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Water Resources of the Three Rivers Area, Otero and Lincoln Counties, New Mexico

By

James W. Hood and E. H. Herrick

Open-file

July 1962

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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James W. Hood and E. H. Herrick

Prepared in cooperation with the

U.S. Army, Corps of Engineers

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Abstract

The Three Rivers drainage basin, a tributary to the Tularosa Basin of south-central New Mexico, is a potential source of supplementary water for the Bonito Lake pipeline that supplies water to the town of Alamogordo and Holloman Air Force Base.

The Three Rivers area includes about 150 square miles of mountain uplands and alluvial slopes that border the lowlands of the Tularosa Basin. Altitudes in the area range from about 4,600 feet to about 12,000 feet, and although the terrain is mountainous in the eastern part, most of the area is semiarid. Annual precipitation ranges from about 9.5 inches in the lowlands to more than 25 inches in the mountains.

Rocks exposed in the area range in age from Triassic to Recent. Consolidated sedimentary rocks include the Dockum Group, Dakota(?) Sandstone, Mancos Shale, Mesaverde Group, and Cub Mountain Formation of Bodine (1956). Unconsolidated rocks consist of fluvial gravel, sand, silt, and clay and eolian silt. Part of the area is underlain by relatively impermeable extrusive and intrusive igneous rocks. Sills and dikes, which are numerous in the eastern part of the area, restrict the movement of ground water.

The regional dip is eastward in the western part of the area and northeastward in the eastern part. Faults having displacements of several hundred feet trend northwestward and northeastward. A poorly defined syncline trends northwestward through the area.

Most of the streams in the area flow only after thunderstorms. Three Rivers Canyon and Indian Creek, however, are perennial in their upper reaches. During 1956 and part of 1957, flow in both streams was low, and both were dry for periods of a few days to several weeks. During the latter part of 1957 and in 1958, a wet period, streamflow increased about 300 percent. Both streams are influent in some reaches, and flow reaches the lowlands only occasionally. In the lower parts of the drainage basin, streamflow is intermittent but frequently is of great magnitude. During the 29 months of record, Three Rivers Canyon yielded about 2,900 acre-feet of water, or an average of about 1.1 mgd (million gallons per day). Indian Creek yielded about 4,660 acre-feet during the same period, or an average of about 1.8 mgd. Other streams in the area were not gaged.

Water from streams in the higher elevations of the Three Rivers area generally contains only small quantities of dissolved solids, owing to the scarcity of readily soluble minerals in that part of the area. Water in upper Three Rivers Canyon generally contains 230 to 340 ppm (parts per million) of dissolved solids, including 99 to 119 ppm of sulfate. Water from Indian Creek is even less mineralized. Stream water in the lower part of the drainage basin is variable in mineralization in part because the intermittent flow flushes away salts that accumulate during dry periods.

The aquifers in the Three Rivers area that contain potable or near-potable water are alluvium of Quaternary age and sandstones in the lower part of the Mesaverde Group and the Cub Mountain Formation of Bodine (1956). Some older formations probably contain highly mineralized water. Water in the alluvium is unconfined, and water in the older, consolidated rocks is under artesian pressure. The depth to water ranges from nearly 200 feet to near the land surface. The ground-water surfaces slope westward, in much the same direction as does the land surface. Recharge is from precipitation in the area, mostly on the mountain slopes of the eastern part, where precipitation is greatest. Some recharge is rejected during wet years. Ground water is discharged mainly by movement through the aquifers westward out of the area. Artificial discharge through wells is estimated to be, at a maximum, only about 1,000 gpm (gallons per minute).

Logs of test wells indicate that the alluvium is thin and in some areas is unsaturated. However, the alluvium is relatively permeable, and where it is thickest it should yield as much as 200 gpm to wells. The Mesaverde Group and the Cub Mountain Formation of Bodine (1956) are much less permeable than the alluvium but should yield as much as 100 gpm to wells in selected locations. Wells that tap the alluvium and the Mesaverde and Cub Mountain would have the largest yields.

Most ground water in the Three Rivers area is of fair to poor chemical quality. Of 67 samples of water, only 1 had a sulfate content of less than 250 ppm and a dissolved-solids content of less than 600 ppm. Most of the ground water is of the calcium magnesium sulfate type. The sulfate content may be used to judge the water quality because where the sulfate content is low the chloride content is much lower. All the ground water is hard.

The Three Rivers area has an estimated minimum annual yield of about 560 acre-feet of ground water containing less than 500 ppm of sulfate. The potential surface-water yield may be as much as 3,500 acre-feet per year, but the average annual yield is estimated to be about 1,700 acre-feet. By impounding surface water of good quality and mixing it with ground water of fair to poor quality, the area should yield, on an average annual basis, about 2,300 acre-feet of water containing 200 ppm or less of sulfate.

Introduction

Holloman Air Force Base, acting through the Corps of Engineers, U.S. Army, and the town of Alamogordo, has extended its search for water supplies through an area more than 80 miles long and as much as 20 miles wide along the west side of the Sacramento Mountains. Unappropriated potable water supplies are meager in this area. The dearth of potable water together with the rapid growth in population in the Alamogordo area has led to the investigation of areas in which there is a possibility of developing additional supplies.

The Three Rivers area, so named from the master stream of the area, is considered to be a potential source of water to supplement the supply to the Bonito Lake pipeline, which transports water to Holloman Air Force Base and the town of Alamogordo. The Three Rivers drainage basin is one of many basins tributary to the vast semiarid Tularosa Basin of south-central New Mexico. (See fig. 1.)

Figure 1.--Map showing location and extent of the Three Rivers area (shaded), Otero and Lincoln Counties, N. Mex.

The earliest water-resource investigations in the Tularosa Basin were those by Meinzer and Hare (1915). Their work, however, provides only meager data pertaining to the Three Rivers area. Schmaltz (1955) mapped the geology of the Three Rivers and Oscura quadrangles, which include the western part of the area of the present investigation. Herrick and others (1959) described the Three Rivers area in an appraisal of the water supply of the Tularosa Basin and adjacent areas.

The U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers began this study of the general availability of water in the Three Rivers area in June 1956. Intensive field work was concluded in October 1957 with the completion of the test-drilling program. The principal purpose of the study was to determine the amount and quality of surface water and ground water that might be developed to supplement the supply being delivered through the Bonito Lake pipeline. The pipeline parallels U.S. Highway 54 along the west side of the Three Rivers area.

The investigation in the Three Rivers area included a study of the geology to determine which formations would yield usable quantities of water, approximately 2½ years of gaging the main streams of the area, a study of the ground-water supplies based on wells and springs in the area, subsequent test drilling to confirm preliminary conclusions concerning the ground-water supplies and to obtain data that were not otherwise available, and a study of the chemical quality of the ground water and surface water. This report explains the general availability of water, as determined from these data.

Base maps for the study were prepared from U.S. Geological Survey topographic maps, which are available in both the 15-minute and the 7½-minute quadrangle series. About two-thirds of the area was mapped geologically; greatest effort was given to the central part of the area around the confluence of the several tributaries to Three Rivers.

Where possible, the depths of wells and the water levels were accurately measured, and other information pertaining to wells and springs was recorded. Water samples for chemical analysis were obtained from most wells and some springs.

Several wells were selected for observation of water levels, and these have been measured at least four times a year from January 1957 through January 1960.

The most promising area for the production of ground water was determined, and eight test holes were drilled to determine the subsurface distribution of the geologic formations and their hydrologic properties.

Surface-water investigations included the installation of four recording gages in Three Rivers Canyon and on Indian Creek above the confluence of the several tributaries of the main stem of Three Rivers. Recording rain gages were maintained at three of the stations. Several measurements were made at sites above the recording gage in Three Rivers Canyon, and a few samples of surface water for chemical analysis were taken from selected points in the drainage system.

Basic data from the investigation are given in tables 2-7 and 9-11.

Acknowledgments

The investigation described in this report was carried out under the supervision of E. H. Herrick. After Mr. Herrick's untimely death, R. A. P. Gaal of the Geological Survey mapped the geology of the Three Rivers area and prepared much of the description of the formations. J. W. Hood was assigned the preparation of the report.

T. F. Ryan, III, and the Mescalero Apache Tribe, who won nearly all the area investigated, permitted entry to their lands for the purposes of study. Other property owners in the area cooperated in a similar manner. Messrs. Johnson, Cozzens, and McDonald, local residents, not only provided information but also did much to aid the investigators.

Holloman Air Development Center provided auxiliary services, such as road construction and maintenance, which aided greatly during the investigation.

Location-Numbering System

In this report, a numbering system is used that is based on the Federal system of subdivision of public lands to designate locations of wells, springs, and surface-water sampling and gaging points. The location number has four segments: the first denotes the township; the second denotes the range, the third denotes the section; and the fourth, consisting of three digits, denotes the particular 10-acre tract of the section in which the point is located. For this purpose the section is divided into four quarters, numbered 1, 2, 3, and 4 for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts. Thus a point numbered 11.9.11.322 is in the NE$\frac{1}{4}$NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 11, T. 11 S., R. 9 E.

If a point cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If a point cannot be located more closely than the section, the fourth segment of the location number is eliminated. The letters a, b, c, and so on, are added to the last segment to designate the second, third, fourth, and subsequent items in the same 10-acre tract. The method of numbering sections within a township and tracts within a section is illustrated in figure 2.

Figure 2.--System of numbering wells and locations in New Mexico.

Geography

Location and Extent of the Area

The Three Rivers area includes about 150 square miles east of Three rivers station on the Southern Pacific Railroad and U.S. Highway 54, about 20 miles north of Tularosa, N. Mex. The area includes parts of T. 10 S., Rs. 8 and 10 E., Lincoln County, and parts of Tps. 11 and 12 S., Rs 9, 9½, and 10 E., Otero County, N. Mex. (See fig. 5.)

Topography

The Three Rivers area is in the Sacramento section of the Basin and Range province (Fenneman, 1931, p. 394), at the east side of the Tularosa Basin. The eastern margin of the area is on the west slope of the Sacramento Mountains, whose crest forms the divide between the Tularosa Basin and the Pecos River basin. From the crest of Sierra Blanca, altitude 12,003 feet, the terrain descends precipitously to the west, its slopes as steep as 2,500 feet per mile. In the central part of the Three Rivers area the grade decreases, and at the confluence of the tributaries of Three Rivers it is about 125 feet per mile. At Three Rivers station on the Southern Pacific Railroad, altitude 4,568 feet, the grade is only about 50 feet per mile.

Although Sierra Blanca dominates the landscape, there are several lesser spurs of the mountain mass in the Three Rivers area. The Godfrey Hills, a low range, are in the north-central part of the area, between the Sierra Blanca and the Tularosa Basin proper.

Except for the Three Rivers reentrant, most of the lower slopes adjacent to the Sierra Blanca and the Godfrey Hills are coalescing alluvial fans that slope westward; these are cut by subparallel arroyos and interrupted by small masses of consolidated rock. The Three Rivers reentrant, or embayment, is enclosed by the Godfrey Hills on the west, an adjoining spur of the Sierra Blanca on the north, Sierra Blanca on the east, and a high-level pediment on the southeast. The reentrant was formed because the sedimentary rocks were eroded more rapidly than the surrounding igneous rocks. The adjoining high-level pediment apparently was developed because the amount of streamflow was less on the pediment than in the reentrant. The most promising area for development of ground water is within the Three Rivers reentrant.

Climate

The western part of the Three Rivers area is semiarid and is characterized by scant precipitation, low relative humidity, and strong winds during the spring. Winters generally are mild, and the summers have hot days but cool nights. The eastern part of the area, however, has a somewhat different climate because the precipitation increases and the air temperature decreases with altitude. (See fig. 3.) The amount of precipitation on the Sierra Blanca is

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Figure 3.--Graph showing relation of temperature and precipitation to altitude on west side of Sacramento Mountains, Otero and Lincoln Counties, N. Mex.

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considerably greater than that in the lowlands. Owing to the lower temperatures, much of the precipitation, especially in winter, is stored as snow and ice, which contributes to the perennial flow in the tributaries of Three Rivers.

Except for precipitation records from 1909 to 1932 at Three Rivers station, long-term climatic records are not available for the Three Rivers area; records of the automatic rain gages were obtained for only 2½ years or less. (See section on surface water, p. _____.)

Because local precipitation is the source of recharge to the water-bearing formations, a general knowledge of the amount of precipitation and its distribution is desirable. Table 1 shows the records of precipitation for the period 1956-59, and the normal monthly precipitation, as calculated by the U.S. Weather Bureau, at six stations near the Three Rivers area. Records at these stations range in length from 33 to 52 years. The table shows that about 60 percent of the annual precipitation is distributed from May through September, a period during which most precipitation comes in thunderstorms. The data show also that precipitation varied widely during the four years, ranging from nearly 70 percent below normal at Alamagordo in 1956 to about 60 percent above normal at Tularosa in 1958. The last of a series of drought years was 1956. Precipitation at all stations was near or slightly above normal in 1957, above normal in 1958, and near normal in 1959. These year-to-year fluctuations are reflected in the records of ground-water levels and streamflow.

Table 1.--Monthly and annual precipitation and departures from normal at six observation stations near the Three Rivers area, New Mexico, 1956-59

[Data from U.S. Weather Bureau, ~~1956-59,~~ Annual Summaries. Values for normal precipitation based on period of record. Values for all stations revised by Weather Bureau in 1957; 1957 revision used herein. E, estimated; T, trace]

Year	January		February		March		April		May		June		July		August		September		October		November		December		Annual	
	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure	Precipitation	Departure
Alamogordo - 44 years of record - Elevation 4,350 feet																										
1956	0	-0.62	E0.45	-0.07	0	-0.44	E0	-0.41	0	-0.57	0.43	-0.32	0.86	-0.66	0.08	-1.66	0.23	-1.18	0.69	-0.22	0	-0.59	0.19	-0.49	E2.93	-7.23
1957	.44	-.33	1.22	.68	.93	.62	.37	E0	0	-.51	T	-.75	.96	.72	4.39	2.97	.93	-.67	3.25	2.46	.84	.42	T	-.60	E13.33	3.57
1958	E.89	.12	.45	-.09	3.02	2.71	.58	.21	.44	-.07	1.07	.32	1.12	-.56	2.70	1.28	3.09	1.49	1.50	.71	.39	-.03	T	-.60	E15.25	5.49
1959	T	-.77	.54	0	T	-.31	.10	-.27	.66	.15	.41	-.34	1.35	-.33	6.67	5.25	.02	-1.58	.45	-.34	.04	-.38	.54	-.06	10.78	1.02
Normal	.77	~~.77~~	.54	~~.54~~	.31	~~.31~~	.37	~~.37~~	.51	~~.51~~	.75	~~.75~~	1.68	~~1.68~~	1.42	~~1.42~~	1.60	~~1.60~~	.79	~~.79~~	.42	~~.42~~	.60	~~.60~~	9.76	~~9.76~~
Carrizozo - 48 years of record - Elevation 5,438 feet																										
1956	0.30	-0.35	0.54	-0.18	0	-0.70	0.06	-0.58	0.14	-0.67	0.67	-0.29	2.15	-0.18	2.50	0.26	0.04	-1.49	0.83	-0.10	0	-0.56	T	-0.79	7.23	-5.63
1957	.36	-.39	1.62	.85	1.76	1.03	.62	-.08	.39	-.56	.11	-1.03	2.07	-.12	2.67	.40	.24	-1.84	2.34	1.42	1.21	.66	.20	-.63	13.59	-.29
1958	.49	-.26	.32	-.45	2.75	2.02	1.30	.60	1.37	.42	3.22	2.08	4.00	1.81	1.30	-.97	4.50	2.42	1.45	.53	.95	.40	.20	-.63	21.85	7.97
1959	.13	-.62	.32	-.45	.06	-.67	.50	-.20	.68	-.27	1.50	.36	2.79	.60	3.54	1.27	.14	-1.94	1.16	.24	.10	-.45	1.25	.42	12.17	-1.71
Normal	.75	~~.75~~	.77	~~.77~~	.73	~~.73~~	.70	~~.70~~	.95	~~.95~~	1.14	~~1.14~~	2.19	~~2.19~~	2.27	~~2.27~~	2.08	~~2.08~~	.92	~~.92~~	.55	~~.55~~	.83	~~.83~~	13.88	~~13.88~~
Cloudcroft Ranger Station - 52 years of record - Elevation 8,700 feet																										
1956	1.16	-0.55	2.25	0.65	0	-1.37	0.57	-0.29	0	-1.14	1.42	-0.29	6.01	1.00	3.84	-0.80	0.02	-2.88	1.55	-0.03	T	-1.16	0.90	-0.61	17.72	-7.47
1957	1.50	-.26	2.74	1.16	3.51	2.01	1.01	.11	.56	-.64	.40	-1.59	3.02	-2.75	7.02	2.45	.41	-2.19	4.72	3.25	2.40	1.52	.34	-1.22	27.63	1.85
1958	3.16	1.40	3.28	1.70	7.31	5.81	1.06	.16	.65	-.55	1.25	-.74	4.66	-1.11	7.51	2.94	4.78	2.18	3.06	1.59	.85	-.03	.23	-1.33	37.80	12.02
1959	.04	-1.72	1.31	-.27	.10	-1.40	.05	-.85	.32	-.88	1.53	-.46	8.84	3.07	6.90	2.33	.05	-2.55	.64	-.83	.06	-.82	1.22	-.34	21.06	-4.72
Normal	1.76	~~1.76~~	1.58	~~1.58~~	1.50	~~1.50~~	.90	~~.90~~	1.20	~~1.20~~	1.99	~~1.99~~	5.77	~~5.77~~	4.57	~~4.57~~	2.60	~~2.60~~	1.47	~~1.47~~	.88	~~.88~~	1.56	~~1.56~~	25.78	~~25.78~~
Mescalero - 33 years of record - Elevation 6,585 feet																										
1956	0.50	0.30	0.18	-0.84	0	-0.87	0.28	-0.42	0.08	-0.98	1.88	0.46	1.97	-2.09	4.21	0.43	0	-2.24	1.68	0.31	0	-0.92	0.45	-0.69	11.23	-8.15
1957	1.47	.53	1.85	.86	1.56	.70	.65	-.05	.74	-.15	.57	-.74	4.51	.90	6.30	2.80	.90	-1.32	3.97	2.82	2.08	1.41	.14	-.99	24.74	6.77
1958	1.46	.52	1.55	.56	3.97	3.11	1.18	.48	.76	-.13	3.98	2.67	3.15	-.46	4.47	.97	5.94	3.72	1.55	.40	1.15	.48	.20	-.93	29.36	11.39
1959	.03	-.91	1.70	.71	.06	-.80	.04	-.66	1.10	-.21	1.37	.06	2.57	-1.04	5.59	2.09	0	-2.22	.82	-.33	0	-.67	1.61	.48	14.89	-3.08
Normal	.94	~~.94~~	.99	~~.99~~	.86	~~.86~~	.70	~~.70~~	.89	~~.89~~	1.31	~~1.31~~	3.61	~~3.61~~	3.50	~~3.50~~	2.22	~~2.22~~	1.15	~~1.15~~	.67	~~.67~~	1.13	~~1.13~~	17.97	~~17.97~~
Mountain Park - 36 years of record - Elevation 6,720 feet																										
1956	0.50	-0.68	0.75	-0.30	0	-0.85	0	-0.70	0	-0.84	1.69	0.28	2.36	-0.69	3.58	0.13	T	-2.29	1.19	-0.27	0	-0.85	0.30	-0.85	10.37	-7.91
1957	.90	-.15	2.38	1.36	2.50	1.63	.25	-.37	T	-.74	0	-1.33	3.36	.21	5.45	2.37	.15	-1.88	4.40	3.10	1.54	.89	T	-1.01	20.93	4.08
1958	2.39	1.34	1.45	.43	4.91	4.04	.96	.34	1.57	.83	1.40	.07	3.16	.01	1.84	-1.24	4.51	2.48	2.69	1.39	.45	-.20	.10	-.91	25.43	8.58
1959	0	-1.05	1.20	.18	0	-.87	.15	-.47	.48	-.26	.65	-.68	3.39	.24	5.85	2.77	0	-2.03	.46	-.84	T	-.65	1.05	.04	13.23	-3.62
Normal	1.05	~~1.05~~	1.02	~~1.02~~	.87	~~.87~~	.62	~~.62~~	.74	~~.74~~	1.33	~~1.33~~	3.15	~~3.15~~	3.08	~~3.08~~	2.03	~~2.03~~	1.30	~~1.30~~	.65	~~.65~~	1.01	~~1.01~~	16.85	~~16.85~~
Tularosa - 47 years of record - Elevation 4,450 feet																										
1956	T	-0.47	E0.25	-0.27	0	-0.45	0	-0.47	0.02	-0.48	T	-0.78	0.50	-0.93	0.84	-0.72	1.10	-0.51	2.52	1.85	0	-0.47	0.13	-0.51	E5.36	-4.21
1957	E.52	.05	1.18	.66	1.12	.67	.25	-.22	.25	-.25	0.28	-.50	2.00	.57	2.43	.87	.31	-1.30	2.80	2.13	.67	.20	0	-.64	E11.81	2.24
1958	1.05	.58	.21	-.31	2.59	2.14	.57	.10	.34	-.16	1.80	1.02	.73	-.70	3.06	1.50	3.42	1.81	1.50	.83	.50	.03	0	-.64	15.77	6.20
1959	.05	-.42	.36	-.16	0	-.45	.03	-.44	.61	.11	E.64	-.14	E1.59	.16	2.10	.54	.04	-1.57	.54	-.13	.01	-.46	E1.07	.43	E7.04	-2.53
Normal 1/	.47	~~.47~~	.52	~~.52~~	.45	~~.45~~	.47	~~.47~~	.50	~~.50~~	.78	~~.78~~	1.43	~~1.43~~	1.56	~~1.56~~	1.61	~~1.61~~	.67	~~.67~~	.47	~~.47~~	.64	~~.64~~	9.57	~~9.57~~

1/ Normal used by Weather Bureau for 1956 retained for use in 1957-59. ~~owing to shift of station of less than 0.2 mile.~~ Weather Bureau records show no departure values for 1957-59.

Drainage

Drainage in the Three Rivers area is westward from the Sierra Blanca and its adjacent uplands through arroyos that are dry except during and immediately after thundershowers. The large arroyos head in mountain canyons; the small arroyos head on the alluvial fans. None of the arroyos drain large basins.

Three Rivers, the master stream in the area, parallels the trend of the arroyos and has only a few short tributaries in its lower reaches. From the south end of the Godfrey Hills eastward, however, the Three Rivers drainage system has a well-developed dendritic pattern. Four major tributaries join at the south end of the Godfrey Hills: Minnie Hall Draw, an arroyo, drains southward; Three Rivers Canyon, which heads on Sierra Blanca, is perennial in its upper reaches and drains west-southwestward; Indian Creek, which also heads on Sierra Blanca, is perennial and flows west-northwestward; and Golondrina Draw, which heads on the south slopes of Sierra Blanca, drains northwestward. Three Rivers Canyon and Indian Creek yield the most water, owing to the high altitudes of their upper reaches.

Geology

The following description of rocks in the Three Rivers area includes the work of R. A. P. Gaal, who mapped the area during the summer of 1956. His work consisted of a reconnaissance of about 100 square miles and detailed mapping, at a scale of 1:62,500 on Geological Survey topographic maps, of the reentrant area and the area from U.S. Highway 54 eastward to the Godfrey Hills and southward to the Three Rivers (fig. 4). The field data have been modified in

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Figure 4.--Geology of the Three Rivers area, Otero and Lincoln Counties, N. Mex.

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accord with data from test drilling and have been highly generalized and simplified, particularly in the reentrant area.

Geologic formations and their water-bearing properties

Sedimentary rocks exposed in the mapped area range in age from Triassic to Recent. They include a sequence of consolidated to unconsolidated detrital deposits. Extrusive and intrusive igneous rocks of Tertiary(?) age also are exposed and underlie large parts of the area.

Triassic System

Dockum Group

Red beds of the Dockum Group crop out sporadically in the area. The group consists of dark-red to maroon shale, silty shale, and light-gray siltstone at the top. Its thickness in the Three Rivers area, estimated from cross sections, is about 150 feet.

The Dockum Group is not known to yield water to wells in the Three Rivers area; it was not penetrated during test drilling in the Three Rivers reentrant.

Cretaceous System

Dakota(?) Sandstone

The lower part of the Dakota(?) Sandstone (fig. 4) consists of a massive yellow to brown conglomeratic quartzose sandstone, the exposed surface of which commonly is masked by dark-brown or black desert varnish. The lower part of the Dakota(?) is thick bedded, is highly resistant to erosion, and contains numerous rounded quartzite pebbles in a thin zone at its base.

A thicker sequence of thin- to thick-bedded white, buff, and gray to pale-green sandstone and siltstone characterize the upper part of the formation. Total thickness of the formation is about 65 feet.

The Dakota(?) Sandstone yields water to wells and springs in nearby areas, but in most of the Three Rivers area it is deeply buried and probably contains water of poor quality. The Dakota(?) was not penetrated during test drilling in the Three Rivers reentrant.

Mancos Shale

Interbedded gray to black fissile marine shale, siltstone, and gray or white calcareous fine-grained sandstone of the Mancos Shale is poorly exposed along Three Rivers near Ryan Ranch and in the arroyos west of the Godfrey Hills. Locally the sandstone contains disklike ironstone nodules and veinlets. A thin gray limestone occurs near the base. The units appear to be highly lenticular. The Mancos Shale probably is as much as 1,000 feet thick in the Three Rivers area.

The Mancos Shale was not penetrated during test drilling in the Three Rivers reentrant.

Three wells in the Three Rivers area probably obtain water from the Mancos Shale: wells 11.9.25.412, 11.9.26.433, and 11.9.35.122. The Gatehouse well 1 (11.9.35.122) had a reported yield of 5 to 6 gpm; water from the well contained 2,530 ppm (parts per million) of dissolved solids, or nearly twice that of most wells in the area. Most of the formation is relatively impermeable, and the quality of water in it probably is poor.

Mesaverde Group

The Mesaverde Group is well exposed west and east of the Godfrey Hills and along Three Rivers in the southwestern part of the mapped area. The lower of two units consists of a series of pale-yellow to white, buff-weathering thin- to thick-bedded fine- to medium-grained quartzose sandstone and some thin beds of gray siltstone and seams of low-rank coal. The upper unit contains less siltstone and more thick-bedded massive sandstone, commonly cross laminated, which apparently grades upward into the red siltstone and massive white sandstone of the overlying Cub Mountain Formation of Bodine (1956).

Selenite bands and rosettes occur in many of the upper silt and claystone units. Polygonal patterns on weathered surfaces characterize the upper sandstone beds. Total thickness of the group probably is 500 to 600 feet.

Rocks of the Mesaverde Group were penetrated in all but three of the test holes drilled in the Three Rivers reentrant.

