aquifer is located consists generally of yellowish-brown gravelly sand containing pebbles, cobbles, and boulders (Scott and Wobus, 1973). Well logs from wells SC15-66-13CCA2 and SC15-66-13CCA3, located at artificial-recharge site 7, SC15-66-24ACB1 and SC15-66-24ACB2, located at site 8, and SC15-66-25AAA3 and SC15-66-25AAA4, located at site 9 (Supplemental Information), indicate that the coarse alluvium is overlain by 4 to 13 ft (1.2 to 4.0 m) of clayey silt to very fine sand. The fine-grained sediments may impede artificial recharge to the aquifer. Artificial-recharge site 6 was located in an abandoned sand and gravel pit. Well logs from wells SC15-66- 3BCA3 and SC15-66- 3BCA4, located at site 6, indicate that the fine-grained sediments are absent.

The bedrock formation underlying Jimmy Camp Valley and the Widefield aquifer in Fountain Valley is the Cretaceous Pierre Shale. The shale has very low hydraulic conductivity and transmits little or no water. Ground-water losses from the alluvial aquifers due to percolation into the bedrock are negligible.

ARTIFICIAL RECHARGE

Description of Tests

Nine artificial-recharge pits were excavated at locations shown on figure 1. Three pits were excavated in upper Black Squirrel Creek basin (fig.2), two in Jimmy Camp Valley, and four in the Widefield aquifer in Fountain Valley (fig. 3). Each pit was excavated to a depth of about 3 ft (0.9 m) and an average surface area of 9,200 ft^2 (850 m^2). Obstructions encountered during excavation at artificial-recharge sites 4 and 8 prevented the pits from being excavated to the desired dimensions. Due to an insufficient water supply at site 4, the area of the pit was later reduced to 1,400 ft^2 (130 m^2). Two observation wells were drilled at each site to monitor the effects of artificial recharge on the water table in the alluvial aquifer. Water for each of the tests was obtained from a nearby well or water-supply main. The characteristics of the sites are compiled in table 2. Two samples of the alluvial material were collected to a depth of about 6 in. (150 mm) at the bottom of each pit to determine grain-size distribution. The particle-size analyses are given in table 3.

Table 2.--*Characteristics of artificial-recharge sites*

Site number	Location	Pit dimensions (feet)	Observation well number	Distance from observation well to pit (feet)	Distance from observation well to water-supply well (feet)
		UPPER BLACK SQUIRREL CREEK BASIN			
1	SW¼NE¼ sec. 31, T. 13 S., R. 62 W.	96×97	SC13-62-31ACC2	27	187
			SC13-62-31ACC3	57.5	[1]212
2	NE¼NE¼ sec. 5, T. 14 S., R. 62 W.	98×101	SC14-62- 5BBC1	23	176
			SC14-62- 5BBC2	52	[1]205
3	NE¼SW¼ sec. 5, T. 14 S., R. 62 W.	95×99	SC14-62- 5CAA1	22.5	241
			SC14-62- 5CAA2	53	[1]270
		JIMMY CAMP VALLEY			
4	SW¼SE¼ sec. 10, T. 15 S., R. 65 W.	94×98 [2](-23×20)	SC15-65-10DCB2	27	197
		[3]35×40	SC15-65-10DCB3	57	227
5	NW¼SE¼ sec. 22, T. 15 S., R. 65 W.	189×45	SC15-65-22DBA5	26	168
			SC15-65-22DBA6	55	195
		FOUNTAIN VALLEY (Widefield aquifer)			
6	SW¼NW¼ sec. 3, T. 15 S., R. 66 W.	138×72	SC15-66- 3BCA3	82	153
			SC15-66- 3BCA4	94	181.7
7	SW¼SW¼ sec. 13, T. 15 S., R. 66 W.	95×95	SC15-66-13CCA2	23	325
			SC15-66-13CCA3	54.5	356.5
8	SW¼NE¼ sec. 24, T. 15 S., R. 66 W.	95×98	SC15-66-24ACB1	19.3	217
		[2](-6×13)	SC15-66-24ACB2	48.5	243
9	NE¼NE¼ sec. 25, T. 15 S., R. 66 W.	190×46	SC15-66-25AAA3	18.4	620
			SC15-66-25AAA4	52.5	636

[1]Distance from observation well to water-supply main.

[2]Obstruction prevented excavation of pit to size planned. Pit area equals pit dimensions minus obstruction dimensions in parentheses.

[3]Pit size reduced October 1975.

Table 3.--*Particle-size analyses of samples from bottom of artificial-recharge pits*

[Analyses by U.S. Geological Survey, Lakewood, Colo. Percentage composition by weight. Particle size in millimeters]

Sample location	Clay (less than 0.004)	Silt (0.004-0.0625)	Very fine sand (0.0625-0.125)	Fine sand (0.125-0.25)	Medium sand (0.25-0.5)	Coarse sand (0.5-1)	Very coarse sand (1-2)	Very fine gravel (2-4)	Fine gravel (4-8)	Medium gravel (8-16)	Coarse gravel (16-32)	Very coarse gravel (32-64)	Median size
UPPER BLACK SQUIRREL CREEK BASIN													
Pit 1 north	6.4	10.3	13.3	12.9	24.2	15.3	11.7	5.7	0.12	0	0	0	0.31
Pit 1 south	6.5	8.3	10.6	19.3	17.3	13.4	16.1	8.5	.07	0	0	0	.31
Pit 2 north	11.9	30.1	29.3	16.9	4.0	4.0	1.8	1.4	.70	0	0	0	.076
Pit 2 south	7.0	14.9	22.2	27.4	12.9	7.0	2.7	2.9	2.3	.67	0	0	.15
Pit 3 north	0.78		1.5	6.3	11.1	19.5	15.0	29.2	14.9	1.7	0	0	1.7
Pit 3 south	.83		.9	3.1	5.0	20.6	26.9	22.5	14.8	5.0	.52	0	1.7
JIMMY CAMP VALLEY													
Pit 4 north	20.3	15.4	10.4	15.6	17.4	20.0	0.81	0	0	0	0	0	0.15
Pit 4 south	20.6	15.8	12.3	23.0	22.2	5.8	.23	0	0	0	0	0	.13
Pit 5 east	24.8	23.4	16.7	24.1	9.7	1.1	.15	0	0	0	0	0	.07
Pit 5 west	20.4	23.9	18.0	23.0	9.2	3.1	1.2	.62	.48	0	0	0	.078
FOUNTAIN VALLEY (Widefield aquifer)													
Pit 6 north	0.48		0.75	2.2	5.0	15.0	15.6	19.5	16.3	9.1	3.6	12.6	3.0
Pit 6 south	5.3	2.7	2.1	5.4	9.6	16.5	27.8	13.8	7.6	4.4	2.9	1.8	1.2
Pit 7 north	4.1	3.2	3.4	5.3	7.8	10.8	17.3	13.8	11.2	9.8	5.6	7.8	1.9
Pit 7 south	17.0	30.5	23.2	14.3	5.0	2.7	.72	2.5	2.3	.82	.97	0	.067
Pit 8 north	8.8	5.9	3.4	7.8	7.9	18.0	25.8	15.4	6.4	.43	0	0	.93
Pit 8 south	18.7	37.0	12.3	8.8	7.1	7.4	4.7	3.5	.6	0	0	0	.045
Pit 9 north	50.8	35.4	8.7	2.8	.89	.97	.46	0	0	0	0	0	.0031
Pit 9 south	59.1	25.3	14.1	.95	.37	.12	0	0	0	0	0	0	.00097

A schematic diagram of a typical artificial-recharge site, related control devices, and method of monitoring effects of recharge are shown on figure 4. The water supply to the ponds was controlled by a valve except at artificial-recharge sites 2, 5, and 7, where regulation was achieved by stopping flow to the ponds. Flow to the ponds was measured using various methods and devices including a low-pressure-flow meter, Hoff meter, flume, bucket and stop watch, and the method for measuring flow from a horizontal or inclined pipe as described by Anderson (1973). The particular circumstances encountered at each artificial-recharge site dictated the means used to monitor flow to the ponds. Fluctuations in stage in the ponds were measured using a nonrecording gage or a graphic water-stage recorder. Water-table changes were obtained by periodic measurements of the water levels in the observation wells. The low mound in the water table shown on figure 4 is the expected response of the aquifer to artificial recharge.

Artificial-recharge tests of approximately 10 days' duration (referred to as test 10 in the report) were conducted at each of the nine artificial-recharge sites, and one extended artificial-recharge test of approximately 30 days' duration (referred to as test 30 in the report) was conducted at one site in each of the three study areas. Plastic strips were placed in the ponds during the artificial-recharge tests to collect periphyton.

Results of Tests

Other artificial-recharge studies indicate that the rate of artificial recharge varies with time even when the pond stage is maintained at a constant level. Initially, the rate increases rapidly to a maximum and then gradually declines after several days or weeks, due to the clogging effects of silt and clay particles and periphyton growth on the bottom of the pond. Because the recharge water was virtually sediment-free, the clogging effects of the fine-grained sediments were minimal. Identification of the periphyton collected from the artificial-recharge ponds is summarized in table 4. Although present, the growth of periphyton was insufficient to cause noticeable declines in the artificial-recharge rates because of the low temperature of the recharge water and the short duration of the tests. Several artificial-recharge studies have shown correlations between particle-size distribution of surface or near-surface sediments and rate of infiltration. No correlations were apparent in this study. However, data for each of the study areas may be insufficient to determine the existence of correlations between particle distribution from the pit bottoms (table 3) and the rates of infiltration.

A decrease in water temperature causes the viscosity of the water to increase, resulting in a decline in the hydraulic conductivity of the alluvium and a decline in the rate of artificial recharge. Water temperatures in the artificial-recharge ponds were monitored but no consistent correlation between water temperature and artificial recharge was observed. Due to the short duration of the tests and the lack of precipitation during the tests, no corrections were necessary for precipitation or evaporation.

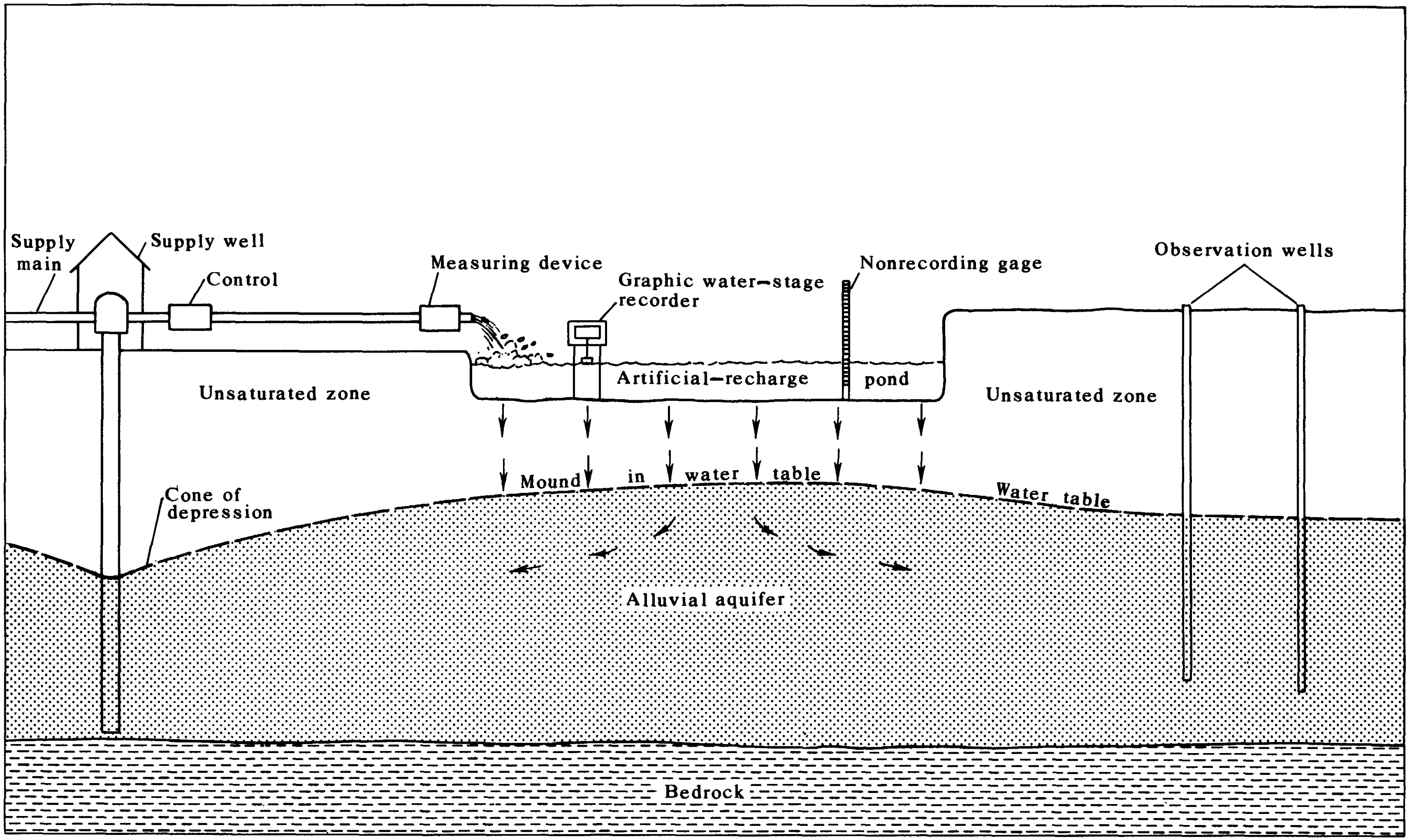


Figure 4.--Schematic diagram showing artificial–recharge pond.

