GROUND-WATER FLOW AND SHALLOW-AQUIFER PROPERTIES IN THE RIO GRANDE INNER VALLEY SOUTH OF ALBUQUERQUE, BERNALILLO COUNTY, NEW MEXICO

By Kathy D. Peter

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot	0.3048	meter
foot per day	.3048	meter per day
foot squared per day	.09290	meter squared per day
cubic foot per second	.02832	cubic meter per second
mile	1.609	kilometer
square mile	2.590	square kilometer
foot per mile	.1894	meter per kilometer
micromho per centimeter at 25° Celsius	1.000	microsiemen per centimeter at 25° Celsius

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

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ABSTRACT

The purpose of this investigation was to describe the water-table configuration and its temporal variations, estimate aquifer properties, and evaluate the interaction of ground water and surface water in the inner valley of the Rio Grande in southern Albuquerque, New Mexico, where ground-water contamination is a continuing concern. The upper 150 feet of sedimentary deposits in the inner valley, mostly alluvium that consists of cobbles, gravel, sand, silt, and clay, was emphasized because of its susceptibility to contamination. A map of the water table on February 28, 1986 shows that flow generally is parallel to the river and the gradient is approximately 5 feet per mile or 0.001. In areas affected by municipal and industrial ground-water withdrawals, declines may exceed 10 feet, and the water-table gradient is as much as 20 feet per mile or 0.004. The gradient also is steeper near drains, particularly during the irrigation season. In the area east of the community of Mountainview the direction of water movement may have reversed between 1936 and 1986; flow now appears to be toward the east or southeast. Groups of four piezometers, each screened at a different depth, were monitored to describe seasonal changes of the water table. Vertical gradients between piezometers ranged from 0.014 upward to 0.047 downward from July 1985 to June 1986, but were downward most of the year, particularly during the irrigation season. The horizontal hydraulic conductivity of a 15-foot-thick clay and silt bed beneath Rio Bravo Boulevard is estimated to be 0.001 foot per day. The average interstitial velocity down through this bed is estimated to range from about 0.0002 to 0.0005 foot per day. The fluctuations of the water table at the piezometers nearest the Rio Grande do not appear to be affected by the riverside drain.

INTRODUCTION

Contamination of ground water in the inner valley of the Rio Grande south of Albuquerque, N. Mex., (fig. 1) is a continuing source of concern (New Mexico Environmental Improvement Division, 1985, and U.S. Environmental Protection Agency, 1985). Contaminated ground water is known to have moved from the alluvium to the Quaternary and Tertiary Santa Fe Group, affecting the water supply for the city of Albuquerque and its population of about 400,000. This contamination is a potential threat to the health of the residents of the area and a potential problem to continued industrial growth.

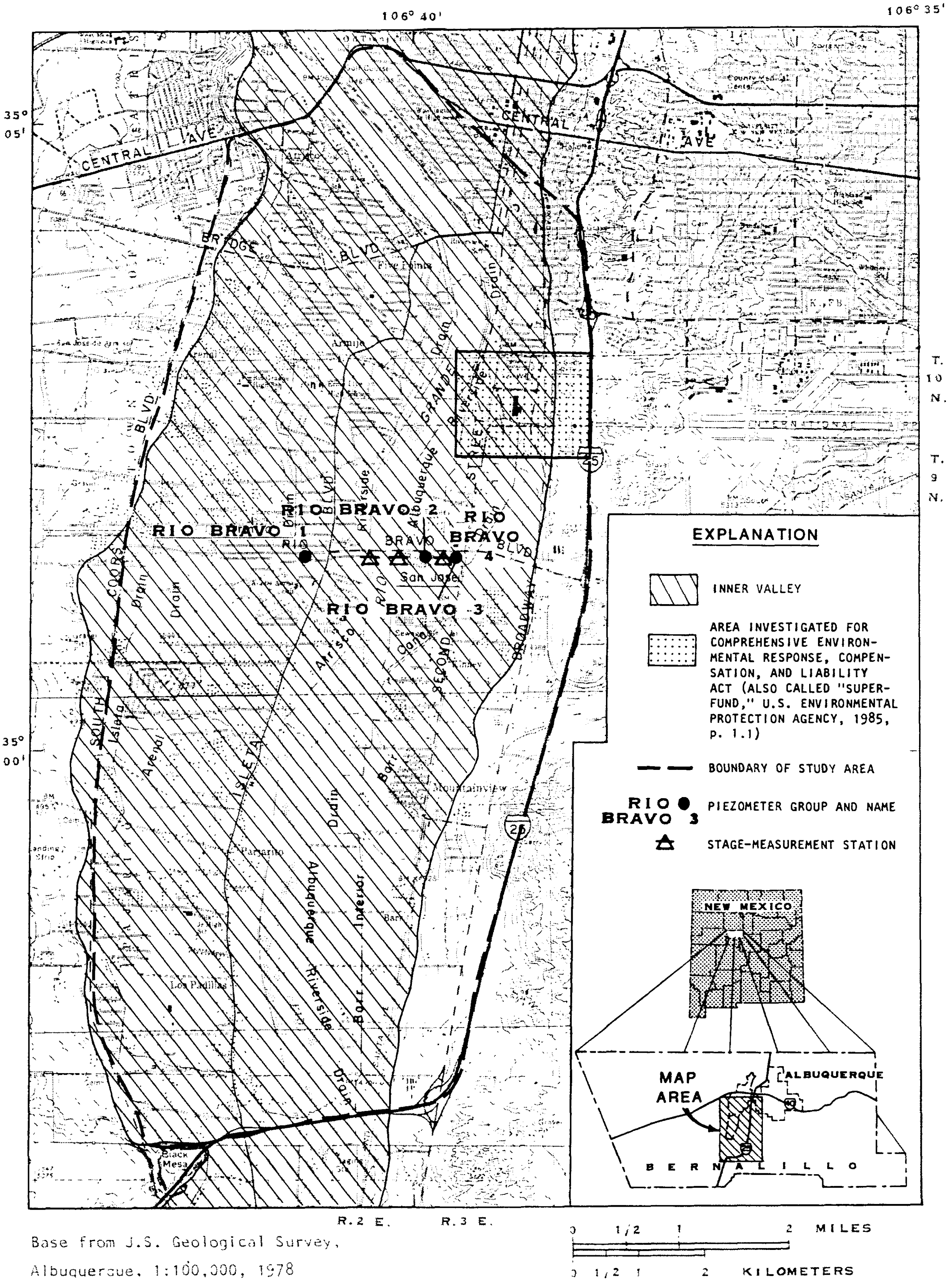
The New Mexico Environmental Improvement Division has identified and mapped a variety of hazardous ground-water contaminants or conditions leading to undesirable water quality (New Mexico Environmental Improvement Division, 1985, p. 4). Organic chemicals, including volatile organics that necessitated the abandonment of two Albuquerque water supply wells, have been detected in an area designated as New Mexico's highest priority abandoned hazardous wastesite and are being investigated as part of the U.S. Environmental Protection Agency's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund") (fig. 1). Gasoline contamination has been detected in several areas, particularly along Isleta Boulevard, formerly a major highway. The concentration of nitrate in ground water is large enough to pose a potential health threat to infants in isolated areas west of Coors Boulevard and in the community of Mountainview (fig. 1). Between Coors Boulevard and the Rio Grande, anaerobic ground-water conditions result in undesirably large dissolved concentrations of iron, manganese, and hydrogen sulfide.

An understanding of the aquifer hydraulics is needed to predict direction and rates of contaminant movement and to evaluate potential hazards caused by contamination. Direction and rate of movement of contaminants in ground water are controlled, in part, by proximity of the water table to the contaminant source, horizontal and vertical gradient of the ground water, and porosity and hydraulic conductivity of the aquifer. Many factors that control contaminant movement change with time. Variations in climatic conditions, irrigation, withdrawal rates, and surface-water conditions combine to change the direction and rate of flow.

Purpose, Scope, and Study Area

The purpose of this investigation was to describe the water-table configuration and its temporal variations, estimate aquifer properties, and evaluate the interaction of ground water and surface water. This report describes the methods used and the results obtained, and provides information that enhances an understanding of ground-water movement in the inner valley of the Rio Grande south of Albuquerque.

This investigation was of ground-water flow in the shallow sediment in the inner valley of the Rio Grande south of Albuquerque (fig. 1), an area of about 45 square miles. The shallow sediment, approximately the upper 150 feet, was investigated because it is the most susceptible to contamination



Base from U.S. Geological Survey, Albuquerque, 1:100,000, 1978

Figure 1.--Location of the study area.

from activities on the land surface. Only the saturated zone, which is the sediment beneath the water table, was studied. The unsaturated zone above the water table contains water at less than atmospheric pressure in the pore spaces of the sediment. Flow of water through this zone is important in the movement of contaminants. However, because contamination already has been identified in the saturated zone, this study focuses on the saturated zone.

The study area boundaries are U.S. Interstate 25 on the east, Coors Boulevard on the west, Central Avenue on the north, and Interstate 25 on the south (fig. 1). The east and west boundaries were chosen because they are approximately coincident with steep bluffs that roughly define the area of shallow ground-water conditions. The north and south boundaries were arbitrarily chosen.

Approach and Methods

The approach of this investigation was to compile available data, collect additional data, and interpret the data by using standard hydrologic procedures. Water-level measurements were made at 21 existing wells and 32 piezometers that were installed for this study (table 1). Sixteen of these piezometers were installed in groups of four, each screened at a different depth, along Rio Bravo Boulevard (figs. 1 and 2 and table 1). Water levels in the three deepest piezometers at each of the four groups were measured hourly and used to describe seasonal changes of the water table and the hydraulic head at depths of as much as 150 feet below land surface. These instrumented piezometers are indicated in the remarks column in table 1 as having recorders and are referred to in this report as shallow (for the piezometer about 50 feet deep), middle (for the piezometer about 100 feet deep), and deep (for the piezometer about 150 feet deep). Water levels in the riverside drains and the Barr Canal were measured every 15 minutes at stations on Rio Bravo Boulevard (fig. 1). Hydrographs of the Rio Bravo 4 piezometer group were used to estimate hydraulic conductivity as described later in this report.