The beds of sandstone of the Mesaverde Group are a source of ground water in the Three Rivers area although the sandstone is relatively fine grained and is cemented; as a result, its permeability is low, and wells finished in the group have relatively small yields. The group probably would yield larger amounts of water where it has been distorted structurally or shattered. The quality of water in the Mesaverde is good where it crops out in the eastern part of the area. Where the sandstone is buried, however, and is some distance from the outcrop, the quality of water is poor. The selenite is one source of sulfate in the ground water.

Cretaceous(?) and Tertiary(?) Systems

Cub Mountain Formation of Bodine (1956)

Clastic sedimentary rocks of the Cub Mountain Formation of Bodine (1956) of Cretaceous(?) to Tertiary(?) age crop out erratically in the northern part of the reentrant and along the steep northern escarpment of the pediment adjacent to Indian Creek.

The Cub Mountain is mostly variegated shale; however, massive sandstone, interbedded red to variegated siltstone, and some claystone, containing selenite and gypsum rosettes, occur near the base of the formation, and a sequence of thinner bedded siltstone and sandstone appears toward the top of the formation.

Thin lenticular zones of silica-pebble conglomerate occur near the contact of the Mesaverde Group and the Cub Mountain. For expediency in mapping, the lowermost red siltstone was arbitrarily mapped as the base of the Cub Mountain.

A complete section of the formation was not found in the Three Rivers area, but the total thickness is greater than 500 feet and may be as much as 1,000 feet. The Cub Mountain was penetrated in test holes T-1, T-4, T-5, and T-7; the maximum thickness of Cub Mountain penetrated was 260 feet in test hole T-7 (table 7).

The test drilling shows that the water-bearing characteristics of the Cub Mountain Formation are much the same as those of the Mesaverde Group. The sandstones of the Cub Mountain have low permeability except in areas of structural distortion. The formation yields moderate quantities, 50 to 100 gpm, of water of good quality to wells near the outcrops in the eastern and east-central parts of the area.

Igneous Rocks

Sierra Blanca has a syenitic core that has been intruded by large monzonite dikes and stocks of relatively uniform composition. The western flanks of Sierra Blanca are composed mostly of andesite porphyry, breccia, agglomerate, tuff, and associated rhyolite and latite flows of Tertiary(?) age. A major part of the alluvium between Three Rivers Canyon and Indian Creek was derived from these rocks.

The Godfrey Hills are composed of a thick complex sequence of andesite, latite, basalt, tuff, and breccia and presumably constitute an outlier of the main volcanic complex exposed in the Sierra Blanca.

The Cub Mountain Formation and older rocks have been intruded and cut by numerous igneous dikes and sills of varying composition, including andesite, latite, quartz monzonite, rhyolite, and lamprophyre. Such intrusive rocks can be seen at the surface and in the cuttings from test holes T-6, T-7, and T-8.

Topographic prominences have resulted from the resistance to erosion of sills and dikes. Excellent examples of these occur in the west- tral part of the Three Rivers reentrant and also immediately west of the Godfrey Hills, as at Pictograph Hill, which is capped by an andesite porphyry sill.

Little is known of the water-bearing characteristics of the igneous rocks. The only data available are for a few wells and a spring in the Godfrey Hills. The sills and dikes of the reentrant apparently are impermeable and invluence the movement of ground water in the formations they have invaded.

Quaternary System

Unconsolidated terrace deposits rest on the remnant of an ancient stream-cut terrace or pediment south of Indian Creek. Silt, angular sand, gravel, and large boulders derived from the Sierra Blanca compose the deposits.

The bedrock floor beneath the reentrant east of the Godfrey Hills is overlain to variable depths by a mantle of alluvium, which is thickest in the vicinity of Three Rivers Canyon and near the confluence of Three Rivers Canyon and Indian Creek. The maximum thickness of alluvium penetrated by the test holes was about 130 feet at test hole T-5. About 105 feet of alluvium was penetrated in test hole T-2. At all the other test holes, the alluvium was less than 100 feet thick; the minimum thickness was 30 feet at test hole T-1.

The alluvium is a heterogeneous mixture of clay, silt, sand, gravel, and boulders derived from the flanking mountains. This material was deposited on stream terraces, in associated stream channels, and probably in several depressions created by faulting of the underlying consolidated rocks.

Reddish-brown eolian silt and fluvial gravel mantle the western terrace slopes and the fans and flats west of the Godfrey Hills. Some of the silt beds are cemented with caliche and contain Indian relics, which date the beds as Recent and indicate that the caliche probably was emplaced during the past 1,000 years.

The alluvium of Quaternary age is the most permeable stratigraphic unit in the Three Rivers area, owing to large grain size and lack of cement and consolidation. The alluvium is relatively permeable, and it yields several hundred gallons of water per minute to wells in favorable areas. The saturated zone in the alluvium is thin in many areas, and the alluvium is above the water table in others. The quality of water in the alluvium varies from one part of the area to another and, as in the Mesaverde Group and the Cub Mountain Formation of Bodine (1956), is best in the central and eastern parts of the area.

Structure

The regional structure is characterized by general low to moderate northeastward dips. The attitudes of beds change considerably in the reentrant area, where the dips also are generally northeastward but are steeper.

The major faults in the Three Rivers area trend northwestward and northeastward and have normal displacements of several hundred feet. Minor faults are widespread and trend generally northeastward. The extensive deposits of alluvium and talus conceal many of the faults, some of which have been discovered by test drilling. The faults affect the thickness of the zone of saturation in the alluvium and probably affect the movement of water in the consolidated sedimentary rocks.

The Godfrey Hills lie in a poorly defined northwest-trending syncline. Pictograph Hill and the adjacent outcrops of consolidated rocks form northeastward-dipping cuestas, and the area immediately south of the Three Rivers reentrant and adjacent to Indian Creek is a dissected pediment.

Water Resources

The studies upon which this report is based included evaluations of the supplies of water in streams in the Three Rivers area and the supplies of ground water in the several geologic formations. Because of the wide fluctuations in stream discharge, ground water was considered to be a desirable supply. The presence of several irrigation wells and numerous stock wells in the Three Rivers area indicated that ground water was available.

Surface Water

To implement the study of the surface-water supplies, four stream-gaging stations were installed and equipped with recording gages from May 1956 through September 1958. Three of these stations are on principal streams--on Three Rivers near Three Rivers (station 1, above Lincoln Canyon, sec. 34, T. 10 S., R. 10 E.), on Indian Creek near Three Rivers (station 2, above all diversions), and on Indian Creek at mouth near Three Rivers (station 5). (See fig. 5.) The

Figure 5.--Hydrologic data and quality of water in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

fourth recording gage was on Indian Creek flume near Three Rivers (station 3, sec. 9, T. 11 S., R. 10 E.), through which passes most of the water diverted from Indian Creek for irrigation. Diversions from Indian Creek through a small ditch that leaves the creek just above gaging station 5 at the mouth of the creek were measured also (station 4). Supplementary miscellaneous measurements were made in Three Rivers Canyon above the gage in the area where flow apparently is perennial and below the gage where flow generally is intermittent. The monthly flow past the recording gages, in acre-feet, and the precipitation, as measured by recording rain gages at three of the stations, are shown in table 2. Results of the miscellaneous measurements in Three Rivers Canyon are shown in table 3.

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Table 2.--Runoff and precipitation at gaging stations in Three Rivers area, Otero and Lincoln Counties, N. Mex., 1956-58

(See fig. 5 for locations of stations.)

Station	1 Three Rivers near Three Rivers ~~Canyon above Lincoln Canyon~~ (sec. 34, T. 10 S., R. 10 E.)		2 Indian Creek near Three Rivers (sec. 10, T. 11S. R. 10 E.)		3 Indian Creek ~~flume~~ near Three Rivers (sec. 9, T. 11 S., R. 10 E.)	4 Diversion from Indian Creek above gage of ~~at~~ Indian Creek ~~at mouth~~ (sec. 13, T. 11 S., R. 9 E.)	5 Indian Creek at mouth near Three Rivers (sec. 13, T. 11 S., R. 9 E.)		Difference in flow of Indian Creek between stations 2 and 5; (includes diversions at stations 3 and 4)	
Drainage area	6.9 sq mi		6.8 sq mi		-	-	10.9 sq mi		-	
	Runoff (acre-feet)	Precipitation (inches)	Runoff (acre-feet)	Precipitation (inches)	Diversion (acre-feet)	Diversion (acre-feet)	Runoff (acre-feet)	Precipitation (inches)	Acre-feet	Percent of flow at Indian Creek gage
1956										
May	0	-	-	-	-	5.8	0.7	-	-	-
June	0	-	6.7	-	8.6	1.6	26	-	+29.5	440
July	0	-	51	-	17	0	45	-	+11	22
August	7.3	-	406	-	177	0	220	-	-9	2.2
September	0	-	16	-	18	0	1.9	0.99	+3.9	24
October	0	0.80	11	1.10	11	0	.4	.50	+ .4	3.6
November	0	-	9.9	-	8.1	0	.5	-	-1.3	13
December	0	.35	8.2	.25	6.6	0	.5	.04	-1.1	13
1957										
January	0	.83	12	.86	8.4	0	.7	.35	-2.9	24
February	11	1.45	23	1.67	19	0	.8	.97	-3.2	14
March	61	1.24	101	1.94	89	0	1.4	1.28	-10.6	10
April	127	.40	211	.39	167	0	.6	.23	-43.4	21
May	89	-	224	-	193	0	.2	.10	-30.8	14
June	24	.10	87	-	69	0	0	-	-18	21
July	4.6	2.42	31	4.89	19	0	131	.12	+119	384
August	62	1.48	185	3.78	127	0	94	.59	+36	19
September	202	.10	240	.40	40	0	83	1.89	-117	49
October	96	1.92	229	3.49	100	0	107	2.66	-22	9.6
November	96	.35	173	.53	17	0	31	.36	-125	72
December	43	.11	74	.11	48	9.1	6.9	.03	-10	14
1958										
January	25	.32	27	.54	26	12	3.5	.11	+14.3	53
February	35	.17	47	.20	45	8.4	5.8	.11	+12.2	26
March	220	3.02	158	3.81	123	4	14	2.71 est.	-17	11
April	905	.80	847	1.20	104	6.1	428	.22	-308.9	36
May	596	1.42	860	.48	139	6.5	512	.13	-202.5	24
June	72	.72	146	1.60	95	5	78	.60	+32	22
July	14	.92	34	1.40	23	0	47	.10	+36	106
August	34	1.10	34	.37	-	0	41	.55	-	-
September	179	1.90	412	-	-	0	146	-	-	-

Table 3.--Miscellaneous measurements of flow in Three Rivers Canyon, Three Rivers area, Otero and Lincoln Counties, N. Mex., 1957-58

Description and location of gaging site	Flow in cubic feet per second, and date														
	1957											1958			
	3-25	4-9	5-21	6-24	7-23	8-20	9-18	10-22	11-6	11-20	12-18	1-15	2-19	3-18	4-3
North Branch, north fork of Three Rivers Canyon: NW¼NW¼SW¼ sec. 30 (projected), T. 10 S., R. 11 E.	-	-	0.50	-	0.15	0.07	0.61	-	-	-	-	-	-	-	-
South Branch, north fork: NW¼NW¼SW¼ sec. 30 (projected), T. 10 S., R. 11 E.	-	-	.81	-	.01	.56	.31	-	-	-	-	-	-	-	-
North fork: SE¼SE¼SE¼, sec. 25, T. 10 S., R. 10 E.	-	-	1.33	-	.02	.42	.47	-	-	-	-	-	-	-	-
Three Rivers Canyon below south fork: SW¼NE¼ sec. 36, T. 10 S., R. 10 E.	-	-	1.92	-	.08	.72	.81	-	-	-	-	-	-	-	-
Three Rivers Canyon, 500 feet 1/ above Dry Canyon: NE¼NE¼ sec. 35, T. 10 S., R. 10 E.	0.58	1.45	1.29	0.11	0	.17	.68	-	-	0.88 2/	0.41	0.12	0.58	3.01	7.76
Three Rivers Canyon, 500 feet 1/ below Dry Canyon: NW¼NW¼ sec. 35, T. 10 S., R. 10 E.	-	2.20	1.57	.04	.02	.36	.96	-	-	1.01 2/	.69	.39	.64	3.32	8.68
Three Rivers Canyon at Forest boundary: NE¼NE¼ sec. 34, T. 10 S., R. 10 E.	-	2.23	-	-	-	-	-	-	-	-	-	-	-	-	-
Gaging station in Three Rivers Canyon above Lincoln Canyon: NW¼NW¼ sec. 34, T. 10 S., R. 10 E.	.87	2.12	1.39	0	0	.18	.67	-	-	1.20 2/	.68	.35	.57	3.23	8.50
Three Rivers, half a mile below Minnie Hall Draw: NW¼SW¼ sec. 13, T. 11 S., R. 9½ E.	-	-	-	-	-	-	-	2.94	0.15	-	0	0	0	0	0
Three Rivers, 100 yards above Rattlesnake well: SW¼SW¼NW¼ sec. 23, T. 11 S., R 9½ E.	-	-	-	-	-	-	-	0	0	-	0	0	0	0	0

1/ Sections range in distance from 200 to 500 feet from mouth of Dry Canyon.

2/ Ice along banks of stream during measurements.

Stream Characteristics

Three Rivers Canyon and Indian Creek are perennial in their upper reaches, and all stream courses in the area intermittently carry floodwater, occasionally in large amounts after infrequent heavy thundershowers. Several factors govern the flow characteristics of the several lesser drainage basins, among which are meteorological conditions, topographic variations, geologic phenomena such as structure and character of the rocks underlying the streambeds, and manmade conditions such as diversion works.

Daily rates of discharge in Three Rivers Canyon (station 1) generally do not fluctuate abruptly, but the annual discharge fluctuates more than 30 cfs (cubic feet per second). Flow past the station is maintained both by rainfall and by melting snow and ice. Flow resulting from snowmelt continued to about the middle of June in both 1957 and 1958. Forest cover in the upper reaches of the canyon aids in smoothing the response to summer rains. The canyon channel above the station (altitude approximately 6,175 feet) has a drainage area of about 6.9 square miles.

The gage in Three Rivers Canyon (station 1) recorded no flow during 8 months of 1956 and 1957. Reaches of the stream above the station, however, had perennial flow. General observations throughout the time of the investigation and miscellaneous measurements in 1957-58 (table 3) show that the stream flowed most of the time at most of the sites gaged above the station. The miscellaneous measurements show also that parts of the reach above the station gain in flow, whereas other parts lose water into the streambed. Gains and losses occur several times before the flow finally seeps into the Quaternary alluvium of the lower slopes.

During the water year ended in September 1958, there were only a few days of no flow at the station in Three Rivers Canyon, owing to the above-normal precipitation during that period. Records from the gage show that runoff during the 1957 water year was 581 acre-feet, whereas runoff during the 1958 water year was 2,320 acre-feet.

Daily discharge rates of Indian Creek at the uppermost gage (station 2) generally change smoothly partly because of the forest cover above the station. The annual range in daily discharge is about 35 cfs. Flow resulting from snowmelt ended about the middle of June 1957 and about the end of June 1958. The canyon above the station (altitude approximately 6,250 feet) has a drainage area of about 6.8 square miles.

The record from the gage at station 2 indicates that Indian Creek flows most of the time. During the dry period of 1956 and early 1957, the creek did not flow for 16 days of the period of record beginning May 19, 1956, and it flowed less than 0.1 cfs for several weeks. During the period of above-normal precipitation in 1958, the creek flowed continuously. During the 1957 water year, 1,140 acre-feet of runoff passed the gage; during the 1958 water year, runoff was 3,040 acre-feet.

Diversions from Three Rivers Canyon are small. Water that is diverted is used mainly for stock. Water from Indian Creek, however, is diverted on the Mescalero Apache Reservation for irrigating crops and watering stock. The water is diverted by a rock dam on the creek in sec. 10, T. 11 S., R. 10 E. The amount of water diverted was measured with a recording gage (station 3) on a flume that carried the diverted water over Indian Creek in the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 9, T. 11 S., R. 10 E. Records from this gage show that water nearly always is diverted if the creek is flowing. Of the 1,140 acre-feet of water that passed the upper gage in the 1957 water year, 757 acre-feet was diverted to Indian use. During 10$\frac{1}{2}$ months of the 1958 water year, 720 acre-feet of water was diverted, indicating that use by the Indians is fairly constant if the water is available.

Water is diverted from Indian Creek also by a low dam immediately above the gage on Indian Creek near its mouth, in sec. 13, T. 11 S., R. 9½ E. The flow at the second diversion point was measured with a Parshall flume (station 4). During the period of observation, diversions generally were less than 10 acre-feet per month. During the latter part of the 1956 water year and all of the 1957 water year, no diversions were made, owing to the disrepair of the diversion works.

The lower reaches of Three Rivers Canyon and Indian Creek, the lesser tributaries, and the main stem of Three Rivers generally have common characteristics. These stream courses are dry, except when runoff due to snowmelt is sufficient to reach the lower reaches and when thundershowers fall in the Three Rivers reentrant. Most of the time the stream courses lose water, but occasionally ground water may discharge to the stream. Records from the gaging station on Indian Creek at its mouth (station 5, table 2) indicate the character of flow in the lower reaches. In addition, crest gages on Minnie Hall Draw and Three Rivers at U.S. Highway 54 and several slope-area measurements provide supplemental data.

The gage at station 5 ~~on Indian Creek near its mouth~~ showed that during dry or near-normal years, the creek at that location is dry, or nearly so. Daily discharge rates fluctuate abruptly as a result of flash floods; ~~the~~ annual fluctuations are 65 cfs or more. The record shows that most flow in the creek probably results from rainfall, and only during wet years does much snowmelt pass the station, as in 1958. The Indian Creek drainage basin above the gage (altitude approximately 5,300 feet) includes about 10.9 square miles, 4.1 square miles more than that above the upper gage.

Gaged surface flows during the period of record clearly indicate that Indian Creek between the two gaging stations generally is a losing stream. Table 2 shows monthly losses as great as 300 acre-feet. The difference is computed by subtracting the runoff at the upper gage from the sum of the diversion at the flume, the diversion at the mouth, and the runoff at the mouth of the creek. All but three of the figures that show gain between the two gages are for the summer, during which time heavy showers fell in the reentrant. Taking all gains and losses into account, the net difference for 26 months amounted to an apparent loss of 628 acre-feet. The apparent losses were less than the actual losses, as the contributions of water from the 4.1 square miles of drainage area between the two gaging stations cannot be segregated from the flow past the upper gaging station.

Three Rivers Canyon also loses water, though the losses have not been measured as accurately as those from Indian Creek. Table 3 shows miscellaneous measurements in Three Rivers Canyon. In March and April 1958, during the period of continuous flow from snowmelt, the station above Lincoln Canyon was recording flows of 3 to 9 cfs, but the miscellaneous measurements below Minnie Hall Draw and farther downstream indicated no flow.

Observed floods in the lower parts of the Three Rivers area have lasted from 4 to 6 hours in most of the arroyos, but flows from the major tributaries have lasted several days. Owing to the steep grades and relatively sparse cover, runoff from the lower parts of the area is rapid--unlike the generally smooth runoff of the mountain canyons, where forest cover and ground-water discharge act as controls. Peak discharges in the several streams show that much of the flooding is due to precipitation in the reentrant--for example, on July 26, 1957, the peak discharge at the upper Indian Creek gage was 500 cfs, but at the gage at the mouth of the creek, the peak discharge was 2,260 cfs. This same relation has been observed several other times--though the discharge rates were less, on the order of 100 to 500 cfs. Large floodflows have been observed in most of the arroyos of the area, but few have been measured accurately. One measured discharge, considered provisional, was in Minnie Hall Draw on July 31, 1956. Rainfall on the 9.89 square miles above the crest gage produced a peak discharge of 685 cfs, as determined by the slope-area method. On the same date, provisional data indicate a peak discharge of about 850 cfs in Three Rivers at the U.S. Highway 54 bridge.

Potential Supplies from the Streams

The records accumulated during the investigation of the surface-water supplies in the Three Rivers area show that an appreciable amount of surface water is available. During 29 months of gaging in Three Rivers Canyon, about 2,900 acre-feet of water passed the station. This amount is equivalent to 3.3 acre-feet per day, or about 1.1 mgd (million gallons per day). During 28 months of gaging, about 4,660 acre-feet of water (about 1.8 mgd) passed the upper gage on Indian Creek, and about 2,030 acre-feet of water (about 0.7 mgd) passed the gage at the mouth of Indian Creek. Thus, if the water diverted from Indian Creek and the losses downstream were neglected, 1.8 to 2.9 mgd would have been available if the flow of the two streams had been impounded during the period of observation. These figures include only that water which passed the gages and do not include floodflows from lower Three Rivers Canyon, Minnie Hall Draw, Golondrina Draw, and the lesser tributaries.

Potential supplies such as those cited above do not take into account variations in streamflow. Figures 6, 7, and 8 show that for

Figure 6.--Duration curve of daily flows, Indian Creek (sec. 10, T. 11 S., R. 10 E.) near Three Rivers, N. Mex.

7.--Duration curve of daily flows, Three Rivers ~~Canyon~~ (above Lincoln Canyon), near Three Rivers, N. Mex.

8.--Duration curve of daily flows, Indian Creek at mouth, near Three Rivers, N. Mex.

the 28 to 29 months of observation at the three gaging stations the discharge at the upper Indian Creek gage exceeded 1 mgd (1.55 cfs) only 37 percent of the time, that at Three Rivers Canyon only 21 percent of the time, and that at the mouth of Indian Creek only 11 percent of the time. Table 2 shows the changes in streamflow from a dry to a wet year. These data on changes in streamflow illustrate the necessity for storage reservoirs, if the surface waters of the Three Rivers area are to be utilized.

Chemical quality of surface water

Chemical analyses of 15 samples of surface water from the Three Rivers area are given in table 4. Of these, 5 samples are from Indian Creek, 4 samples from upper Three Rivers Canyon, and 6 from Three Rivers Canyon in the lower parts of the reentrant and the main stem of Three Rivers.

The water from both upper Three Rivers Canyon and Indian Creek generally contained only small amounts of dissolved solids (table 4). Three of the four water samples from upper Three Rivers Canyon contained ~~from~~ 230 to 340 ppm of dissolved solids, including 99 to 119 ppm of sulfate. Water from Indian Creek generally contained even smaller amounts of dissolved solids; the amounts in 3 of 4 samples ranged from 162 to 220 ppm. The sulfate content in 4 of 5 samples was less than 90 ppm. One sample from each of the streams contained larger amounts of dissolved solids. A sample from Three Rivers Canyon at the ford in the NW$\frac{1}{4}$ sec. 34, T. 10 S., R. 10 E., contained 714 ppm of dissolved solids, including 283 ppm of sulfate. A sample from Indian Creek below the diversion dam near the center of sec. 10, T. 11 S., R. 10 E., contained 861 ppm of dissolved solids, including 393 ppm of sulfate. Both samples were taken at low flow in the streams. The reasons for the higher mineral content of these two samples ~~is~~ are not known. Despite the higher mineral content, the two samples were as good in quality as the best ground water in the Three Rivers area.

Table 4.--Chemical analyses of surface water in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

[Results in parts per million except as indicated. Analyses by U.S. Geological Survey. Dissolved solids is residue on evaporation except as indicated.]

Location No.	Stream and description of sampling site	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
10.10.34.121	Three Rivers Canyon, at ford	4-17-56	-	31	-	137	29	45	256	283	38	0.4	0.1	714	0.94	461	251	18	0.9	1,000	7.4	Estimated discharge = 0.1 cfs. Clear.
34.121	Three Rivers Canyon, 0.25 mile above Lincoln Canyon	3-16-56	59	17	0.01	56	11	21	98	119	17	.6	.1	291	.39	184	104	20	.7	446	8.0	Discharge = 0.10 cfs. Clear. Total iron = 0.11 ppm.
35.111	Three Rivers Canyon at National Forest boundary	4-25-57	55	37	-	41	9.7	9.0	43	99	16	.5	.2	230	.32	142	108	12	.3	338	7.6	Water clear.
11.9½.13.144	Three Rivers Canyon, at ford ~~on~~ county road.	4-25-57	68	41	-	64	13	22	102	142	19	.6	.3	346	.48	213	130	18	.6	506	8.1	Do.
13.144	do.	7-17-57	74	-	-	-	-	-	364	2.7	1.2	-	-	-	-	286	0	-	-	564	7.1	Collected shortly after thunderstorm. Estimated discharge = 6.7 cfs. Very muddy. Odor of H_2S.
13.144	do.	8-1-57	-	-	-	-	-	-	336	466	25	-	-	-	-	800	524	-	-	1,300	7.7	Flood flow, near maximum stage, at 1:30 p.m. Contained sediment.
13.144	do.	8-1-57	-	-	-	-	-	-	326	230	15	-	-	-	-	500	233	-	-	906	7.9	Flood flow, as flood receding, at 4:00 p.m. Contained sediment.
23.311	Three Rivers, below confluence of main tributaries	11-6-57	-	-	-	-	-	-	239	651	105	-	-	-	-	815	619	-	-	1,720	7.7	Estimated discharge = 1 cfs. Clear.
10.10.5.112	Three Rivers Canyon, behind Johnson's ranch house	4-25-57	68	40	-	64	13	9.9	101	118	19	0.6	0.5	340	0.43	213	130	9	0.3	498	7.8	Water clear.
.9.221	Indian Creek flume, at road crossing	3-16-56	49	11	.00	46	7.8	12	78	85	13	.5	.1	217	.29	147	83	15	.4	348	7.9	Discharge = 0.47 cfs. Clear. Total iron = 0.31 ppm.
10.120	Indian Creek flume, at upper end	4-20-54	65	14	-	-	-	13	91	76	10	.5	.0	-	-	140	66	17	-	336	-	Estimated discharge = 1.1 cfs. Clear.
10.140	Indian Creek, above diversion dam	4-25-55	-	12	-	33	9.9	3.0	56	65	10	.8	.2	162 1/	.22	123	77	5	.1	264	7.6	Total flow above first diversion. Estimated flow = 0.6 cfs.
10.140	Indian Creek, below two diver- ~~diver~~sions	3-16-56	57	22	.01	183	38	29	185	393	81	.6	.1	861	1.14	613	462	9	.5	1,210	7.9	Discharge = 0.19 cfs. Clear. Total iron = 0.01 ppm.
10.410	Indian Creek, above all diver- ~~diver~~sions	3-16-56	53	11	.00	47	8.8	9.9	80	86	13	.5	.3	220	.29	154	88	12	.3	352	7.9	Discharge = 0.48 cfs. Clear. Total iron = 0.24 ppm.
12.9.3.322	Three Rivers, at U.S. Highway 54	8-1-57	-	-	-	-	-	-	802	220	44	-	-	-	-	910	253	-	-	1,570	7.7	Flood flow, at 4:25 p.m. Contained sediment.

1/ Calculated from sum of constituents determined in analysis.

Water of good quality in the upper reaches of the streams is to be expected. The rocks in the Sierra Blanca are intrusive and extrusive igneous rocks, all of which contain only small amounts of readily soluble minerals. The ground water that issues from seeps and springs and maintains the low flow of the two streams comes from such rocks and from the soils derived from the rocks. Runoff from snowmelt and rains in the mountains should contain even less dissolved solids.