Table 4.-*Identification of periphyton collected from artificial-recharge ponds*

[Analyses by U.S. Geological Survey, Atlanta, Ga.]

Site number	Artificial-recharge test	Period of sampling (days)	Water temperture (degrees Celsius)	Identification of periphyton	
				Common name	Organism (genus)
			UPPER BLACK SQUIRREL CREEK BASIN		
1	10	11	11.5-16	No organisms reported	----------------
	30	31	1 -11.5	Green algae	*Ulothrix*
				Diatoms: Pennate	**Nitzschia*
2	10	10	12.5-19.5	Green algae	*Scenedesmus*, **Stigeoclonium*
				Diatoms: Pennate-Naviculoid	*Amphora*, *Cymbella* *Navicula*, *Pinnularia* **Nitzschia*
				Blue-green algae: Filamentous	**Lyngbya*
3	10	9	.5- 9.5	Diatoms: Pennate-Naviculoid	**Navicula*
			JIMMY CAMP VALLEY		
4	10	--	---------	Not sampled	----------------
	30	29	8 -15.5	No organisms reported	----------------
5	10	10	16 -19.5	No organisms reported	----------------
			FOUNTAIN VALLEY (Widefield aquifer)		
6	10	10	14.5-16	Diatoms: Pennate	**Hantzschia*
7	10	--	---------	Not sampled	----------------
8	10	10	12 -16	No organisms reported[1]	----------------
9	10	10	17 -19	Green algae	*Oedogonium*, **Protococcus*
				Diatoms: Pennate	*Nitzschia*
				Blue-green algae: Filamentous	**Oscillatoria*
	30	30	7.5-13.5	Green algae	**Microspora*, **Protococcus*, **Ulothrix*
				Diatoms: Pennate	*Hantzschia*, **Nitzschia*

*Dominant organism.
[1]Water supply was chlorinated.

Artificial recharge to the aquifer is measured as the rate of infiltration of recharge water from the spreading pond expressed as the number of feet of decline in the water level in the pond for a 1-day period. The rate of infiltration is computed using the equation:

$$I = \frac{V-\Delta SA}{AT},$$

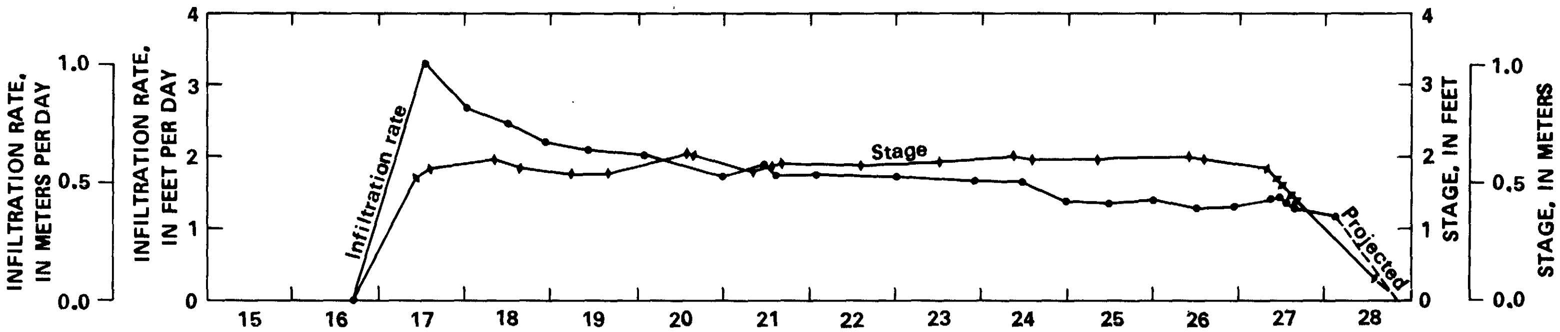
where I = the rate of infiltration, in feet per day;
V = the volume of inflow to the pond, in cubic feet;
ΔS = the change in stage (positive for stage increases and negative for stage decreases) in the pond, in feet, during time T;
A = the bottom surface area of the pond, in square feet; and
T = the time elapsed, in days.

Upper Black Squirrel Creek Basin

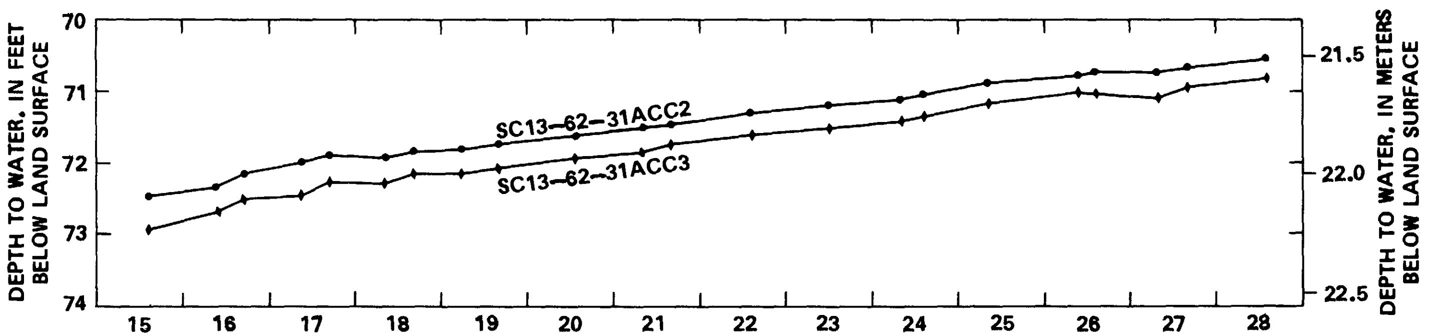
The results of artificial-recharge tests conducted in upper Black Squirrel Creek basin are given on figures 5 through 8 and are tabulated in table 5. The average rate of infiltration for test 10 at site 1 (fig. 5) was 1.7 ft/d (0.5 m/d), with an average stage in the artificial-recharge pond of 1.8 ft (0.5 m). Examination of the hydrographs of the water levels in observation wells SC13-62-31ACC2 and SC13-62-31ACC3 indicates a maximum water-table rise of about 2 ft (0.6 m). The water levels in the wells responded to artificial recharge and the recovery of the water table from recent cessation of pumping of a nearby municipal well. Of the 2-ft (0.6-m) rise, about 1 ft (0.3 m) was attributable to artificial recharge. The average rate of infiltration for test 30 at site 1 (fig. 6) was 1.2 ft/d (0.4 m/d), with an average stage of 1.5 ft (0.5 m). The hydrographs of the water levels in the observation wells indicate a maximum water-table rise of about 1.5 ft (0.5 m). Again, the water levels in the wells responded to artificial recharge and the recovery of the water table from recent cessation of pumping. Of the 1.5-ft (0.5-m) rise, about 0.3 ft (0.1 m) was attributable to artificial recharge.

The average rate of infiltration for test 10 at site 2 (fig. 7) was 1.0 ft/d (0.3 m/d), with an average stage in the artificial-recharge pond of 1.5 ft (0.5 m). Approximately 30 percent of the pit was excavated into a very hard, dark-gray clay which probably reduced the artificial recharge at the site. The irregular shape of the stage hydrograph was caused by the shutting off of the supply-well pump after each filling of the pond. Water levels in observation wells SC14-62- 5BBC1 and SC14-62- 5BBC2 rose a maximum of 0.8 ft (0.2 m). The water-level rise was caused by artificial recharge and recovery of the water table from recent cessation of pumping of a nearby municipal well. The part of the water-table rise attributable to artificial recharge could not be determined. The rapid decline in water levels in the observation wells, beginning August 28, was a result of the initiation of pumping of the nearby municipal well.

The average rate of infiltration for test 10 at site 3 (fig. 8) was 1.3 ft/d (0.4 m/d), and the average stage was 2.1 ft (0.6 m). The hydrographs of water levels in observation wells SC14-62- 5CCA1 and SC14-62- 5CCA2 indicate

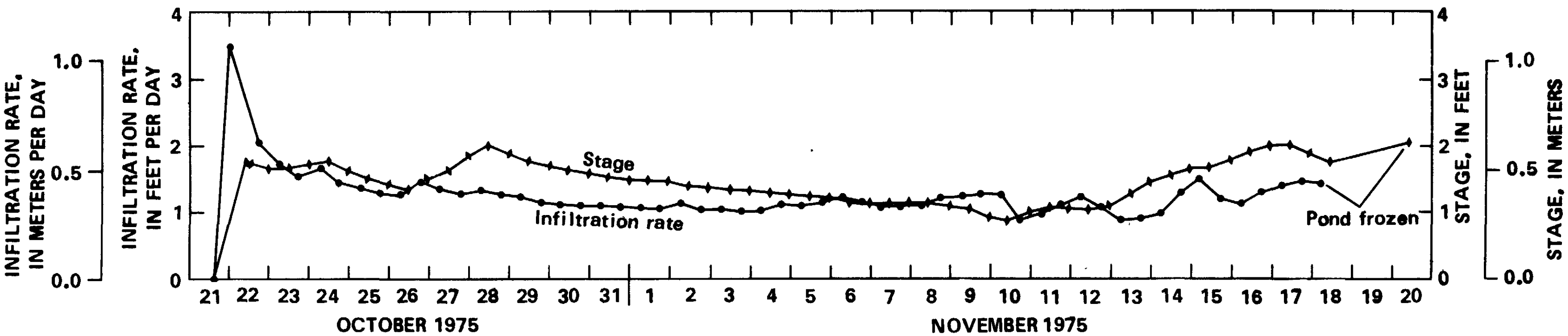


A.--Infiltration rate and stage.

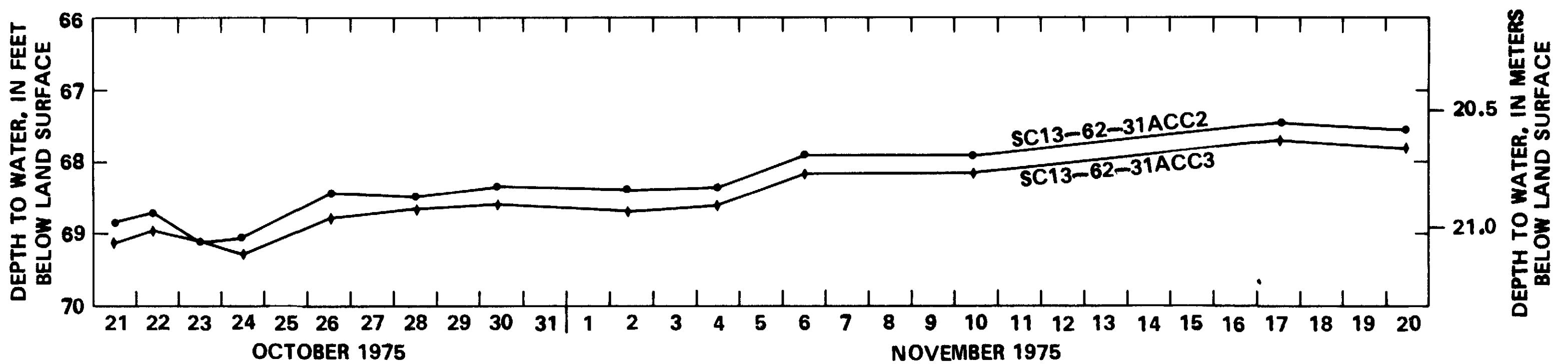


B.--Hydrographs of observation wells.

Figure 5.--Results of artificial-recharge test 10 at site 1.

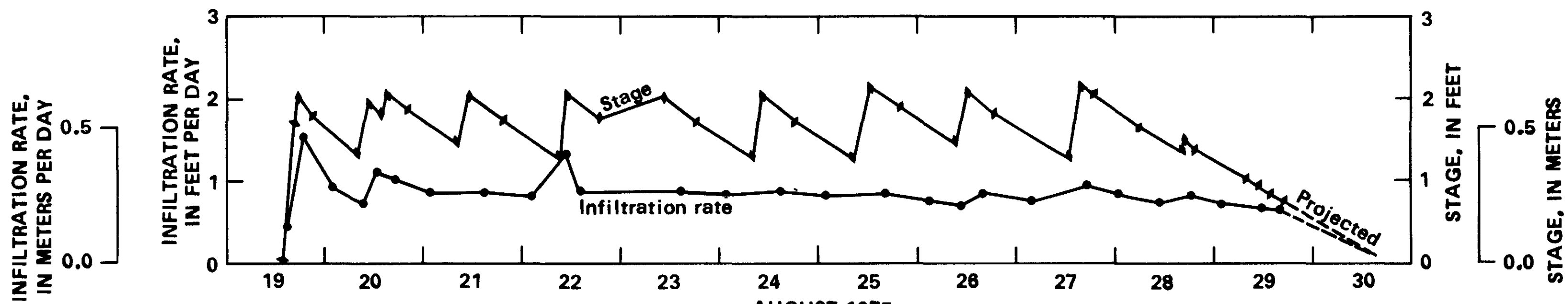


A.--Infiltration rate and stage.