Geophysical logs of the deepest hole at each piezometer group along Rio Bravo Boulevard were used to define the subsurface geology (fig. 2) along the section defined by the groups in figure 1. The description of specific geologic units by using only lithologic descriptions of samples taken during drilling was not practical because of the heterogeneity of the material and the mixing that occurs when the sediments are transported to the surface by the drilling fluid. Extensive subsurface geologic mapping was not done because there are few geophysical logs of the upper 100 feet of alluvium. The units shown in figure 2 are based on the major lithology.

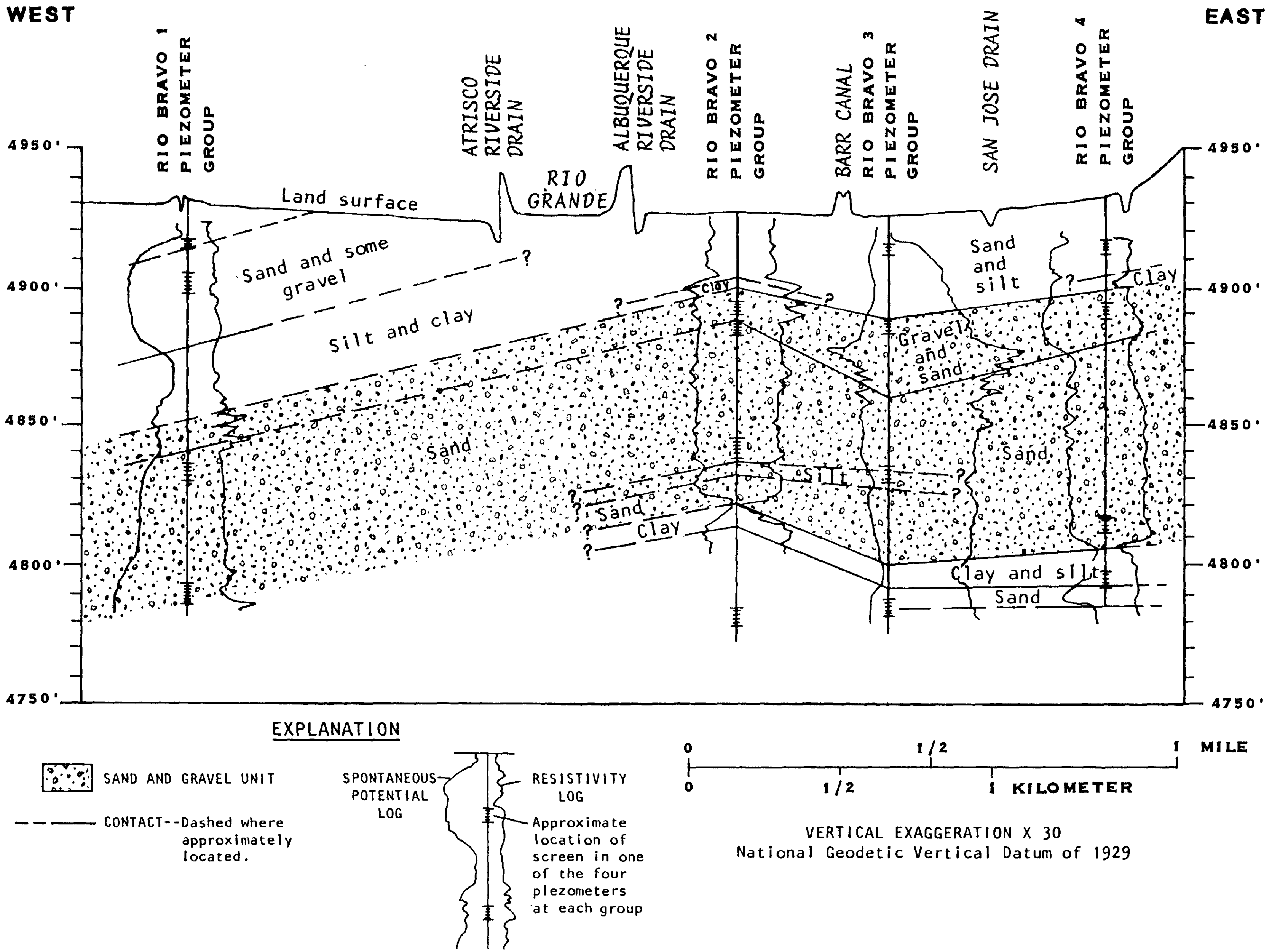


Figure 2.--Generalized geologic section along Rio Bravo Boulevard and the approximate configuration of piezometer groups.

Table 1. Water-level measurements, February 28, 1986

[Measuring point top of casing, except where noted in remarks; NGVD, National Geodetic Vertical Datum of 1929]

Number in figure 4	Well or piezometer name	Identification number based on latitude and longitude	Well depth, in feet below measuring point	Depth to water, in feet below measuring point	Altitude of measuring point, in feet above NGVD	Remarks
		Piezometers installed by the U.S. Geological Survey				
1	GS1	350408106394401	10.0	8.00	4,942,83	
2	GS3	350335106391101	13.5	10.95	4,939.60	
3	GS4	350258106395301	13.5	8.14	4,935.25	
4	GS5	350207106422501	13.5	10.39	4,929.47	
5	Rio Bravo 1-04	350137106410504	13.5	11.26	4,931.28	
6	Rio Bravo 1-03	350137106410503	38.4	10.55	4,930.58	Recorder
7	Rio Bravo 1-02	350137106410502	103.8	10.99	4,930.81	Recorder
8	Rio Bravo 1-01	350137106410501	148.5	11.05	4,930.88	Recorder
9	Rio Bravo 2-04	350138106395504	39.2	10.58	4,929.19	
10	Rio Bravo 2-03	350138106395503	48.60	10.29	4,928.91	Recorder
11	Rio Bravo 2-02	350138106395502	91.16	10.18	4,928.84	Recorder
12	Rio Bravo 2-01	350138106395501	153.53	10.33	4,928.71	Recorder
13	Rio Bravo 3-04	350138106393204	13.5	10.63	4,926.76	
14	Rio Bravo 3-03	350138106393203	49.33	10.10	4,927.48	Recorder
15	Rio Bravo 3-02	350138106393202	101.0	9.97	4,927.40	Recorder
16	Rio Bravo 3-01	350138106393201	148.0	9.78	4,927.14	Recorder
17	Rio Bravo 4-04	350135106390604	20.5	12.34	4,933.33	
18	Rio Bravo 4-03	350135106390603	49.33	18.06	4,932.81	Recorder
19	Rio Bravo 4-02	350135106390602	124.23	17.86	4,932.75	Recorder
20	Rio Bravo 4-01	350135106390601	149.4	14.44	4,932.65	Had been flooded Recorder
21	GS10	350044106424501	13.5	8.90	4,922.42	
22	GS11	350029106401501	34.7	24.26	4,937.11	
23	GS12	350003106405601	17.0	13.99	4,920.27	Top of casing 3.6 feet above land surface
24	GS13	350003106400301	31.0	24.88	4,935.89	
25	GS14	345928106424701	10.0	7.47	4,913.40	

Table 1. Water-level measurements, February 28, 1986 - Continued

Number in figure 4	Well or piezometer name	Identification number based on latitude and longitude	Well depth, in feet below measuring point	Depth to water, in feet below measuring point	Altitude of measuring point, in feet above NGVD	Remarks
26	GS15	345922106402701	13.5	10.78	4,917.05	
27	GS16-01	345909106395801	39.8	18.94	4,925.11	
28	GS16-02	345909106395802	27.5	18.96		Damaged
29	GS17	345854106413001	24.0	9.04	4,913.41	
30	GS18	345725106424701	10.0	6.90	4,901.06	
31	GS19	345711106410901	10.0	5.81	4,902.61	
32	GS20	345726106402601	10.0	6.84	4,904.06	
		Existing wells				
33	Teeple	350501106412401	50	9.89	4,951.15	
34	S. Coors Truck Salvage	350356106420601	104	75.59	5,005.73	
35	Rodgers' Farm	350325106403801	55	11.75	4,942.29	
36	Rio Grande High School	350257106413401	71	14.21	4,937.93	Top of casing 2.5 feet above land surface
37	Alpha SW	350149106392901	87	9.44	4,927.94	
38	Harrison Middle School	350105106403901	120	9.12	4,923	
39	Mountainview Elementary School	350005106394302	170	47.93	4,956	
40	Guzman	345940106393401	125	69.66	4,977.96	Measuring point at land surface
41	Price's Valley Gold Dairy	345907106405901	110	8.03	4,912.54	Measuring point at land surface
42	Straka-01	345739106415201	180	7.04	4,903.26	
43	Straka-02	345739106415202	30	6.60	4,902.43	
44	Police Farm	350105106355801		245.69	5,134.04	
45	San Jose 3	350343106390101	1,036		4,946	Formerly San Jose 8. Recorder

Table 1. Water-level measurements, February 28, 1986 - Concluded

Number in figure 4	Well or piezometer name	Identification number based on latitude and longitude	Well depth, in feet below measuring point	Depth to water, in feet below measuring point	Altitude of measuring point, in feet above NGVD	Remarks
46	San Jose 9	350256106390801	764.5	28.92	4,941	Recorder. Measuring point at land surface
47	SV-3	350254106384201	28	19.13	4,939.48	
48	SV-4	350254106384202	24	18.60	4,939.74	
49	SV-5	350237106382401	96	91.09	5,001.66	
50	SV-6	350237106382402	96.5	90.35	5,001.66	
51	SV-10	350238106382001	101	Dry	5,007.12	
52	SV-11	350257106384201	25	22.65	4,943.64	
53	PA-6, Palmer	350150106430206	65	33.24		

Geologic Setting

A stratigraphy of the sediments in the upper 150 feet of flood-plain deposits is difficult to define. Alluvium of Holocene age underlies the flood plain of the Rio Grande. The alluvium consists of cobbles, gravel, sand, silt, and clay and is similar in appearance and composition to the underlying Santa Fe Group of Miocene through Pleistocene age. The Santa Fe Group is the principal source of the alluvial material and the contact between the alluvium and the Santa Fe Group is difficult to identify. Based on a change in lithology and consolidation, the contact is between 80 and 120 feet below land surface in the Albuquerque area (Bjorklund and Maxwell, 1961, p. 14 and 22).