In the lower reaches of Three Rivers Canyon and on the main stem of Three Rivers, the quality of the surface water is variable. Owing to the wide range of discharge rates and the different geologic environments of the several runoff areas, the dissolved-solids content of the water samples ranged from 346 to more than 1,000 ppm (the latter figure based on the specific conductance of water for which the dissolved solids was not determined). Sulfate in the water ranged from 2.7 to 651 ppm.

The mineralization of the surface water in the Three Rivers reentrant and the lower Three Rivers area depends to a large extent on the area from which the water flows and the duration of the flow. Those areas in which the Cub Mountain Formation of Bodine (1956) and older sedimentary rocks crop out and those in which the alluvium is derived from those formations should yield water having a comparatively great mineral load in solution, because the Cub Mountain and older sedimentary ~~formations~~ rocks contain large quantities of readily soluble minerals, such as selenite and gypsum (calcium sulfate). Erosion of these rocks provides exposure of the soluble minerals to water flowing over the surface of the ground. In addition, springs and seeps discharging from these older formations add to the mineral load of the surface water, and, during a period when ground water discharges from the alluvium in the reentrant, the surface water also gains additional mineral load.

The variability of the quality of surface water during flood discharge after thunderstorms is apparent from the analyses (table 4). These changes in chemical quality are attributed to the events that precede such periods of storm runoff. During drought or periods of light rainfall, formations that contain readily soluble minerals develop a coating or crust of minerals because water from light showers soaks only a short way into the ground, leaches the soluble minerals, and, by capillary action, brings them to the surface, where the water is again evaporated during periods of high temperature and low humidity. Water from springs in the Cretaceous, Cretaceous(?), and Tertiary(?) sedimentary rocks characteristically precipitate crusts of calcareous and gypsiferous material. Along the streambeds during low flow and in areas where the water table is immediately below the surface of the streambed, considerable quantities of water are evaporated during hot and dry periods, again leaving crusts of soluble mineral matter. Subsequently, when heavy showers fall, the first water that runs off dissolves part of these soluble deposits and carries them away in the first part of the floodflow. Later precipitation also dissolves some of the residue, but to a lesser extent, because most of the soluble residue already has been removed.

An example of the high mineral content of the first part of floodflow is shown by the results of analyses of samples of water collected in Three Rivers Canyon at the County road ford (11.9½.13.144) on Aug. 1, 1957. At the approximate maximum stage of the flood, the sulfate content of the water was 466 ppm. During the recession of the flood, 2½ hours later, the sulfate content was only 230 ppm, and the other determined constituents also were significantly lower. If the flow had been prolonged and if a later sample had been obtained, the sulfate content might well have been still lower--perhaps to the 2.7 ppm of a sample obtained from the same location on July 17, 1957.

The chemical quality of surface water from the eastern higher parts of the Three Rivers area is superior to that of most ground water. Surface water that results from storm runoff in the lower parts of the area is one to three times as mineralized as that from the upper part. The poorest surface water and the best ground water are roughly comparable in chemical quality.

Ground Water

The principal aquifers in the Three Rivers area are the alluvium of Quaternary age, the sandstones in the lower part of the Cub Mountain Formation of Bodine (1956), and the upper part of the Mesaverde Group. Older formations, owing to their great depth and poor circulation of water, probably contain highly mineralized water.

Occurrence

Water in the alluvium of the Three Rivers area generally is unconfined, although it may be confined locally beneath lenses of clay or silt. Water in the older, consolidated sedimentary rocks of the Cub Mountain Formation of Bodine (1956) and the Mesaverde Group generally is confined under considerable pressure. Such conditions are to be expected. The alluvium is a relatively thin mantle upon the older rocks and it is not well stratified, whereas the older rocks consist of stratified beds of almost impermeable silt and shale between water-bearing sandstones.

The depth to water in most of the Three Rivers reentrant ranges from about 50 feet below the land surface in some of the interstream areas to only a few feet beneath the streambeds. North of the reentrant, water levels are more than 100 feet below the land surface, as in the Bataan Lodge well (10.10.4.441, table 5). South of Indian Creek, the depth to water apparently increases as the altitude of the land surface increases. West of the confluence of the tributaries of Three Rivers and west of the Godfrey Hills, the depth to water also appears to be a function of the altitude of the land surface. Water levels in wells along Three Rivers range from 4 to 35 feet below land surface, but in the adjacent upland the depth to water may be as much as 110 feet, as in well 11.9.11.212.

Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

Location number: See p. 9 for description of well-numbering system.

Altitude above sea level: E, estimated from topographic map; M, level run by U.S. Air Force.

Depth of well: M, measured; R, reported.

Water level; depth below surface: P, pumping level; R, reported.

Type of pump: W, wind; C, cylinder; N, none; E, electric (number gives horsepower); T, turbine; J, jet.

Use of water: S, stock; N, none; D, domestic; I, irrigation.

list in alphabetical order

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical analysis	Remarks
10.8.23.123	Truman Spencer (Jackson well)	-	-	4745E	83M	-	-	-	76.07	11-10-55	W, C	S	-	
10.9.8.121	I-X Ranch	-	-	5195	-	-	-	Quaternary alluvium or Mesaverde group	-	-	W, C	S	X	Yield 2½ gpm on September 20, 1955.
13.212	Barnevell well	Ray Taylor	1952	6010E	45M	4	-	Tertiary(?) igneous rock	21.22	8-21-56	W, C	S	X	Cased to 45 feet; casing torch-slotted. Reported yield 12 gpm. Temperature 61°F.
24.412	Minnie Hall well	do.	1944	5805E	170M	6	-	Cub Mountain formation or Mesaverde(?) group	16.08 22.69	2-22-56 8-21-56	W, C	S	X	Cased to 126 feet; casing torch-slotted. Reported yield 70 gpm by bailing. Temperature 63°F.

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Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex. - Continued

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical Analysis	Remarks
10.9.30.322	Taylor well	Perry Bros.(?)	1928	4960E	80M	6	-	-	60.50	7-26-56	W, C	S	-	Cased to 80 feet; Casing torch-slotted. Reported yield 10 to 12 gpm.
34.211	Halfway well	Don Smith	1947	5630E	235M 250R	4	Volcanic rock	Tertiary(?)	182.16	8-15-56	W, C	S	X	Cased to 250 feet. Casing torch-slotted. Reported yield 5 to 6 gpm. Temperature 65°F. Hole reported to be very crooked.
35.211	Boyd well	Buck Nosker	1943	5600E	52M	10	Shale and sandstone	Mesaverde(?) group	44.00 42.48	8-15-56 1-13-60	N	N	-	Originally drilled to 65 feet in 1916; Deepened to 250 feet in 1943; Caved in, then Reported yield 2 gpm. No increase in yield when deepened. Reported poor quality.
10.10.4.441	Bataan Lodge well	-	-	6505E	221M	7	-	-	103.97	1-4-57	W, C	S	X	Estimated yield 3 gpm. Temperature 56°F.
5.222	I-X Ranch and T. F. Ryan III	-	-	6130E	114M	8	-	-	110P	1-4-57	W, C	S	X	Estimated yield 3 gpm. Temperature 59°F.
6.122	I-X Ranch	-	-	6030E	181M	7	-	-	158.3P	12-5-56	W, C	S	-	Yield reported weak.
17.343	Gamble well	Ray Taylor	1952	6150E	23M 60R	6	-	Tertiary(?) igneous rocks	16.76	8-22-56	W, C	S	-	Cased to 60 feet; Casing torch-slotted. Quality of water reported poor.
29.414	Brownfield well	-	1916	5835E	56M 60R	8	Gravel	Quaternary alluvium(?)	41.83 35.77	6-27-56 1-13-60	W, C	S	X	Cased to 60 feet. Reported yield 8 to 10 gpm. Temperature 62°F.
32.334	T-1	Perry Bros.	1956	5622M	301M	8	Sandstone	Mesaverde group	35.78 8.43	12-28-56 5-7-58	N	N	X	See table 7. Temperature 61°F.

Ground water is brought to the land surface through several small springs, such as S11.10.6.214 (table 6), where eastward-dipping impermeable rocks intersect the water table and act as subsurface dams. Some of the impermeable rocks are the intrusive igneous sills in the reentrant area. A perched water table exists also in the Tertiary(?) igneous rocks of the Godfrey Hills. Chapel Spring (S11.9½.13.124) discharges from porphyritic volcanic rock.

The water table in the Three Rivers area slopes in much the same direction as the land surface (fig. 5). It slopes southward from the northern part of the reentrant and westward from the eastern part. South and west of the Godfrey Hills it slopes rather uniformly westward into the Tularosa Basin. The relatively steep slope of the water table is due both to the thinness of the aquifer in the alluvium and to the relatively low permeability of the Cub Mountain Formation of Bodine (1956) and the Mesaverde Group.

Table 6.--Records of springs in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

[Altitude: E, estimated altitude from topographic map. Yield: E, estimated yield.]

Location number	Owner	Name	Topographic situation	Altitude	Structure	Character of opening	Stratigraphic unit	Yield (gpm)	Date of measurement	Use of water	Listed in chemical analysis table
S10.10.20.231	T. F. Ryan, III	Trinadad	Hillside	6150	-	Multiple fractures	Tertiary (?) volcanic tuff	3-10 1/	Reported	stock 2/	No
S11.9½.13.124	do.	Chapel	Hillside	5350E	-	Gallery	Tertiary volcanic porphyry	2-3 E	4-25-55	stock	Yes
S11.9½.13.422	do.	-	Bottom of Indian Creek	5300E	Gravel bed in creek	Seep	alluvium	2-3 3/ E	2-29-56	stock	Yes
S11.9½.23.232	do.	Jack Fall	Base of small bluff	5175E	-	Tunnel	alluvium (?)	1-2 E	8-20-56	irrigation	No
S11.10.6.214	do.	-	Gentle slope	5540E	Alluvium overlying porphyry(?)	Seep	alluvium	2-3 E	2-29-56	stock 2/	Yes
S12.10.7.444	-	Aquilar	Edge of arroyo	4875E	Alluvium(?)	-	-	-	-	-	No
S12.10.19.123	-	Kitty	do.	4775E	do.	-	-	-	-	-	No

Footnotes:

1/ ranges from 3-5 gpm in summer to 8-10 gpm during winters that have a lot of rain.

2/ flows to downstream stock pond.

3/ Reported to dry up when well 11.9½13.244 is pumped.

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Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex. - Continued

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical Analysis	Remarks
10.10.32.421	Trammel well 1	-	1900	5760E	23M	-	-	Cub Mountain formation(?) 1/	19.31	8-21-56	N	N	-	Dug well. Temperature 60.5°F.
32.421a	Trammel well 2	Ray Taylor	1955	5805E	76M	6	-	do.	22.59 20.02	8-21-56 1-13-60	N	N	-	Cased to 76 feet; Casing torch-slotted. Reported yield 30 gpm.
33.131	Trammel well 3	do.	1953	5830E	45M 55R	6	-	do.	35.50 30.90	8-21-56 7-30-57	W, C	S	X	Cased to 55 feet; Casing torch-slotted. Reported yield 45 gpm. Temperature 62°F.
11.9.11.212	New well	~~Ray Taylor~~ do.	1954	4860E	162M	6	Gravel	-	110.40	7-26-56	W, C	S	-	Cased to 162 feet; Casing torch-slotted. Reported yield 10 gpm.
11.322	Porter well	D. E. Smith and Don Perry	1949	4815E	109M 119R	6	-	-	82.27	7-26-56	N	N	-	Cased to 119 feet; Casing torch-slotted. Quality of water reported too poor even for stock.
22.441	Sand well	Ray Taylor	1952	4650E	158M 185R	6	Sand	-	134.10	7-26-56	W, C	S	X	Cased to 185 feet; Casing torch-slotted. Reported yield 3 to 5 gpm. Temperature 69°F.
25.412	Farm Corral well	do.	1943	4790E	52M 83R	8	-	Quaternary alluvium and Mancos shale(?)	35R	1953	E, T	S	-	Cased to 80 feet; Casing is torch-slotted. Reported yield 10 gpm.
26.433	Gatehouse well 2	do.	1953	4690E	70R	8	-	do.	25R	1953	E(1½), T	I	-	Cased to 70 feet; Casing torch-slotted. Reported yield 20 gpm.
35.122	Gatehouse well 1	do.	1951	4650E	60M	6	-	do.	16.53	7-27-56	W, C	D, S	X	Cased to 60 feet; Casing torch-slotted. Reported yield 5 to 6 gpm. Temperature 70°F.

51 abc

Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex. - Continued

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical Analysis	Remarks
11.9½.11.132	Crawford well	Don Perry	1949	5600E	231M	4	Vesicular lava	Tertiary(?) igneous rock	191.99	8-15-56	W, C	S	-	Cased to 231 feet; casing torch-slotted. Reported yield 10 gpm. Temperature 70°F.
12.422	Pete Crawford	-	-	5380E	50±M	6	-	Quaternary alluvium(?)	47.16	2-28-56	N	N	-	-
									31.23	1-13-60				
13.234	T-6	Perry Bros.	1951	5296M	300M	-	Sand and gravel	Quaternary	17.15	4-8-57	N	N	X	See table 7. Temperature 68°F.
									14.68	1-13-60				
13.244	Bosque well	-	1912(?)	5335E	80R	-	-	Quaternary alluvium	15.29	1-30-57	E(10)T	D, S, I	X	Reportedly dug to 80 feet with a 60-foot drift at depth of 33 ft. Reported yield 390 gpm for limited period of time.
									8.70	1-13-60				
22.244	Rattlesnake well	-	1918	5080E	24M	8	-	do.	9.46	8-22-56	E(5) T	I	X	10-foot concrete culvert sunk into alluvium. Estimated yield 150 gpm. Temperature 60°F.
									3.25	1-13-60				
22.323	Pino well	Leroy Perry	1951	5025E	52M	8	-	Mesaverde group	28.99	8-22-56	E, T	S, I	-	Casing is torch-slotted. Temperature 63°F.
23.124	T-8	Perry Bros.	1957	5145E	500M	8(?)	Sand, gravel, and sandstone	Quaternary alluvium and Mesaverde group	25.0	10-16-57	N	N	X	See table 7. Temparature 67°F.
28.214	Fishpond well no. 1	D. E. Smith	1943	4950E	107M	10, 8, 6	-	Quaternary alluvium and Mesaverde (?) group(?)	15.93	7-30-56	E(5) T	I	X	45 ft. of 8-inch and 10-inch casing and 85 feet of 6-inch casing. Reported yield 120 gpm while pumping from 96 feet. Temperature 63°F.

Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex. - Continued

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical Analysis	Remarks
11.9½.28.214a	Fishpond well 2	-	1918	4939E	33M	120	-	Quaternary alluvium	4.22	8-22-56	N	N	-	Dug well lined with concrete culvert(?).
11.10.5.112	Johnson well 1	Buck Nosker	1943	5625E	36M	8	-	do.	30.81	8-23-56	W, C	D	X	Drilled to about 47 feet and cased to about 45 feet with torch-slotted casing. Reported yield 65 gpm. Temperature 62°F.
5.121	Johnson well 2	Don Perry	1949	5625E	101R	10	-	Quaternary alluvium and Cub Mountain formation[1]	-	-	E(1),J	D	X	Cased to 101 feet. Casing torch-slotted. Reported to "dry up" after pumping 10 gpm for 24 hours. Temperature 66°F.
5.121a	Johnson well 3	do.	1949	5625E	200+R	-	-	-	-	-	N	N	-	Reported ~~to have~~ encountered very small quantity of water at 30-40 feet; ~~and~~ no more to depth of ~~more than~~ 200 feet.
5.332	T-5	Perry Bros.	1957	5557M	300M	8	Sand and gravel	Quaternary alluvium	54.16 50.75	3-21-57 1-13-60	N	N	X	See table 7. Temperature 64°F.
6.333	T-2	do.	1957	5391M	300M	8	~~Sand and gravel~~	Quaternary alluvium and Mesaverde group	39.25 29.06	1-29-57 1-13-60	N	N	X	See table 7. Temperature 65°F.
6.433	T-3	do.	1957	5453M	300M	8	Sand, gravel, and sandstone	do.	43.64 34.73	2-6-57 1-13-60	N	N	X	See table 7. Temperature 64°F.

Table 5.--Records of wells in the Three Rivers area, Otero and Lincoln Counties, N. Mex. - ~~Continued~~ Concluded

Location No.	Owner or Name	Driller	Year completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of casing (in.)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (feet)	Water level: Date of measurement	Type of pump	Use of water	Chemical Analysis	Remarks
11.10.7.234	Foley test hole	Gus Ostic	1956	5450E	116R	10	Sand and gravel	Quaternary alluvium	26.57 27.10	2-1-56 1-10-60	N	N	X	See table 7. Temperature 62°F.
7.234a	T-7	Perry Bros.	1957	5450E	500M	8	Sand, gravel, and sandstone	Quaternary alluvium and Cub Mountain formation1/	31.49 26.13	4-29-57 7-30-57	N	N	X	See table 7. Temperature 63°F.
7.411	Schoolhouse corral well	Ray Taylor	1953	5415E	44M	4	Sand	Quaternary alluvium	22.51	8-9-56	W, C	S	X	Drilled and cased to 50 feet. Reported yield 8 to 10 gpm. Temperature 67°F.
8.311	T-4	Perry Bros.	1957	5486M	300M	8	Sand and gravel	do.	34.05 27.75	2-15-57 1-13-60	N	N	X	Casing perforated from 40-60 ft., 155-165 ft., 230-240 ft., and 288-298 ft. Yield was 10 gpm, with 257 ft. of drawdown after bailing 1 hour. Temperature 63°F.
8.331	Martinez well	D. E. Smith	1948	5515E	138M	4	-	Quaternary alluvium and Cub Mountain(?) formation1/	49.99	8-10-56	W, C	S	X	Drilled and cased to 160 feet. Temperature 75°F.
17.442	Mescalero Apache Indian Reservation "Indian well"	Leroy Perry	1952	5675E	382+M	-	-	do.	139.99	8-10-56	W, C	S	X	Yield estimated 2 to 3 gpm. Temperature 68°F.
19.132	Golondrina well	D. E. Smith	1948	5435E	102M	8	-	do.	77.86	8-4-56	W, C	S	X	Drilled and cased to about 150 feet. Estimated yield 4 to 8 gpm. Temperature 67°F.

1/ Cub Mountain formation of Bodine (1956).

Recharge and Discharge

The water-bearing formations in the Three Rivers reentrant are recharged from precipitation in the area and from infiltration of the several streams that issue from the Sierra Blanca. Some water that falls upon or flows over the coarse-grained alluvium sinks into the ground and continues downward to the water table. Water enters the consolidated sedimentary rocks at a lesser rate, partly by movement from temporary storage in the alluvium. Data are insufficient on which to estimate the amount of annual recharge. Some potential recharge is rejected because the aquifer is full locally. In the reentrant area, artificial recharge might salvage some of the floodwater that now flows to the lowlands of the Tularosa Basin.

Most ground water in the Three Rivers area is discharged by movement westward, and some is discharged by vegetation along the stream channels. Losses by transpiration are probably greatest in the Three Rivers reentrant, where vegetation is comparatively abundant. Although the vegetation is sustained mainly by soil moisture provided by precipitation, many of the grasses and deciduous plants undoubtedly obtain a part of their supply from ground water, especially during drought. The generally healthy condition of plants in the reentrant supports such a conclusion. In addition to movement out of the area and transpiration, water is discharged naturally from the Three Rivers area by evaporation in areas of shallow water table and in the vicinity of springs. In some of the stream channels the water table is immediately below the streambed, and during dry, windy periods, such as in spring, considerable ground water is evaporated.

Discharge from wells in the Three Rivers area is small. Of the 44 wells inventoried (table 5), 16 were unused, owing to insufficient quantity or poor quality of the water, 5 were or had been irrigation wells, 4 were domestic wells, and 23 were stock wells. Generally, those used for domestic or irrigation purposes were used also for stock. The reported yields of the stock wells ranged from 2 to 70 gpm. Most of the stock wells are equipped with cylinder pumps and windmills that pump 2 to 10 gpm.

The Bosque well (11.9½.13.244) has the largest yield of the irrigation wells. The well initially yields nearly 400 gpm, but the discharge rate declines rapidly after a few hours. Although part of the decline is due to increased pumping head, most of the large initial yield of the well is due to the unusual well construction. The well consists of a vertical shaft at least 50 feet deep and a horizontal tunnel 60 feet long at a depth of 33 feet. The tunnel reportedly was constructed in coarse-grained stream deposits containing numerous boulders. The Gatehouse well 2 (11.9.26.433), which was drilled and cased to 70 feet, yields only about 20 gpm; the yield of the Pino well (11.9½.22.323), which was drilled to 86 feet, is not known; the Fishpond well 1 (11.9½.28.214), which was drilled and cased to about 130 feet, yields 120 gpm (reported) from 96 feet. The Rattlesnake well (11.9½.22.244), like the Bosque well, was dug and reportedly is only about 25 feet deep, presumably in alluvium. It has a 10-foot-diameter concrete well casing and an 8-inch casing in which the pump is installed. Although the water is only 15 to 20 feet deep in the well, the yield is estimated to be 150 gpm.

The combined maximum discharge by pumping in the area is about 1,000 gpm. Because of the probable amount of ground water that is available in the 150 square miles investigated, a discharge of 1,000 gpm is insignificant.

Water Levels

The depth to water was measured in most of the wells and test holes in the Three Rivers area (table 5). The water levels in the test holes were measured many times during testing. After most of the fieldwork was done in the area, 15 wells were measured at regular intervals, and 12 wells finally were selected as observation wells that were measured quarterly from January 1957 through January 1960. Hydrographs of water levels in the observation wells are shown in figures 9 through 17.

The water-level data obtained during 1956 and 1957 were used for the water-table contour map (fig. 5). Ground water moves from areas of recharge to areas of discharge, perpendicular to the contours. Changes in the slope of the water table give a rough indication of changes in the transmissibility of the water-bearing formations.

The contour map shows that the water table slopes generally westward from Sierra Blanca at a gradient of 100 to 150 feet per mile. In most of the Three Rivers area the direction of slope is westward, but within the northwestern part of the reentrant it is southward. This difference in direction indicates that most water moving westward from Sierra Blanca is diverted around the Godfrey Hills rather than passing through or beneath them. The apparent diversion is due to the easier movement of water through the alluvium of Quaternary age than that through the less permeable older sedimentary and igneous rocks in the Godfrey Hills.

Water-Level Fluctuations

In most ground-water reservoirs the water available to wells is in constant, though slow, movement from the area of recharge to the area of discharge. The amount of ground water in a reservoir from which there is only natural discharge is nearly constant because over a long period the discharge is equal to the recharge. In such a ground-water system, the position of the water table is governed mainly by the amount of recharge and discharge and the shape and permeability of the aquifer. The water table is nearly always rising or falling, though the amount of change may be very small. An excess of recharge over discharge will increase the amount of water in storage and cause the water table to rise. Similarly, an increase in discharge will cause a decline. Fluctuations of the water level that are due to natural changes largely are seasonal, annual, or long-term effects.

If wells are drilled into the reservoir and pumped, a new discharge is introduced into a system that previously was in equilibrium. Such withdrawals must result in reduced rates of natural discharge, reduction in ground-water storage, increased rates of recharge, or a combination of these. Pumping in the Three Rivers area would cause some reduction in storage, but in part of the main stem of Three Rivers and in the reentrant, the lowering of water levels by means of pumping would result ir some increase in recharge and some reduction in natural discharge in those areas where the water table is immediately below the beds of the stream courses.

Records of water levels in the Three Rivers area prior to 1956 do not exist except for a few reported levels. During 1956, most wells in the area were measured. Late in 1956, the Foley test hole (11.10.7.234) was equipped with an automatic water-level recorder, from which an intermittent record of water-level changes was obtained until October 1959. Fourteen other wells in the area, including seven test holes, were measured at least quarterly for periods of ½ to 3 years. (See figs. 9-17.) Twelve of the wells are now measured as a part of the basic-records program in New Mexico.

Figure 9.--Hydrographs of the Brownfield well (10.10.29.414) and the Boyd well (10.9.35.211), 1956-60, Three Rivers area, Lincoln County, N. Mex.

10.--Hydrograph of test hole T-1 (10.10.32.334), 1956-58, Three Rivers area, Lincoln County, N. Mex.

11.--Hydrographs of Trammell well 2 (10.10.32.421a) and Trammell well 3 (10.10.33.131), 1956-60, Three Rivers area, Lincoln County, N. Mex.

12.--Hydrograph of the Pete Crawford well (11.9½.12.422), 1956-60, Otero County, N. Mex.

13.--Hydrographs of the Bosque well (11.9½.13.244) and test hole T-6 (11.9½.13.234), 1957-60, Three Rivers area, Otero County, N. Mex.

14.--Hydrographs of the Rattlesnake well (11.9½.22.244) and test hole T-5 (11.10.5.332), 1957-60, Three Rivers area, Otero County, N. Mex.

15.--Hydrographs of test hole T-2 (11.10.6.333) and test hole T-3 (11.10.6.433), 1957-60, Three Rivers area, Otero County, N. Mex.

16.--Hydrographs of test hole T-7 (11.10.7.234a) and test hole T-4 (11.10.8.311), 1957-60, Three Rivers area, Otero County, N. Mex.

17.--Hydrograph of the Foley test hole (11.10.7.234), 1956-60, Three Rivers area, Otero County, N. Mex.

The water-table fluctuations shown in the hydrographs represent changes due largely, if not entirely, to natural causes. Several seasonal rises and declines were caused by recharge from runoff of snowmelt in the spring and rains in the fall and by drier periods between. The recharge effects were delayed in reaching some of the wells, owing to the greater distance of these wells from streams. Superimposed on these seasonal rises and declines are a variety of minor changes, doubtless due to the varying local geologic and hydrologic conditions near the individual wells.

A general rise of water levels from the middle of 1957 through 1958 is striking. During this period water levels in nearly all the wells rose from 7 to nearly 30 feet above the preceding low level. In most wells, the seasonal changes were superimposed on the general rise, and once a maximum height was reached, the water level began to decline. Rattlesnake well (11.9½.22.244), in which the water level continued to rise through January 1960, is an exception. The reason for the general rise was a change in the rate of precipitation from 1956 to 1957. A drought that had lasted for several years in southern New Mexico ended in 1956. During 1957 the amount of precipitation increased to slightly more than normal for the region, and during 1958 it was about 150 percent of normal. During 1959 the amount of precipitation was somewhat below normal,and, consequently, recharge was less than the previous year. Water-level declines ensued.