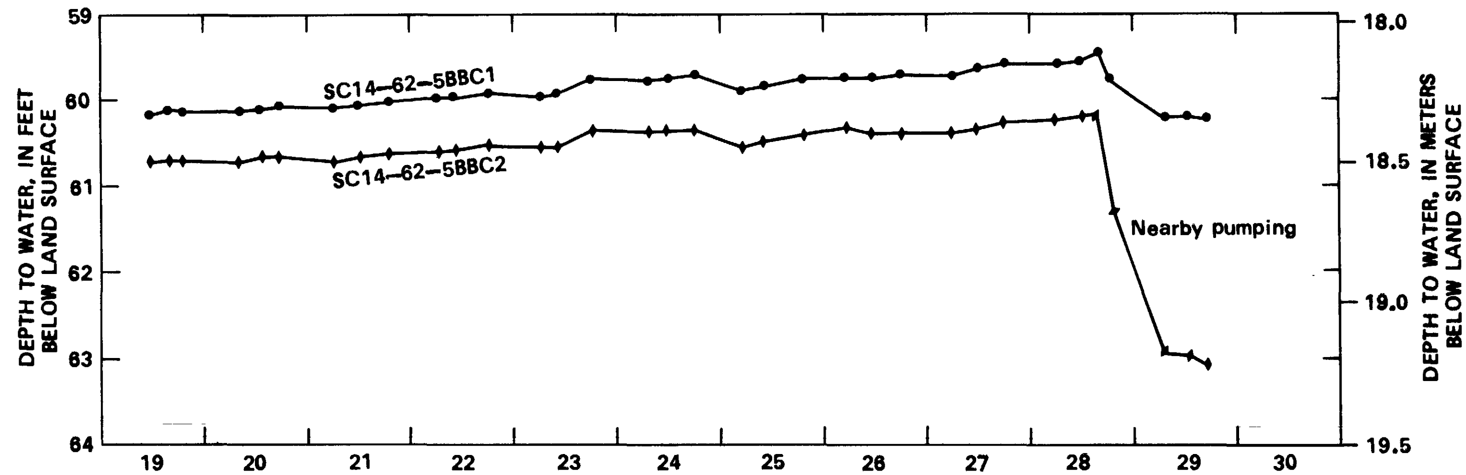


B.--Hydrographs of observation wells.

Figure 6.--Results of artificial-recharge test 30 at site 1.

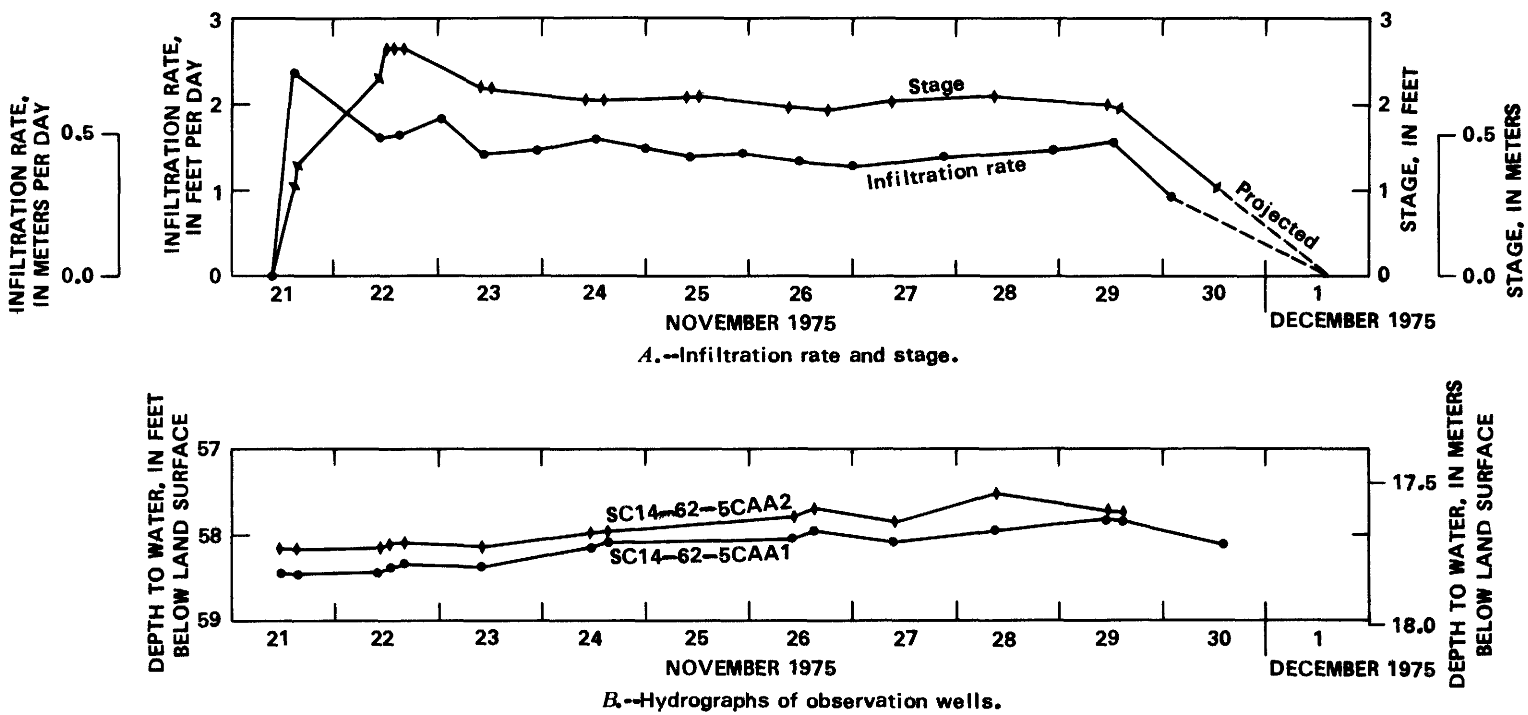


A.--Infiltration rate and stage.



B.--Hydrographs of observation wells.

Figure 7.--Results of artificial-recharge test 10 at site 2.



A.--Infiltration rate and stage.

B.--Hydrographs of observation wells.

Figure 8.--Results of artificial-recharge test 10 at site 3.

Table 5.--*Results of artificial-recharge tests in upper Black Creek basin*

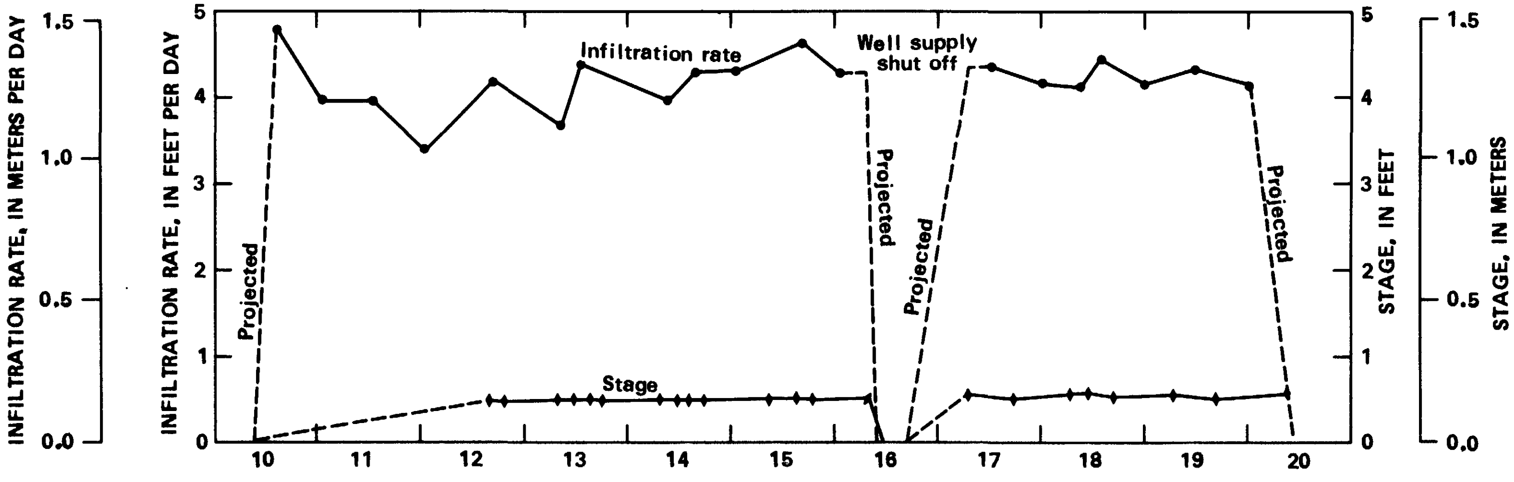
Site no.	Artificial-recharge test	Test dates in 1975	Pit area (square feet)	Water temperature (degrees Celsius)	Maximum recharge rate (feet per day)	Average recharge rate (feet per day)	Average stage (feet)
1	10	9-17 to 9-28	9,300	11.5-16	3.3	1.7	1.8
	30	10-21 to 11-18	9,300	1 -11.5	3.5	1.2	1.5
2	10	8-19 to 8-31	9,900	12.5-19.5	1.8	1.0	1.5
3	10	11-21 to 12- 1	8,400	.5- 9.5	2.4	1.3	2.1

a maximum rise of about 0.6 ft (0.2 m). The water levels in the observation wells responded to artificial recharge and recovery of the water table from recent cessation of pumping of a nearby municipal well. Of the 0.6-ft (0.2-m) rise, about 0.2 ft (0.06 m) was attributable to artificial recharge.

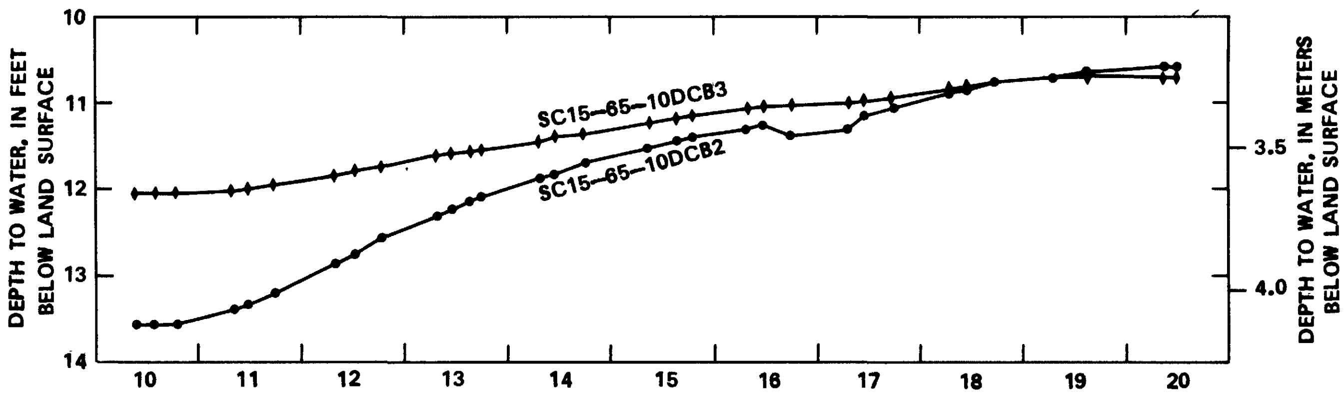
The alluvium in upper Black Squirrel Creek basin contains thin beds of silt and clay which can reduce significantly the infiltration rate of recharge water. The largest median-grain size of the alluvium (table 3) sampled in upper Black Squirrel Creek basin was from the pit at site 3 and the smallest median-grain size from the pit at site 2. Both sites, however, have nearly the same rate of infiltration. Clay and silt similar to that found at site 2 probably are present beneath the pit at site 3, resulting in much lower rates of infiltration. The rates of infiltration measured at site 1 may be representative of rates which could be expected in similar types of alluvium in the basin. The rates of infiltration measured at sites 2 and 3 may be representative of areas in the basin underlain by beds of silt and clay.