A hydrologic boundary between the alluvium and Santa Fe Group may not exist over a large area. Water circulates between the coarser beds in both units, driven toward discharge areas by higher hydraulic heads in the recharge areas. Units that are less permeable because they are fine grained, cemented, or consolidated slow the movement of water and deflect its path between the transmissive units. The continuity of fine-grained units in the subsurface is unknown. Lateral changes in grain size in alluvial deposits are common; though the major lithology of sediments penetrated by one hole may be clay, the grain size may be coarser laterally and, therefore, more permeable.

Spontaneous-potential and resistivity logs of the alluvium beneath Rio Bravo Boulevard indicate there is a unit penetrated by all four holes that consists of sand and gravel and is about 65 to 95 feet thick (fig. 2). This unit may correlate with the "intermediate aquifer" described at the CERCLA site north of Rio Bravo Boulevard (U.S. Environmental Protection Agency, 1985, p. 6.7). Along Rio Bravo Boulevard the top of this sand and gravel unit is about 30 to 80 feet below land surface and is deepest at the Rio Bravo 1 piezometer group. Within the sand and gravel unit there appears to be some discontinuous, fine-grained zones.

Above the sand and gravel unit is a fine-grained unit that is difficult to distinguish on the geophysical logs. At Rio Bravo 2 and 4 there is a clayey unit less than 5 feet thick, but this unit is not identifiable on the Rio Bravo 3 logs. The continuity of units between Rio Bravo 1 and 2 is not well defined, but there is a silt and clay unit about 50 to 80 feet below land surface at Rio Bravo 1 that may correlate with the fine-grained material near the surface at Rio Bravo 2 (fig. 2). Overall, the material overlying the sand and gravel unit appears to be coarser east of Rio Bravo 2 and contains more silt and clay west of Rio Bravo 2.

Beneath the sand and gravel unit east of the Rio Grande is a 6- to 15-foot-thick clay and silt unit that appears to be continuous from Rio Bravo 2 to Rio Bravo 4. Beneath this fine-grained unit is a sand unit, which is the deepest unit penetrated at Rio Bravo 2, 3, and 4.

Acknowledgments

Bruce Gallaher, New Mexico Environmental Improvement Division, and Michelle Dorlon assisted in the measurement of water levels on February 28, 1986. Water-level measurements made during February 24-26, 1986, were provided by CH_2M-Hill. Personnel of the Middle Rio Grande Conservancy District supplied maps and information on the irrigation system in the inner valley. They also cooperated in installation of piezometers and stream-gaging stations. Numerous owners of private and commercial wells allowed water-level measurements.

GROUND-WATER FLOW

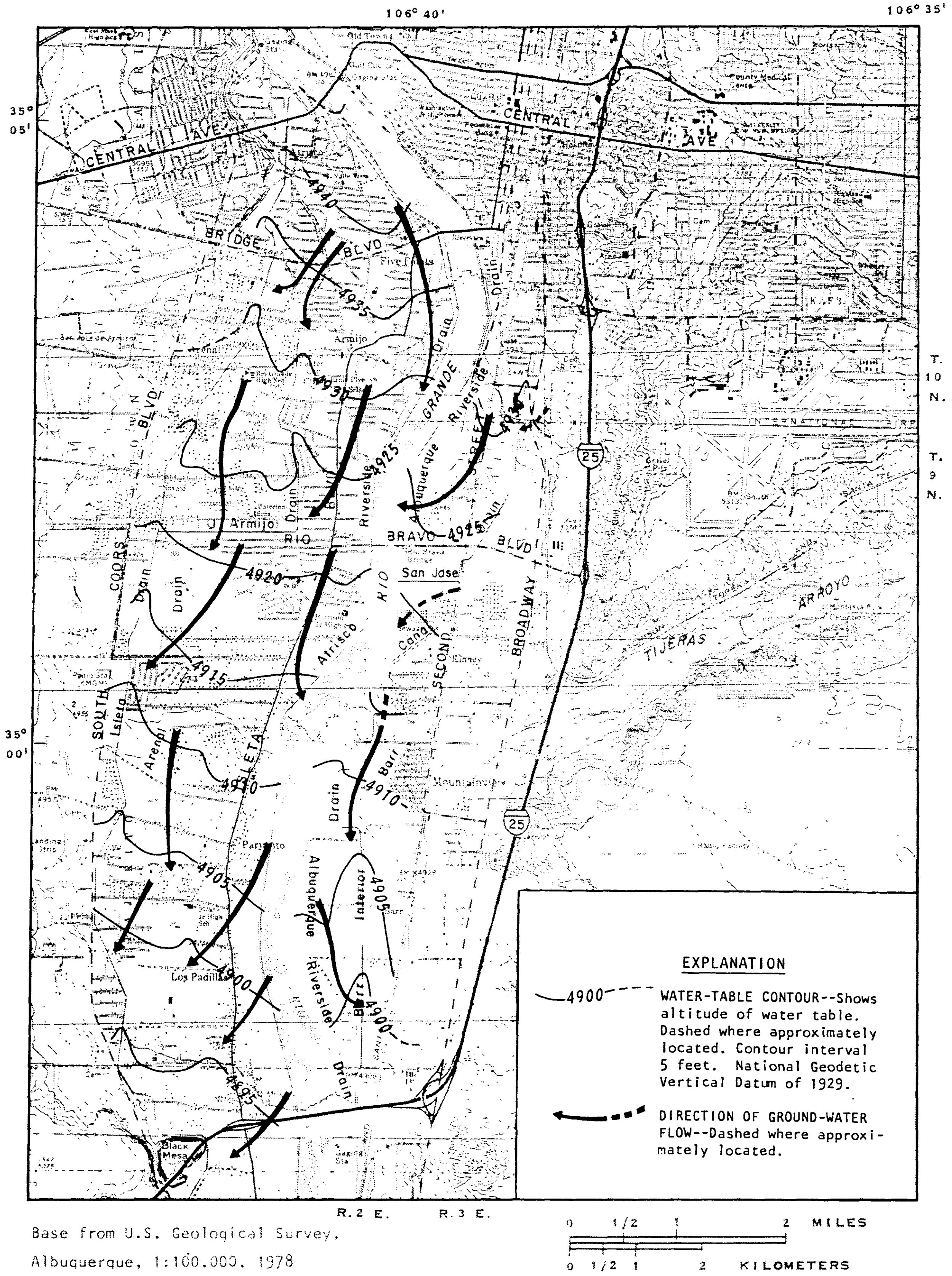
Four major factors that control the direction of shallow ground-water flow in the inner valley of the Rio Grande in the area of Albuquerque are: (1) the Rio Grande, (2) riverside and interior drains, (3) irrigation, and (4) ground-water withdrawals by the city of Albuquerque and industry. The Rio Grande is an aggrading river; that is, over time it has deposited sediment and elevated its channel above the adjacent flood plain. As a result, water from this perennially flowing river seeps into the underlying alluvium.

Water that infiltrates the wetter highland areas adjacent to the inner valley, particularly on the slopes near the Sandia and Manzano Mountains (fig. 1), moves through the Santa Fe Group toward the inner valley. Excess water from irrigation, which has been practiced for hundreds of years in this area, also infiltrates to the water table. Until the early 1930's, when an extensive drainage system was installed, evapotranspiration was the major mechanism of ground-water discharge.

The drainage system installed in the early 1930's by the Middle Rio Grande Conservancy District with the assistance of the U.S. Bureau of Reclamation modified the ground-water flow system. Though evapotranspiration is still a major mechanism of discharge, the drains also remove water from the ground-water system and return it to the Rio Grande.

Since the installation of the drains, the shallow ground-water flow is, in part, from the Rio Grande to the riverside drains, which were constructed so that their stage is below that of the river. Some water from the Rio Grande flows under the riverside drains and moves toward the interior drains (Theis, 1938, p. 279). Irrigation water, leakage from drains and canals, and recharge from the adjacent highlands also contribute to the inner-valley ground-water system.

Ground-water flow in 1936 generally was parallel to the river in the part of the valley bounded by the riverside drains and the bluffs. Figure 3 is a simplified version of a larger map of the water table in the Middle Rio Grande Conservancy District presented by Theis (1938, pl. 6). The average gradient was about 5 feet per mile to the south (Theis, 1938, p. 278) or about 0.001. Locally, flow was toward the interior and riverside drains (fig. 3). The original map was drawn using data from about 135 points, had a 1-foot contour



Base from U.S. Geological Survey, Albuquerque, 1:100,000, 1978

Figure 3.--Altitude of the water table in October 1936

(modified from Theis, 1938, pl. 6).

interval, and showed that flow in the inner valley mainly is toward the interior drains rather than toward the riverside drains. It also showed the steep water-table gradient near the drains.