The responses to increases and decreases in recharge demonstrate the sensitivity of aquifers in the Three Rivers area to changes in recharge rate. Although it might be expected that wells under artesian pressure generally respond rapidly to changes in storage, it is clear that some of the wells finished in the alluvium respond in a similar manner. The water level in Pete Crawford's well (11.9½.12.422) rose 27 feet. The well is 50 feet deep and apparently is entirely in alluvium. The water level in the Bosque well (11.9½.13.244), which also is in alluvium, rose about 11 feet. Thus, the 1956 conditions in the Three Rivers area represent the approximate minimum storage that would follow a severe drought and demonstrate that the water-bearing formations can receive recharge readily when it is available.

The aquifer in the alluvium of the lower part of the reentrant probably reached maximum storage capacity in 1958. At well 11.9½.12.422 and at well 11.9½.13.244 the highest water level measured was at the approximate altitude of the nearby streambeds. The streams probably became effluent at the time, and water levels did not rise higher because of drainage into the streams. After water levels declined below the streambed, further declines were caused by downgradient movement of the water through the permeable alluvium.

Results of Test Drilling

Advance geologic data from wells was limited mainly to those from the Foley test hole (11.10.7.234), which was drilled for Holloman Air Force Base in 1956. Although the alluvium appeared to be the best aquifer in the area, few wells were located where the alluvium was thought to be thickest. Moreover, the alluvium masked the older formations in much of the area. Therefore, test holes were drilled to determine the subsurface distribution of the water-bearing formations and to test their water-yielding capacity.

The Corps of Engineers contracted for the drilling of six test holes, each to a depth of 300 feet. The contract specified that samples of the drill cuttings were to be obtained; that driller's descriptive and drilling-time logs were to be kept for each well; that casing be installed as needed; and that bailing tests, development, and test pumping were to be performed and recorded as required by the inspectors. Holloman Air Force Base contracted for the drilling of two holes to a depth of 500 feet each, to obtain additional information.

Personnel of the Geological Survey acted as observers and advisors to the inspectors of the Corps of Engineers and the Air Force during drilling of the eight test holes.

Lithologic logs of the test holes are given in table 10. The driller's logs and the drilling time for each 5-foot interval are given in table 11. Most of the pertinent information from each test hole is summarized in table 7; however, the following data are given to supplement the table.

Table 7.--Summary of results of test drilling in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

Test hole	Location	Depth of hole (feet)	Depth of casing (feet)	Perforated interval (feet)	Formations penetrated and depth (feet)	Principal aquifer	Non-pumping depth to water: Date measured	Non-pumping depth to water: Feet below land-surface datum	Step-pumping test: Date	Yield (gpm)	Hours pumped (successive)	Draw-down (feet)	Indicated maximum yield of hole (gpm)
T-1	10.10.32.334	300	300	120-140 170-195 200-210 220-235 270-300	Alluvium 0-30; Cub Mountain 1/ 30-90; Mesaverde 90-300	Sandstone in Mesaverde Group	2-14-57	23	1-2-57	50 100 75	2 1½ 1½	52 263 134	75
T-2	11.10.6.333	300	300	50-110 200-220 275-300	Alluvium 0-105; Mesaverde 105-300	Alluvium	2-25-57	40	2-25-57	25 50 60 75	2 2 1 ½	11 27 31 119	
									3-4-57	75 50	2 2	58 25	75
T-3	11.10.6.433	300	300	60- 90 155-165 210-215 295-300	Alluvium 0-85; Mesaverde 85-300	Alluvium and sandstone of Mesaverde Group	3-4-57	46	3-12-57	25 35	2 2	26 50	35
T-4	11.10.8.311	300	300	40- 60 155-165 230-240 288-298	Alluvium 0-60; Cub Mountain 1/ 60-300	Alluvium	2-26-57	33	Bailing test only 2-26-57		1	257	10
T-5	11.10.5.332	300	300	75- 95 100-110 135-145 255-260 295-300	Alluvium 0-130±; Cub Mountain 1/ 130-300	~~Alluvium~~ do.	3-8-57	55	Bailing test only 3-9-57		1	235	10
T-6	11.9½.13.234	300	300	30- 60 65- 80 295-300	Alluvium 0-75; Tertiary igneous rock 75-255; Cub Mountain 1/ 255-300	~~Alluvium~~ do.	3-12-57	17	3-28-57	25 50 25	2 3/4 1¼	29 ~~217~~ 274 185	25
T-7	11.10.7.234a	500	420	35- 85 260-290 380-400	Alluvium 0-85; Cub Mountain 1/ 85-345; Mesaverde 345-500	Alluvium and sandstone in Cub Mountain 1/	5-7-57	29	7-29-57	72 130	2 2	11 20	
									8-8-57	153-260	8	220	165+ 2/
T-8	11.9½.23.124	500	385	40- 60 260-270 360-380	Alluvium 0-55; Mesaverde 55-500	Alluvium; sandstone in Mesaverde	10-16-57	25	10-16-57	50	4	136	40
Foley	11.10.7.234	116 3/	103	23-103	Alluvium 0-116 3/	Alluvium	3-14-57	29	2-7-56	105	6	62	100
									-	160 4/	-	-	-

1/ Cub Mountain Formation of Bodine (1956).
2/ Results of test not conclusive; pump ran erratically, and well apparently needed additional development.
3/ Reported.
4/ Reported yield, after additional development.

Test hole T-1.--Water was obtained at depths of 17 and 130 feet and probably at depths of 175, 190, and 260 feet. Because the amount of water at 17 feet was negligible and the water was highly mineralized, the upper water-bearing zone was cased off. At a depth of 130 feet, the hole was bailed for 1 hour at an average of 32.5 gpm. The drawdown was 120 feet; the specific capacity was 0.27 gpm per foot of drawdown. The hole was then drilled to a depth of 300 feet and was tested by bailing for 1 hour at an average of 50 gpm. The drawdown was 65 feet, and the specific capacity was 0.77 gpm per foot of drawdown. Casing perforated at selected intervals was installed, and the hole was developed for 3 hours in ½-hour cycles of surging with surge blocks followed by bailing. A pump was installed, and the hole was alternately surged and pumped for 8 hours.

On January 2, 1957, pumping was started at 50 gpm. (See table 7.) After 120 minutes the pumping rate was increased to 100 gpm, but that rate was greater than the yield of the well, and after 92 minutes the rate was reduced to 75 gpm. The well was pumped 1½ hours at 75 gpm. At the end of the first 120 minutes of pumping the drawdown was 52 feet, and the water level was still declining; at the end of 212 minutes of pumping the drawdown was 263 feet; but at 300 minutes (the end of the test) the drawdown was only 134 feet. The water level recovered to 42 feet in 300 minutes after the pump was stopped.

Test hole T-2.--Water was first found at a depth of about 40 feet, and the zone yielded about 15 gpm. The saturated alluvium extended to a depth of about 105 feet. Water may also have entered the hole in the intervals of 125-150, 180-205, and 225-250 feet. The Geological Survey representative suggested that the casing be perforated at these depths. However, the casing was perforated at intervals selected previously. (See table 7.) After the casing was installed, the hole was tested by bailing for 1 hour at approximately 45 gpm. The well was developed by six ½-hour cycles of surging with surge blocks and bailing and by 8 hours of surging and pumping with the test pump.

On February 25, 1957, pumping was started at 25 gpm. Subsequent steps were 50, 60, and, briefly, 75 gpm. At the end of 5½ hours of pumping the net drawdown was 119 feet (table 7). The pumping test indicated that additional development was needed. The well was alternately pumped and back-flushed, and a large amount of sand was removed, indicating that the well had been further developed.

A 4-hour pumping test was made on March 4, 1957, beginning at 75 gpm. After 2 hours of pumping, the rate was reduced to 50 gpm. The net drawdown at the end of 4 hours of pumping was about 25 feet.

Test hole T-3.--Water was found in the hole at about 58 feet; the saturated portion of the alluvium was about 27 feet thick. When the hole was 110 feet deep, a yield of about 40 gpm with a drawdown of about 31 feet was obtained during a 1-hour bailing test (about 1.3 gpm per foot of drawdown). Water probably entered the hole also at depths of about 155, 210, and 295 feet. After the casing was installed, the hole was surged and bailed in the manner described for test hole T-2. Subsequently, the pump was installed and the hole was pumped, surged, and back-flushed for 8 hours.

On March 12, 1957, the yield of the hole was tested at 25 gpm for 2 hours and 35 gpm for 2 hours. The net drawdown at the end of 4 hours of pumping was 50 feet.

Test hole T-4.--Water was first found at 40-45 feet, indicating only about 20 feet of saturated alluvium. Cuttings from the deeper rocks indicated that little water could be obtained from the hole. A bailing test on February 26, 1957, showed that the hole could be bailed dry in about 52 minutes. The hole was capped without further work.

Test hole T-5.--Water was reported by the driller to have been found at 82 feet, and additional water possibly was found at 98 feet. Examination of the drill cuttings indicated a yield comparable to that of test hole T-4. A bailing test March 9, 1957, indicated a yield of 10-12 gpm. No further work was done on the hole.

Test hole T-6.--Water was found at 26 feet. Approximately 50 feet of saturated alluvium and 180 feet of igneous rock was penetrated. Deeper sedimentary rocks were mostly clay and silt of low permeability. After the hole was cased, it was tested by bailing for 1 hour, developed with surge blocks, and subsequently developed for 8 hours with the test pump.

A pumping test was started on March 28, 1957, at 25 gpm. At the end of 2 hours pumping the drawdown was 29 feet, and the rate of discharge was increased to 50 gpm. After 40 minutes of pumping at 50 gpm the water level was at the intake of the pump, indicating a drawdown of about 274 feet. The discharge was reduced again to 25 gpm for $1\frac{1}{4}$ hours. At the end of the 4-hour pumping period, the net drawdown was 185 feet. After about $4\frac{1}{2}$ hours of recovery the residual drawdown was approximately 2.6 feet.

Test hole T-7.--Water was first found at 37 feet, and the saturated zone in the alluvium below was 48 feet thick. The two zones that showed most promise as aquifers were the saturated alluvium from 37 to 85 feet and a sandstone from 380 to 400 feet. On May 7, 1957, when the hole was 235 feet deep, it was tested by bailing for 1 hour at an average of about 50 gpm. The drawdown at the end of the test was approximately 7 feet (about 7 gpm per foot of drawdown). The water level recovered to 0.5 foot below the prepumping level in 35 minutes. During the test, the drawdown in the adjacent Foley test hole was 1.4 feet. On June 20, when the hole was 490 feet deep, the yield by bailing was about 45 gpm and the drawdown was small. When the hole was completed at a depth of 500 feet, it was bailed for 1 hour at about 60 gpm. The estimated drawdown was 20 feet, and the specific capacity was about 3gpm per foot of drawdown. The hole was surged with surge blocks for 3 hours and bailed. A test pump was installed to a depth of 400 feet, and the hole was pumped and surged for 4 hours.

On July 29, 1957, the hole was pumped at about 70 gpm for 2 hours and at 130 gpm for 2 hours more. The drawdown at the end of 4 hours was 20 feet. During the test the pump operated erratically, and the test was inconclusive. On August 8, the hole was tested again, and the discharge varied from 153 to 260 gpm. The drawdown was about 220 feet. After the 8-hour test, it was apparent that the hole would yield more than 165 gpm indefinitely but that the hole would have to be developed further before it could be accurately tested.

Test hole T-8.--Water was found between 30 and 35 feet, indicating a saturated section of alluvium about 25 feet thick. The rocks below the alluvium appeared to have low permeabilities. Casing was set at 385 feet, and the well was surged and bailed for 5 hours. Subsequently, the hole was surged and pumped for 8 hours.

On October 16, 1957, the hole was tested by pumping for 4 hours at 50 gpm. The drawdown at the end of 4 hours was 136 feet, which is equivalent to about 0.37 gpm per foot of drawdown.

Foley test hole.--Prior to the beginning of the water-resource~~s~~ investigation in the Three Rivers area, officials of Holloman Air Force Base considered the Three Rivers area as a potential source of water because of the water rights that could be purchased in the area. Several irrigation wells had been drilled there ~~in the area~~, so the Air Force drilled the Foley test hole (11.10.7.234). The test of this hole prompted the investigations described in this report. Records of the early work at the test hole are not complete, but the hole has served as an observation well throughout and following this investigation.

Transmissibility of the Water-Bearing Formations

Test pumping indicated the quantity of water that could be produced from the test wells and provided data that indicate the ability of the formations to transmit water. Not all the pumping tests were sufficiently controlled or long enough to provide accurate aquifer data, but they do indicate the general magnitude of the coefficient of transmissibility (T).

The coefficient of transmissibility is the rate of flow of water in gallons per day through a strip of the aquifer 1 foot wide extending the full height of the aquifer under a hydraulic gradient of 1 foot per foot. Expressed in terms that more closely approximate natural conditions, the transmissibility is the rate of flow of water through a strip of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile.

Two methods were used to derive T from the Three Rivers pumping-test data. One is Theis' straight-line recovery method (Wenzel, 1942, p. 95-96), using the formula

$$T = \frac{264\ Q}{s} \log_{10} \frac{t}{t'}$$

wherein T = coefficient of transmissibility

Q = discharge rate during the test, in gpm

s = residual drawdown, in feet

t = time, in minutes, since pumping started

t' = time, in minutes, since pumping stopped

A plot of s versus t/t' on semilogarithmic graph paper, using the logarithmic scale for t/t' should be a straight line. The value of $\frac{\log_{10} t/t'}{s}$ is the slope of the line, which is taken as the change in s (Δs) over one log cycle, so that the formula is resolved to $T = \frac{264\ Q}{\Delta s}$. Most of the tests in the Three Rivers area were step tests during which the test holes were pumped at two or more rates without stopping between steps. The coefficient of transmissibility can be calculated from measurements of the rate of recovery of the water level after such step tests by use of the formula:

$$T = \frac{264}{s} [Q_1 \log_{10} \frac{t_1 + t'}{t_2 + t'} + Q_2 \log_{10} \frac{t_2 + t'}{t_3 + t'} + \text{---} Q_n \log_{10} \frac{t_n + t'}{t'}]$$

wherein s = residual drawdown, in feet, at the pumped well

T = coefficient of transmissibility in gallons per day per foot

Q = discharge of the well, in gallons per minute during the step indicated by the subscript

t = time since pumping started for the step indicated by the subscript to the time that all pumping stopped

t' = time since pumping stopped

The procedure applies to a computation of transmissibility from the recovery after any number of pumping steps--an additional term in brackets being added for each additional step. The values of residual drawdown are plotted on linear graph paper against the values of the term in brackets for each time that s was measured after pumping stopped. These points theoretically should fall along a straight line. By selecting two points on the line and dividing the difference in the two values of the term in brackets at those points by the difference in the two values of residual drawdown at those two points and multiplying the quotient by 264, a value for the coefficient of transmissibility is obtained.

Conditions in the aquifer rarely meet all the assumptions on which aquifer-test formulas are based. Alluvium, such as that in the Three Rivers area, commonly departs far from the assumptions, and the values for transmissibility may be greatly in error. In addition, most of the tests involved not only the alluvium, but several consolidated aquifers whose characteristics diverge widely from that of the alluvium.

The analyses of the pumping test at the Foley test hole, test holes T-1, T-2, T-3, T-6, and T-8 are shown in figures 18 through 23. The

Figure 18.--Recovery data from pumping test at Foley test hole (11.10.7.234), Three Rivers area, Otero County, N. Mex., February 7, 1956.

Figure 19.--Recovery data from step-pumping test at test hole T-1 (10.10.32.334), Three Rivers area, Lincoln County, N. Mex., January 2, 1957.

Figure 20.--Recovery data from step-pumping test at test hole T-2 (11.10.6.333), Three Rivers area, Otero County, N. Mex., March 4, 1957.

Figure 21.--Recovery data from pumping test at test hole T-3 (11.10.6.433), Three Rivers area, Otero County, N. Mex., March 11, 1957.

Figure 22.--Recovery data from step-pumping test at test hole T-6 (11.9½.13.234), Three Rivers area, Otero County, N. Mex., March 28, 1957.

Figure 23.--Recovery data from pumping test at test hole T-8 (11.9½.23.124), Three Rivers area, Otero County, N. Mex., October 16, 1957.

data shown for the Foley test hole are meager, but the computed value for transmissibility is in the right order of magnitude. These data are important because this test hole was the only one completed entirely in alluvium, and the transmissibility of 5,000 gpd per foot indicates that the alluvium, though thin, is capable of transmitting appreciable quantities of water.

Test hole T-1, unlike the Foley test hole, tapped only the older, consolidated sedimentary rocks. The alluvium was cased off and presumably did not contribute water to the hole during the test. The computed value for transmissibility was 1,300 gpd per foot, which indicates that the Mesaverde Group can transmit appreciable quantities of water and should be considered when a well field in the Three Rivers reentrant is designed.

The geologic and hydrologic conditions in the area surrounding test holes T-2, T-3, T-6, and T-8, all of which were finished in both the alluvium and the older sedimentary rocks, are too complex for accurate analysis of the hydraulic properties of the aquifers, as indicated by the marked changes of slope in figures 20-23. The early parts of the recovery curves were used to compute the transmissibilities, as they most nearly reflect the physical conditions in the immediate vicinity of the wells. The very low value for transmissibility obtained at test hole T-6 (50 gpd per foot) probably is the result of the thick and presumably impermeable section of igneous rock penetrated in the hole.

Only bailing tests were made at test hole T-4 and T-5, which proved to have low yields. From the bailing test of hole T-4, the transmissibility of the water-bearing zones at that location was estimated to be approximately 40 gpd per foot. Two pumping tests were made at test hole T-7, but the data from neither were suitable for suitable for analyses, owing to the erratic operation of the test pump. From the results of a test on May 7, 1957, when the hole was bailed ~~at~~ about 50 gpm, the transmissibility at test hole T-7 is estimated to be 2,000 to 3,000 gpd per foot; this bears out the results at the Foley test hole.

The results of the pumping-test analyses are summarized in table 8. These results are only approximations.

Table 8.--Summary of approximate aquifer coefficients determined from test holes in the Three Rivers area, Otero and Lincoln Counties, N. Mex., 1957

Test hole No.	Coefficient of transmissibility (gpd per foot)	Discharge rate at end of test (gpm)	Specific capacity at end of test (gpm per foot of drawdown)	Duration of test (minutes)
Foley test hole	1/ 5,000	105	1.7	360
T-1	1,300	75	.56	300
T-2	600	50	2	240
T-3	400	35	.7	240
T-4	1/ 40	-	-	60
T-6	50	25	.14	240
T-7	1/ 2,000-3,000	-	-	60
		190±	.9±	480
T-8	120	50	.4	240

1/ Based on data from bailer tests.

Chemical Quality of Ground Water

Most of the ground water from wells and springs in the Three Rivers area is of fair to very poor quality for municipal or domestic use. According to the standards for drinking water to be used on interstate carriers (U.S. Public Health Service, 1946), such water should not contain more than 250 ppm of either sulfate or chloride. The dissolved-solids content should not be more than 1,000 ppm, and preferably should be 500 ppm or less. However, water of poorer quality is being used by many communities without apparent deleterious effects. Of the 67 analyses of ground water given in table 9, only the one for Trammel well 3 (10.10.33.131) meets the standards set forth above. Of the 67 samples, 15 had sulfate content of less than 300 ppm, and 33 had dissolved-solids content of less than 1,000 ppm. All but 5 of the samples had chloride content of less than 250 ppm.

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

[Analyses by U.S. Geological Survey. ~~Results~~ Chemical constituents in parts per million except as indicated. Dissolved solids is residue on evaporation.]

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
10.9.8.121	I-X Ranch	Alluvium of Quaternary age or Mesaverde group	9-20-55	69	-	-	-	-	514	155	1,030	278	1.0	4.0	-	-	480	353	70	10	2,940	7.2	Sample collected from end of 25-foot discharge pipe. Slightly turbid.
13.212	Barnevell well	Tertiary(?) igneous rock(?)	8-23-56	61	25	-	349	55	112	165	1,010	106	.6	4.6	~~1,740~~ 2,150	2.37	1,100	962	18	1.5	2,540	7.4	Water clear.
24.412	Minnie Hall well	Cub Mountain formation[1] or Mesaverde(?) group(?)	4-17-56	-	26	-	474	65	238	126	1,310	350	1.1	5.1	2,630	3.44	1,450	1,350	26	2.7	3,180	7.5	Estimated yield 6-8 gpm. Water clear.
34.211	Halfway well	Tertiary(?) volcanic rock	8-15-56	65	72	-	147	51	47	122	340	153	.7	8.3	968	1.20	576	416	15	.8	1,320	7.5	Slightly turbid. ~~Dissolved solids is residue on evaporation.~~
10.10.4.441	Bataan Lodge well	-	1-4-57	56	20	-	72	3.8	213	298	300	71	.8	.1	850	1.13	195	0	70	6.6	1,250	7.4	Estimated yield 3 gpm. Turbid(?). ~~Dissolved solids is residue on evaporation.~~
5.222	I-X Ranch and T. F. Ryan III	-	1-4-57	59	39	-	318	71	175	241	917	213	.4	15	1,970	2.54	1,090	888	26	2.3	2,460	7.4	Estimated yield 3 gpm. Water clear.

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
10.10.29.414	Brownfield well	Alluvium of Quaternary(?) age	8-27-56	62	40	-	266	59	95	250	746	90	0.5	3.3	~~1,420~~ 1,580	1.93	906	701	19	1.4	1,890	7.5	Water clear.
32.334	T-1	~~Cub Mountain formation and~~ Mesaverde group	11-27-56	61	14	-	137	26	44	240	284	36	.6	.4	698	.90	449	252	18	.9	991	7.5	Bailed sample. Muddy. Depth of hole 132 feet. Measured yield 32.5 gpm. ~~Dissolved solids is residue on evaporation.~~
32.334	do.	do.	12-6-56	61	13	-	121	27	60	227	293	35	.8	.1	696	.90	413	227	24	1.3	980	7.8	Sample bailed from near bottom of hole. Turbid. Depth of hole 295 feet. ~~Dissolved solids is residue on evaporation.~~
32.334	do.	do.	12-7-56	61	21	-	137	25	51	246	293	34	.8	.3	727	.93	445	224	20	1.1	997	7.7	Sample bailed from 125 to 140 feet. Turbid. Depth of hole 300 feet. Measured yield 50.4 gpm. ~~Dissolved solids is residue on evaporation.~~
32.334	do.	do.	12-7-56	-	-	-	-	-	-	282	308	30	-	-	-	-	508	227	-	-	1,050	7.3	Sample bailed from 17 to 30 feet. Clear. Measured yield 5 gpm.
32.334	do.	do.	12-28-56	62	23	-	137	35	36	246	298	36	.8	.6	747	.93	486	284	14	.7	1,010	7.3	Sample collected after 41 minutes pumping at measured yield of 750 gpm.
32.334	do.	do.	1-2-57	62	23	0.00	137	30	63	298	292	36	.8	.5	742	.99	466	222	23	1.3	1,010	7.0	Sample collected after 290 minutes pumping at average of 62 gpm. Clear. ~~Dissolved solids is residue on evaporation.~~
33.131	Trammel well No. 3	Cub Mountain(?) formation(?) 1/	8-28-56	61	25	-	104	~~22~~ 21	29	194	200	28	.6	1.1	554	.69	346	187	15	.7	769	7.3	Water clear. ~~Dissolved solids is residue on evaporation.~~
11.9.22.441	Sand well	-	7-26-56	69	2.2	-	357	78	152	274	1,010	187	.4	.8	~~1,920~~ 2,020	2.61	1,210	986	21	1.9	2,470	6.9	Estimated yield 3 to 5 gpm. Turbid.
35.122	Gatehouse well No. 1	Alluvium of Quaternary age and Mancos (?) shale(?)	7-30-56	70	13	-	536	97	128	276	1,360	262	.7	1.2	2,530	3.44	1,740	1,510	14	1.3	3,070	7.1	Measured yield 1 gpm. Clear.

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Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
S11.9½.13.124	Chapel spring	Tertiary volcanic rock ~~porphyry~~	4-25-55	-	-	-	-	-	-	117	486	156	-	-	-	-	730	634	-	-	1,520	7.5	Water clear.
11.9½.13.234	T-6	Alluvium of Quaternary age	2-20-57	63	-	-	-	-	-	184	1,300	108	-	-	-	-	1,510	1,360	-	-	2,550	7.5	Bailed sample. Very muddy. Depth of hole approximately 40 feet.
13.234	do.	do.	3-19-57	69	-	-	-	-	-	125	480	93	-	-	-	-	485	382	-	-	1,360	7.4	Sample bailed from bottom of hole. Muddy. Depth of hole 303 feet.
13.234	do.	do.	3-28-57	65	23	-	189	41	33	178	451	67	0.6	0.4	966	1.21	640	494	10	0.6	1,300	7.2	Sample collected after 32 minutes pumping at measured yield of 25 gpm. Slightly muddy. ~~Dissolved solids is residue on evaporation.~~
13.234	do.	do.	3-28-57	68	-	-	-	-	-	~~180~~ 186	-	79	-	-	-	-	650	498	-	-	1,280	7.3	Sample collected after 179 minutes pumping at measured yield of 25 gpm. Almost clear.
13.244	Bosque well	~~Alluvium~~ do.	4-25-55	-	29	-	202	49	25	196	438	100	.8	1.1	~~941~~ 1,230	1.28	706	545	7	.4	1,350	7.3	Water clear.
S11.9½.13.422	T. F. Ryan III	~~Quaternary alluvium~~ do.	2-29-56	59	25	-	169	34	26	161	349	85	.7	.1	787	1.04	562	430	9	.5	1,120	7.5	Seep issues from gravel in bottom of Indian Creek. Estimated yield 2 to 3 gpm. Clear. ~~Dissolved solids is residue on evaporation.~~
11.9½.22.244	Rattlesnake well	do.	4-22-55	60	-	-	-	-	-	234	682	128	-	-	-	-	940	748	-	-	1,850	7.1	Water clear.
22.244	do.	do.	8-22-56	65	30	-	264	52	70	236	642	114	.5	.2	~~1,290~~ 1,460	1.75	872	679	15	1.0	1,800	7.1	Estimated yield 100 to 200 gpm. Water slightly turbid.
22.244	do.	do.	11-6-57	-	-	-	-	-	-	81	656	104	-	-	-	-	655	588	-	-	1,570	7.9	Sample collected after 5 minutes pumping at estimated 200 gpm.
23.124	T-8	Alluvium of Quaternary age and Mesaverde group	8-16-57	-	-	-	-	-	-	95	792	180	-	-	-	-	950	872	-	-	2,020	7.8	Bailed sample. Contained sediment. Depth of hole 42 feet.
23.124	do.		9-13(?)-57	-	-	-	-	-	-	228	992	179	-	-	-	-	1,100	913	-	-	2,390	7.1	Depth of hole 385 feet.
23.124	do.		10-16-57	-	-	-	-	-	-	146	821	149	-	-	-	-	750	630	-	-	2,050	7.1	Pumped sample. Depth 500 feet, cased to 385 feet.
23.124	do.	do.	10-16-57	67	-	-	-	-	-	142	823	149	-	-	-	-	745	628	-	-	2,050	7.0	Sample collected after 3 hours pumping at measured yield 50 gpm.
23.124	do.	do.	10-16-57	67	26	-	250	28	197	132	818	145	1.1	.1	1,580	2.08	739	631	37	3.1	2,020	7.3	Sample collected after 4(?) hours pumping. Measured yield 50 gpm.