Jimmy Camp Valley

The results of artificial-recharge tests conducted in Jimmy Camp Valley are given on figures 9 through 11, and are tabulated in table 6. The average rate of infiltration for test 10 at site 4 (fig. 9) was 3.8 ft/d (1.2 m/d), with an average stage of 0.4 ft (0.1 m). The hydrographs of the water levels in observation wells SC15-65-10DCB2 and SC15-65-10DCB3 indicate a maximum water-table rise of about 3 ft (0.9 m). The water-level rise was a direct result of artificial recharge. The loss of water in the pond and resulting decline in the water level in observation well SC15-65-10DCB2 on September 16 was caused by a malfunction of the supply-well pump. The average infiltration rate for test 10 was approximated because the water supply was insufficient to cover more than 30 to 50 percent of the pit bottom. For test 30, the size of

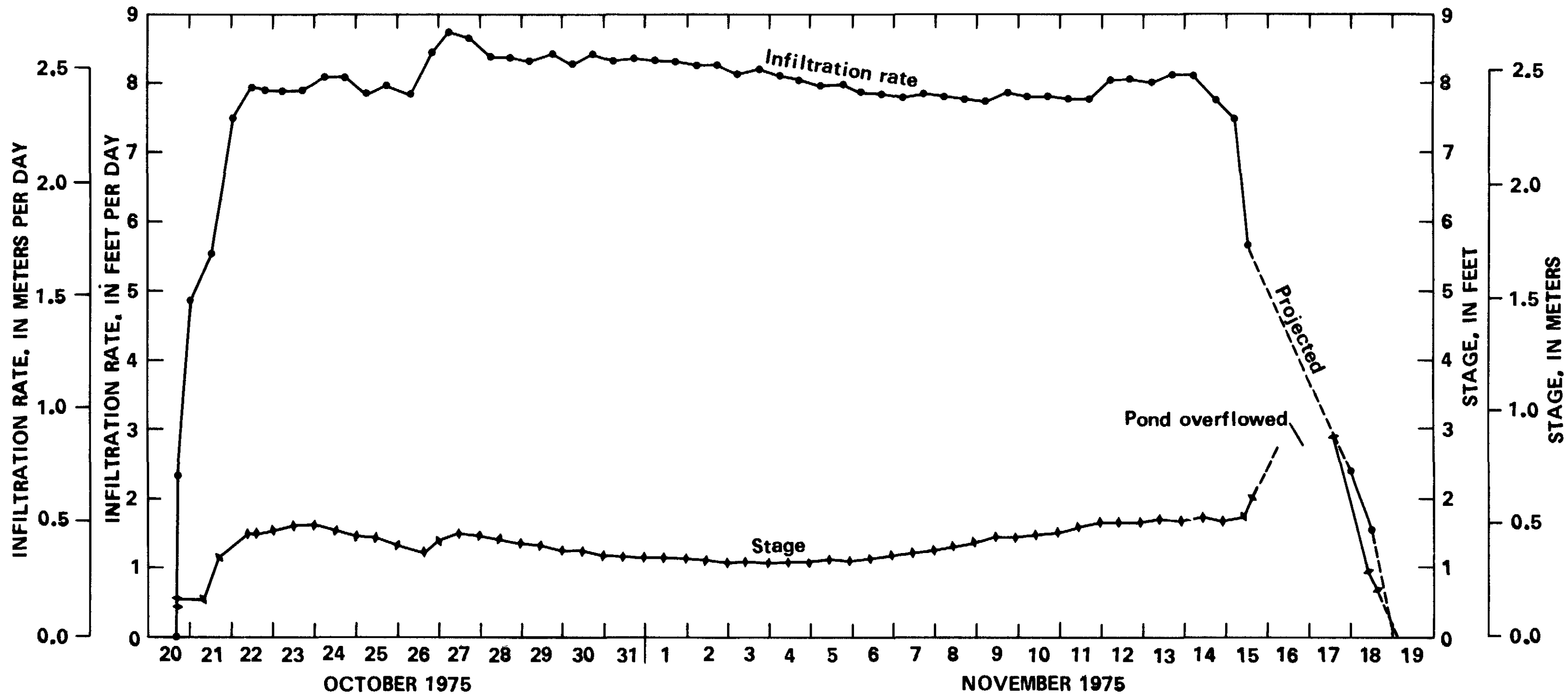


A.--Infiltration rate and stage.



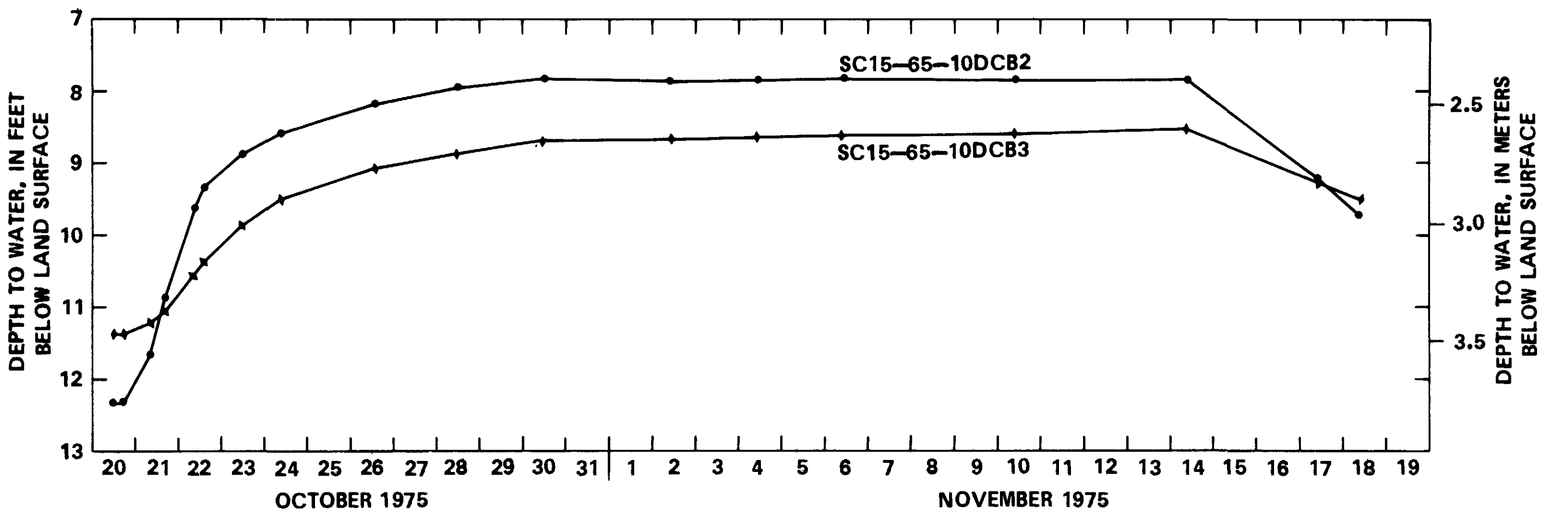
B.--Hydrographs of observation wells.

Figure 9.--Results of artificial-recharge test 10 at site 4.



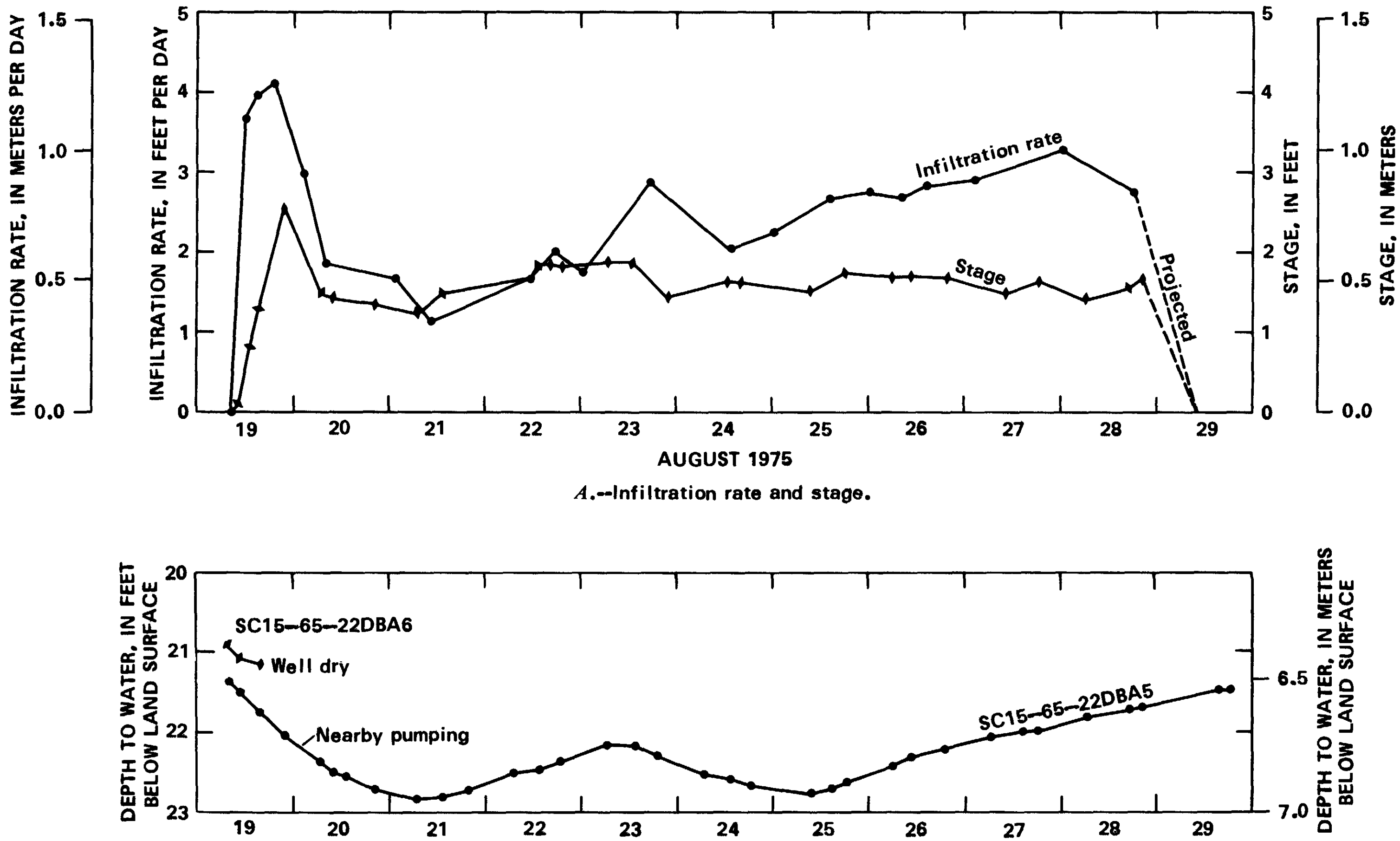
A.--Infiltration rate and stage.

Figure 10.--Results of artificial-recharge test 30 at site 4.



B.--Hydrographs of observation wells.

Figure 10.--Results of artificial–recharge test 30 at site 4--Continued.



A.--Infiltration rate and stage.

B.--Hydrographs of observation wells.

Figure 11.--Results of artificial-recharge test 10 at site 5.

the pit was reduced to 1,400 ft^2 (130 m^2). The reduced size allowed for a full pit and a more accurate determination of the rate of infiltration. The average rate of infiltration for test 30 at site 4 (fig. 10) was 7.9 ft/d (2.4 m/d), with an average stage in the pond of 1.3 ft (0.4 m). As a result of artificial recharge, the water levels in the observation wells rose a maximum of about 4.5 ft (1.4 m).

Table 6.--*Results of artificial-recharge tests in Jimmy Camp Valley*

Site no.	Artificial-recharge test	Test dates in 1975	Pit area (square feet)	Water temperature (degrees Celsius)	Maximum recharge rate (feet per day)	Average recharge rate (feet per day)	Average stage (feet)
4	10	9-10 to 9-20	8,800	10-13	4.8	3.8	0.4
	30	10-20 to 11-19	1,400	8-15.5	8.8	7.9	1.3
5	10	8-19 to 8-29	8,500	16-19.5	4.1	2.4	1.5

On November 15, several hundred cattle were released into the pasture where artificial-recharge site 4 was located. The cattle may have gone into the pond for water and compacted the bottom sediments which resulted in a reduction in the infiltration rate. The decline in the rate of infiltration caused the pond stage to rise to overflow level and the water levels in the observation wells to decline.

The average rate of infiltration for test 10 at site 5 (fig. 11) was 2.4 ft/d (0.7 m/d), with an average stage of 1.5 ft (0.5 m). The reason for gradual increase in the infiltration rate with time is uncertain. The drawdown caused by the pumping of the supply well lowered the water table below the bottom of observation well SC15-65-22DBA6 shortly after the test began. The hydrograph for observation well SC15-65-22DBA5 shows effects of the growth of the cone of depression and artificial recharge. As shown on figure 11, between August 19 and 21, pumping lowered the water level in the observation well. Beginning on August 21, recharge water caused the water level to rise. The reason for the water-level decline between August 23 and 25 is uncertain.

Examination of the well logs of the observation wells(Supplemental Information) in Jimmy Camp Valley does not indicate the presence of surficial materials or layers which differ significantly in texture from the general character of the alluvial-aquifer materials. The limited quantity of data collected prevents the interpretation of possible relationships which may exist between the grain-size distribution of the alluvium and rates of infiltration.