Theis (1938, p. 281) reported that for six sites along the Barr Drain gradients ranged from -0.00097 to 0.00599 (negative numbers indicating flow away from the drain) during 8 months in 1936. The steepest gradients occurred in June, when irrigation may have raised the water table in the surrounding farmland. The flattest gradients generally were in January.

Since 1936 Albuquerque has expanded, changing the land use in the inner valley from predominantly agricultural to a mixture of residential, industrial, and agricultural. Increased withdrawals by deep wells have resulted in several changes in the ground-water conditions. As Albuquerque has grown and ground-water use has increased, deep wells (exceeding depths of 200 feet) have removed water from storage, lowering the water table in and near the city. Declines may exceed 10 feet in the area east of the Rio Grande and north of Rio Bravo Boulevard, as indicated by comparing figures 3 and 4. Flow in this area is now almost due east, perpendicular to the direction of flow in 1936. Declines exceed 75 feet in wells about 5 miles east of Interstate 25 outside the study area (U.S. Geological Survey, Albuquerque, N. Mex., unpublished data). The water-table gradient between the Albuquerque Riverside Drain and Interstate 25 in the area north of Rio Bravo Boulevard is as much as 20 feet per mile, or 0.004, to the east.

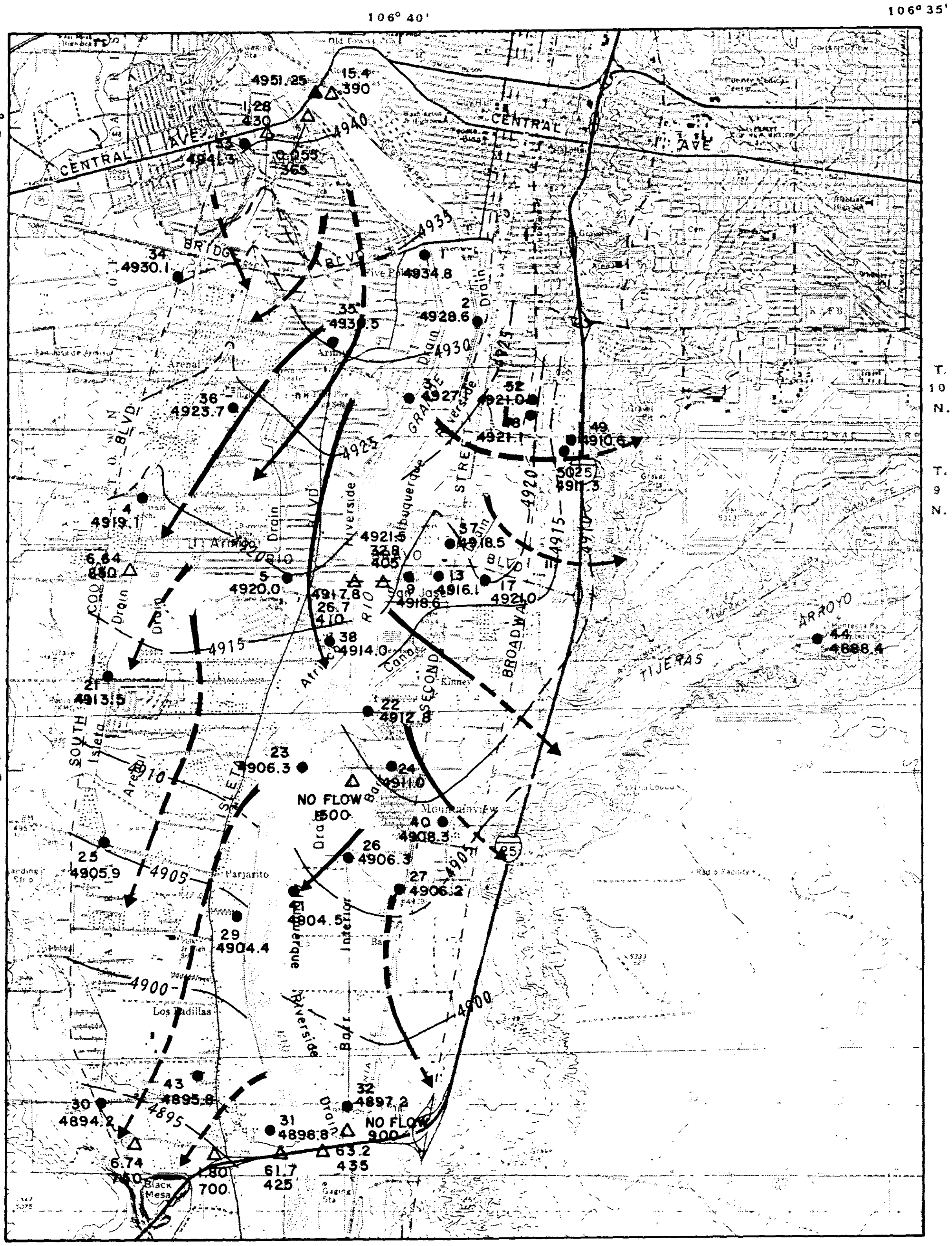
Comparison of figures 3 and 4 indicates that the water table west of the Rio Grande and north of Rio Bravo Boulevard may have declined as much as 5 feet, but the general direction of ground-water flow is still approximately parallel to the river. The water-table gradient is still approximately 5 feet per mile, or 0.001, and is steeper near the drains. On February 28, 1986, discharge in the Isleta Drain was 1.28 cubic feet per second at Central Avenue and 6.64 cubic feet per second at Rio Bravo Boulevard (fig. 4 and table 2). The increase of 5.36 cubic feet per second is due to ground-water contributions.

Seasonal changes of the water table may be deduced by comparison of the area east of the Rio Grande and south of Rio Bravo Boulevard in figures 3 and 4. October is the end of the irrigation season and water added to the system by irrigation is still draining, as shown by the water-table configuration about the Barr Drain in 1936 (fig. 3). In contrast, February 28th is near the end of winter, when the irrigation canals have no water and there has not been any irrigation since October. Though there was water in the Barr Drain on February 28th, there wasn't any measurable movement of water (table 2), indicating an immeasurably small ground-water contribution; the water-table map (fig. 4) was drawn accordingly.

Table 2. Discharge, specific conductance, and dissolved-solids concentration of water in drains and canals on February 28, 1986

Name	Discharge, in cubic feet per second	Specific conductance, in microsiemens per centimeter at 25° Celsius	Dissolved-solids concentration, in milligrams per liter[1]
Isleta Drain at:			
Central Ave.	1.28	430	320
Rio Bravo Blvd.	6.64	850	640
Malpais Rd.	6.74	750	560
Arenal Main Canal at			
Malpais Rd.	1.80	700	520
Atrisco Riverside Drain at:			
Central Ave.	0.055	365	274
Rio Bravo Blvd.	26.7	410	310
Interstate 25	61.7	425	319
Albuquerque Riverside Drain at:			
Central Ave.	15.4	390	290
Rio Bravo Blvd.	32.8	405	304
Interstate 25 above Barr Drain	63.2	435	326
Barr Drain at:			
Shirk Rd.	no flow	1,500	1,100
Interstate 25	no flow	900	700

[1] Calculated from the relation: dissolved-solids concentration = 0.750 times specific-conductance value, based on a linear regression of 61 ground-water analyses in the area.



Base from U.S. Geological Survey, Albuquerque, 1:100,000, 1978

Figure 4.--Altitude of the water table on February 28, 1986.

EXPLANATION (FIGURE 4)

———4935— — WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located.

DIRECTION OF GROUND-WATER FLOW--Dashed where approximately located.

● 1 / 4934.8 — SHALLOW WELL--Upper number is well number in table 1. Lower number is altitude of water level.

▲4951.25 — STREAMFLOW-GAGING STATION ON THE RIO GRANDE--Number is altitude of river stage.

4921.5 / 32.8 / 405 — DRAIN STAGE-MEASUREMENT STATION--Upper number is altitude of drain stage, middle number is discharge in cubic feet per second, and lower number is specific conductance in microsiemens per centimeter at 25° Celsius.

△ 15.4 / 390 — MEASUREMENT SITE--Upper number is discharge in cubic feet per second and lower number is specific conductance, in microsiemens per centimeter at 25° Celsius.

Note: All altitudes are in feet above National Geodetic Vertical Datum of 1929.

In the area east of Mountainview, the direction of water movement may have reversed between 1936 and 1986. There were no piezometers in the Mountainview area in 1936, so there are no water-level data for comparison. However, Theis (1938, p. 282) referred to a steep gradient near the mouth of Tijeras Arroyo and said the largest contributions of recharge come from the arroyos, implying the gradient under Mountainview was westward. Though there are few data in 1986 for this area, the flow now appears to be toward the east or southeast, based on water levels in a well east of Mountainview and in a well in Tijeras Arroyo (fig. 4). Given that water levels in Albuquerque have declined more than 75 feet and are lower than water levels in Mountainview, it is logical that somewhere south of the city there is a ground-water divide. Additional data are needed for this area to determine the location of the divide.