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
11.9½.28.214	Fishpond well ~~No.~~ 1	of Quaternary age alluvium and Mesaverde group	8-24-55	63	-	-	-	-	156	227	976	195	0.4	2.5	-	-	1,140	954	23	2.0	2,390	7.2	Sample collected after 10 ~~minutes~~ pumping. Water clear.
11.10.5.112	Johnson well ~~No.~~ 1	of Quaternary age alluvium	8-15-56	62	14	See remarks	189	39	50	228	488	30	.5	1.3	~~924~~ 1,010	1.26	632	445	15	.9	1,280	7.6	Precipitated iron = 0.18 ppm.
5.121	Johnson well ~~No.~~ 2	of Quaternary age alluvium and Cub Mountain formation 1/	8-14-56	66	24	-	148	33	51	232	347	45	.5	.9	840	1.04	505	315	18	1.0	1,110	7.4	-
5.332	T-5	of Quaternary age alluvium	3-6-57	64	-	-	-	-	-	180	853	137	-	-	-	-	990	842	-	-	2,060	7.6	Bailed sample. Muddy. Depth of hole 210± ~~feet~~.
S11.10.6.214	T.F. Ryan III	do.	2-29-56	62	30	-	172	42	93	257	464	76	.7	1.6	~~1,010~~ 1,020	1.37	602	391	25	1.7	1,420	7.6	Estimated flow 2 to 3 gpm. Clear.
11.10.6.333	T-2	of Quaternary age alluvium and Mesaverde group	12-29-56	-	-	-	-	-	-	171	-	29	-	-	-	-	376	236	-	-	792	7.4	Bailed sample. Turbid and muddy. Depth of hole 65 ~~feet~~.
6.333	do.		1-10-57	62	-	-	-	-	-	145	284	37	-	-	-	-	362	244	-	-	895	7.4	Bailed sample from bottom of hole. Muddy. Depth of hole 205 ~~feet~~.
6.333	do.	do.	1-18-57	65	-	-	-	-	-	207	271	35	-	-	-	-	284	114	-	-	946	6.9	Bailed sample from bottom of hole. Muddy. Depth of hole 297 ~~feet~~.
6.333	do.	do.	1-28-57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	877	-	Sample collected from 40th of 105 bailers. Muddy. Bailed at 45 gpm. Depth of hole 300 ~~feet~~.
6.333	do.	do.	1-28-57	61	-	-	-	-	-	195	289	38	-	-	-	-	436	276	-	-	923	7.4	Sample collected from 102nd of 105 bailers. Muddy. Bailed at 45 gpm.
6.333	do.	do.	2-25-57	63	23	0.00	128	29	33	198	282	37	.6	.6	675	.86	438	276	14	.7	924	7.2	Collected after 40 minutes pumping. Measured yield 25 gpm. Slightly turbid. Total iron = 3.0 ppm. ~~Dissolved solids is residue on evaporation.~~

80c

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
11.10.6.333	T-2	of Quaternary age alluvium and Mesaverde group	2-25-57	62	25	0.00	136	26	35	202	293	36	0.6	0.6	691	0.89	446	281	15	0.7	949	7.2	Collected after 235 minutes pumping. Measured yield 50 gpm. Clear. Total iron = 1.9 ppm. ~~Dissolved solids is residue on evaporation.~~
6.333	do.	do.	3-4-57	65	-	-	-	-	-	200	296	30	-	-	-	-	476	312	-	-	964	7.2	Collected after 235 minutes pumping. Clear.
6.433	T-3	~~Quaternary alluvium~~ do.	2-5-57	-	-	-	-	-	-	185	448	42	-	-	-	-	594	442	-	-	1,230	7.6	Bailed sample. Muddy. Depth of hole 60 feet.
6.433	do.	~~Quaternary alluvium and Mesaverde group~~ do.	2-7-57	63	-	-	-	-	-	170	437	62	-	-	-	-	586	446	-	-	1,230	7.6	Bailed sample. Muddy. Depth of hole 105 feet.
6.433	do.	do.	3-12-57	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,210	-	Sample collected after 31 minutes pumping. Measured yield 25 gpm. Depth 300 feet.
6.433	do.	do.	3-12-57	64	24	-	168	36	44	176	416	60	.4	1.5	915	1.14	567	423	15	.8	1,190	7.4	Collected after 233 minutes pumping. Measured yield 35 gpm. Clear. ~~Dissolved solids is residue on evaporation.~~
7.234	Foley test hole ~~No. 1~~	of Quaternary age alluvium	2-2-56	-	-	-	-	-	-	256	744	91	-	-	-	-	1,040	830	-	-	1,790	7.1	Water clear. Sample from ditch.
7.234	do.	do.	2-7-56	62	27	-	152	28	21	195	286	56	.8	1.6	703	.91	494	334	9	.4	983	7.4	Sample collected after 6 hours pumping at 105 gpm. Slightly cloudy. ~~Dissolved solids is residue on evaporation.~~

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
11.10.7.234	Foley test hole	Alluvium of Quaternary age	9-17-56	-	-	-	-	-	-	212	362	73	-	-	-	-	625	452	-	-	1,170	7.2	Bailed sample. Contained sediment.
7.234a	T-7	Alluvium of Quaternary age and Cub Mountain formation 1/	4-27-57	-	47	-	260	51	26	197	622	72	0.5	1.7	1,210	1.60	858	696	6	0.4	1,530	7.6	Sample bailed from bottom of hole. Depth of hole 50 ft.
7.234a	do.		5-16-57	65	-	-	-	-	-	-	506	66	-	-	-	-	-	-	-	-	1,370	-	No casing in hole. Sample bailed from bottom of hole. Very muddy. Depth of hole 257 ft.
7.234a	do.	do.	6-6-57	-	-	-	-	-	-	222	659	67	-	-	-	-	845	663	-	-	1,600	7.5	Cased off to 282 ft. Sample bailed from bottom of hole. Muddy. Depth of hole 386 ft.
7.234a	do.	do.	6-21-57	-	-	-	-	-	-	194	716	73	-	-	-	-	1,000	841	-	-	1,690	7.4	Sample from 50 ft with sampler. Turbid. Depth of hole 500 ft.
7.234a	do.	do.	6-21-57	-	-	-	-	-	-	224	662	70	-	-	-	-	940	756	-	-	1,610	7.4	Sample from 400 ft with sampler. Turbid.
7.234a	do.	do.	7-24-57	-	-	-	-	-	-	241	688	78	-	-	1,490	2.03	985	788	-	-	1,610	7.3	Bailed sample. Contained some clay. Measured yield 62 gpm. ~~Dissolved solids is residue on evaporation.~~
7.234a	do.	do.	8-8-57	63	-	-	-	-	-	214	446	69	-	-	-	-	720	544	-	-	1,260	7.4	Sample collected after 1 hr pumping.
7.234a	do.	do.	8-8-57	63	-	-	-	-	-	215	-	67	-	-	-	-	715	539	-	-	1,260	7.4	Sample collected after 3.5 hrs pumping.
7.234a	do.	do.	8-8-57	63	-	-	-	-	-	75	-	68	-	-	-	-	570	508	-	-	1,120	8.0	Sample collected after 5 hrs pumping.
7.234a	do.	do.	8-8-57	63	-	-	-	-	-	213	-	69	-	-	-	-	705	530	-	-	1,280	7.4	Sample collected after 6 hrs pumping.
7.234a	do.	do.	8-8-57	63	29	-	216	37	24	214	452	68	.5	.9	1,000	1.27	691	516	7	.4	1,280	7.3	Sample collected after 6 hrs pumping. Measured yield 200 gpm. Contained some sediment.

Table 9.--Chemical analyses of water from wells and springs in the Three Rivers area - Continued

Location No.	Owner or name	Principal water-bearing formation	Date collected	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) and Potassium (K) as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non carbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
11.10.7.411	Schoolhouse Corral well	Quaternary alluvium of Quaternary age	8-9-56	67	35	-	294	52	24	212	629	120	0.5	0.4	~~1,260~~ 1,350	1.71	948	774	5	0.3	1,660	7.5	Water clear.
8.311	T-4	do.	2-15-57	63	-	-	-	-	-	195	261	39	-	-	-	-	444	284	-	-	896	7.4	Bailed sample. Muddy. Depth of hole 55 ~~feet~~ ft.
8.331	Martinez well	Quaternary alluvium of Quaternary age and Cub Mountain (?) formation(?) 1/	8-10-56	75	15	-	441	90	181	146	1,130	400	1.2	.8	~~2,330~~ 2,540	3.17	1,470	1,350	21	2.1	3,090	7.2	Estimated yield 2 to 3 gpm. Turbid.
17.422	Mescalero Apache Indian Reservation "Indian well"	do.(?)	8-10-56	68	22	-	445	124	239	204	1,170	534	.4	1.9	~~2,640~~ 2,930	3.59	1,620	1,450	24	2.6	3,630	7.3	Estimated yield 2 to 3 gpm. Turbid.
19.132	Golondrina well	do.(?)	8-4-56	67	20	-	468	74	97	190	1,190	204	.2	1.2	~~2,150~~ 2,260	2.92	1,470	1,320	13	1.1	2,600	7.4	Estimated yield 4 to 8 gpm. Clear.

1/ Cub Mountain formation of Bodine (1956).

80 F

Ground water in the Three Rivers area is largely of the calcium magnesium sulfate type. As is true of the water from some parts of the Tularosa Basin, the sulfate content governs the potability, because the chloride content is much lower than the sulfate content. Wherever the water is classed as usable with regard to sulfate, it is classed usable also with regard to chloride. In analyses in which most of the anions were determined, the nitrate content was less than 15 ppm, and in most samples less than 2 ppm; fluoride was less than 1.5 ppm; both are well below the maximum amounts considered permissible in water for domestic use. Dissolved solids ranged from 554 ppm in well 10.10.33.131 to 2,640 in well 11.10.17.422. All the ground water sampled is hard.

The pattern of chemical quality (fig. 5) shows that supplies of usable ground water occur in a rather restricted area of the reentrant. In the northern part of the reentrant, from sec. 30, T. 10 S., R. 10 E. northward, samples from existing wells indicate that the ground water contains 700 ppm or more of sulfate. South of Indian Creek, the three existing wells all yield water containing more than 1,000 ppm of sulfate. From these wells, and from the south end of the Godfrey Hills down the water gradient to Three Rivers station, the ground water contains increasingly larger amounts of sulfate.

The remaining area, some 5 to 7 square miles in the central and southwestern parts of the Three Rivers reentrant, contains ground water with a sulfate content of 200 to about 500 ppm, except for a sulfate content of 853 ppm in water from well 11.10.5.332 (test hole T-5) near the eastern boundary of this area. In this area there is maximum opportunity for recharge with water of initially low dissolved-solids content. The alluvium in the area is in large part derived from rocks containing few readily soluble minerals. In the other parts of the Three Rivers area, water moves through sedimentary rocks rich in sulfate minerals and through alluvium derived from those rocks. In those sulfate-rich areas, too, the amount of recharge from precipitation is less, owing both to the lesser amount of precipitation and to the generally low permeability of the rocks.

The analyses show that ground water produced from the area would have to be mixed with water of a better quality in order to produce water that is within the U.S. Public Health Service standards (1946). For any constituent or for the dissolved-solids content, the quality of a mixed water can be computed by the use of a dilution formula:

$$C_m = \frac{C_p Q_p + C_g Q_g}{Q_m}$$

wherein C_m = concentration of constituent or dissolved solids in the mixed water, in ppm

C_p = concentration in the poorer water

C_g = concentration in the better water

Q_p = quantity of the poorer water used in the mixture

Q_g = quantity of the better water

Q_m = quantity of the mixture, or $Q_p + Q_g$

Thus if 1,000 gallons of water containing 500 ppm of sulfate were mixed with 1,000 gallons of water containing 50 ppm of sulfate, the resulting 2,000 gallons would contain 275 ppm of sulfate.

Water from the Tertiary volcanic rocks in the Godfrey Hills, as represented by the sample from Chapel Spring (S11.9½.13.124), was very high in dissolved solids, especially sulfate. Water from volcanic rocks in New Mexico generally contains only small amounts of dissolved solids, especially if the sampling point is close to the recharge area. The volcanic rocks of the Godfrey Hills apparently contain a separate water body not connected with that in the alluvium of Quaternary age and older sedimentary rocks. Recharge to the water table in the Godfrey Hills comes from precipitation directly on the hills. The origin of the higher mineral content of the water is not known, but the mineral matter may be carried into the volcanic rocks by hydrothermal activity in connection with some of the small bodies of intrusive rocks, or from soluble minerals carried as dust on the prevailing southwesterly winds from the Tularosa Basin.

Potential Development of Ground-Water Supplies

The best aquifer in the Three Rivers area, with respect to both quantity and quality of the water, is the alluvium of Quaternary age. The Cub Mountain Formation of Bodine (1956) and the Mesaverde Group also yield water that is potable, or nearly so, but in much smaller quantities. On the basis of available data, the area that would yield the largest quantities of water of the best quality in the Three Rivers reentrant is in the following tracts: SE$\frac{1}{4}$ sec. 12 and NE$\frac{1}{4}$ sec. 13, T. 11 S., R. 9$\frac{1}{2}$ E., the S$\frac{1}{2}$ sec. 6 and that part of sec. 7, T. 11 S., R. 10 E. north of Indian Creek. The area between well 11.9$\frac{1}{2}$.13.244 and test hole T-7 (11.10.7.234a) appears to be the most promising. In most of the area thus described, carefully constructed and thoroughly developed wells no more than 300 feet deep should yield more than 100 gpm each. In the area of test hole T-7, it should be possible to construct wells that would yield approximately 200 gpm each. If six wells yielding 100 gpm and three wells yielding 200 gpm were constructed and pumped 8 hours daily, the yield of the area would be 0.58 mgd of water containing not more than 500 ppm of sulfate. Spacing of such production wells should be as great as possible, certainly 0.1 mile or more apart, to reduce mutual interference.

Elsewhere in the reentrant, prospects for large, or even moderate, quantities of potable or near potable ground water are not good. The northern part of the reentrant apparently does not contain appreciable thicknesses of alluvium, and data from existing wells imply that the quality of ground water is poor there. The poor quality of ground water south of Indian Creek and west of the Godfrey Hills removes those areas from consideration. Only one other part of the Three Rivers reentrant may be worth consideration as a potential well area--the vicinity of Three Rivers Canyon in sec. 32 and the W½ sec. 33, T. 10 S., R. 10 E. On the basis of the yield of test hole T-1 and the quality of water from and ~~the~~ reported yield of well 10.10.33.131, the area could be developed as a supplemental supply to the potential well field in the lower part of the reentrant. Yields from wells in the upper Three Rivers Canyon area probably would not exceed 100 gpm; however, the quality of the water to be obtained apparently is much better than in the area downstream in the reentrant.

Conclusions

Streams in the Three Rivers area flow in response to precipitation from thunderstorms and as a result of snowmelt on Sierra Blanca. The streams in Three Rivers Canyon and Indian Creek are perennial in their upper reaches. During the 2½ years of observation on the two streams, Indian Creek yielded about 60 percent more water than the stream in Three Rivers Canyon. Both streams at times are dry, or nearly so, and both occasionally flood. Storage reservoirs would be necessary to make full use of the surface water. The average yield of surface water from the Three Rivers drainage basin is estimated conservatively to be about 1,700 acre-feet per year. Yields during years of above-normal precipitation could be as much as 3,500 acre-feet, or more. Surface water in the Three Rivers area generally is of good chemical quality, especially the water of upper Three Rivers Canyon and upper Indian Creek. In both streams, the sulfate content is usually about 100 ppm, or less.

The Three Rivers area contains both sedimentary and igneous rocks that have been complexly faulted and intruded. Of these rocks, only the alluvium of Quaternary age and sandstones of the Cub Mountain Formation of Bodine (1956) and the Mesaverde Group can supply appreciable quantities of water to wells.

The aquifers are recharged by precipitation in the area and by streamflow from the flanks of Sierra Blanca, east of the area. Most ground water is discharged westward out of the area. Of the approximately 150 square miles investigated, only 5 to 7 square miles is underlain by ground water containing less than 500 ppm of sulfate, the constituent by which the potability of the water can be judged. Even within this smaller area, most ground water contains more dissolved solids than is generally considered acceptable for domestic use. Such ground water would have to be mixed with water of better chemical quality to produce an acceptable sulfate concentration.

A minimum of 0.5 mgd of ground water, or about 560 acre-feet per year based on an 8-hour pumping day, probably could be pumped from the most favorable area in the Three Rivers reentrant.

The total supply of water in the Three Rivers area that is suitable for supplying domestic needs in Alamogordo and Holloman Air Force Base, water containing 200 ppm or less, of sulfate, is estimated to average approximately 2,300 acre-feet per year.

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Table 10.--U.S. Geological Survey Sample logs of test holes in the Three Rivers area,

Otero and Lincoln Counties, N. Mex.

Test hole T-1 (10.10.32.334)

Material	Thickness (feet)	Depth (feet)
~~Quaternary~~ alluvium:		
Sand and gravel	15	15
Sand, gravel, and boulders	2	17
Clay, blue, with sand and gravel	13	30
~~Tertiary(?)~~ Cub Mountain formation of Bodine (1956):		
Clay, red	20	50
Clay, red, and some sand	30	80
Clay, red	10	90
~~Cretaceous~~ Mesaverde group:		
Sandstone, gray	10	100
Shale, sandy, gray	5	105
Shale, gray	5	110
Shale, sandy, gray	5	115
Sandstone, gray, and gray shale	10	125
Sandstone, gray, fine- to medium-grained, poorly cemented; water	10	135
Sandstone, gray, hard, and gray shale	5	140
Shale, gray	5	145
Shale, reddish-brown	20	165
Shale, gray	5	170

Table 10.--U.S. Geological Survey Sample logs ~~of test holes~~ - Continued

Test hole T-1 (10.10.32.334) - Continued

Material	Thickness (feet)	Depth (feet)
~~Cretaceous,~~ Mesaverde Group - Continued		
Sandstone, very fine- to medium-grained, yellow, gray, and brown, slightly calcareous, slightly pyritic; probably more water	25	195
Shale, blue-gray, calcareous	5	200
Sandstone, fine- to medium-grained, yellow-brown, calcareous and gray quartzitic shale	10	210
Shale, silty and sandy, brown, very calcareous	5	215
Quartzite, and sandstone, very fine- to medium-grained, calcareous, ferruginous, much silt and clay	5	220
Limestone, blue-gray (may be chert), and some calcite and pyrite	13	233
Shale, blue and gray	2	235
Shale, gray	10	245
Shale, sandy, gray	10	255
Sandstone, very fine- to fine-grained, very silty	10	265
No sample	5	270

Table 10.--U.S. Geological Survey sample logs ~~of test holes~~ - Continued

Test hole T-1 (10.10.32.334) - Continued

Material	Thickness (feet)	Depth (feet)
~~Cretaceous/~~Mesaverde Group - Continued		
Sand, fine- to medium-grained, very slightly calcareous	12	282
Sand and silt, some blue-gray clay	13	295
Sand, very fine- to medium-grained, light gray, subangular to subrounded	5	300

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-2 (11.10.6.333)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Silt, clay and sand	5	5
Sand, silt, and gravel ~~, with some clay~~	15	20
Sand, silt, gravel, and boulders ~~, with some clay~~	15	35
Gravel, clay, silt, and sand, slightly calcareous; water encountered at about 45 feet, reportedly 15 gpm	15	50
Silt, sand, and gravel	5	55
Silt, sand, gravel, few ~~some~~ cobbles, and little ~~some~~ clay	15	70
Sand, gravel, silt, and clay	5	75
Sand, gravel, and clay	25	100
No sample (reported--sand, gravel, and clay)	5	105
Mesaverde Group:		
Clay, very sandy, partly ~~with some~~ silty, gray, moderately calcareous, ~~some~~ pyrite	15	120
Sand, very fine- to medium-grained, gray, silt and clay, very slightly to moderately calcareous, ~~Some~~ pyrite and limonite	35	155
No sample	5	160
Sandstone, poorly sorted, gray, slightly calcareous	15	175

Table 10.--U.S. Geological Survey Sample logs ~~of test holes~~ - Continued

Test hole T-2 (11.10.6.333) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Shale, gray, and very poorly sorted sand ----	5	180
Clay, very sandy, gray, gravel and cobbles reported ----------------------------------	21	201
Clay, very sandy, blue-gray, slightly calcareous --------------------------------	24	225
Sandstone, poorly sorted, moderately calcareous, and dark gray shale ------------	15	240
Shale, dark gray; and light gray, calcareous, very sandy clay -------------------------	25	265
Clay, sandy, gray; and shale, dark gray, calcareous --------------------------------	5	270
Shale, slightly sandy, dark gray, calcareous	15	285
Clay, moderately sandy, gray; and shale, dark gray, calcareous -----------------------	5	290
Samples missing ----------------------------	10	300

U.S. Geological Survey

Table 10.---Sample logs ~~of test holes~~ - Continued

Test hole T-3 (11.10.6.433)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Gravel, very fine- to medium-grained, sand, and calcareous clay ----------------------	30	30
Gravel, fine-grained, sand, and clay, brown, very slightly calcareous ~~clay~~ ----------------	5	35
Gravel, fine-grained, sand, and slightly to moderately calcareous clay ---------------	20	55
Gravel, fine sand, and very slightly calcareous clay; water reported at 58 feet	5	60
Gravel, fine- to coarse-grained, sand, and very slightly calcareous clay ------------	25	85
Mesaverde Group:		
Clay, sandy, reddish-brown, moderately calcareous, coarse material probably caved from above --------------------------------	15	100
Sandstone, gray, silt and clay, slightly to very calcareous -------------------------	10	110
Sandstone, brownish-gray, very poorly sorted, much silt and clay, very slightly calcareous --------------------------------	15	125
Clay, very sandy, yellow, black, and gray ---	10	135

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-3 (11.10.6.433) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Sandstone, very fine- to medium-grained, gray, and much clay, slightly calcareous, --	15	150
Sandstone, very fine- to medium-grained, gray, moderately calcareous, ~~some~~ clay, gray, and shale, black ------------------------------	15	165
Clay, sandy, reddish-brown and gray, very slightly to moderately calcareous, ~~sandy~~ -----------	5	170
Sandstone, very fine- to medium-grained, brownish-gray, moderately calcareous, clay, and trace of pyrite -----------------------	45	215
Shale, light gray and dark gray, very slightly calcareous, and very little sand ~~with a slight amount of sand~~ ------------------------------------	5	220
Clay (or shale) silty and sandy, gray, moderately calcareous ---------------------	20	240
Shale, dark gray, non-calcareous; medium gray clay, very calcareous; very silty, slightly calcareous sandstone near top ----	45	2~~4~~85
~~Shale, dark gray, non-calcareous, medium gray, very calcareous, silty, clay --------------~~	~~40~~	~~285~~

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-3 (11.10.6.433) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Clay, slightly sandy, medium gray, slightly calcareous, and sandstone ------------------	5	290
Sandstone, very fine- to coarse-grained, some silt and clay, slightly to moderately calcareous --------------------------------	10	300

Table 10.--U.S. Geological Survey ~~S~~ample logs ~~of test holes~~ - Continued

Test hole T-4 (11.10.8.311)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Clay, very sandy, brownish-gray, calcareous	5	5
Sand and gravel, with clay and silt; water encountered between 40-45 feet	40	45
Sand, very fine- to very coarse-grained, much silt and clay	5	50
No sample	5	55
Sand, very fine- to coarse-grained, silty, some clay	5	60
Cub Mountain formation of Bodine (1956):		
Clay, silty, light blue-gray, slightly calcareous	5	65
Shale, dark gray, slightly calcareous	5	70
Sandstone, very fine- to coarse-grained, very silty and clayey ~~much clay~~, moderately calcareous	35	105
Sandstone, silty, with little ~~some~~ clay	15	120
Clay, very silty, maroonish-gray, micaceous, slightly calcareous	5	125
Sandstone, very fine- to coarse-grained~~,~~; partly siliceous; much clay and silt; ~~some quartzite, and some~~ medium-gray shale	20	145

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-4 (11.10.8.311) - Continued

Material	Thickness (feet)	Depth (feet)
Cub Mountain formation of Bodine (1956) - Continued		
Clay, silty and sandy, light gray, some dark gray shale, moderately calcareous ---------	35	180
Sandstone, very fine- to medium-grained, very silty, some clay, moderately calcareous ---	10	190
Sand, very fine- to fine-grained, much silt and clay, slightly calcareous; some dark gray shale; very small amount of coal ----------	30	220
Clay, sandy, light greenish-gray, very slightly calcareous ----------------------	5	225
Sand, very fine- to coarse-grained, moderate amount of silt and clay, not calcareous ---	5	230
Clay and shale, sandy and silty gray, brown and red ----------------------------------	70	300

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-5 (11.10.5.332)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Sand, gravel, silt and clay, slightly to very calcareous	130	130
Cub Mountain formation of Bodine (1956):		
Clay, very sandy, gray and reddish-brown, moderately calcareous	10	140
Gravel, very fine- to coarse-grained, sandy, very clayey, ~~with much clay~~, reddish-brown and gray, slightly calcareous	5	145
Clay, sandy, reddish-brown and gray, very slightly calcareous	40	185
Clay, very sandy and silty, gray and brownish-red, micaceous, slightly calcareous	15	200
Shale, sandy, dark gray, moderately calcareous	10	210
Clay, brownish-red and gray, sandy, silty, slightly calcareous	15	225
Clay, sandy, medium gray, moderately calcareous; shale, dark gray	5	230
Shale, dark gray, not calcareous; and reddish-brown clay, very calcareous, sandy,	25	255

Table 10.--U.S. Geological Survey Sample logs ~~of test holes~~ - Continued

Test hole T-5 (11.10.5.332) - Continued

Material	Thickness (feet)	Depth (feet)
Cub Mountain formation of Bodine (1956) - Continued		
Sandstone, fine- to medium-grained, light greenish-gray and gray, some hematite, slightly calcareous	5	260
Clay, sandy, marly, gray and reddish-brown; dark gray, not calcareous shale	35	295
Sandstone, very fine- to coarse-grained, white, not calcareous; brownish-red clay	5	300

Table 10.--U.S. Geological Survey sample logs ~~of test holes~~ - Continued

Test hole T-6 (11.9½.13.234)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Sand, very fine- to very coarse-grained; very calcareous silt and clay -------------	20	20
Gravel, very fine- to fine-grained, very fine- to very coarse-grained sand, silt, and clay -----------------------------------	10	30
Gravel, very fine- to medium-grained, ~~some~~ sand, and silt -----------------------------	20	50
Sand, very fine- to coarse-grained, silty, moderate amount of clay, very calcareous --	10	60
Gravel, very fine- to medium-grained, with coarse sand and a ~~slight~~ small amount of clay ---	15	75
~~Tertiary~~ Intrusive or extrusive rock:		
Crystalline rock, partly granitic, partly basaltic, possible flow material ----------	160	235
Crystalline rock, granitoid, and cream-colored clay ---------------------------------	20	255
Cub Mountain Formation of Bodine (1956):		
Clay, reddish-gray and green, with small amounts of calcite, quartz, pyrite, and igneous rock ------------------------------	20	275
Shale, silty, light green, waxey, calcareous, with ~~some~~ little pyrite, and red shale ------------	10	285
Clay, slightly silty, red -------------------	15	300