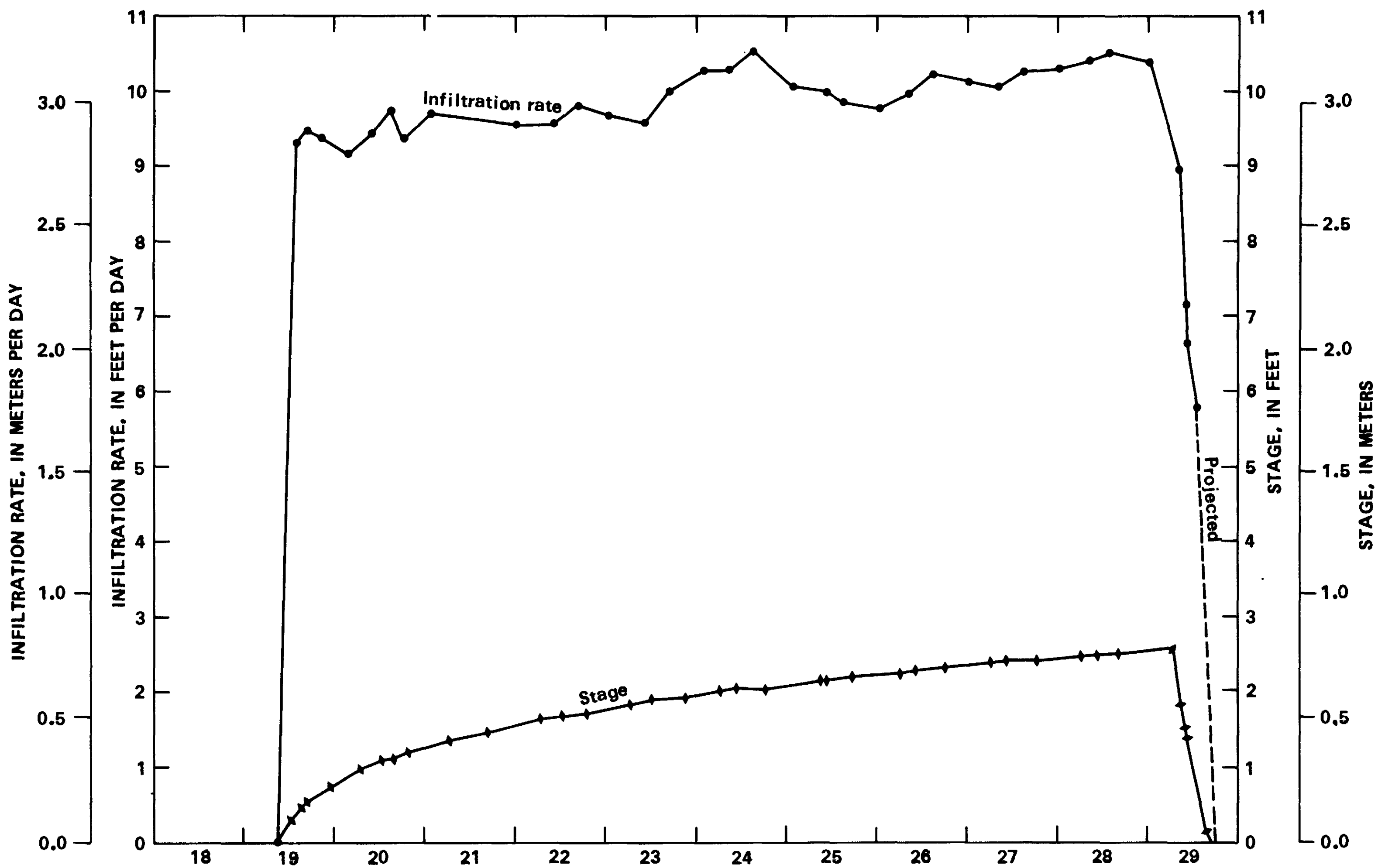
Fountain Valley (Widefield Aquifer)

The results of artificial-recharge tests conducted on the Widefield aquifer in Fountain Valley are given on figures 12 through 16 and are tabulated in table 7. The average rate of infiltration for test 10 at site 6 (fig. 12) was 9.9 ft/d (3.0 m/d), with an average stage in the artificial-recharge pond of 1.9 ft (0.6 m). The increasing rate of infiltration with time was caused, in part, by the increasing pond stage which directly affects the rates of infiltration. The hydrographs of the water levels in observation wells SC15-66-3BCA3 and SC15-66- 3BCA4 indicate that equilibrium conditions were attained in the aquifer on August 20, the third day of the test. The initial decline of about 3 ft (0.9 m) in the water level on August 18 and 19 was caused by pumping of the nearby supply well. On August 20, artificial recharge caused the water table to recover about 1 ft (0.3 m) and remain nearly constant for the remainder of the test.

The average rate of infiltration for test 10 at site 7 (fig. 13) was 5.8 ft/d (1.8 m/d), with an average stage of 1.4 ft (0.4 m). The extreme fluctuations in the pond stage and the rate of infiltration were caused by an unregulated water supply which was controlled by starting and stopping the supply-well pump. The water levels in observation wells SC15-66-13CCA2 and SC15-66-13CCA3 increased a maximum of 5.6 ft (1.7 m) due to artificial recharge. The small daily declines in water levels in the observation wells reflect the intermittent pumping of the nearby supply well and the large daily fluctuations in the infiltration rate.

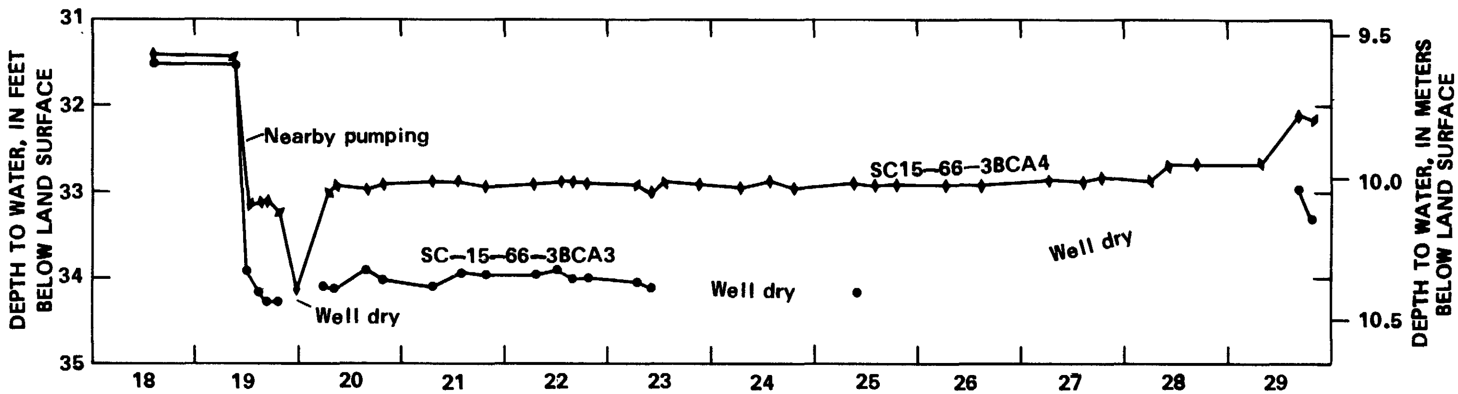
The average infiltration rate for test 10 at site 8 (fig. 14) was 4.6 ft/d (1.4 m/d) and the average pond stage was 1.0 ft (0.3 m). The reason for the increasing rate of infiltration with time is uncertain. The water levels in observation wells SC15-66-24ACB1 and SC15-66-24ACB2 responded to the effects of pumping and artificial recharge. Well SC15-66-24ACB1, located nearest to the artificial-recharge pond, declined during the first day of the test due to pumping. By September 11, artificial recharge resulted in the recovery of the water table and a rise of about 1 ft (0.3 m) above the initial water level. The hydrograph of the water levels in well SC15-66-24ACB2 indicates that pumping caused the water level to decline on September 10 and 11, the first 2 days of the test. On September 11, artificial recharge caused the water table to begin recovery. By September 15, an approximate equilibrium between pumping and recharge apparently occurred, resulting in the water level remaining nearly constant for the remainder of the test.

The average infiltration rate for test 10 at site 9 (fig. 15) was 1.3 ft/d (0.4 m/d), with an average stage in the artificial-recharge pond of 1.4 ft (0.4 m). The hydrographs of the water levels in observation wells SC15-66-25AAA3 and SC15-66-25AAA4 indicate the water levels rose a maximum of 1.2 ft (0.4 m) due to artificial recharge. The average infiltration rate for test 30 at site 9 (fig. 16) was 1.4 ft/d (0.4 m/d) and the average pond stage was 0.9 ft (0.3 m). The loss of water in the artificial-recharge pond and subsequent decline in the rates of infiltration on November 2 and 10 were caused by the inadvertent shutoff of the supply-well pump. The water levels in the observation wells rose a maximum of 2.1 ft (0.6 m) as a result of artificial recharge during the test.



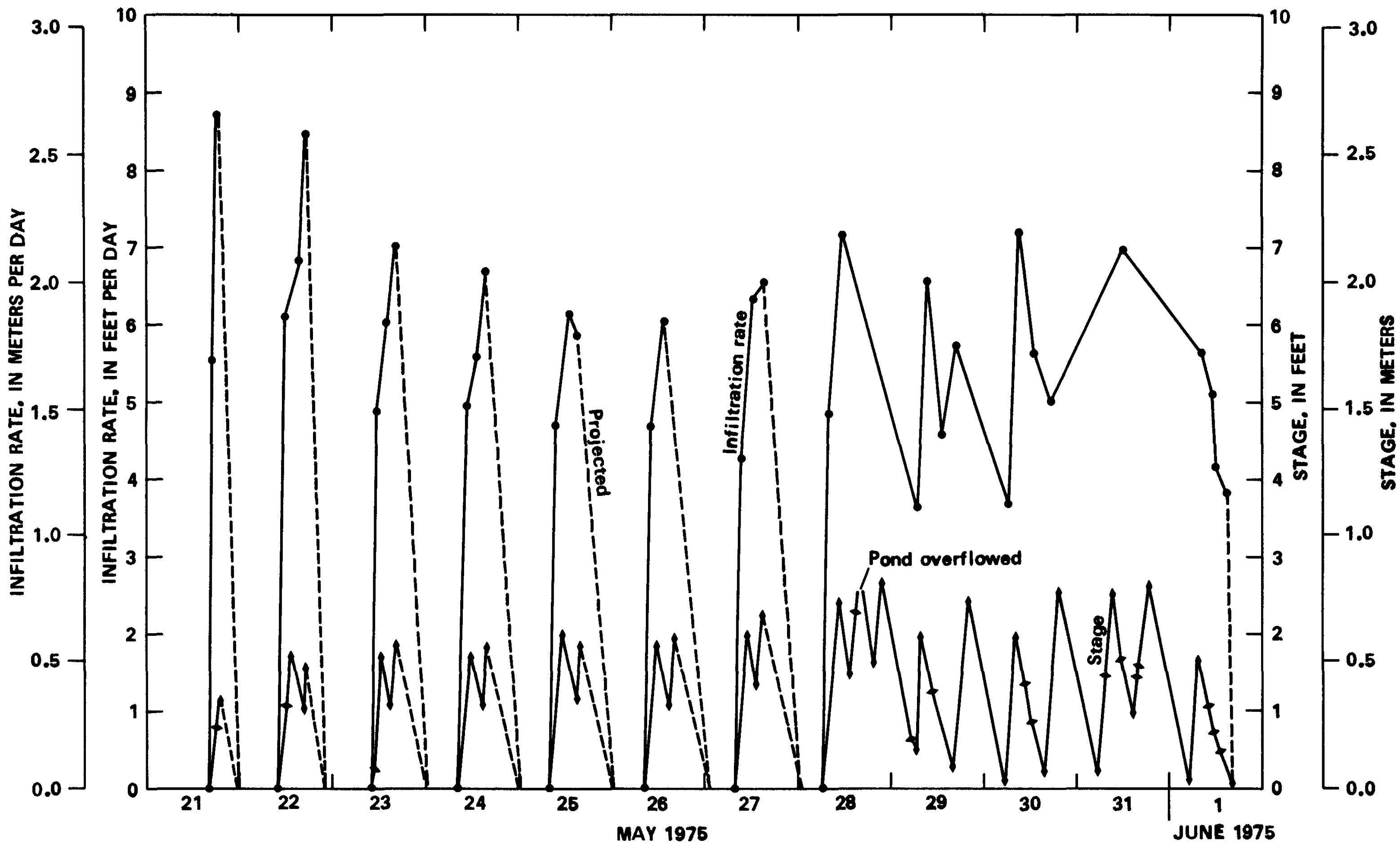
A.Infiltration rate and stage.

Figure 12.--Results of artificial–recharge test 10 at site 6.



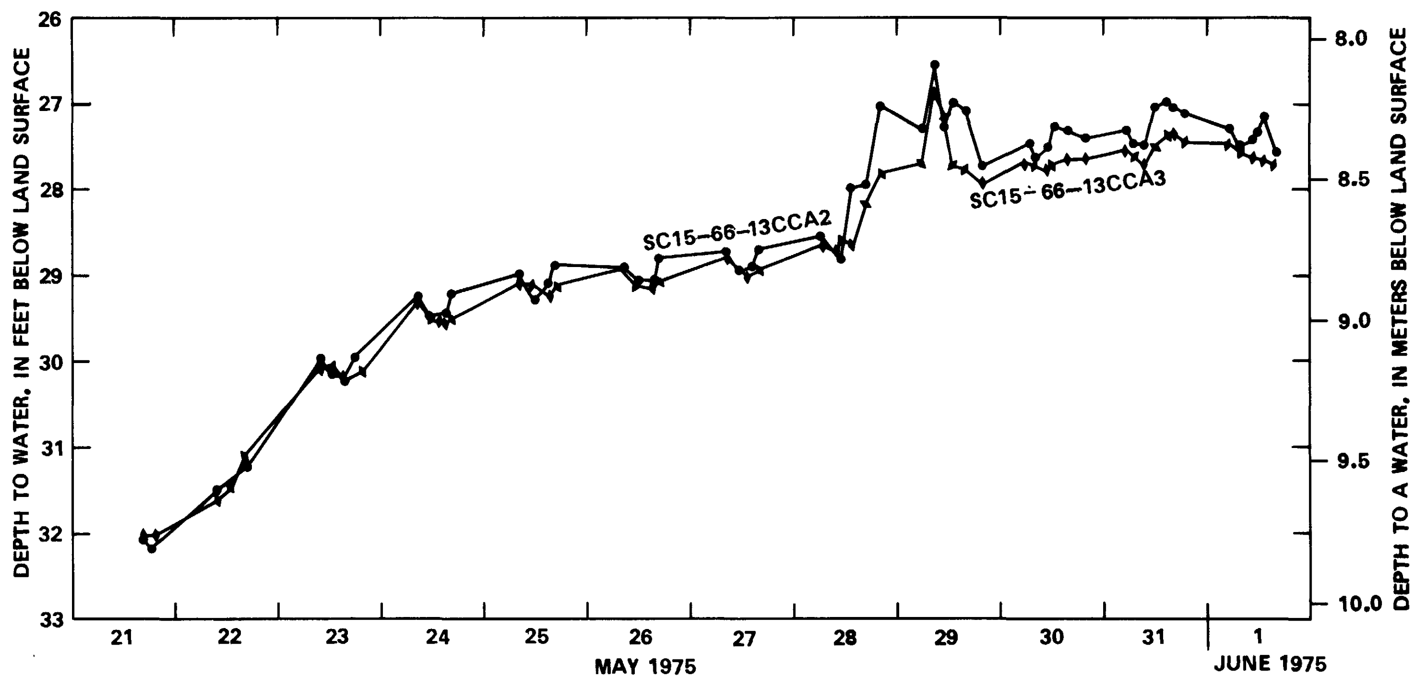
B.--Hydrographs of observation wells.