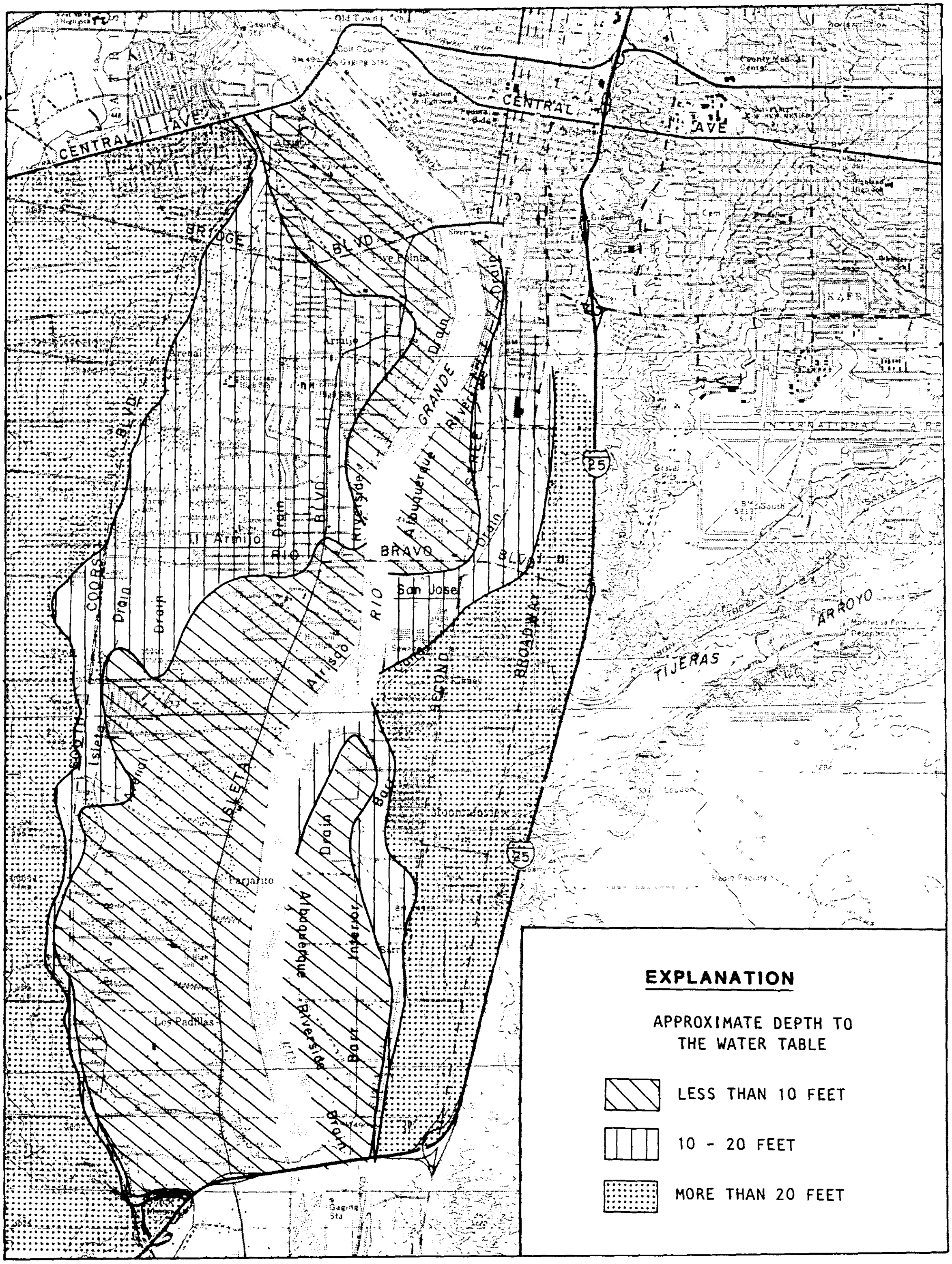
The water table west of the Rio Grande and south of Rio Bravo Boulevard has not changed significantly since 1936 (figs. 3 and 4). The general direction of flow is southwestward and the gradient is approximately 5 feet per mile, or 0.001. Flow is in part toward the Isleta Drain. On February 28th, 1986, the discharge in the Isleta Drain was 6.64 cubic feet per second at Rio Bravo Boulevard and 6.74 cubic feet per second at Malpais Road (table 2), which is essentially the same discharge, given the error of measurement may be 5 to 10 percent. As explained for Barr Drain, more water may be discharging from the ground-water system to the drain during the irrigation season than during the winter. Steeper gradients near the drains, particularly during the irrigation season, are likely.

The depth to the water table affects the occurrence and movement of contamination of ground water for several reasons, such as influencing the effectiveness of septic tanks. Certain contaminants, such as gasoline, tend to float on the water table, moving along it as well as up and down as the water table rises and declines. The upward vertical movement of the water table can allow contaminants in the unsaturated zone to be dissolved in the laterally moving ground water.

The depth to the water table varies areally and temporally because topography, river stage, irrigation, and ground-water withdrawals vary over the area and during the year. The approximate depth to the water table on February 28, 1986, is shown in figure 5, which was drawn using water-level measurements and values interpreted from comparison of figure 4 and a topographic map with a 10-foot contour interval. Locally, such as in small depressions, on small hills, or near drains and canals, it may not be an accurate representation of the depth to water. On February 28, 1986, in the area north of Rio Bravo Boulevard and east of the Albuquerque Riverside Drain, the depth to the water table was least at the drain and increased eastward toward the area of largest drawdown and higher land surface. North of Rio Bravo Boulevard between Coors Boulevard and the Atrisco Riverside Drain, the water table generally was 10 to 20 feet below land surface. The water table was within 10 feet of the surface in most of the area south of Rio Bravo Boulevard, excluding the Mountainview area (fig. 5). The water table beneath Mountainview was more than 20 feet deep, because the area is topographically higher.

In general, the water table declines in the summer and rises in the winter in areas affected by withdrawals from municipal wells, which is about the northern one-third of the study area. The southern two-thirds of the study area, in general, has more irrigated land and the water table generally rises in the summer and declines in the winter, as shown by the hydrographs in figure 6.

Water in the shallow ground-water system moves vertically, varying by time and place as to the amount and direction. Contamination of city wells from sources at land surface and water-level maps by Kues (1986, p. 10-11) have indicated downward movement. There also is a vertical component of flow as irrigation water moves from land surface to a drain. The water-level hydrographs for the Rio Bravo 1, 2, and 3 piezometer groups (fig. 6) show that the water levels generally are lowest in the deepest piezometers, which means that ground water is moving down as well as horizontally, particularly during the irrigation season. The casing of the deepest piezometer at the Rio Bravo 4 group was periodically flooded by surface water, as indicated by the sharp rises in water level shown in figure 6; therefore, the piezometer water level does not always represent the aquifer water level. The vertical hydraulic gradients between the piezometers installed with recorders (table 1), excluding the deep piezometer at Rio Bravo 4, ranged from 0.014 upward to 0.047 downward from July 1985 to June 1986 (table 3).



Base from U.S. Geological Survey, Albuquerque, 1:100,000, 1978

Figure 5.--Approximate depth to the water table on February 28, 1986.

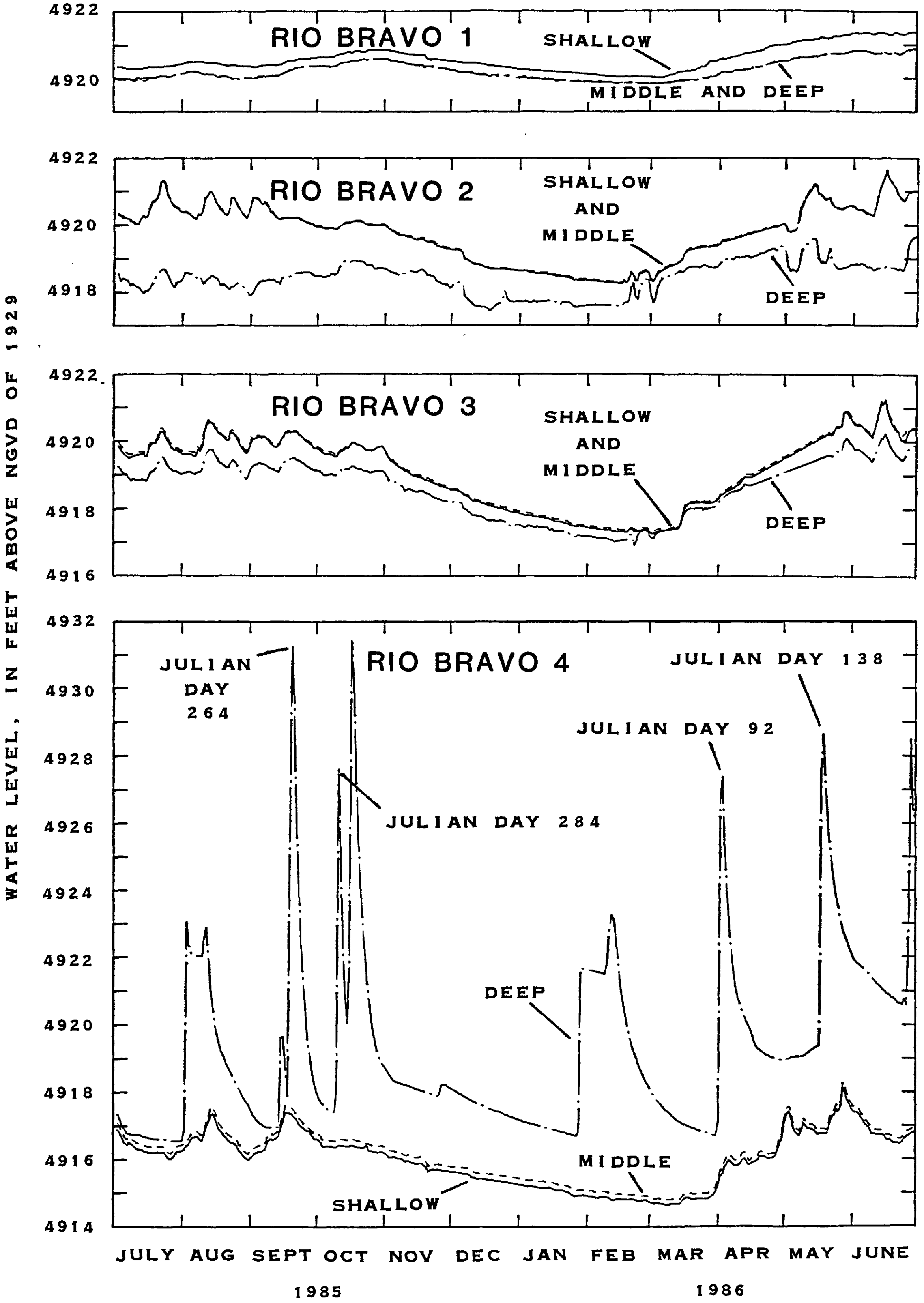


Figure 6.--Daily average water levels in four piezometer groups on Rio Bravo Boulevard (July 1985 - June 1986).