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-8 (11.9½.23.124)

Material	Thickness (feet)	Depth (feet)
Alluvium: ~~Quaternary:~~		
Soil, silty, tan to brown --------------------	5	5
Silt, brown to tan --------------------------	25	30
Silt, brown to tan, with ~~some~~ gravel --------	5	35
Silt, brown, with ~~some~~ very coarse-grained sand and fine-grained gravel, contains black igneous particles ------------------------	10	45
Sand, fine- to coarse-grained, and small subangular gravel --------------------------	10	55
Mesaverde group:		
Sand, greenish-gray, fine- to coarse-grained, with some subangular to well-rounded gravel; fragment of selenite, and some flakes of "vein filling" -------------------------	10	65
Shale, very dark greenish-~~black~~ gray, with minute calcareous veinlets ---------------------------------	5	70
Silt, gray; very uniform grain-size ---------	5	75
Silt, gray, slightly sandy, -----------------	10	85
Silt, slightly sandy, brownish gray ~~gray, slightly brown and sandy~~ --------	10	95
Silt, gray, with small angular black fragments (fissile shale?), fragment of calcite at 100-105, black fragments abundant at 125-130 feet; -----------------	40	135

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-8 (11.9½.23.124) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Shale, greenish-yellow-gray, with black fragments	5	140
Silt, sandy, gray to tan	5	145
Sand, very fine- to fine-grained, subangular to rounded; some black fragments	10	155
Silt, sandy gray	5	160
Rock, igneous, red ground mass, probably a contact zone; much calcite and mafic minerals.	5	165
Silt, dark gray, with numerous fragments of sulfate "vein filling." Some black fragments, abundant 180-190. Sandy below 175 feet	25	190
Silt, very sandy, tan, with many fragments of igneous(?) black to light gray rock. Some pyrite(?)	5	195
Sand, silty, brown, with many black fragments	5	200

Table 10.--U.S. Geological Survey sample logs ~~of test holes~~ - Continued

Test hole T-8 (11.9½.23.124) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Sand, silty, greenish-gray, with many black fragments; considerable calcite 210-215 feet, 225-230 feet and 245-255 feet; some igneous fragments 225-230 feet, and contact metamorphic minerals 245-250 feet	~~55~~ 60	260
Sand, silty, very pale brownish ~~tan~~-gray, with many black fragments	5	265
Silt, sandy, brown, subangular to rounded, with considerable calcite	15	280
Silt, sandy, gray, with black fragments	5	285
Silt, dark gray, with considerable fine black gravel	15	300
Silt, dark gray, with ~~some~~ black very coarse-grained sand	10	310
Silt, very pale brownish ~~tan~~-gray, with ~~some medium (5 mm)~~ angular fragments of black rock (5 mm ±) ~~Silt mainly is gray 320-325 feet~~	20	330

U.S. Geological Survey

Table 10.--Sample logs ~~of test holes~~ - Continued

Test hole T-8 (11.9½.23.124) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Silt, ~~very pale brownish~~ ~~tan~~-gray, with large angular fragments of black and red igneous rock; much calcite as coatings and "vein filling" ----	5	335
Sand, silty, dark gray to tan, with large angular fragments of porphyry, gray groundmass and black euhedral inclusions --------	5	340
Silt, gray ----------------------------------	5	345
Silt, gray, with very fine-grained black fragments; much calcite as "vein filling" and cement from 375-380 feet --------------	35	380
Sand, silty, gray to black, with considerable calcite fragments ------------------------	10	390
Silt, sandy, greenish-gray, with many small black fragments, some angular -------------	10	400
Sand, fine-grained, silty, gray ------------	5	405
Sample missing -----------------------------	10	415
Silt, sandy, gray, with fine-grained, black fragments, some angular -------------------	5	420
Silt, sandy, tan ---------------------------	10	430
Silt, sandy, gray --------------------------	5	435

Table 10.--U.S. Geological Survey sample logs ~~of test holes~~ - Continued

Test hole T-8 ($11.9\frac{1}{2}.23.124$) - Continued

Material	Thickness (feet)	Depth (feet)
Mesaverde group - Continued		
Basalt, or similar igneous rock, black, with much calcite	10	445
Silt, tan-gray, with fine-grained black fragments	5	450
Silt, tan-gray, with black fragments, ~~Some~~ clay, ~~content,~~ sample set hard, ~~Somewhat~~ tan ~~colored~~ 465-470 feet,	25	475
Silt, sandy, tan, with black fragments, ~~Somewhat~~ gray 490-495 feet,	20	495
Silt, sandy, gray, with black fragments	5	500

Table 11.--Driller's logs of test holes in the Three Rivers area,

Otero and Lincoln Counties, N. Mex.

Test hole T-1 (10.10.32.334)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil	5	5	30
Gravel and boulders	5	10	90
Sand, gravel, and boulders	5	15	60
Sand, gravel, and boulders. Very slow drilling	2	17	60
Clay, blue, sand, and gravel. Water at 17 feet. 5 gpm	3	20	120
Clay, blue, sand, and gravel	5	25	120
Clay, blue, sand, and gravel	3	28	120
Clay, blue, sand, and gravel	2	30	120
Clay, red, sand, and gravel	15	45	360
Clay, red, sand, and gravel. Hole caved in to 26 feet (between work days)	3	48	60
Clay, red, and sand. Cleaned out hole (of caved material)	12	60	660
Clay, red. Lowered 12-inch casing to shut off water and caving formation	15	75	360
Clay, red	15	90	360
Sandstone, gray	10	100	240

Table 11.--Driller's logs of test holes - Continued

Test hole T-1 (10.10.32.334) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Shale, gray sandy. Solid formation; no caving	5	105	120
Shale, gray	5	110	60
Shale, gray, sandy	5	115	60
Sandstone, gray	10	125	120
Sand, gray. Bailer test. Water	10	135	105
Sandstone, gray	5	140	50
Shale, gray	5	145	45
Shale, brown. Built up bit. Slow drilling, sticking	10	155	135
Shale, red	10	165	100
Shale, gray	5	170	50
Sandstone, yellow. More water	5	175	100
Sandstone, brown. Stuck tools at 180 feet	5	180	155
Sandstone, brown. Very hard. Built up bit	10	190	585
Sandstone, blue. Very hard drilling	5	195	180
Shale, blue. Softer, with gas showing	5	200	180
Sandstone, yellow	5	205	180
Shale, blue, and sandstone. Built up bit	5	210	195

Table 11.--Driller's logs of test holes - Continued

Test hole T-1 (10.10.32.334) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Shale, brown ----------------------------	5	215	180
Shale, brown, and sandstone ------------	5	220	180
Lime, blue. Hard drilling -------------	5	225	150
Lime, blue. Built up bit --------------	4	229	300
Lime(?), blue. Very hard --------------	1	230	180
Limestone, blue and gray. Softer ------	5	235	210
Shale, blue gray -----------------------	5	240	210
Shale, gray ----------------------------	5	245	90
Shale, gray, sandy. Built up bit -------	5	250	90
Shale, gray, sandy ---------------------	5	255	150
Shale, gray, sandy ---------------------	5	260	75
Sandstone, gray. Built up bit ---------	10	270	230
Sandstone, gray. Built up bit ---------	15	285	185
Sandstone and blue shale ---------------	5	290	130
Shale, blue ----------------------------	5	295	65
Sandstone, gray ------------------------	5	300	100

Table 11.--Driller's logs of test holes - Continued

Test hole T-2 (11.10.6.333)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil, sandy	5	5	35
Sand and gravel	10	15	60
Gravel and boulders	10	25	80
Sand and gravel. Water at about 40 feet. About 15 gpm. More water at 50 feet	30	55	135
Sand and gravel, with clay. Water level 37 feet	20	75	100
Sand and gravel. Water level 37 feet	20	95	140
Sand, gravel, and clay	10	105	95
Shale, blue	15	120	305
Sandstone, gray	5	125	50
Sandstone, gray	5	130	60
Sandstone, gray	5	135	100
Sandstone, gray	5	140	60
Sandstone, gray	5	145	75
Sandstone, gray. Water level 37 feet	5	150	235
Sandstone, gray	5	155	135
Sandstone, gray, and shale	10	165	195
Clay, blue, and shale	10	175	255
Clay, blue, and gravel	10	185	480
Clay and gravel. Hole caving when 200 feet deep	15	200	190

Table 11.--Driller's logs of test holes - Continued

Test hole T-2 (11.10.6.333) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Clay, blue, and shale ------------------	20	220	290
Sandrock, yellow ----------------------	5	225	75
Sandrock, gray. Water level 37 feet ---	25	250	285
Sandstone, gray, and shale. Water level 37 feet ------------------------------	10	260	140
Shale, blue, and clay -----------------	40	300	485

Table 11.--Driller's logs of test holes - Continued

Test hole T-3 (11.10.6.433)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil, sand, and gravel	10	10	125
Lime rock, boulders	10	20	145
Sand and gravel	5	25	165
Sand and gravel	5	30	80
Sand and gravel; caving	10	40	260
Sand and gravel	10	50	150
Sand and gravel	5	55	125
Sand rock. Water at 58 feet	10	65	95
Sand and gravel, mixed with clay	20	85	235
Clay, red	15(?)	100	130+
Sandstone, gray. Bailer test at 110 feet. Built up bit	15	115	215
Clay, gray and yellow. Built up bit. Water level 44 feet	20	135	205
Sandstone, gray. Slightly harder 150-155. Built up bit	30	165	290
Clay, red	5	170	75
Sandstone, gray	5	175	120
Sandstone, gray	5	180	165
Sandstone, gray	5	185	70
Sandstone, gray	5	190	115

Table 11.--Driller's logs of test holes - Continued

Test hole T-3 (11.10.6.433) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Sandstone, gray. Water level 44 feet --	5	195	140
Shale, blue ----------------------------	5	200	138
Sandstone, blue ------------------------	5	205	75
Sandstone, blue ------------------------	5	210	130
Sandstone, blue. Built up bit ---------	5	215	240
Sand rock and red clay -----------------	5	220	330
Sand rock and red clay -----------------	5	225	40
Sand rock and red clay -----------------	5	230	75
Sand rock and red clay -----------------	5	235	140
Sand rock and red clay -----------------	5	240	70
Clay, red gumbo ------------------------	10	250	160
Clay, red gumbo ------------------------	5	255	140
Sandstone and clay ---------------------	5	260	170
Shale and shale clay -------------------	5	265	260
Shale and shale clay. Very gummy clay. Water level 44 feet ------------------	5	270	340
Shale and shale clay -------------------	5	275	135
Shale and shale clay. Bad mud rings (causing bit to jar). Built up bit --	5	280	180
Shale, clay, and sandstone -------------	5	285	150
Sandstone, gray ------------------------	5	290	110
Sandstone, gray ------------------------	5	295	285
Sandstone, gray. Hard drilling --------	5	300	155

Table 11.--Driller's logs of test holes - Continued

Test hole T-4 (11.10.8.311)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil ----------------------------------	5	5	80
Gravel and small boulders --------------	5	10	80
Sand, yellow, and gravel. Water at 45-60 feet ----------------------------------	40	50	290
Sand, yellow. Water level 34 feet. Cased to 58 feet --------------------	10	60	560
Shale, blue ----------------------------	10	70	200
Sandstone, yellow ----------------------	30	100	270
Sandstone, gray ------------------------	20	120	190
Shale, brown ---------------------------	5	125	35
Shale, blue, hard. Water level 34 feet	15	140	160
Limestone, blue, hard ------------------	10	150	425
Limestone, blue, hard ------------------	5	155	130
Sandstone, gray, hard ------------------	5	160	210
Sandstone, gray ------------------------	5	165	130
Sandstone, gray ------------------------	15	180	170
Sandstone, gray ------------------------	5	185	120
Sandstone, gray ------------------------	5	190	90
Sandstone, gray ------------------------	15	205	415
Sandstone, gray ------------------------	10	215	120
Sandstone, gray. Hard. Water level 34 feet ----------------------------	5	220	180

Table 11.--Driller's logs of test holes - Continued

Test hole T-4 (11.10.8.311) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Sandstone, gray	5	225	125
Shale, blue	5	230	115
Sandstone, gray	10	240	365
Shale, blue. Water level 34 feet	10	250	110
Shale, purple	5	255	45
Shale, purple	15	270	265
Shale, purple	5	275	120
Limestone, gray, very hard	5	280	240
Shale, blue	5	285	230
Limestone, gray	10	295	375
Shale, blue	5	300	25

Table 11.--Driller's logs of test holes - Continued

Test hole T-5 (11.10.5.332)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil	10	10	75
Clay, red, and gravel	20	30	170
Clay, red, and gravel	25	55	405
Clay, red, gravel, and small boulders	20	75	415
Clay, red, sand, and gravel. First water at 82 feet	10	85	150
Clay, light red, and gravel. Possibly more water at 98 feet. Water level approximately 55 feet	20	105	275
Clay, gray sandy, and gravel	5	110	50
Clay, gray sandy, and gravel	10	120	180
Clay, gray sandy, and gravel	15	135	210
Shale, purple	45	180	445
Shale, gray	20	200	155
Shale, gray. Caving, and mud rings	5	205	75
Shale, purple	15	220	195
Shale, brown, hard	20	240	260
Shale, gray, sandy	35	275	420
Shale, brown, hard	25	300	250

Table 11.--Driller's logs of test holes - Continued

Test hole T-6 (11.9½.13.234)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil	5	5	50
Clay and gravel. Seep of water at 26 feet	25	30	365
Sand and gravel	5	35	165
Sand and gravel. Built up bit	10	45	275
Sand and gravel. Ran casing to stop caving. Slow drilling	5	50	280
Sand, gravel, and boulders	10	60	155
Sand, gravel, and boulders	5	65	160
Sand, gravel, and boulders. Reamed hole and ran 12-inch casing	5	70	35
Solid rock. Built up bit	5	75	50
Lime rock. Built up bit	5	80	690
Solid rock. Very hard	10	90	650
Solid rock. Little softer	5	95	150
Solid rock. Built up bit	10	105	300
Solid rock	5	110	140
Solid rock	5	115	65
Solid rock	5	120	120
Solid rock. Water level 16.7 feet	5	125	310
Solid rock	5	130	185
Solid rock	5	135	45

Table 11.--Driller's logs of test holes - Continued

Test hole T-6 (11.9½.13.234) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Solid rock ------------------------------	15	150	240
Solid rock ------------------------------	5	155	180
Solid rock ------------------------------	5	160	230
Solid rock ------------------------------	5	165	90
Solid rock ------------------------------	5	170	140
Solid rock ------------------------------	5	175	75
Solid rock ------------------------------	10	185	290
Solid rock ------------------------------	5	190	440
Solid rock. Built up bit --------------	2	192	650
Solid rock. Water level 16.6 feet -----	3	195	105
Solid rock with a little clay ----------	5	200	90
Solid rock. Changed bits --------------	5	205	130
Solid rock ------------------------------	10	215	175
Solid rock ------------------------------	5	220	120
Solid rock ------------------------------	10	230	140
Stone and clay -------------------------	30	260	425
Shale and clay. Water level 16.7 feet -	40	300	510

Table 11.--Driller's logs of test holes - Continued

Test hole T-7 (11.10.7.234a)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil	5	5	20
Gravel	10	15	50
Gravel and clay	10	25	75
Sand, gravel, and clay. Water at 37 feet	15	40	85
Sand and gravel. Water level 31.5 feet. Ran 50 feet of casing	35	75	425
Sand and clay	10	85	60
Clay	20	105	90
Solid gray rock	20	125	195
Sand and clay	15	140	70
Gypsum	5	145	45
Sand, clay, and gypsum	20	165	95
Sand and clay	15	180	85
Shale, gray, and clay	25	205	225
Conglomerate and clay	20	225	235
Solid gray rock	5	230	120
Shale, red. Ran bailer test	5	235	60
Clay, red, hard. Ran casing	30	265	360
Shale, clay, and sand	5	270	75
Stone, gray, and shale	15	285	230

Table 11.--Driller's logs of test holes - Continued

Test hole T-7 (11.10.7.234a) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Shale, clay, and sandstone, gray -------	10	295	155
Shale, clay, and sandstone, blue -------	10	305	160
Sandstone, blue -----------------------	10	315	120
Shale, clay, and sandstone -------------	5	320	55
Shale and clay ------------------------	15	335	175
Clay and shale, red --------------------	10	345	120
Shale, blue ---------------------------	5	350	50
Sandstone, blue -----------------------	5	355	120
Sandstone, gray. Water level 29.8 feet	25	380	450
Sand, gray. Water ---------------------	5	385	90
Sandstone, gray -----------------------	5	390	90
Sand, gray, and shale ------------------	5	395	70
Shale, gray, and sand ------------------	15	410	250
Shale and clay ------------------------	10	420	140
Granite, green, hard ------------------	5	425	360
Granite, green, hard ------------------	5	430	600
Granite, green, hard ------------------	10	440	600
Sand, gray. Possible water ------------	15	455	360
Sandstone, gray. Water level 28.4 feet	20	475	360
Clay, gray ----------------------------	10	485	120
Shale and clay. Water level 25 feet. Bailer test at 490 feet --------------	15	500	270

Table 11.--Driller's logs of test holes - Continued

Test hole T-8 (11.9½.23.124)

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Soil	5	5	20
Soil and sand	5	10	30
Sand	5	15	40
Sand and gravel. Caving a little at 30 feet. A little water. Water level 42 feet	30	45	235
Sand. Caving at 45 feet	15	60	210
Rock, solid, gray. Slow drilling	5	65	120
Rock, solid, gray	5	70	160
Rock, solid, gray. Water level 29.8 feet	5	75	200
Rock, solid, gray (and red?). Water level 29.8 feet	10	85	210
Rock, solid, red. Water level 29.8 feet	15	100	295
Rock, solid, blue	5	105	180
Rock, solid, blue. Water level 29.8 feet	35	140	540
Rock, solid, blue	5	145	120
Clay, gray. Made mud rings. Water level 29.8 feet	20	165	355

Table 11.--Driller's logs of test holes - Continued

Test hole T-8 (11.9½.23.124) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Clay, gray, and rock. No mud rings ----	5	170	50
Rock, gray ----------------------------	25	195	370
Rock, gray. Water level 29.8 feet -----	35	230	640+
Volcano rock, gray. Water level 29.8 feet. Slow drilling -----------------	5	235	180
Volcano rock, gray --------------------	5	240	90
Volcano rock, gray. Slow drilling ------	10	250	240
Volcano rock, gray(?). Water level 26.3 feet ------------------------------------	20	270	-
Rock and clay. Water level 26.3 feet --	25	295	1,125
Rock and clay ------------------------	10	305	240
Volcano rock --------------------------	5	310	195
Conglomerate --------------------------	5	315	105
Conglomerate --------------------------	45	360	-
Conglomerate. Slow drilling. Water level 25.7 feet ---------------------	10	370	290
Conglomerate --------------------------	5	375	85
Conglomerate. Water level 25.7 feet ---	10	385	95
No record during trouble with lost tools and bailer. Cased hole to 385 feet --	35	420	-

Table 11.--Driller's logs of test holes - Continued

Test hole T-8 (11.9½.23.124) - Continued

Material	Thickness (feet)	Depth (feet)	Drilling time (minutes)
Volcano rock, gray. Water level 25.8 feet	5	425	180
Volcano rock, gray	15	440	300
Rock, red, and clay	15	455	120
Volcano rock, gray	5	460	165
Volcano rock, gray	5	465	270
Volcano rock, gray	5	470	120
Rock	10	480	280
Rock	5	485	30
Rock, red, and clay	5	490	120
Volcano rock, gray. Water level 26.3 feet. Rock very hard	10	500	-

Water Resources of the Three Rivers Area,

Otero and Lincoln Counties, New Mexico

By

James W. Hood and E. H. Herrick

Figures 1-23

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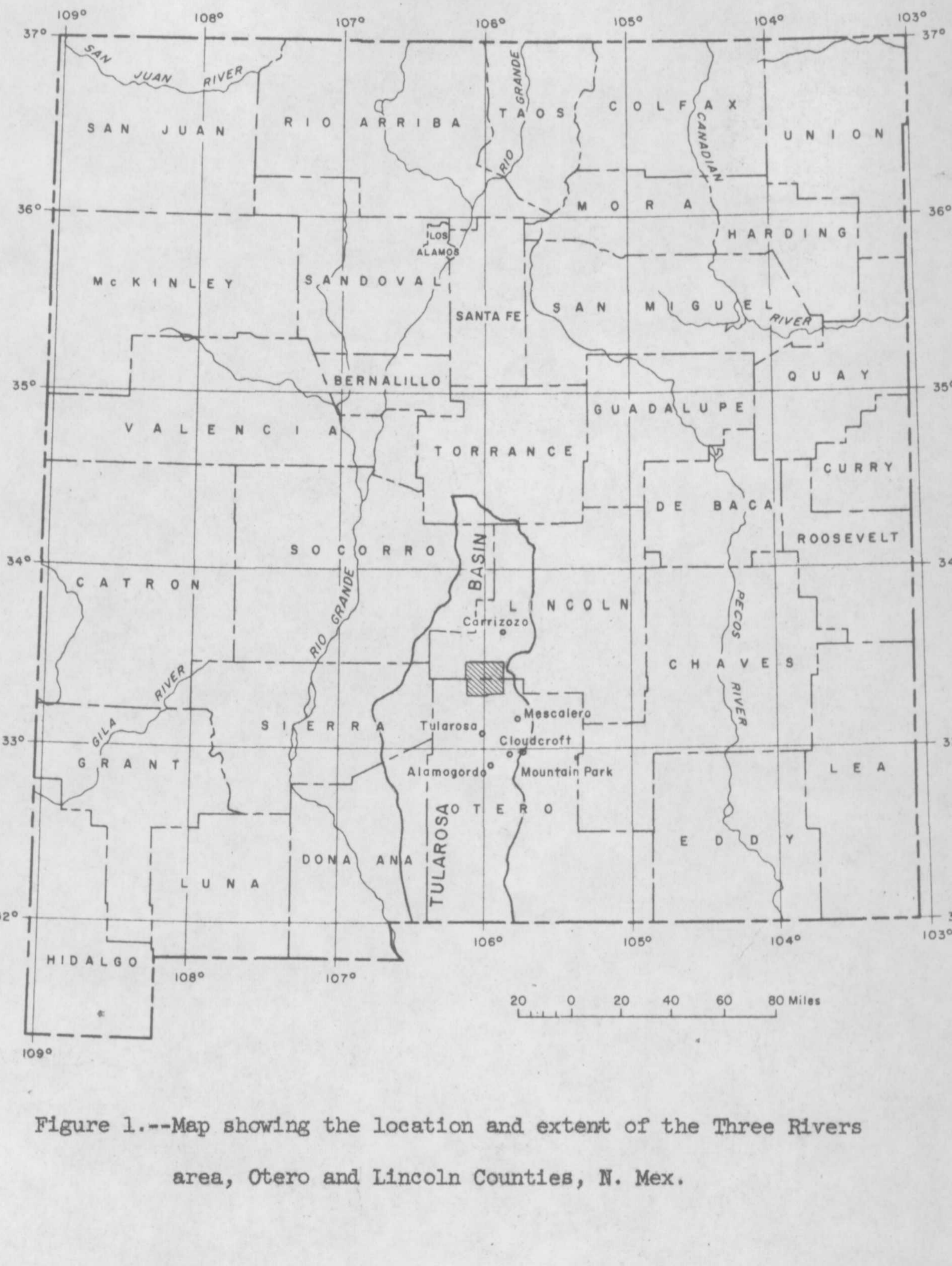

Figure 1.--Map showing the location and extent of the Three Rivers area, Otero and Lincoln Counties, N. Mex.