Figure 12.--Results of artificial-recharge test 10 at site 6--Continued.



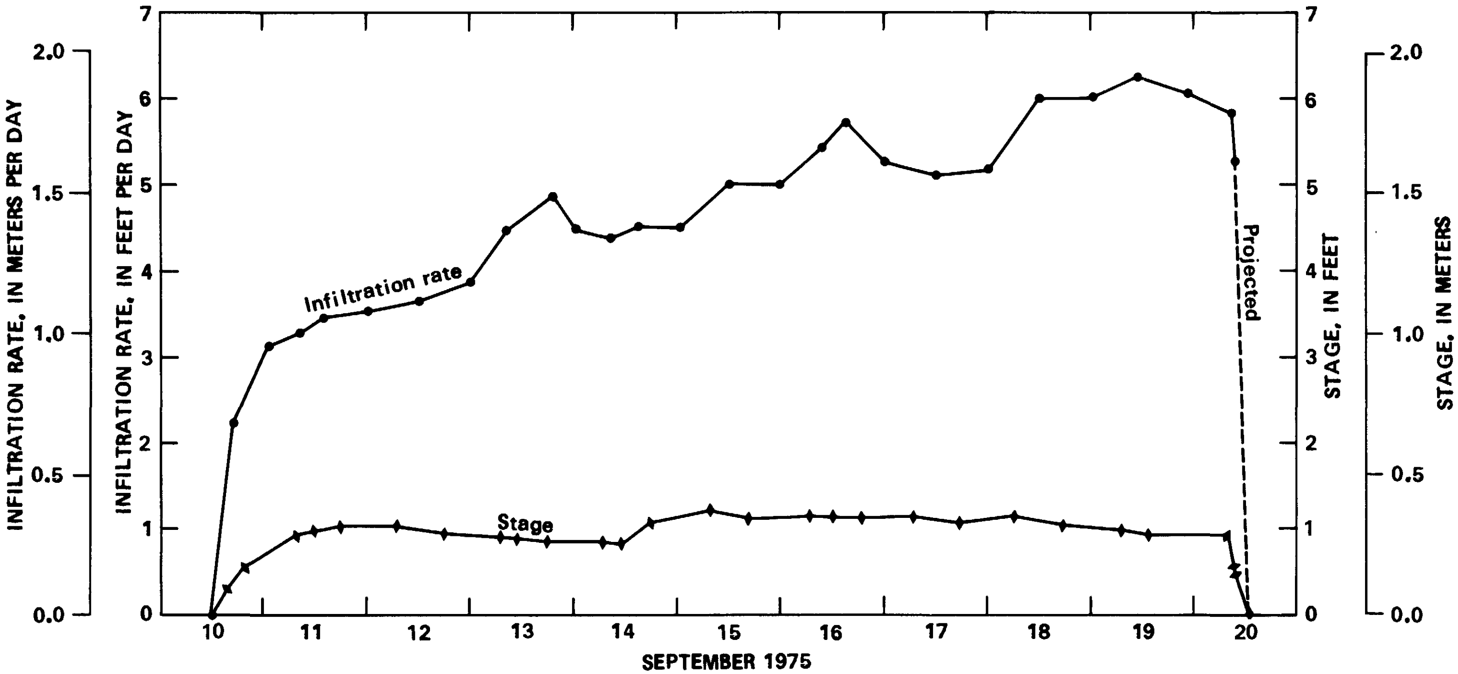
A.--Infiltration rate and stage.

Figure 13.--Results of artificial-recharge test 10 at site 7.

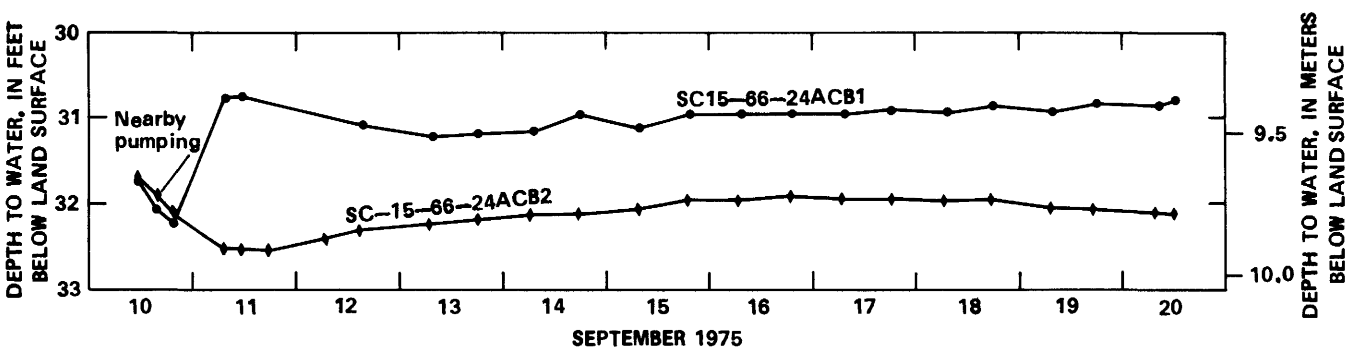


B.--Hydrographs of observation wells.

Figure 13.--Results of artificial-recharge test 10 at site 7--Continued.

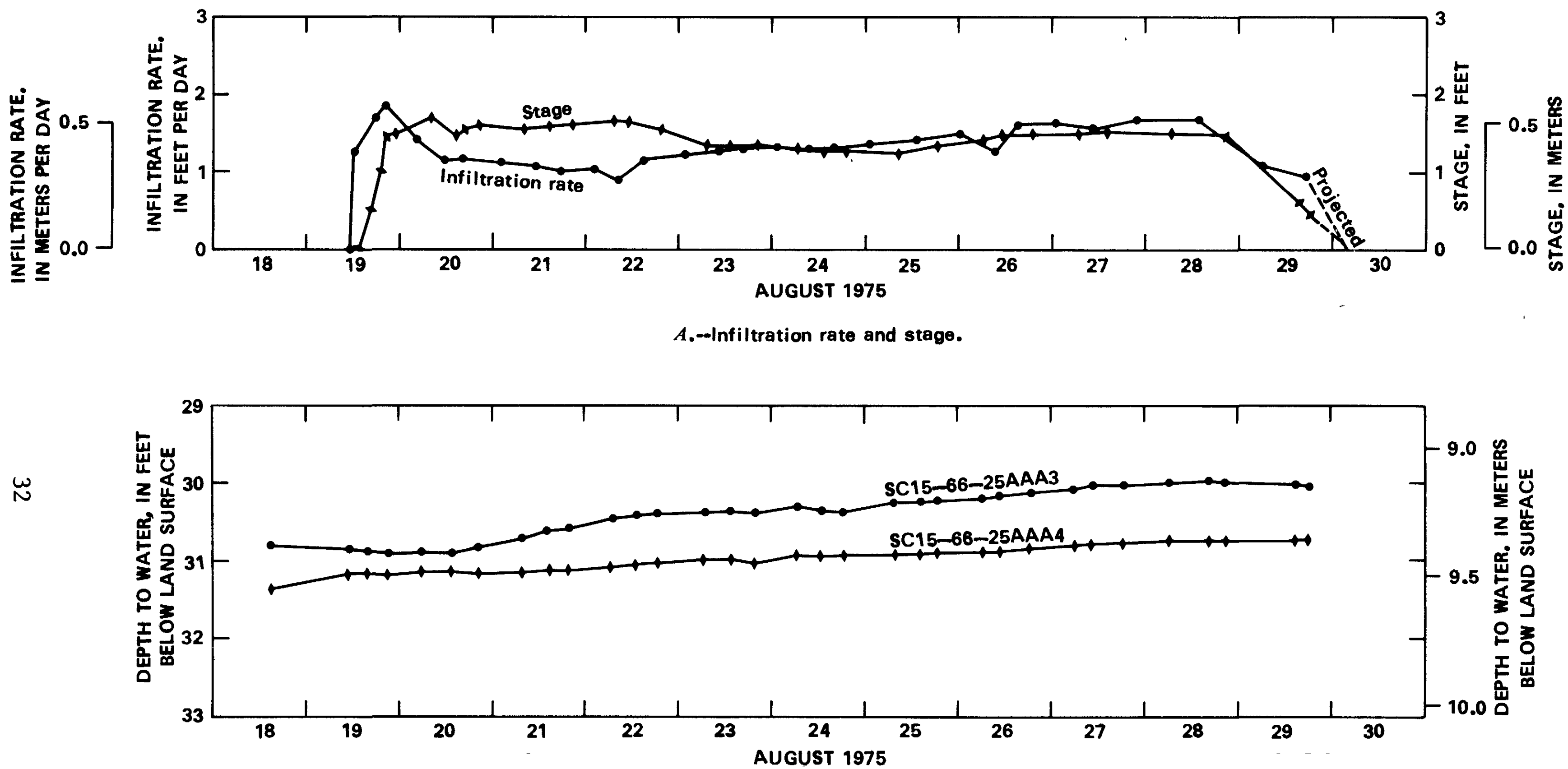


A.--Infiltration rate and stage.



B.--Hydrographs of observation wells.

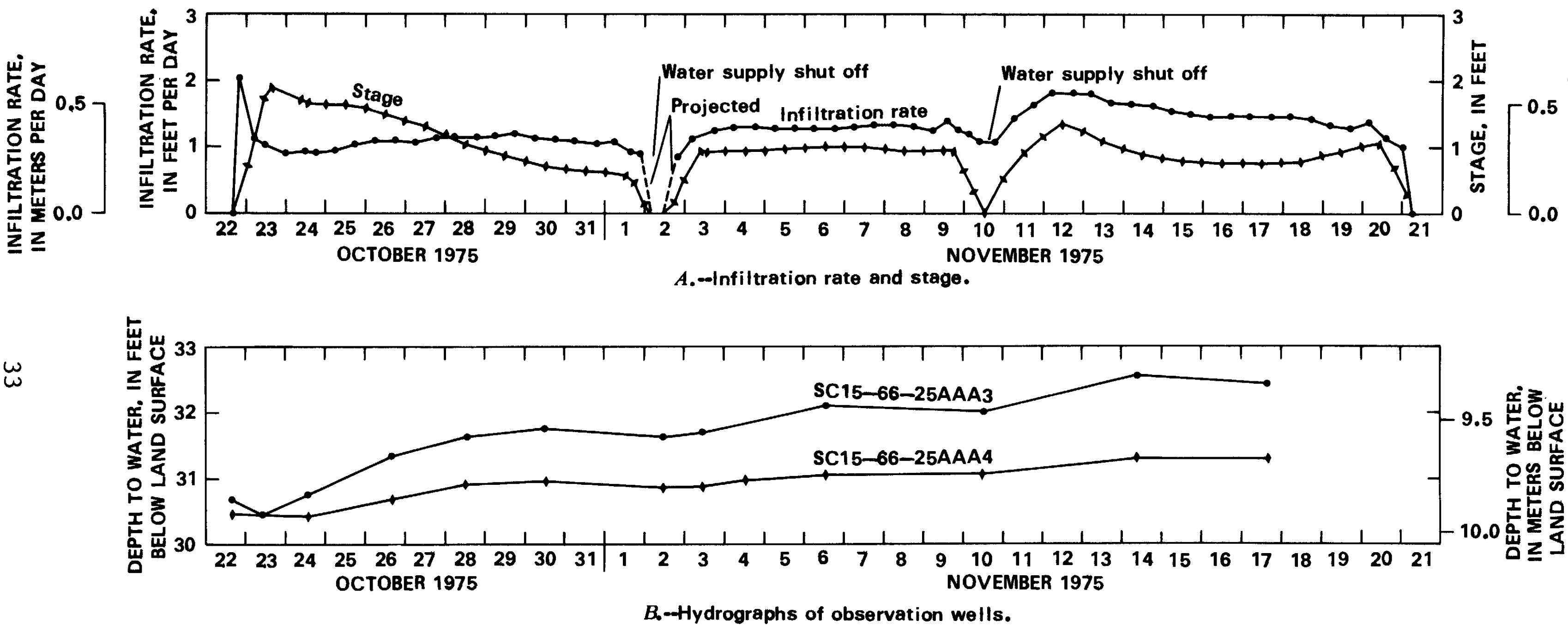
Figure 14.--Results of artificial-recharge test 10 at site 8.



A.--Infiltration rate and stage.

B.--Hydrographs of observation wells.

Figure 15.--Results of artificial–recharge test 10 at site 9.



A.--Infiltration rate and stage.

B.--Hydrographs of observation wells.

Figure 16.--Results of artificial–recharge test 30 at site 9.