Table 3. Vertical hydraulic gradients between piezometers along Rio Bravo Boulevard from July 1985 to June 1986

[Horizontal gradient is about 0.001]

Piezometer pairs	Number of water measurements	Vertical hydraulic gradient[1] Mean	Range	Standard deviation
		Rio Bravo 1		
Shallow to middle	9,037	0.0051	0.0003 to 0.0099	0.0017
Shallow to deep		.0031	.0002 to .0059	.0011
Middle to deep		.0001	-.0062 to .0018	.0004
		Rio Bravo 2		
Shallow to middle	9,040	-.0005	-.0079 to .0063	.0004
Shallow to deep		.012	.0017 to .028	.0060
Middle to deep		.021	.0035 to .047	.0101
		Rio Bravo 3		
Shallow to middle	8,199	-.0011	-.014 to .0081	.0010
Shallow to deep		.005	-.0018 to .014	.0026
Middle to deep		.012	-.0004 to .029	.0053
		Rio Bravo 4		
Shallow to middle	9,027	-.0022	-.0069 to .0063	.0004
Shallow to deep[2]		-0.37	-.16 to .0050	.032
Middle to deep[2]		-.14	-.62 to .028	.12

[1]Vertical hydraulic gradient is determined by using the equation:

$$\frac{\text{Head}(1) - \text{Head}(2)}{L}$$

where Head(1) is the altitude of the water level in the shallower of the two piezometers, in feet above NGVD of 1929;
Head(2) is the altitude of the water level in the deeper of the two piezometers, in feet above NGVD of 1929; and
L is the distance between the tops of the screened intervals in the two piezometers.

[2]The water level in the deep piezometer is affected by flooding of the casing.

At each piezometer group, the vertical gradient between piezometers in the sand and gravel zone is less than or equal to the water-table gradient of 0.001. The middle pairs of piezometers in Rio Bravo 2, 3, and 4 are all screened in the sand and gravel zone (fig. 2). At each group, the water levels in these pairs of piezometers are nearly the same, demonstrating that vertical movement through this coarse zone probably is less than horizontal movement. There is, however, some vertical movement and the direction of this movement varies, as shown in table 3. This change in direction of movement, sometimes upward and sometimes downward, demonstrates one of the factors contributing to the dispersion of a contaminant through an aquifer.

The steepest gradients are between the middle and the deep piezometers at Rio Bravo 2 and 3, which are separated by a unit of clay and silt (fig. 2). If the water-level difference is entirely across this clay and silt unit, which is 7 feet thick at Rio Bravo 2 and 3, the mean vertical gradient across the unit is 0.19 at Rio Bravo 2 and 0.081 at Rio Bravo 3.

The water levels in the deep piezometers at Rio Bravo 2 and 3 are about 1 to 2 feet lower than water levels in the shallow piezometers during the irrigation season of March through October (fig. 6). After the cessation of irrigation, the water levels in all the piezometers decline and by the end of February there is not much difference.

Vertical gradients may be larger in the vicinity of wells, where withdrawals would lower the hydraulic head, forming cones of depression. Vertical gradients measured at piezometer groups near a city well field outside the study area were as much as 0.202 in the upper 100 feet of sediments. Vertical gradients may be larger deeper in the Santa Fe Group, nearer well screens.

AQUIFER PROPERTIES

Estimates of the hydraulic conductivity and porosity of typical alluvial deposits have been made by many investigators. These estimates are applicable to alluvial deposits of the Rio Grande; however, lack of geophysical logs and maps of the subsurface distribution of materials, which range in size from clay to cobbles, limits the ability to calculate the rate of water movement for specific sites.

The rate of movement of a particle of water through pore spaces in alluvium is the interstitial velocity. The velocity and direction of travel vary over a wide range because of irregularities in the geometry of the pore spaces.

The average interstitial velocity (Lohman and others, 1972, p. 14) is determined by the equation:

$$\bar{v}_i = -\frac{K(dh/dl)}{n_e}$$

where

$\bar{v}_i$ is the average interstitial velocity, in feet per day;

K is the hydraulic conductivity, in feet per day;

dh/dl is the hydraulic gradient, dimensionless; and

n_e is the effective porosity, dimensionless.

Graphs for $\bar{v}_i$ versus K for typical hydrologic conditions in the study area are shown in figure 7.

The values in figure 7 for average interstitial velocities may be used for preliminary evaluations and the planning of detailed investigations. Specific hydrologic conditions, locations of hydrologic boundaries, and values for hydraulic conductivity and effective porosity are a few of the factors that need to be determined before the rate of movement of a contaminant can be predicted. For example, the presence or absence of fine-grained units and the vertical gradient near wells are two factors that would affect the rate of movement of a contaminant downward. Also, the movement of a contaminant may be different than that of water because of differences in chemical and physical properties, such as solubility, viscosity, and density. Special situations require individual consideration beyond the scope of this investigation.

Given the variability of grain size and sorting, and hence the hydraulic conductivity and effective porosity of alluvium, only ranges of velocity can be estimated. For example, a reasonable estimate of the hydraulic conductivity of the sand and gravel unit beneath Rio Bravo Boulevard would range from 100 to 1,000 feet per day (fig. 7). If the effective porosity is about 0.1 to 0.3, a reasonable estimate for the sand and gravel unit, and the horizontal gradient is 0.001 (table 3), the estimated average horizontal interstitial velocity would range from about 0.3 to 10 feet per day (fig. 7).

The hydraulic conductivity of the clay and silt unit that underlies the sand and gravel unit at Rio Bravo 4 (fig. 2) was estimated by using a method for analyzing slug-test data. The deepest piezometer at Rio Bravo 4 is screened in this 15-foot-thick silt and clay zone (fig. 2). Periodically, the piezometer casing was flooded by irrigation or storm runoff (fig. 6). Subsequently, the water level in the piezometer gradually declined at a rate proportional to the transmissivity and storage coefficient of the clay and silt. Four of these water-level-decline curves were individually analyzed by using the curve-matching method for slug tests described by Lohman (1979, p. 27-29 and pl. 2). The average transmissivity estimated by this method is

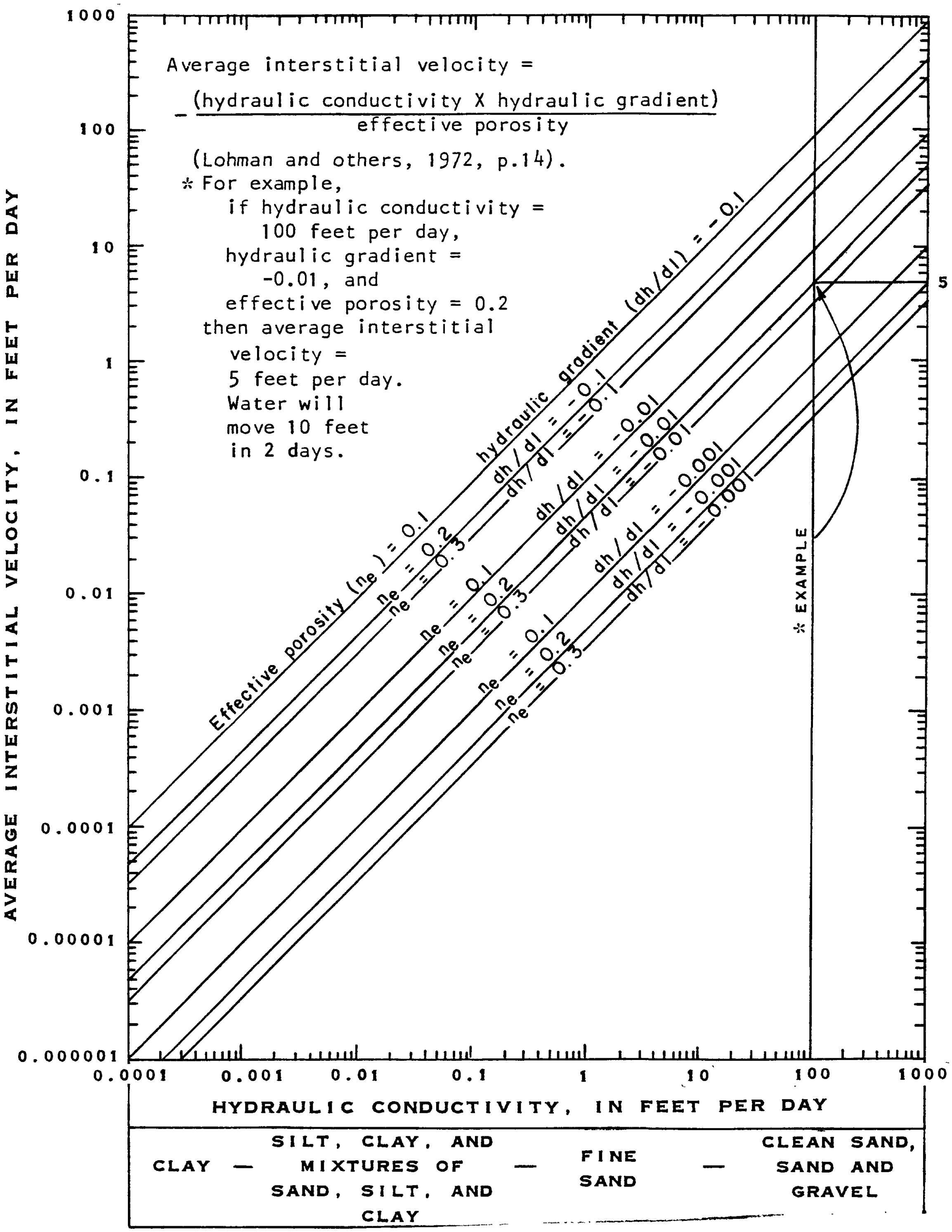


Figure 7.--Relation of average interstitial velocity and hydraulic conductivity for typical values of effective porosity and hydraulic gradient. (Values for hydraulic conductivity modified from U.S. Water and Power Resources Service, 1981, p. 29).