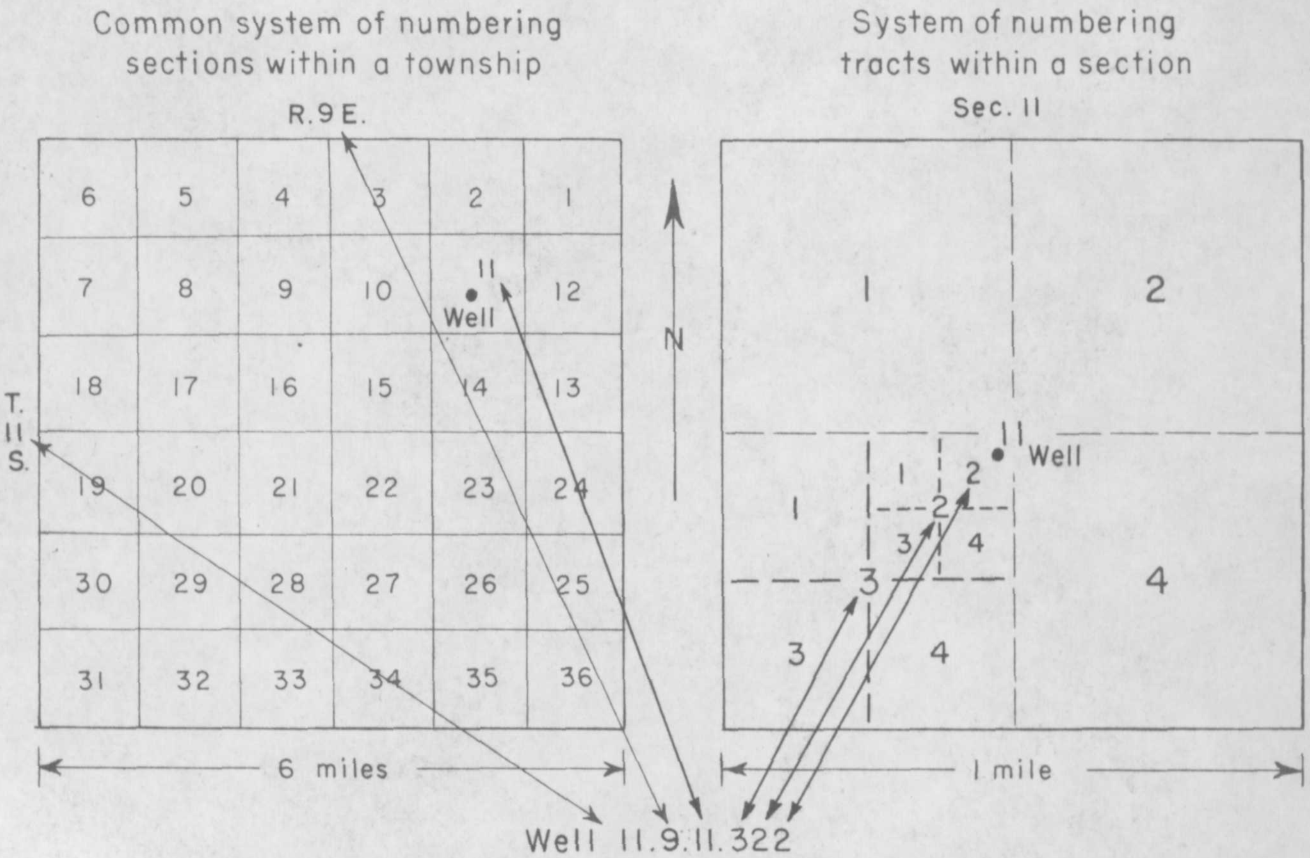

Figure 2. -- System of numbering wells and locations in New Mexico

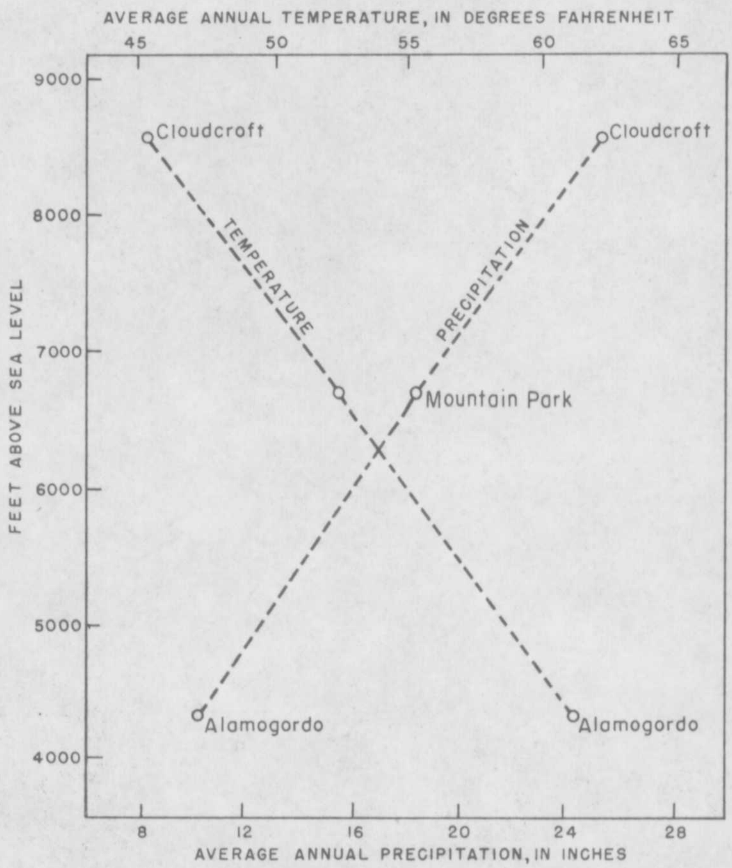

Figure 3.--Graph showing relation of temperature and precipitation to altitude on west side of Sacramento Mountains, Otero and Lincoln Counties, N. Mex.

62-63

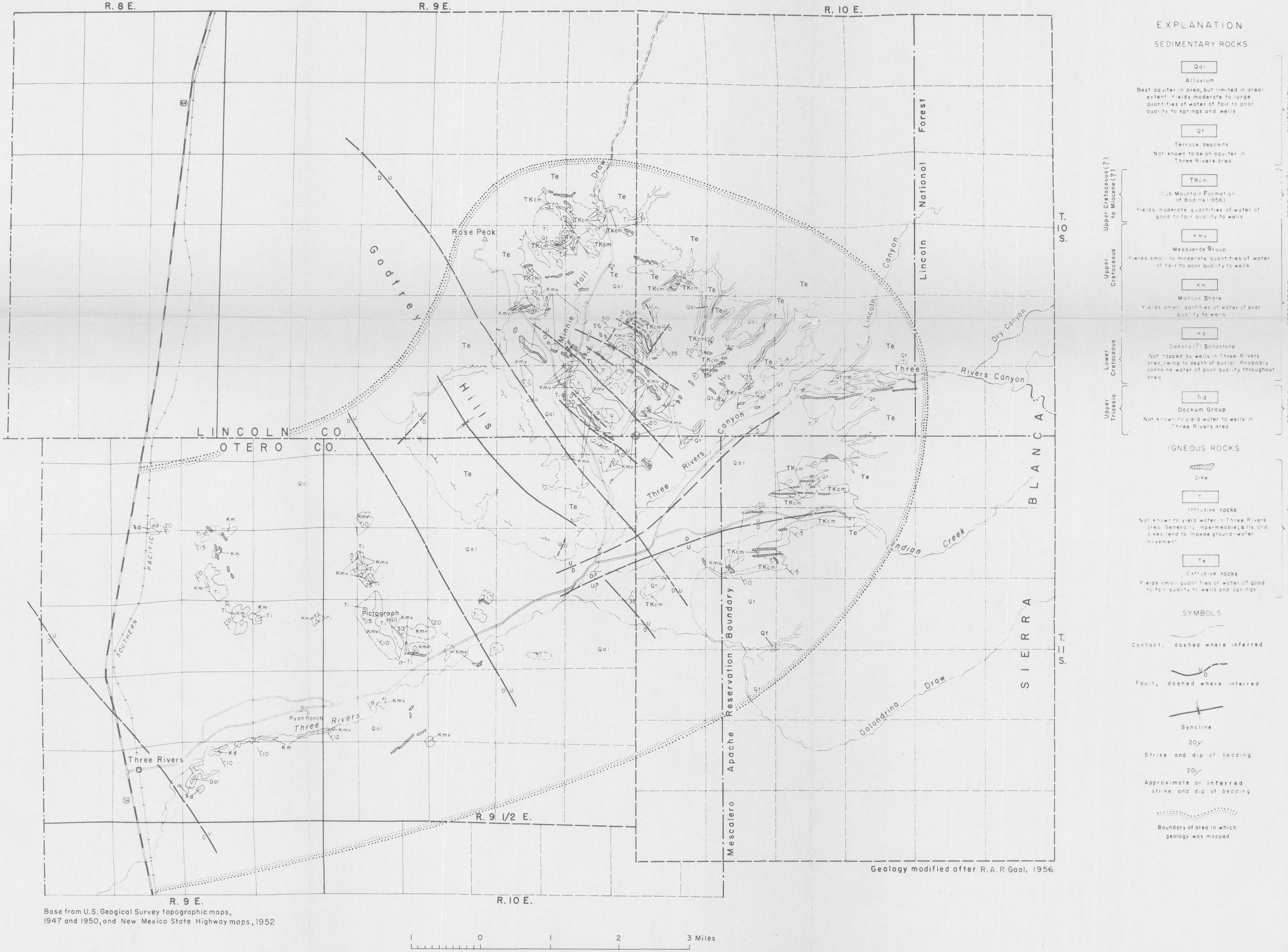

Figure 4.--Geology of the Three Rivers Area, Otero and Lincoln Counties, N. Mex.

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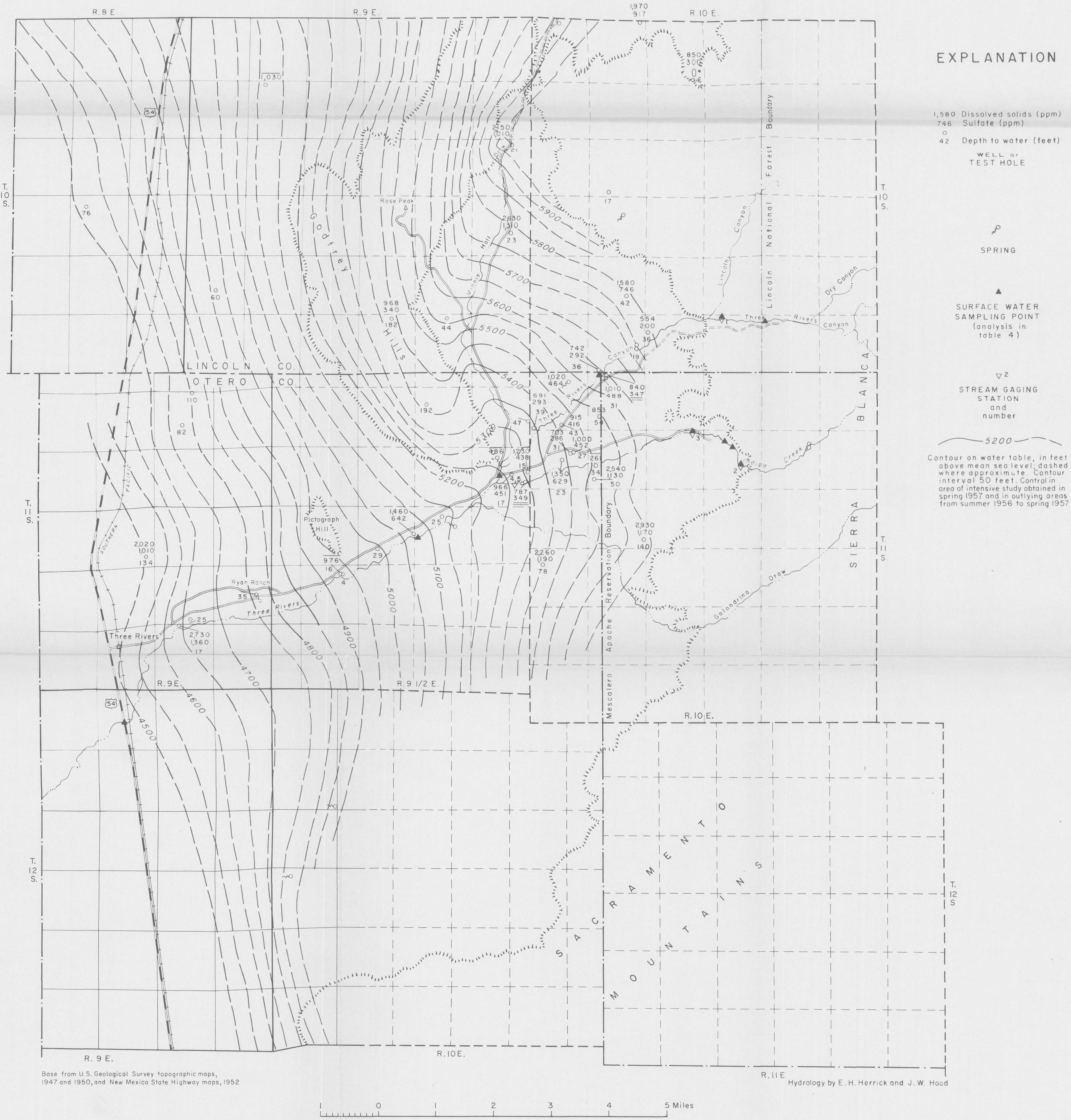

Figure. 5--Water-level contours and quality of water in the Three Rivers area, Otero and Lincoln Counties, N. Mex.

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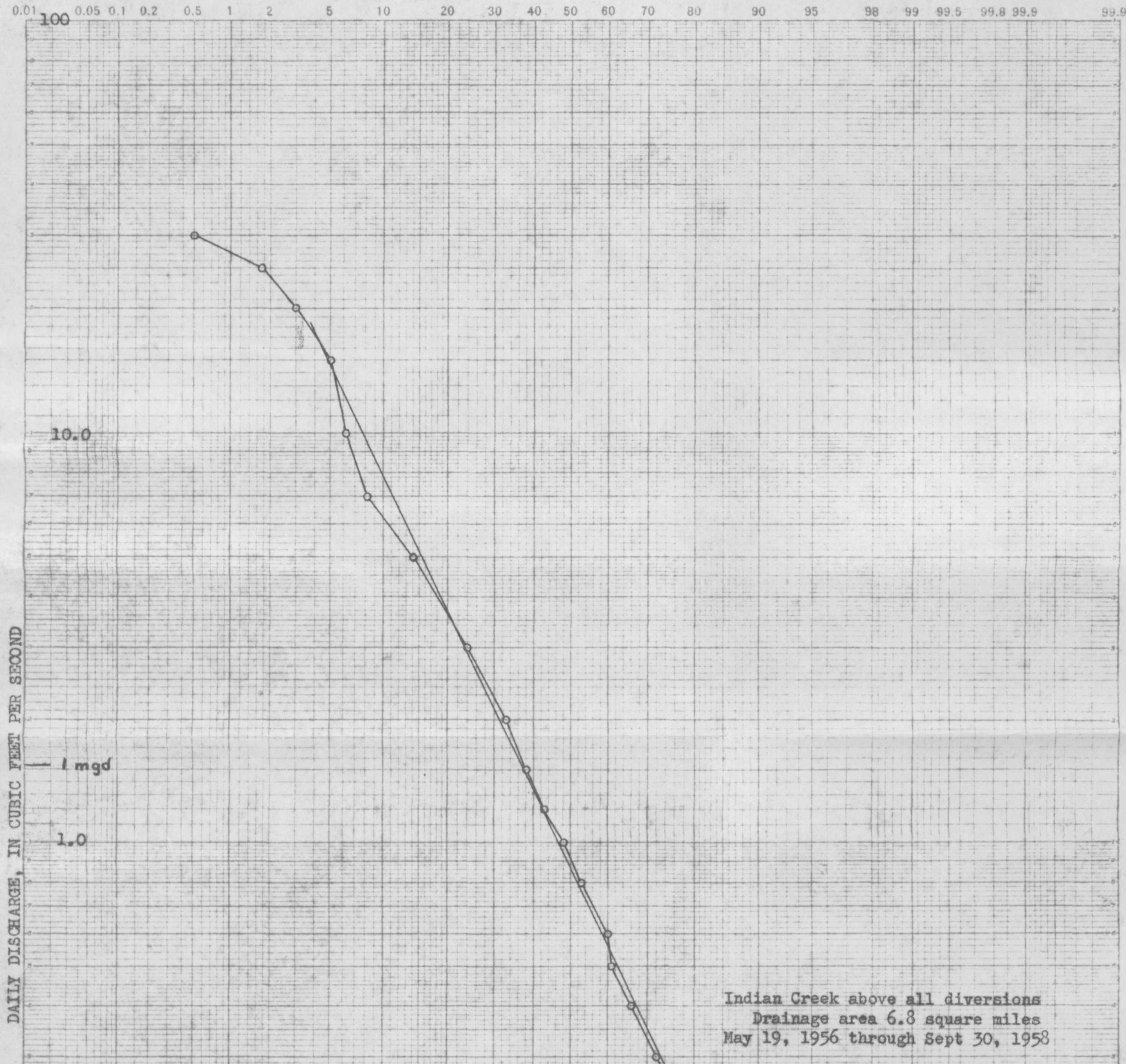

Figure 6.--Duration curve of daily flows, Indian Creek (sec. 10, T. 11 S., R. 10 E.) near Three Rivers, N. Mex.

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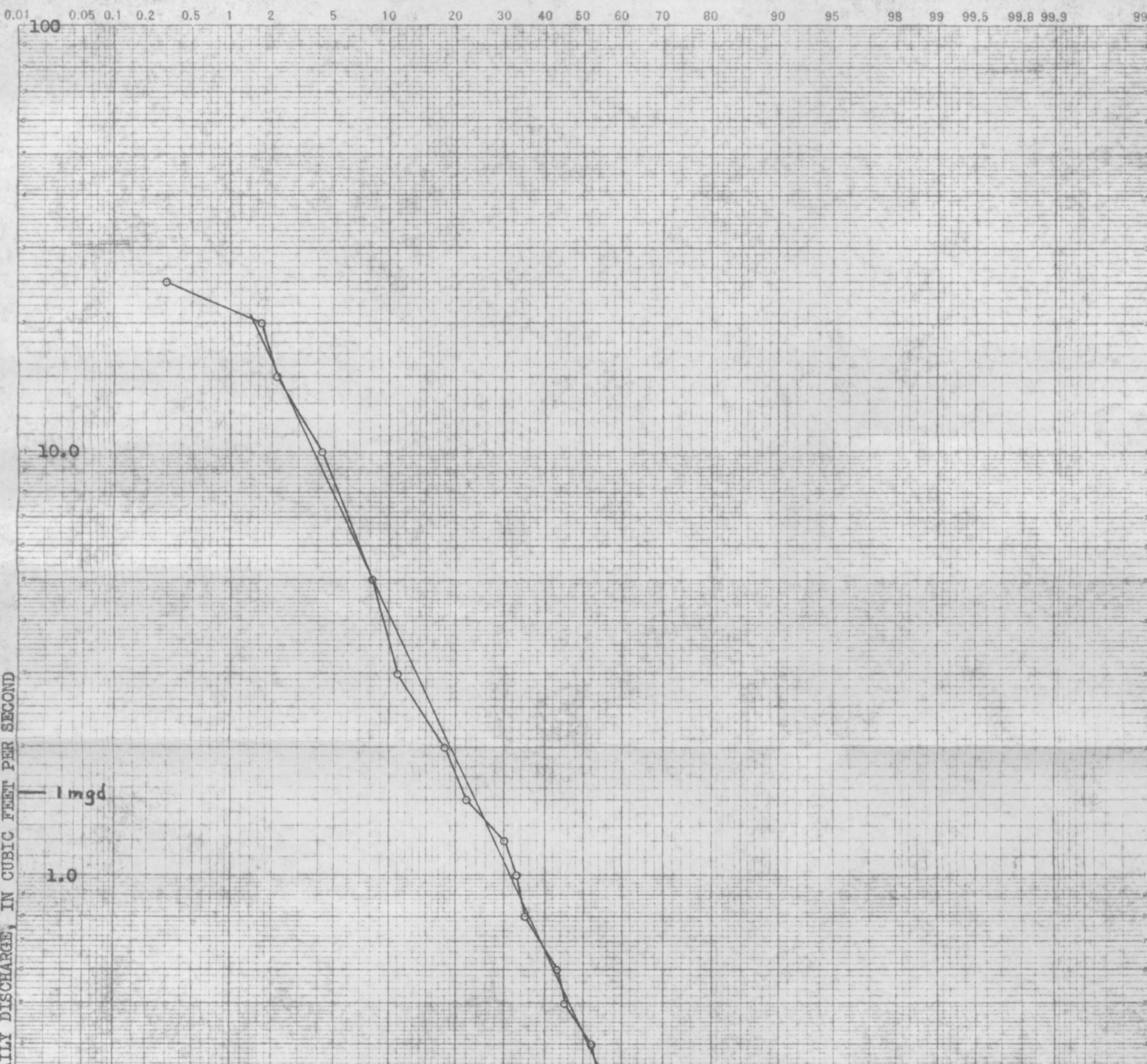

Figure 7.--Duration curve of daily flows, Three Rivers Canyon above Lincoln Canyon, near Three Rivers, N. Mex.

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Duration curve of

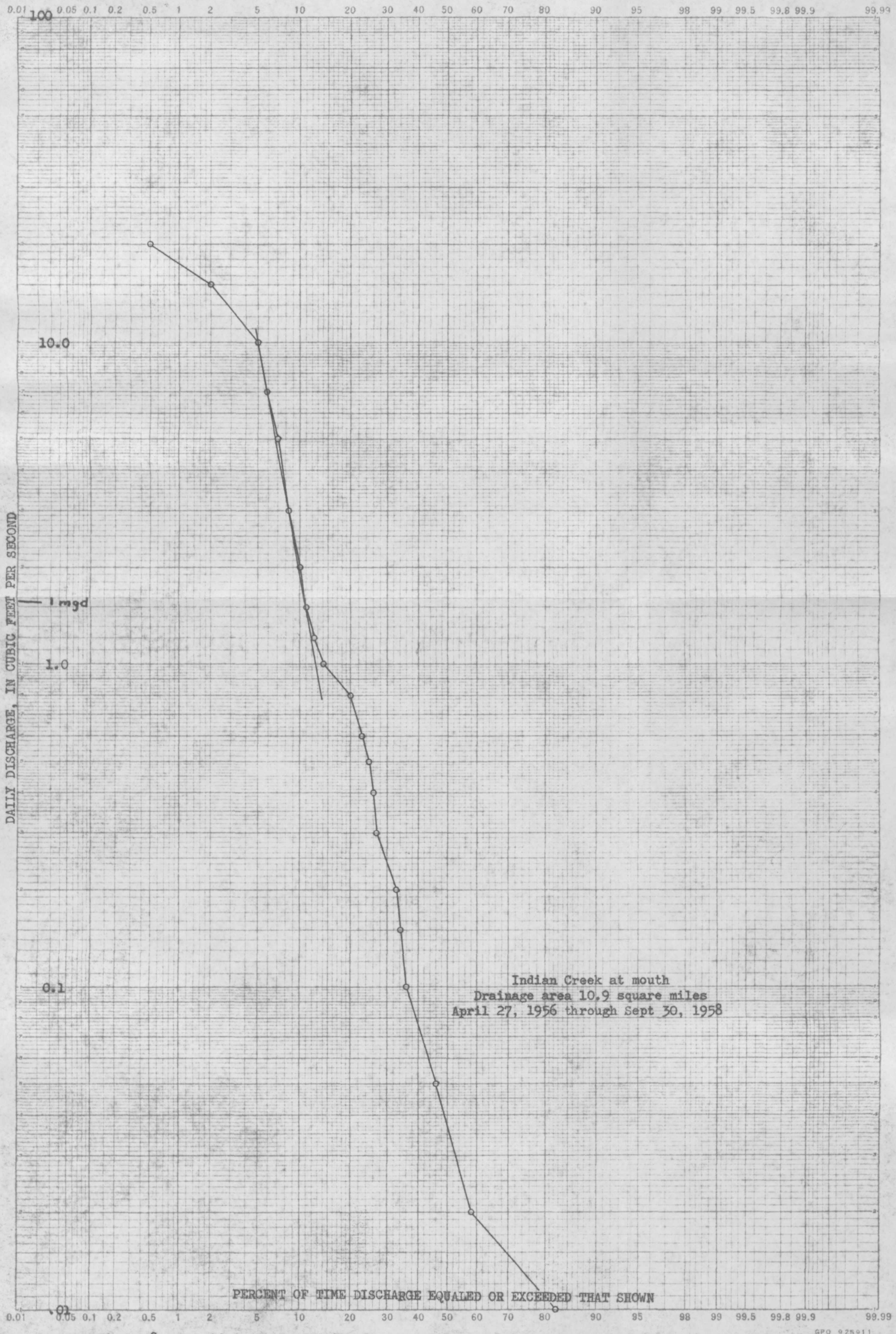

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Figure 8.--Duration curve of daily flows, Indian Creek at mouth, near Three Rivers, N. Mex.

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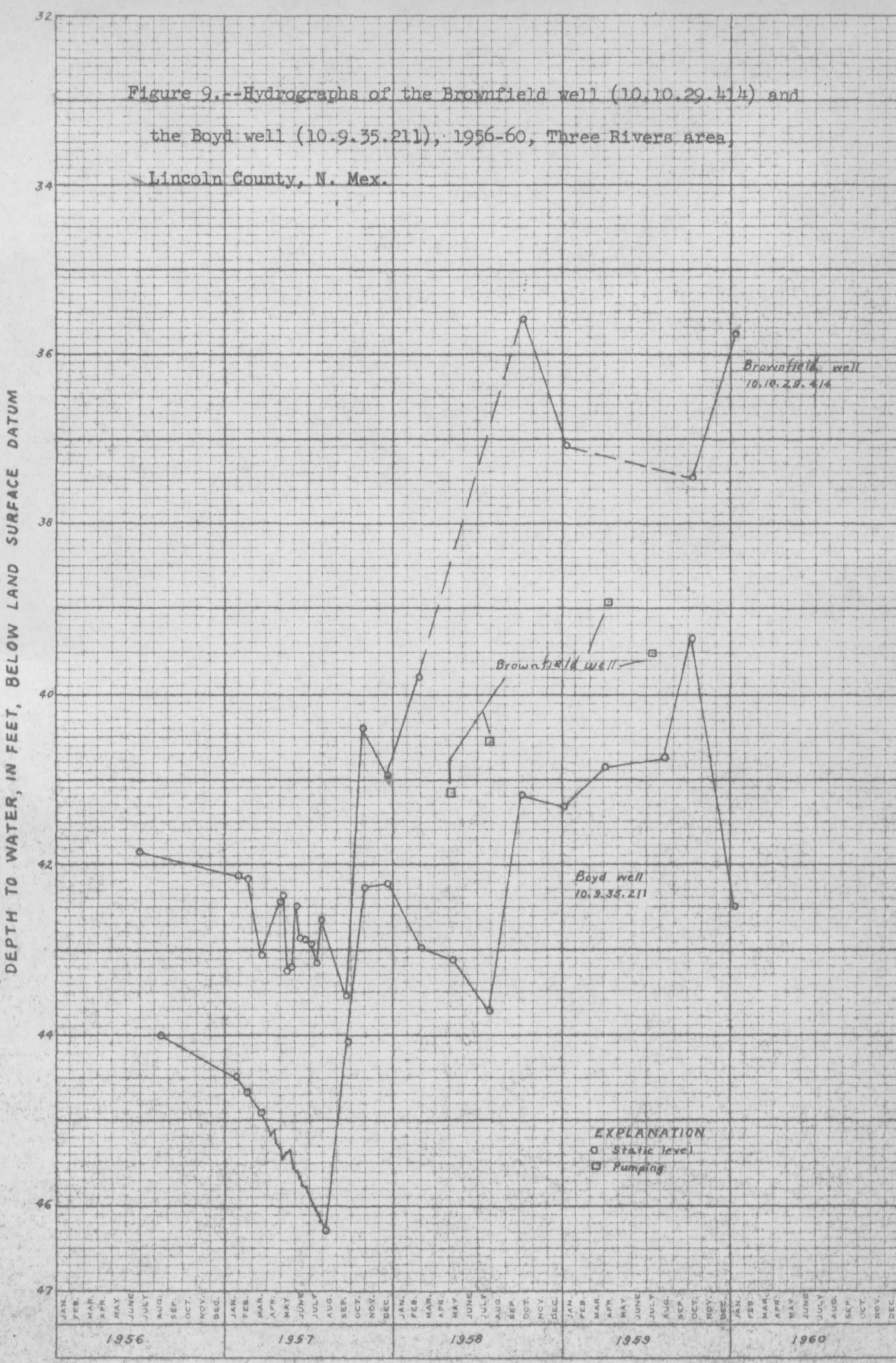
Figure 9.--Hydrographs of the Brownfield well (10.10.29.414) and the Boyd well (10.9.35.211), 1956-60, Three Rivers area, Lincoln County, N. Mex.