Table 7.--*Results of artificial-recharge tests in the Widefield aquifer in Fountain Valley*

Site no.	Artificial-recharge test	Test dates in 1975	Pit area (square feet)	Water temperature (degrees Celsius)	Maximum recharge rate (feet per day)	Average recharge rate (feet per day)	Average stage (feet)
6	10	8-19 to 8-29	9,900	14.5-16	10.4	9.9	1.9
7	10	5-21 to 6- 1	9,000	-------	8.7	5.8	1.4
8	10	9-10 to 9-20	9,200	12 -16	6.3	4.6	1.0
9	10	8-19 to 8-30	8,700	17 -19	1.8	1.3	1.4
	30	10-22 to 11-21	8,700	7.5-13	2.0	1.4	.9

The presence of fine-grained, near-surface sediments may have caused the infiltration rates at sites 7, 8, and 9 to be lower than possible if the subject sediments had been removed. Site 6, located in a sand and gravel pit, lacked fine-grained surface material and may be representative of near-optimum conditions and infiltration rates which could be expected for artificial recharge to the Widefield aquifer.

Most of the logs of test holes reported by Taylor (1975) in the alluvium in Fountain Valley, approximately 7 mi (11 km) south of the Widefield aquifer, indicated the presence of surface clay and silt layers ranging in thickness from 1 to 30 ft (0.3 to 9.1 m). Comparison of particle-size analyses of samples from the artificial-recharge pits in the alluvium overlying the Widefield aquifer (table 3) and the Fountain Valley alluvium (Taylor, 1975) indicates that the near-surface sediments in Fountain Valley are generally finer grained than those at depth. Infiltration rates in the Fountain Valley alluvium were, generally, substantially less than the infiltration rates calculated for the Widefield aquifer.

Water-Management Considerations

General Considerations

Two objectives of artificial recharge in water management are to improve the availability and quality of the water supply. In determining the artificial-recharge potential of an alluvial aquifer, consideration needs to be given to:

1. The availability and quality of the water to be artificially recharged.

The recharge water probably will need to be conveyed to the artificial-recharge sites. The lack of an economical method of conveyance may make isolated locations unsuitable. Recharge water should be free of sediment and biological organisms, and of a chemical quality compatible with the ground water. Sediment carried into the spreading ponds with the recharge water, along with sediment resulting from bank and wind erosion, may clog the recharge-pond bottom and reduce infiltration. Biological organisms in the recharge ponds may cause clogging by bacterial growth in the alluvium beneath the pond and algal growth on the pond bottom. The recharge water may react chemically with the alluvium causing a decrease in the rate of infiltration. The recharge water also may react with the water in the aquifer causing chemical-quality changes in the ground water. The use of poor-quality recharge water over extended periods of time may result in the degradation of the water in the aquifer.

2. The capability of the aquifer to accept the artificial-recharge water.

The alluvium overlying the aquifer needs to be sufficiently permeable to allow reasonably high infiltration rates from the spreading ponds. The presence of low-permeability clay and silt layers in the alluvium may make a site unsuitable for artificial recharge.

3. The availability of adequate storage space in the alluvium for the recharge water.

The volume of artificial-recharge water that may be temporarily stored in the unsaturated alluvium overlying the alluvial aquifer can be calculated from the equation:

$$V = SAh,$$

where V = the volume of additional water to be stored, in acre-feet;
S = the specific yield of the aquifer (dimensionless);
A = the area over which the storage occurs, in acres; and
h = the average rise in the water table, in feet.

The volume of water computed from the above equation is a theoretical maximum and assumes that the water table can be raised an average height h over the entire area A. Ground-water movement and losses from the aquifer affect the computed storage volume.

4. Assurance that the recharge water will not be lost to evapotranspiration or flow out of the area before the water can be used.

To minimize losses by evapotranspiration, the water table needs to be maintained at a depth of more than 10 ft (3.0 m) below land surface. The rate and direction of ground-water movement need to be considered in the location of the artificial-recharge sites to insure that recharge water can be withdrawn before the water moves out of the area of need. Artificial recharge and the subsequent water-table rise may alter the rate and direction of ground-water movement.

The rate of infiltration from the artificial-recharge ponds is dependent on the pond stage. Higher pond stages yield greater infiltration rates. To facilitate comparison of infiltration rates at the artificial-recharge sites, the rates were adjusted for a pond stage of 2.5 ft (0.76 m) using the method of Taylor (1975). The adjusted rates were determined using the curves of artificial recharge and pond stage shown on figures 5 to 16. The adjusted rates of infiltration were calculated as 2.5 times the area under the artificial-recharge curve divided by the area under the pond-stage curve for the same interval of time. Results of 12 adjusted artificial-recharge tests are presented in table 8.

Table 8.--*Adjusted results of artificial-recharge tests*

Site no.	Artificial-recharge test	Adjusted recharge rate[1] (feet per day)	Annual recharge per acre of artificial-recharge pond[2] (acre-feet per year per acre)
		UPPER BLACK SQUIRREL CREEK BASIN	
1	10	2.4	290
1	30	2.1	260
2	10	1.7	210
3	10	1.6	200
Average		[3]1.8	[3]220
		JIMMY CAMP VALLEY	
4	10	24.7	3,010
4	30	15.1	1,840
5	10	3.8	460
Average		[3]9.4	1,150
		FOUNTAIN VALLEY (Widefield aquifer)	
6	10	12.9	1,570
7	10	9.8	1,200
8	10	11.7	1,430
9	10	2.3	280
9	30	3.7	450
Average		[3]9.5	1,160

[1]Based on observed recharge-stage relation and presumed constant pond stage of 2.5 feet.

[2]Based on adjusted artificial-recharge rates and presumed operation for 122 days per year. Annual operation inferred from 50-percent pond usage between mid-March and mid-November.

[3]Thirty-day test used when available.

Artificial-recharge sites constructed for a continuous operation generally consist of two or more spreading ponds. Each spreading pond is used only about 50 percent of the time. As the rate of infiltration decreases below some predetermined value, the artificial-recharge operation is transferred to an adjacent dry pond. The first pond dries, eliminating the clogging bacterial growth on the pond bottom and in the alluvium, if present. The dried pit also allows for the removal of fine-grained sediments that may be present. As the infiltration rate decreases in the second pond, operation is switched back to the first. Artificial-recharge operations in El Paso County probably would have to be suspended from mid-November to mid-March, due to the cold weather that may cause freezing of the ponds.

Storm-runoff water also can be used to recharge, artificially, the ground-water reservoir. Retention dams, possibly also used as flood-control structures, can capture runoff for recharge. Storm-runoff water generally carries large quantities of sediment, making the storage areas behind the dams unsatisfactory for recharge. The retention dams can be used to settle out sediments from the storm-runoff water and the runoff then can be diverted to specially constructed artificial-recharge sites.

The effects of artificial recharge on the aquifers in the three study areas are difficult to determine with available data. Moreland (1970) describes an analytical method for estimating the shape of the water-table mound and the magnitude of the water-level changes produced by artificial recharge. Water movement in the three aquifers also can be simulated using a digital-computer model and the effects of artificial recharge could be determined. Both methods, however, are beyond the scope of this study.

Upper Black Squirrel Creek Basin

The direction of ground-water movement in the alluvial aquifer of the upper Black Squirrel Creek basin is approximately south, and the estimated rate of movement is about 2.5 mi/yr (4.0 km/yr). Based on the direction and rate of ground-water movement, the area located north of the major area of water-level decline shown on figure 2 (Bingham and Klein, 1974), is suitable for artificial-recharge sites. The area of decline has a high storage capacity and the municipal wells located in the area could withdraw the recharge water as needed. Recharge water which moved through the decline area could still be intercepted by the municipal wells located at the south end of the basin.

The 1974 ground-water withdrawal for irrigation in the basin was about 10,000 acre-ft (1.2×10^7 m^3) with an estimated 30-percent return flow to the aquifer. Municipal withdrawal for export from the basin was about 3,500 acre-ft (4.3×10^6 m^3). Between 1964 and 1974, pumping from the alluvial aquifer in upper Black Squirrel Creek basin depleted the ground-water storage by about 50,000 acre-ft (6.2×10^7 m^3). Artificial recharge could be used to augment natural recharge to prevent additional ground-water-storage depletion and to temporarily store additional water for future use. The quantity of water that could be temporarily stored without significant loss cannot be estimated accurately without additional study.

Jimmy Camp Valley

Ground water in Jimmy Camp Valley moves south to southwest at a rate of about 0.5 mi/yr (0.8 km/yr). The area north of artificial-recharge site 5 (fig. 3) would be the most favorable part of the valley for recharge because it is underlain by the thickest unsaturated alluvium. In the northern part of the valley, the water table is generally near land surface in depressions and in the drainage channels. A higher water table caused by artificial recharge would result in some of the recharged water being lost to increased evapotranspiration. Recharge water could be withdrawn from the aquifer by several municipal wells in the vicinity of artificial-recharge site 5. South of site 5, the water table is shallow and ground water is currently discharging into Jimmy Camp Creek. Artificial-recharge water introduced into this area probably would be lost as increased evapotranspiration and as discharge to the creek.

The water level in the alluvial aquifer in Jimmy Camp Valley has remained nearly constant since water-level records were kept, beginning in 1955. The dissolved-solids concentration in the ground water ranges from 500 mg/L (milligrams per liter) in the northern part of the valley to 3,000 mg/L near the intersection of Jimmy Camp Valley and Fountain Valley. Artificial recharge may be used to improve the quality of the ground water. If water of low dissolved solids were available, artificial recharge in the southern part of the valley possibly could improve quality even though losses would be high. Recharged water in the southern part of the valley possibly could be withdrawn by existing municipal wells located at the intersection of Jimmy Camp Valley and Fountain Valley.

Fountain Valley (Widefield Aquifer)

According to Livingston, Klein, and Bingham (1976a), gain-and-loss studies conducted on Fountain Creek indicate that the creek and the Widefield aquifer are hydraulically connected. No significant long-term water-level changes have occurred in the aquifer although withdrawals from the aquifer have increased. The stream-aquifer system is apparently in equilibrium with additional recharge offsetting increased withdrawal.

The direction of ground-water movement in the Widefield aquifer is generally southeast, and the rate of movement is about 1 mi/yr (1.6 km/yr). The area most suitable for artificial recharge is the northern and eastern parts of the aquifer (fig. 3). The direction of ground-water movement in this area may become westerly toward Fountain Creek as a result of the higher water table caused by artificial recharge. The rise in the water table needs to be restricted in order to minimize ground-water movement into Fountain Creek. Recharged water could be withdrawn throughout the aquifer by numerous municipal wells.

The possibility of loss of recharged water to Fountain Creek reduces the practicability of artificially recharging the Widefield aquifer. Livingston, Klein, and Bingham (1976b) state that the dissolved-solids concentration of the water in the Widefield aquifer ranges from 409 to 598 mg/L and the concentration of nitrate ranges from 3.1 to 33.5 mg/L. Chemical quality of the ground water is influenced strongly by the quantity and quality of the natural recharge water. Most of the natural recharge to the Widefield aquifer comes from Fountain Creek which contains large amounts of sewage effluent and from numerous sewage lagoons and canals carrying treated sewage. Artificial recharge could be used to improve the quality of the water in the Widefield aquifer. Losses to Fountain Creek could be minimized by restricting water-table rises.

Taylor (1975) conducted similar artificial-recharge tests on the alluvium in Fountain Valley, approximately 7 mi (11 km) south of the southern end of the Widefield aquifer. Adjusted rates of infiltration ranged from 0.1 to 5.7 ft/d (0.03 to 1.7 m/d) with an average adjusted rate of 1.7 ft/d (0.5 m/d) compared to 2.3 to 12.9 ft/d (0.7 to 3.9 m/d) with an average adjusted rate of 9.5 ft/d (2.9 m/d) (table 8) for the alluvium overlying the Widefield aquifer. The generally higher rates of infiltration for the Widefield aquifer are probably attributable to coarser grained sediments found beneath the artificial-recharge sites.

Fine-grained sediment, ranging from 4 to 13 ft (1.2 to 4.0 m) in thickness, overlies coarser grained alluvial deposits at artificial-recharge sites 7, 8, and 9. Operational artificial-recharge pits could be excavated into the coarser grained, buried alluvium, possibly partly back-filling the deeper pits with coarse-grained material. The removal of the finer grained material should increase the rate of infiltration.

CONCLUSIONS

The average rate of infiltration for four tests conducted in pits in upper Black Squirrel Creek basin ranged from 1.0 to 1.7 ft/d (0.3 to 0.5 m/d) with the average pond stage ranging from 1.5 to 2.1 ft (0.5 to 0.6 m) above pit bottom. The average rate of infiltration adjusted to a constant stage of 2.5 ft (0.8 m) is 1.8 ft/d (0.5 m/d). Each acre of artificial-recharge pond could recharge approximately 220 acre-ft/yr (2.71×10^5 m^3/yr) in 122 days of operation. Based on the direction and rate of ground-water movement, the area north of the major water-level decline would be most suitable for artificial recharge. The presence of thin, discontinuous beds of silt and clay in the alluvium in upper Black Squirrel Creek basin can significantly reduce the rate of infiltration, making some areas unsuitable for artificial recharge.