0.015 foot squared per day (fig. 8), which for a thickness of 15 feet (fig. 2) equals a horizontal hydraulic conductivity of 0.001 foot per day. This value falls within the range of values for clay and silt mixtures shown in figure 7. Though the curves best coincide with type curves for a storage coefficient of 0.01, this method is not reliable for estimating storage coefficient. Olson and Daniel (1981, p. 33) reported ratios of horizontal to vertical conductivity for soft clays ranging from 1.05 to 1.5. Using the value of 1.5, the vertical hydraulic conductivity of the clay and silt unit would be about 0.0007 foot per day. If the vertical hydraulic gradient is about 0.081, as calculated for the same zone at the Rio Bravo 3 group, and the effective porosity ranges from 0.1 to 0.3, the average vertical interstitial velocity would range from about 0.0002 to 0.0005 foot per day (fig. 7).

RELATION BETWEEN GROUND WATER AND SURFACE WATER

The relation of ground water to surface water is an important part of the ground-water system in the inner valley of the Rio Grande. Quantitative knowledge of the relationship of the Rio Grande to ground water in the alluvium and Santa Fe Group is useful in the overall evaluation of the ground-water system; however, the data collected for this study are inconclusive. The most significant finding is that there is little resemblance between water-level hydrographs for Rio Bravo 2 and the riverside drains and the Barr Canal (figs. 9 and 10). There is a vague resemblance of water-level hydrographs for Rio Bravo 2 to those of the river from December 1985 to May 1986; however, the data are inconclusive.

Estimates of the proportions of ground-water contributions from the inner valley and the river to the riverside drains were made based on measurements of discharge and specific conductance of the water in the drains on February 28, 1986 (table 2). In general, the equations used are modified from Hem (1985, p. 206):

$$Q_{du} + Q_r + Q_{gw} = Q_{dd} \quad \text{and}$$

$$Q_{du}\, C_{du} + Q_r\, C_r + Q_{gw}\, C_{gw} = Q_{dd}\, C_{dd}$$

where

- Q_{du} is the discharge in the drain upstream, in cubic feet per second;
- Q_r is the contribution to the drain from the river, in cubic feet per second;
- Q_{gw} is the contribution to the drain from ground water, in cubic feet per second;
- Q_{dd} is the discharge in the drain downstream, in cubic feet per second; and
- C is the concentration of dissolved solids, in milligrams per liter, in the drain upstream (subscript du), the river (subscript r), ground water (subscript gw), or the drain downstream (subscript dd).

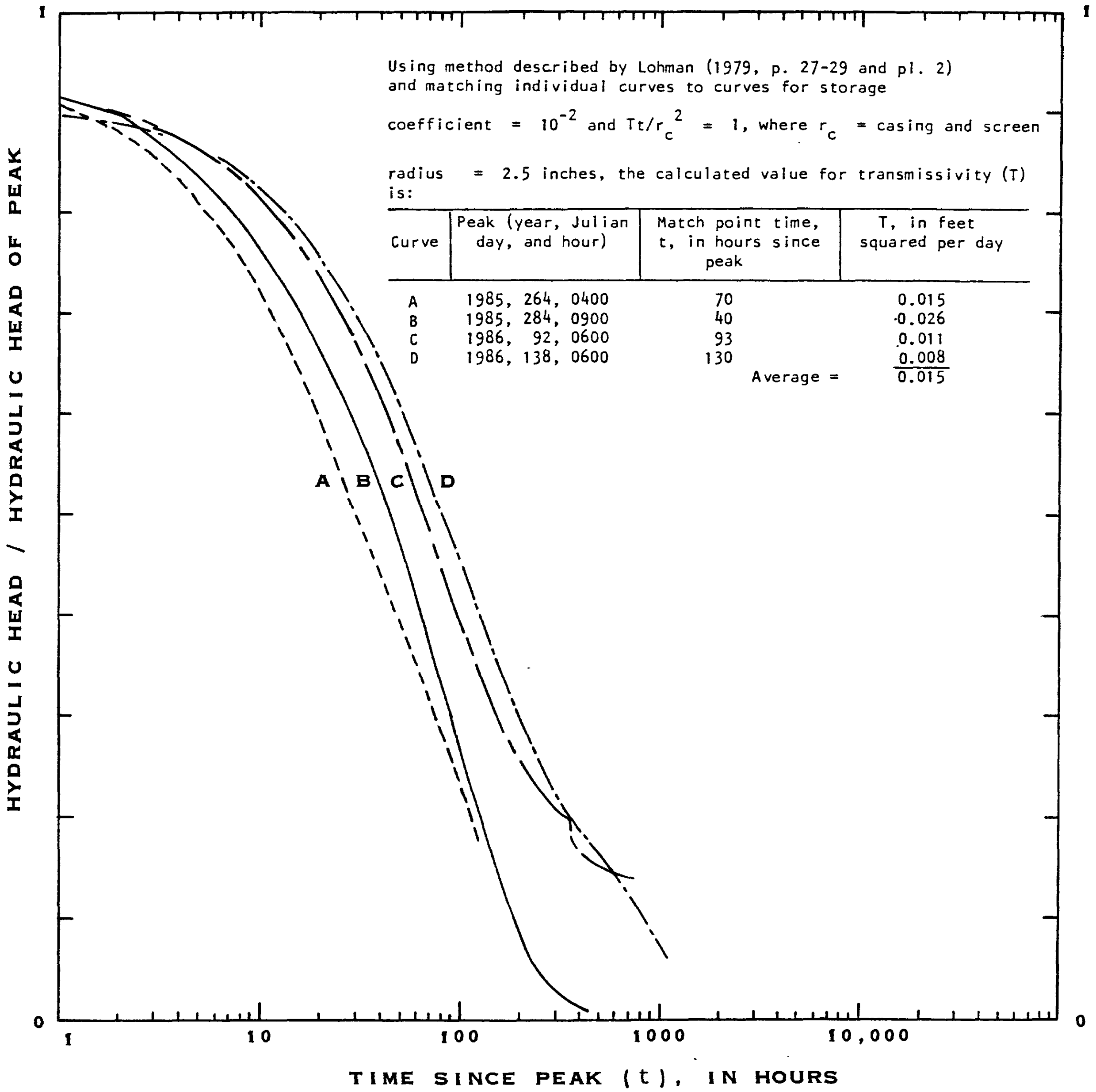


Figure 8.--Recovery of water levels in a piezometer after four separate floods.

The average concentration of dissolved solids in the ground water was estimated to be 720 milligrams per liter by use of a mass-balance calculation of the results of discharge measurements made in the Isleta Drain at Central Avenue and Rio Bravo Boulevard. By use of 720 milligrams per liter for concentration of the ground-water contribution, 274 milligrams per liter for the estimated concentration of dissolved solids in the Rio Grande, and a mass-balance calculation of the discharges in the Atrisco Riverside Drain at Central Avenue and Rio Bravo Boulevard, it is estimated that of the 26.6 cubic feet per second increase in discharge in the drain, 2.4 cubic feet per second is ground water from the alluvium west of the drain. The remaining 24.2 cubic feet per second increase is leakage from the Rio Grande to the drain. The estimated contribution of ground water from the alluvium east of the Albuquerque Riverside Drain from Rio Bravo Boulevard to Interstate 25 is calculated to be 2.9 cubic feet per second by using 900 milligrams per liter for the average concentration of dissolved solids in ground water (average of the two measurements of water in the Barr Drain) and the measurements of discharge in the Albuquerque Riverside Drain at Rio Bravo Boulevard and Interstate 25. The remainder is from the Rio Grande. Because the error of the discharge measurements is 5 to 10 percent and the error in the estimates of the dissolved-solids concentration for ground water may be more than 10 percent, these estimates need to be used cautiously.

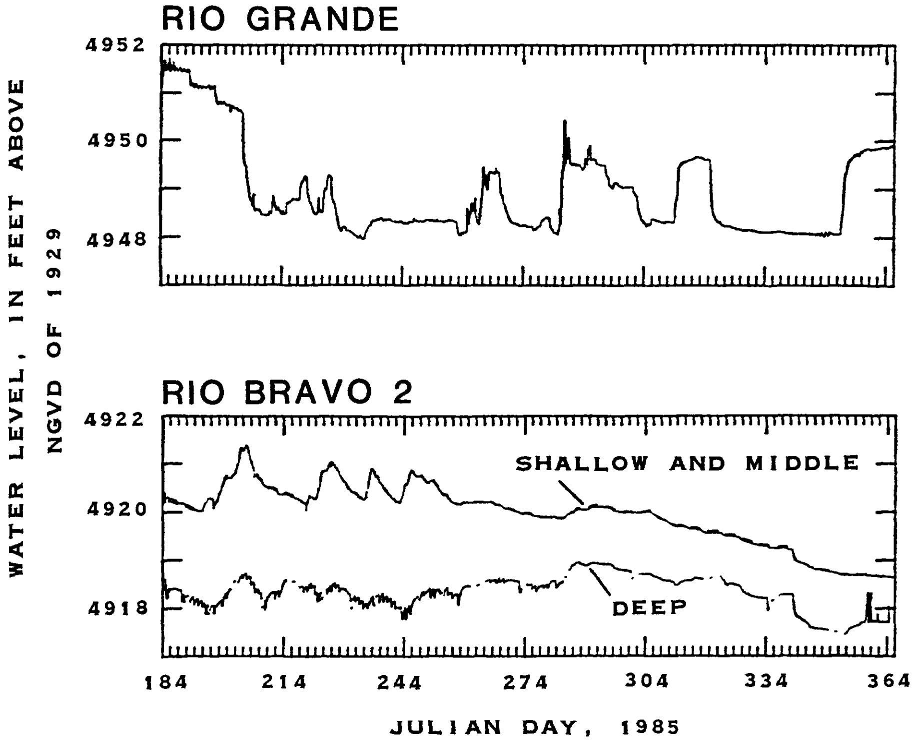


Figure 9.--Water levels in the Rio Grande and the Rio Bravo 2 piezometer group (July 3, 1985, - December 31, 1985).

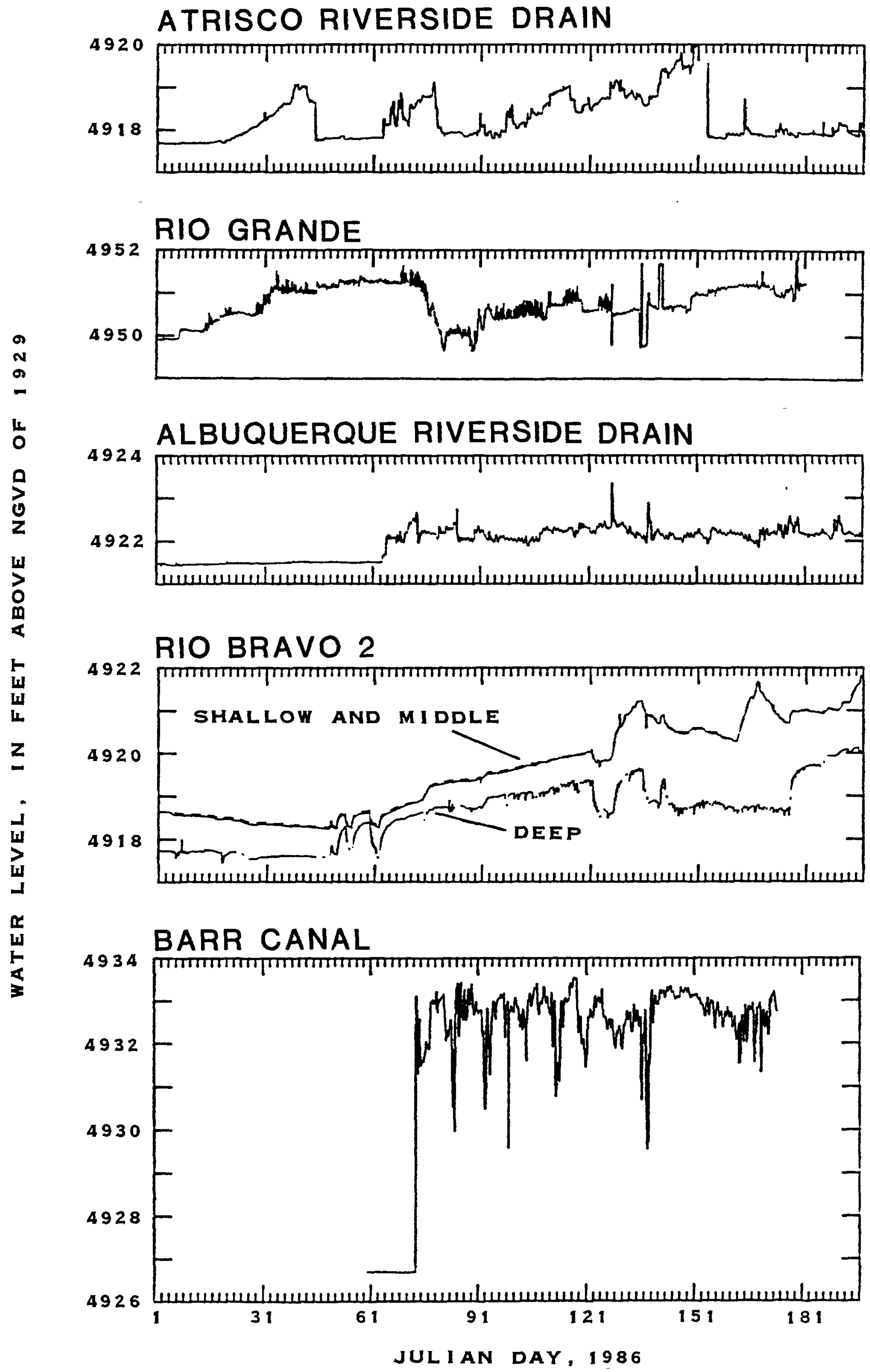


Figure 10.--Water levels in the Atrisco Riverside Drain, the Rio Grande, the Albuquerque Riverside Drain, the Rio Bravo 2 piezometer group, and the Barr Canal (January 1, 1986 - July 16, 1986).

SUMMARY

The four major factors controlling the direction of shallow ground-water flow in the inner valley of the Rio Grande in the area of Albuquerque are: (1) the Rio Grande, (2) riverside and interior drains, (3) irrigation, and (4) ground-water withdrawals by the city of Albuquerque and industry. The shallow ground-water flow is, in part, from the Rio Grande to the riverside drains, which are constructed so their stage is below that of the river. In most of the study area, the general direction of flow is parallel to the river. The water-table gradient generally is to the south at approximately 5 feet per mile, or 0.001; it is steeper near the drains. As Albuquerque has grown and ground-water use has increased, deep wells (exceeding 200 feet) have removed water from storage, drawing down the water table in and near the city. Though long-term measurements are necessary to determine the range of seasonal changes, the water-table drawdown may exceed 10 feet in the area east of the Rio Grande and north of Rio Bravo Boulevard. Water-table gradients in this area are as much as 20 feet per mile, or 0.004. Flow in this area is now almost due east, perpendicular to the direction of flow in 1936. Declines outside the study area are larger, exceeding 75 feet in wells about 5 miles east of Interstate 25.

In the area east of Mountainview, the direction of water movement may have reversed between 1936 and 1986. Whereas flow in 1936 probably was southwestward, away from the debouchure of Tijeras Arroyo, it now appears to be toward the east or southeast. Given that water levels in parts of Albuquerque have declined more than 75 feet, it is logical that somewhere south of the city there is a ground-water divide. Additional data are needed for this area to determine the location of the divide.

The depth to the water table varies areally and temporally in the study area because ground-water withdrawals, irrigation, and river stage vary over the area and during the year. In general, the water table declines in the summer and rises in the winter in areas affected by muncipal ground-water withdrawals, that is, about the northern one-third of the study area. In general, the southern two-thirds of the study area has more irrigated land and the water table generally rises in the summer and declines in the winter. On February 28, 1986, in the area north of Rio Bravo Boulevard and east of the Albuquerque Riverside Drain, the water table was shallowest at the drain and deepened eastward toward areas with the largest drawdown and higher land surface. North of Rio Bravo Boulevard between Coors Boulevard and the Atrisco Riverside Drain, the water table generally was 10 to 20 feet deep. The water table was within 10 feet of the surface in most of the area south of Rio Bravo Boulevard, excluding Mountainview (fig. 5). During the irrigation season, it may be shallower. The water table beneath the community of Mountainview, which is built on a topographic high at the mouth of Tijeras Arroyo, was more than 20 feet deep.

The hydrographs for piezometer groups along Rio Bravo Boulevard show that the water levels generally are lowest in the deepest piezometers, particularly during the irrigation season, which means that ground water is moving downward as well as horizontally. The vertical gradients between the closely spaced piezometers of different depths ranged from 0.014 upward to 0.047 downward from July 1985 to June 1986.

A range of estimated values for the average interstitial velocity can be calculated by using a reasonable estimate of the hydraulic conductivity of the sand and gravel unit beneath Rio Bravo Boulevard. For a sand and gravel unit with hydraulic conductivity that ranges from 100 to 1,000 feet per day, porosity from about 0.1 to 0.3, and horizontal gradient of 0.001, the estimated average interstitial velocity would range from 0.3 to 10 feet per day. Although the interstitial velocity range is large, it would be useful in selecting the locations of observation wells, which could then be used in aquifer tests to determine the aquifer properties more precisely.

The horizontal hydraulic conductivity of a 15-foot-thick clay and silt unit was estimated to be 0.001 foot per day. By using a ratio of horizontal to vertical conductivity of 1.5, a gradient of 0.081, and a range of effective porosity of 0.1 to 0.3, the average interstitial velocity would range from about 0.0002 to 0.0005 foot per day.

Quantitative knowledge of the relation of the Rio Grande to the alluvium and Santa Fe Group would be useful in the overall evaluation of the ground-water system; however, more data need to be collected. There is little resemblance between hydrographs of ground-water levels near the Rio Grande and hydrographs of the riverside drains and the Barr Canal. The piezometer hydrographs slightly resemble the river hydrographs, but the data are inconclusive.

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