The average rate of infiltration for three tests conducted in Jimmy Camp Valley ranged from 2.4 to 7.9 ft/d (0.7 to 2.4 m/d) with the average stage ranging from 0.4 to 1.5 ft (0.1 to 0.5 m). The average rate of infiltration adjusted to a constant stage of 2.5 ft (0.8 m) is 9.4 ft/d (2.9 m/d). Each acre of artificial-recharge pond could recharge approximately 1,200 acre-ft/yr (1.5×10^6 m^3/yr) in 122 days of operation. The southern part of the valley is unsuitable for artificial recharge due to a high water table. A higher water table in the northern part of the valley would result in some of the recharged water being lost to increased evapotranspiration. The area north of artificial-recharge site 5 would be the most favorable part of the valley for artificial recharge. Artificial recharge in the southern part of the valley possibly could improve quality of the ground water even though water losses may be high.

The average rate of infiltration for five tests conducted on the Widefield aquifer in Fountain Valley ranged from 1.3 to 9.9 ft/d (0.4 to 3.0 m/d) with the average stage ranging from 0.9 to 1.9 ft (0.3 to 0.6 m). The average rate of infiltration adjusted to a constant stage of 2.5 ft(0.8 m) is 9.5 ft/d (2.9 m/d). Each acre of artificial-recharge pond could recharge approximately 1,200 acre-ft/yr (1.5×10^6 m^3/yr) in 122 days of operation. The area most suitable for artificial recharge is the northern and eastern parts of the aquifer. To prevent losses of recharged water to Fountain Creek, the water-table rise needs to be restricted. Fountain Creek and the Widefield aquifer form a stream-aquifer system in equilibrium with natural recharge equaling withdrawal from the aquifer. The possibility of loss of recharge water to Fountain Creek casts doubt on the usefulness of artificially recharging the Widefield aquifer for temporary storage. However, artificial recharge could be used to improve the quality of water in the Widefield aquifer.

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SUPPLEMENTAL INFORMATION

System of Numbering Wells in Colorado

The well numbers in the tables indicate their locations as shown on the maps in this report. The numbers are based on the U.S. Bureau of Land Management system of land subdivision and show the location of the site by quadrant, township, range, section, and position within the section. A graphic illustration of this method of location of a well is shown on figure 17. The first capital letter "S" of the location number indicates that the site is located in the area governed by the sixth principal meridian. The second capital letter "C" indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the principal meridian: A indicates the northeast quadrant; B, the northwest; C, the southwest; and D, the southeast. The first number indicates the township; the second, the range; and the third, the section in which the well is located. The letters following the section number indicate the location of the well within the section. The first letter denotes the quarter section; the second, the quarter-quarter section; and the third, the quarter-quarter-quarter section. The letters are assigned within the section in a counterclockwise direction, beginning with A in the northeast quarter. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. Where two or more locations are within the smallest subdivision, consecutive numbers, beginning with 1, are added after the letter designation in the order in which the wells were inventoried. For example, SC15-65-15DAA indicates a well in the NE¼NE¼SE¼ sec. 15, T. 15 S., R. 65 W., southwest quadrant of the area governed by the sixth principal meridian.

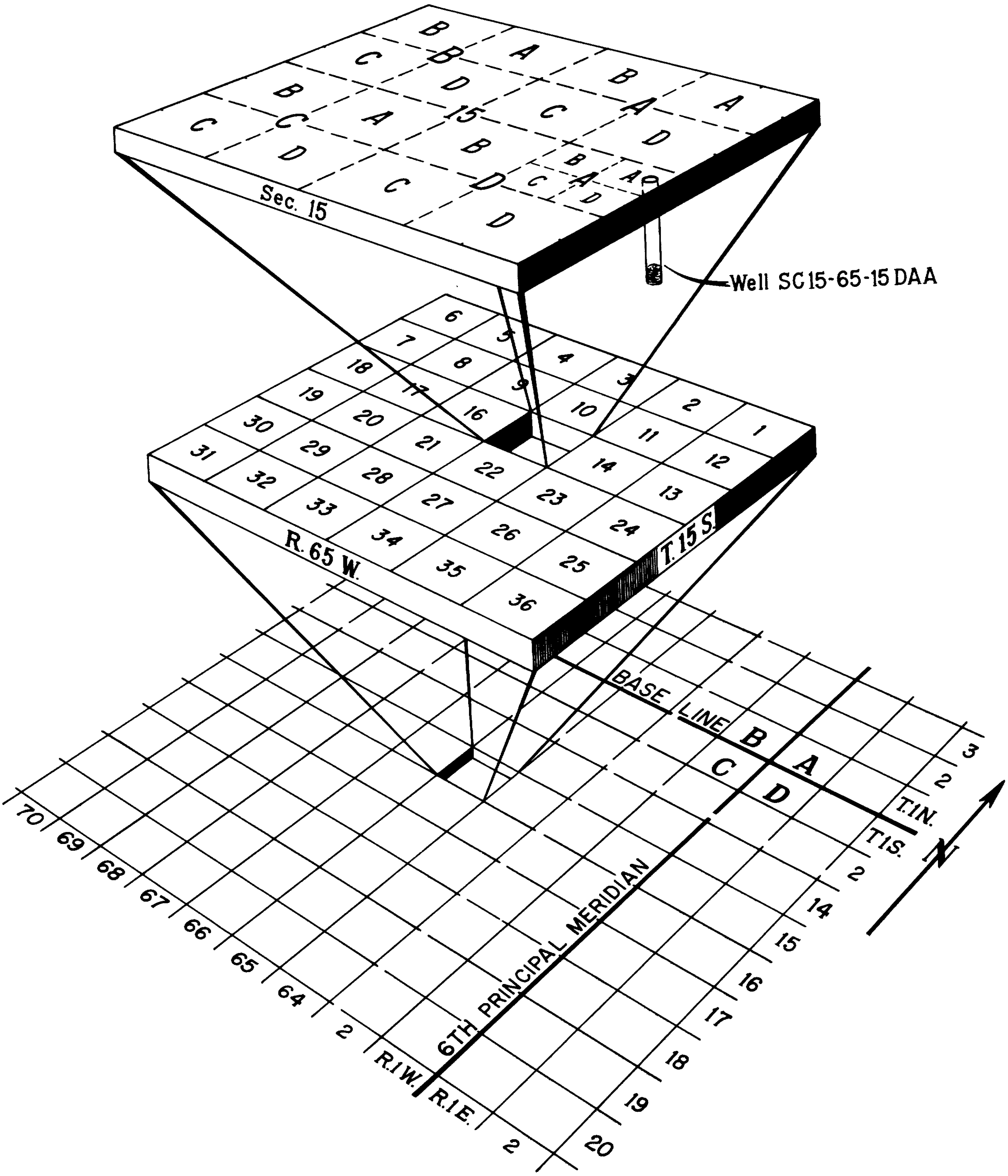

Figure 17.--System of numbering wells.

Logs of Test Holes Drilled by the U.S. Geological Survey

[Altitudes shown are land surface at test-hole sites]

	Thickness (feet)	Depth (feet)
SC13-62-31ACC2. Altitude, 6,115 feet		
Alluvial deposits(?):		
Sand, very fine to fine, reddish-brown; contains small amount of coarse sand to fine gravel	7	7
Eolian deposits:		
Sand, fine, tan	7	14
Alluvial deposits:		
Sand, medium, to fine gravel, yellowish-brown	26	40
Sand, medium, to fine gravel, slightly silty, yellowish-brown	57	97
SC13-62-31ACC3. Altitude, 6,115 feet		
Alluvial deposits(?):		
Sand, very fine to fine, light reddish-brown; contains small amount of medium sand to fine gravel	10	10
Eolian deposits:		
Sand, fine, tan	5	15
Alluvial deposits:		
Sand, medium, to fine gravel, yellowish-brown	13	28
Sand, medium, to fine gravel, slightly clayey to silty, yellowish-brown	65	93
SC14-62- 5BBC1. Altitude, 6,060 feet		
Alluvial deposits(?):		
Sand, medium, to fine gravel, dark-grayish-brown	5	5
Eolian deposits:		
Sand, very fine, light-tan	8	13
Alluvial deposits:		
Sand, medium, yellowish-brown; contains some coarse sand to fine gravel	4	17
Sand, fine, to fine gravel, yellowish-brown	9	26
Sand, medium, to fine gravel, slightly silty, grayish-brown	66	92
SC14-62- 5BBC2. Altitude, 6,060 feet		
Alluvial deposits(?):		
Sand, fine to medium, slightly silty, dark-brown	2	2
Sand, fine to medium, silty, dark-gray	2	4
Sand, medium, to fine gravel, slightly silty, dark-gray	4	8
Eolian deposits:		
Sand, very fine to fine, light-tan	6	14
Alluvial deposits:		
Sand, medium, to fine gravel, yellowish-brown; contains trace of clay and silt	78	92

	Thickness (feet)	Depth (feet)
SC14-62- 5CAA1. Altitude, 6,034 feet		
Alluvial deposits:		
Sand, coarse, to medium gravel, yellowish-brown	6	6
Sand, coarse, to medium gravel, yellowish-brown; contains trace of silt and clay	8	14
Sand, medium, slightly clayey to silty, brownish-yellow	2	16
Sand, coarse, to fine gravel, slightly clayey to silty, yellowish-brown	65	81
SC14-62- 5CAA2. Altitude, 6,034 feet		
Alluvial deposits:		
Sand, coarse, to fine gravel, yellowish-brown; contains trace of silt and clay	45	45
Sand, medium, yellowish-brown	8	53
Sand, medium, to fine gravel, slightly clayey to silty, yellowish-brown	12	65
Sand, coarse, to fine gravel, yellowish-brown; contains trace of silt and clay	15	80
SC15-65-10DCB2. Altitude, 5,770 feet		
Alluvial deposits:		
Sand, very fine to medium, slightly silty, light-brown	11	11
Sand, fine to medium, silty, grayish-brown	9	20
Sand, medium, to fine gravel, silty, grayish-brown	7	27
SC15-65-10DCB3. Altitude, 5,770 feet		
Alluvial deposits:		
Sand, very fine to medium, light-brown	3	3
Sand, fine to medium, clayey, dark-yellowish-brown	14	17
Sand, medium, to fine gravel, silty, dark-yellowish-brown	10	27
SC15-65-22DBA5. Altitude, 5,686 feet		
Alluvial deposits:		
Sand, medium, silty, dark-yellowish-brown; contains trace of coarse sand to fine gravel	19	19
Silt, very fine, to fine sand, dark-yellowish-brown	16	35
Sand, coarse, to fine gravel, slightly silty, dark-yellowish-brown	12	47
SC15-65-22DBA6. Altitude, 5,686 feet		
Alluvial deposits:		
Sand, medium, silty, dark-yellowish-brown	12	12
Sand, coarse, to fine gravel, yellowish-brown	23	35
Clay, gray	2	37

	Thickness (feet)	Depth (feet)
SC15-66- 3BCA3. Altitude, 5,780 feet		
Alluvial deposits:		
Sand, coarse, to fine gravel, dark-reddish-brown-------	25	25
Pierre(?) Shale:		
Clay, dark-gray--	18	43
SC15-66- 3BCA4. Altitude, 5,780 feet		
Alluvial deposits:		
Sand, medium, to fine gravel, reddish-brown------------	21	21
Sand, medium, to fine gravel, reddish-brown; contains silt and clay--	4	25
Pierre(?) Shale:		
Clay, dark-gray--	18	43
SC15-66-13CCA2. Altitude, 5,695 feet		
Alluvial deposits:		
Silt to very fine sand, grayish-brown; contains some coarser sand and fine gravel--------------------	4	4
Sand, coarse, to fine gravel, orangish-brown-----------	28	32
Pierre(?) Shale:		
Clay, dark-gray--	15	47
SC15-66-13CCA3. Altitude, 5,695 feet		
Alluvial deposits:		
Silt to very fine sand, reddish-brown; contains some coarser sand--	4	4
Sand, coarse, to fine gravel, orangish-brown; contains some medium to coarse gravel------------------------	29	33
Pierre(?) Shale:		
Clay, dark-gray--	14	47
SC15-66-24ACB1. Altitude, 5,660 feet		
Alluvial deposits:		
Silt to very fine sand, brownish-gray------------------	3	3
Silt to very fine sand, brownish-gray; contains some coarse sand to fine gravel----------------------------	10	13
Sand, coarse, to fine gravel, orangish-brown-----------	12	25
Sand, coarse, to fine gravel, yellowish-brown; contains some medium gravel-----------------------------------	22	47
SC15-66-24ACB2. Altitude, 5,660 feet		
Alluvial deposits:		
Silt to very fine sand, light-reddish-brown------------	8	8
Sand, coarse, to fine gravel, orangish-brown; contains some medium gravel-----------------------------------	39	47

	Thick-ness (feet)	Depth (feet)
SC15-66-25AAA3. Altitude, 5,640 feet		
Alluvial deposits:		
Sand, very fine to fine, yellowish-brown	10	10
Sand, medium, to fine gravel, slightly silty, reddish-brown	8	18
Gravel, fine to coarse, sandy, reddish-brown	20	38
Pierre(?) Shale:		
Clay, gray	7	45
SC15-66-25AAA4. Altitude, 5,640 feet		
Alluvial deposits:		
Sand, very fine to fine, reddish-brown	4	4
Silt, clayey, grayish-brown; contains trace of medium sand to fine gravel	3	7
Sand, very fine to fine, reddish-brown	11	18
Sand, coarse, to fine gravel, slightly silty, reddish-brown	5	23
Sand, coarse, to medium gravel, grayish-red	18	41
Pierre(?) Shale:		
Clay, gray	6	47

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