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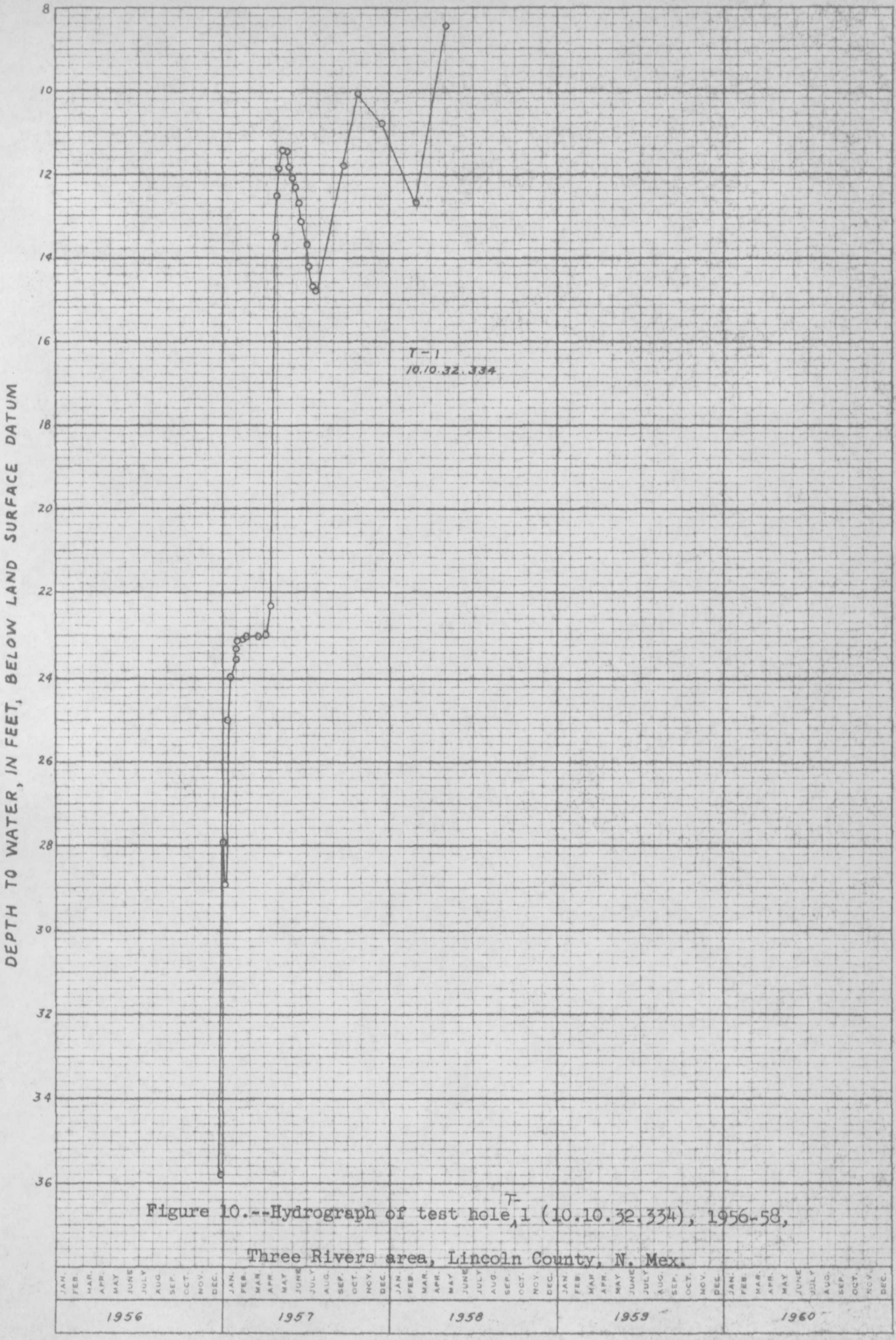

Figure 10.--Hydrograph of test hole T-1 (10.10.32.334), 1956-58,

Three Rivers area, Lincoln County, N. Mex.

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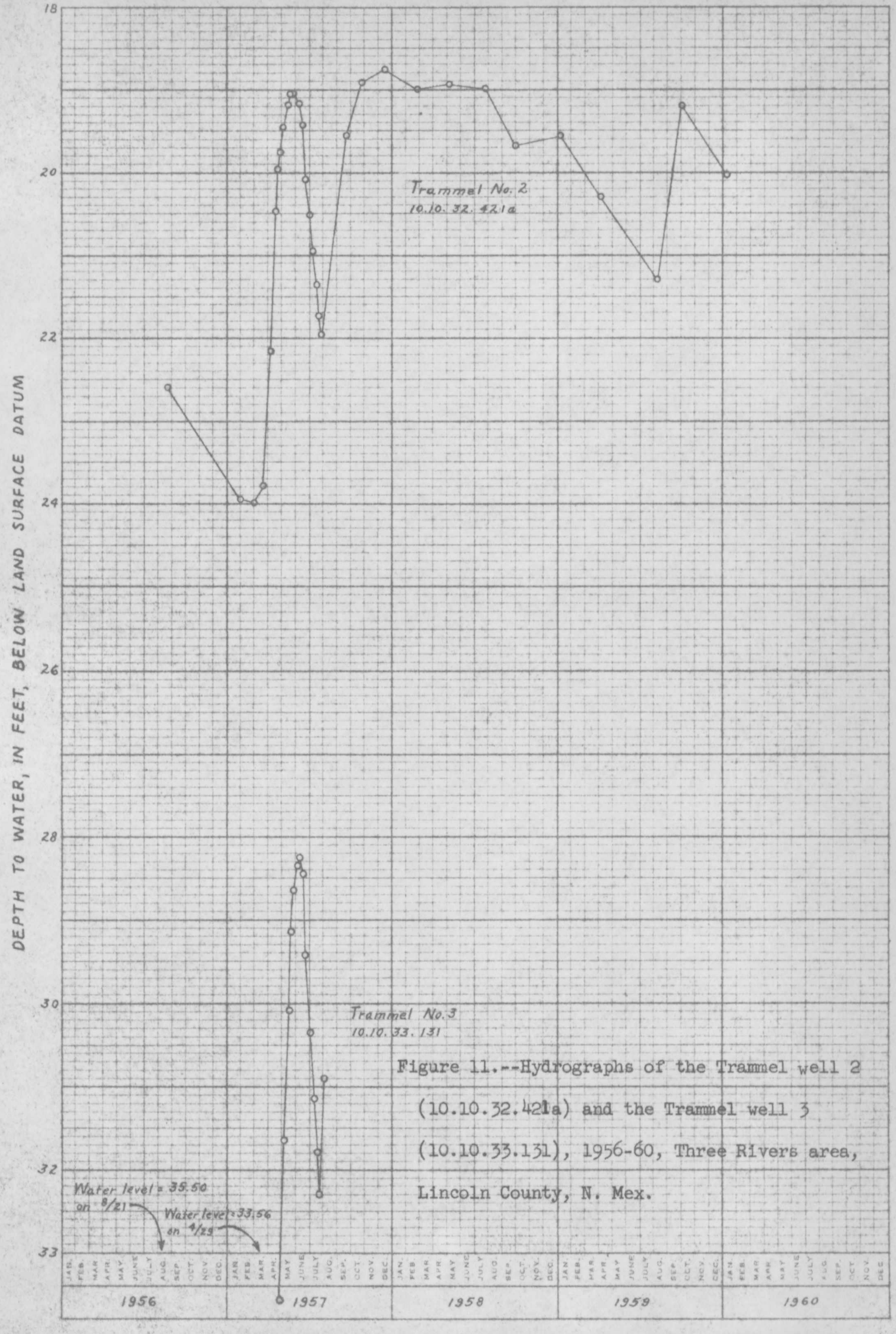

Figure 11.--Hydrographs of the Trammel well 2 (10.10.32.421a) and the Trammel well 3 (10.10.33.131), 1956-60, Three Rivers area, Lincoln County, N. Mex.

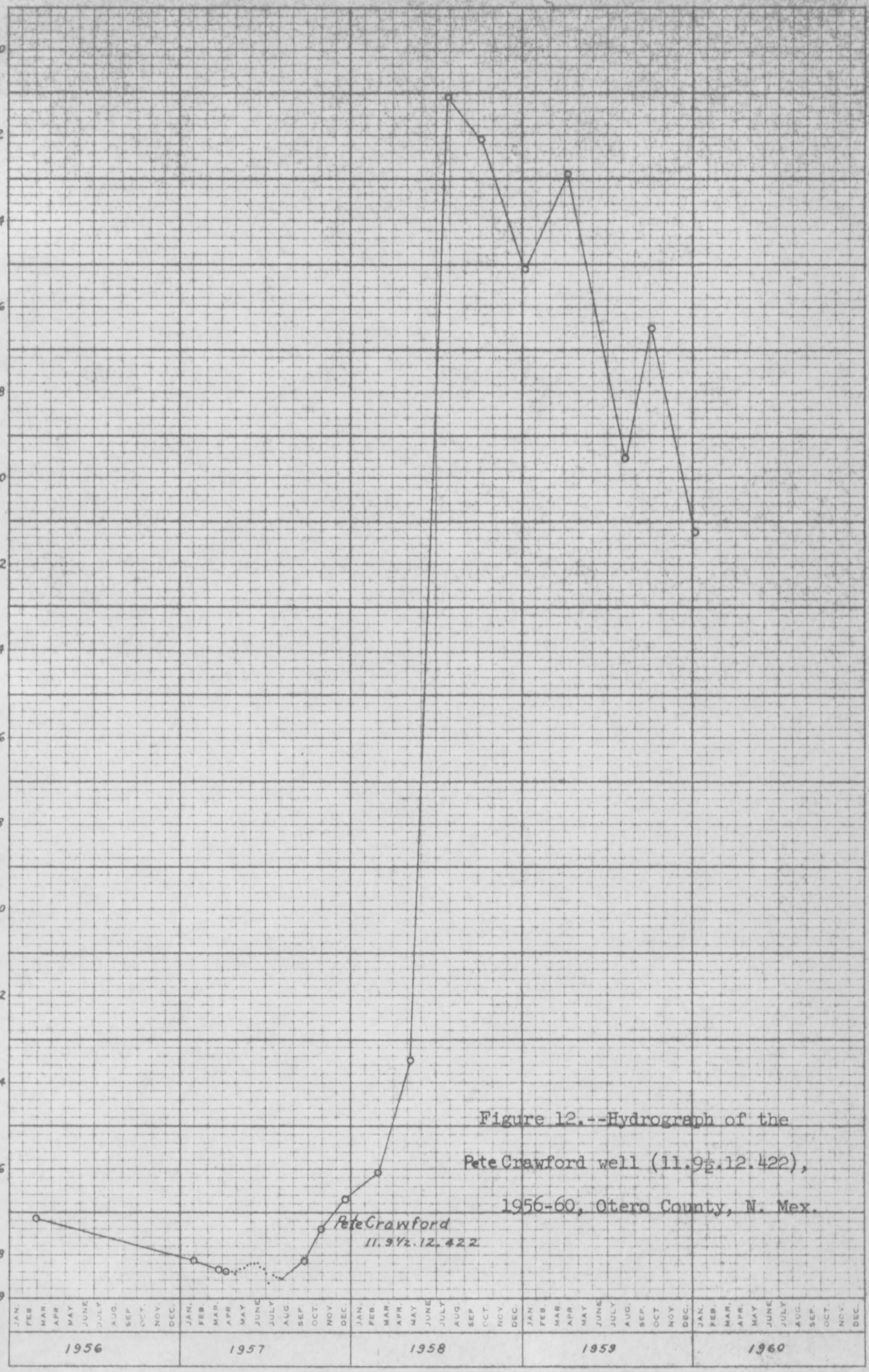

Figure 12.--Hydrograph of the Pete Crawford well (11.9½.12.422), 1956-60, Otero County, N. Mex.

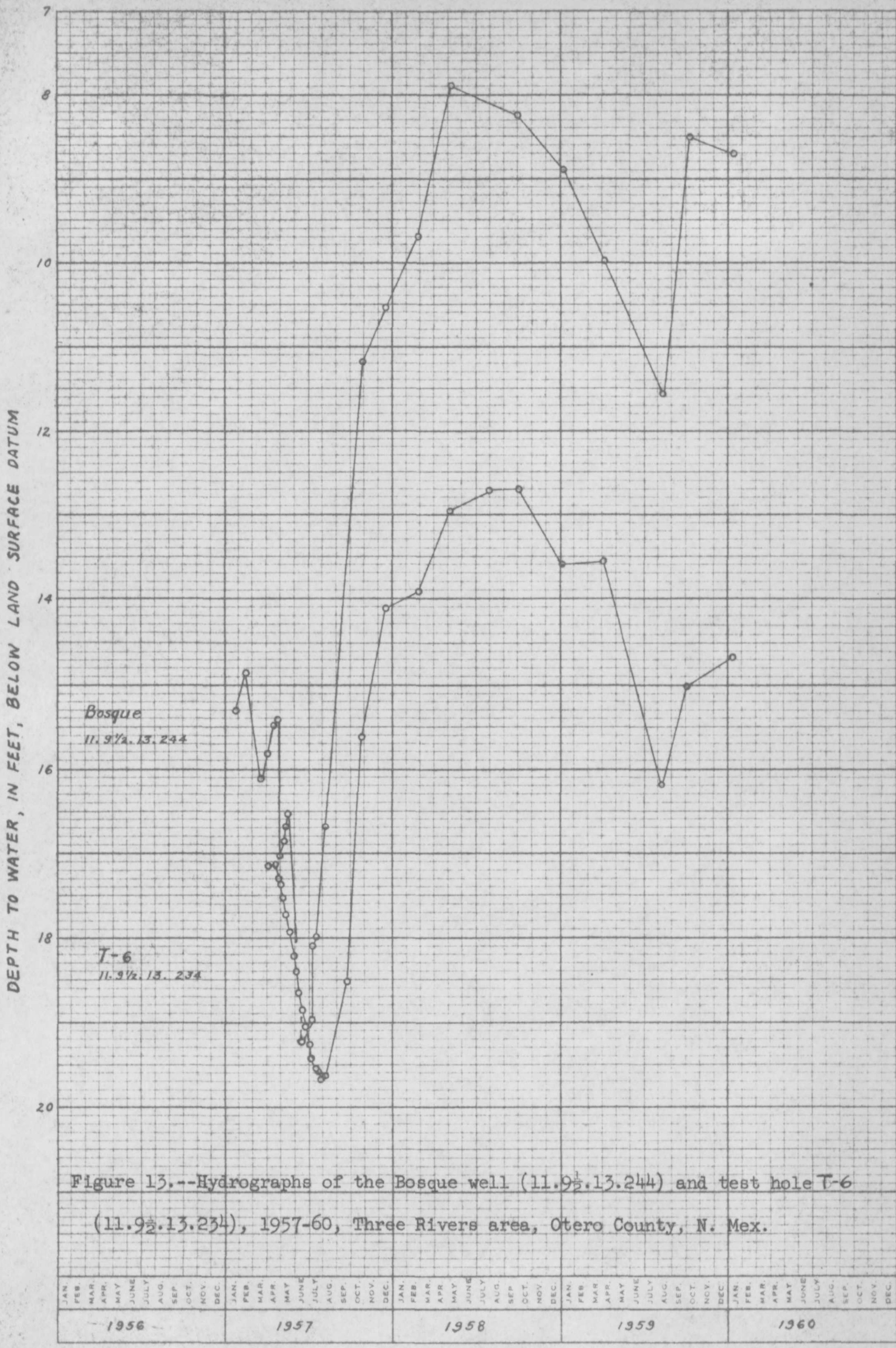

Figure 13.--Hydrographs of the Bosque well (11.9½.13.244) and test hole T-6 (11.9½.13.234), 1957-60, Three Rivers area, Otero County, N. Mex.

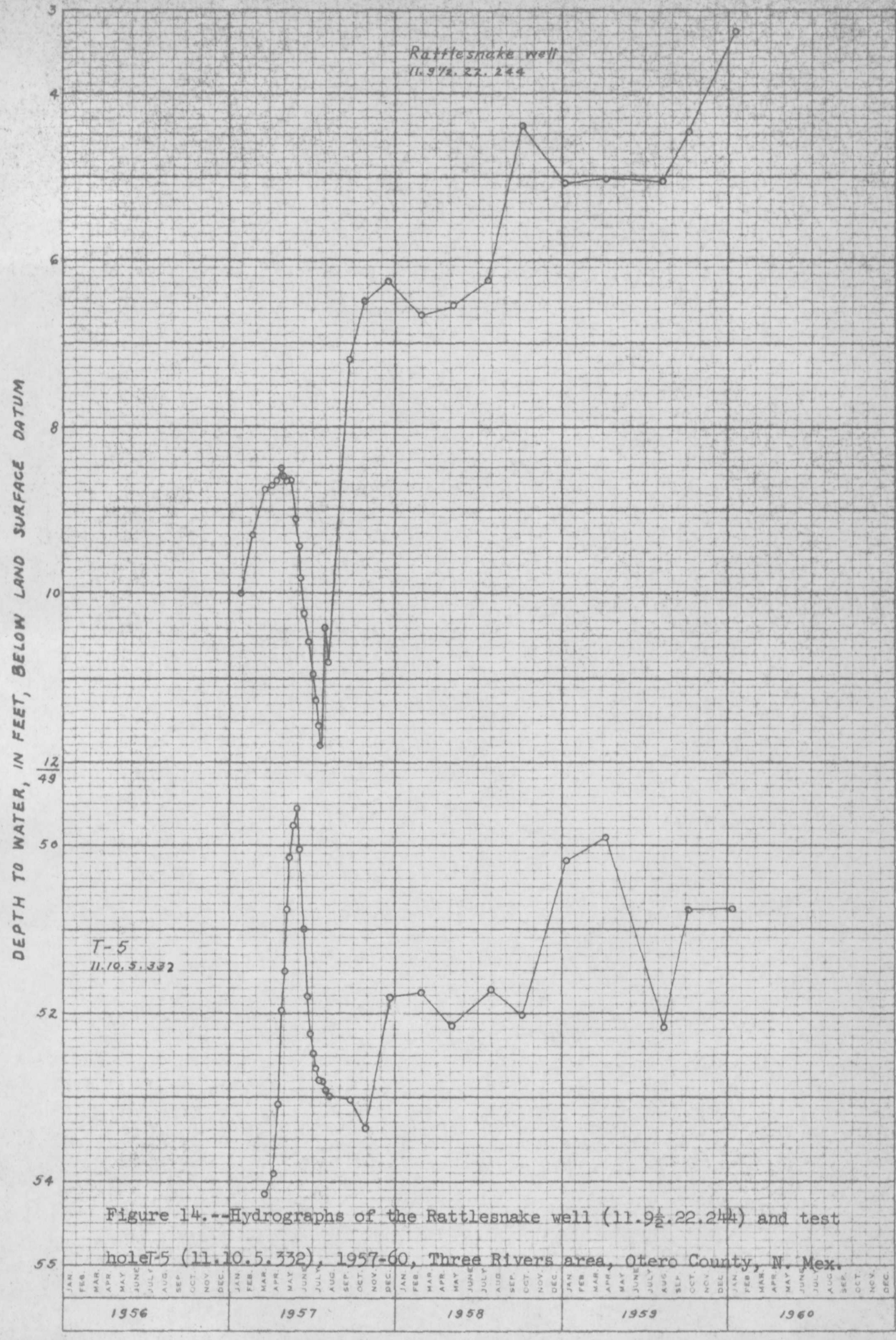

Figure 14.--Hydrographs of the Rattlesnake well (11.9½.22.244) and test holeT-5 (11.10.5.332), 1957-60, Three Rivers area, Otero County, N. Mex.

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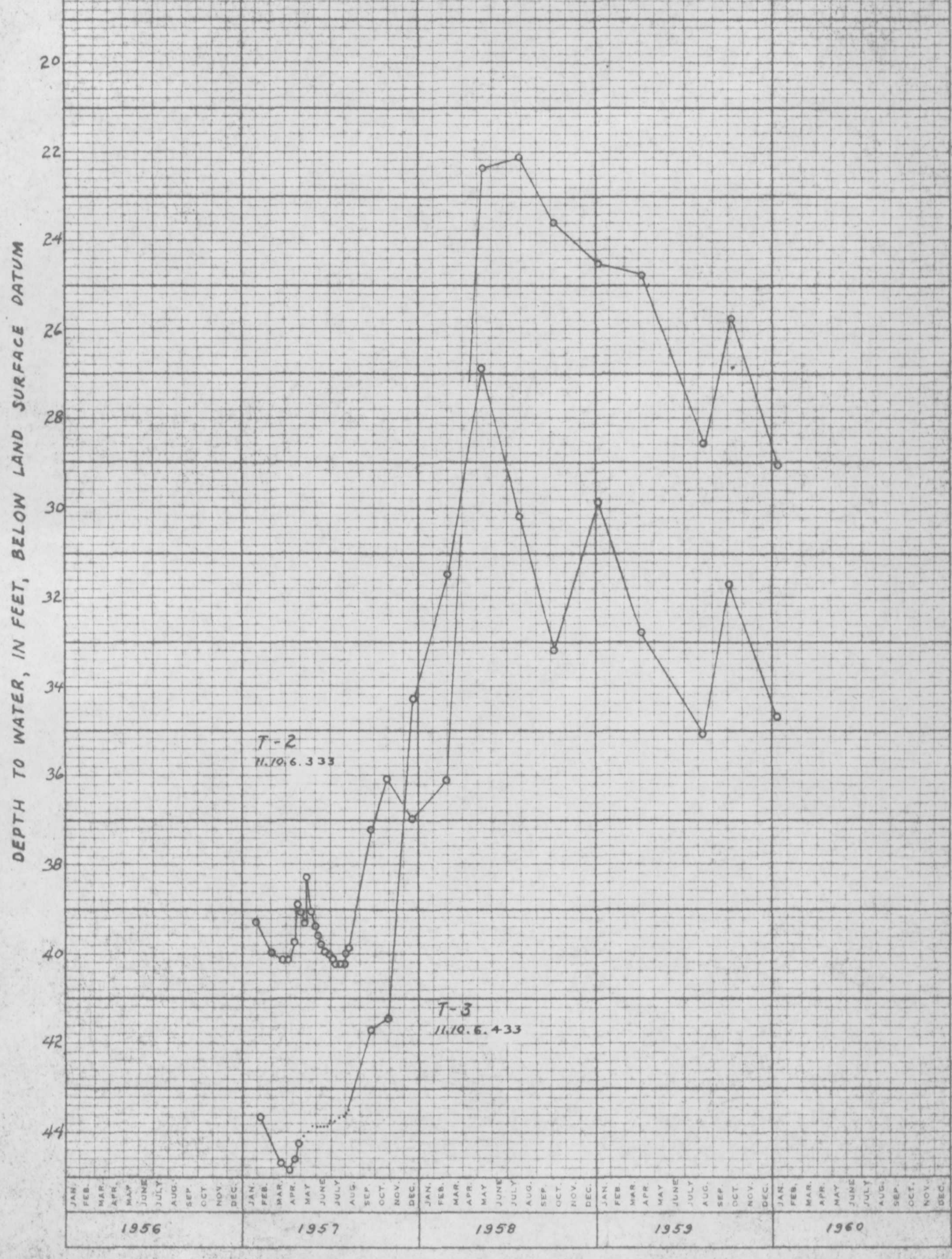
Figure 15.--Hydrographs of test hole T-2 (11.10.6.333) and test hole T-3 (11.10.6.433), 1957-60, Three Rivers area, Otero County, N. Mex.



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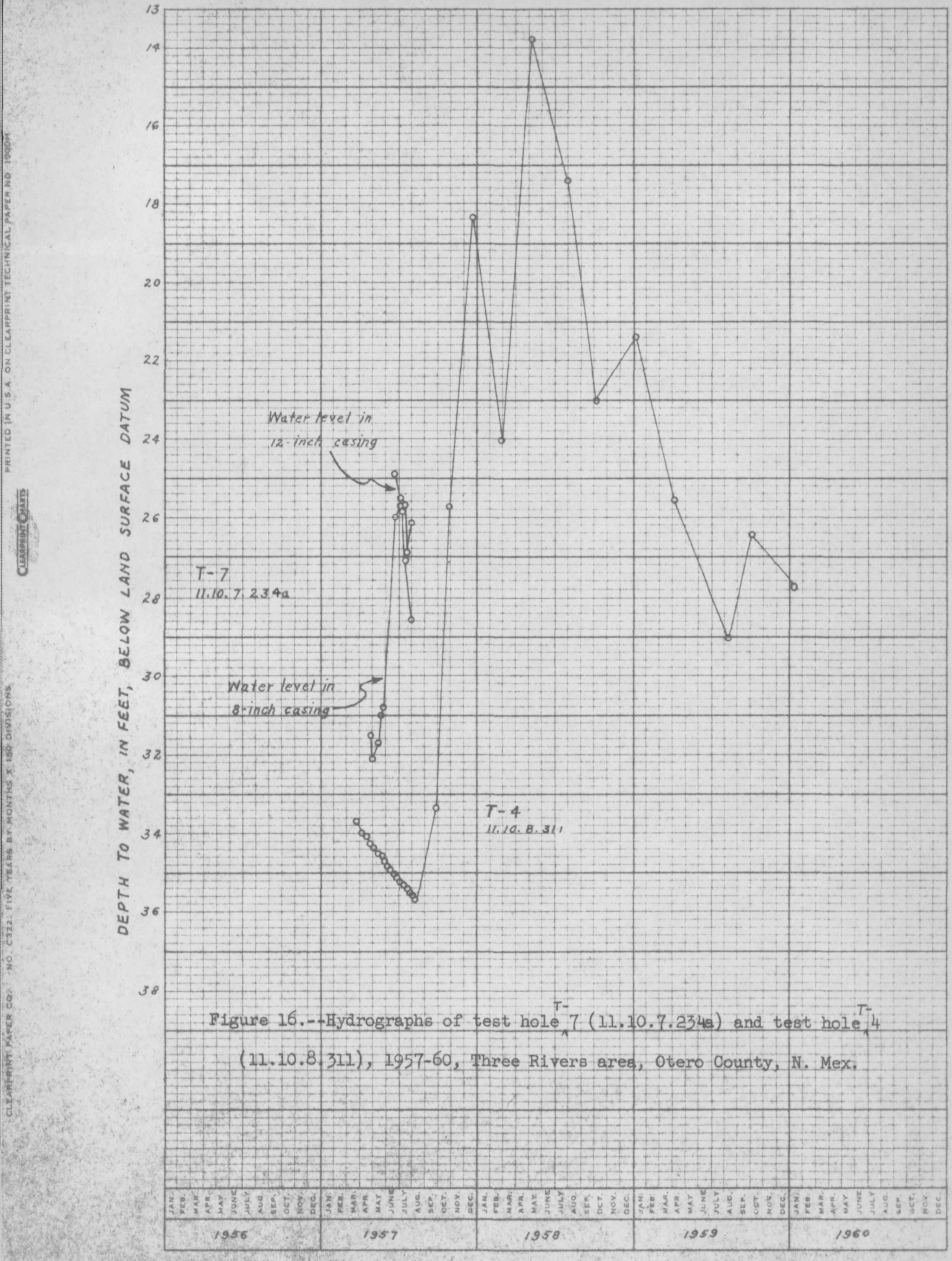

Figure 16.--Hydrographs of test hole T-7 (11.10.7.234a) and test hole T-4 (11.10.8.311), 1957-60, Three Rivers area, Otero County, N. Mex.

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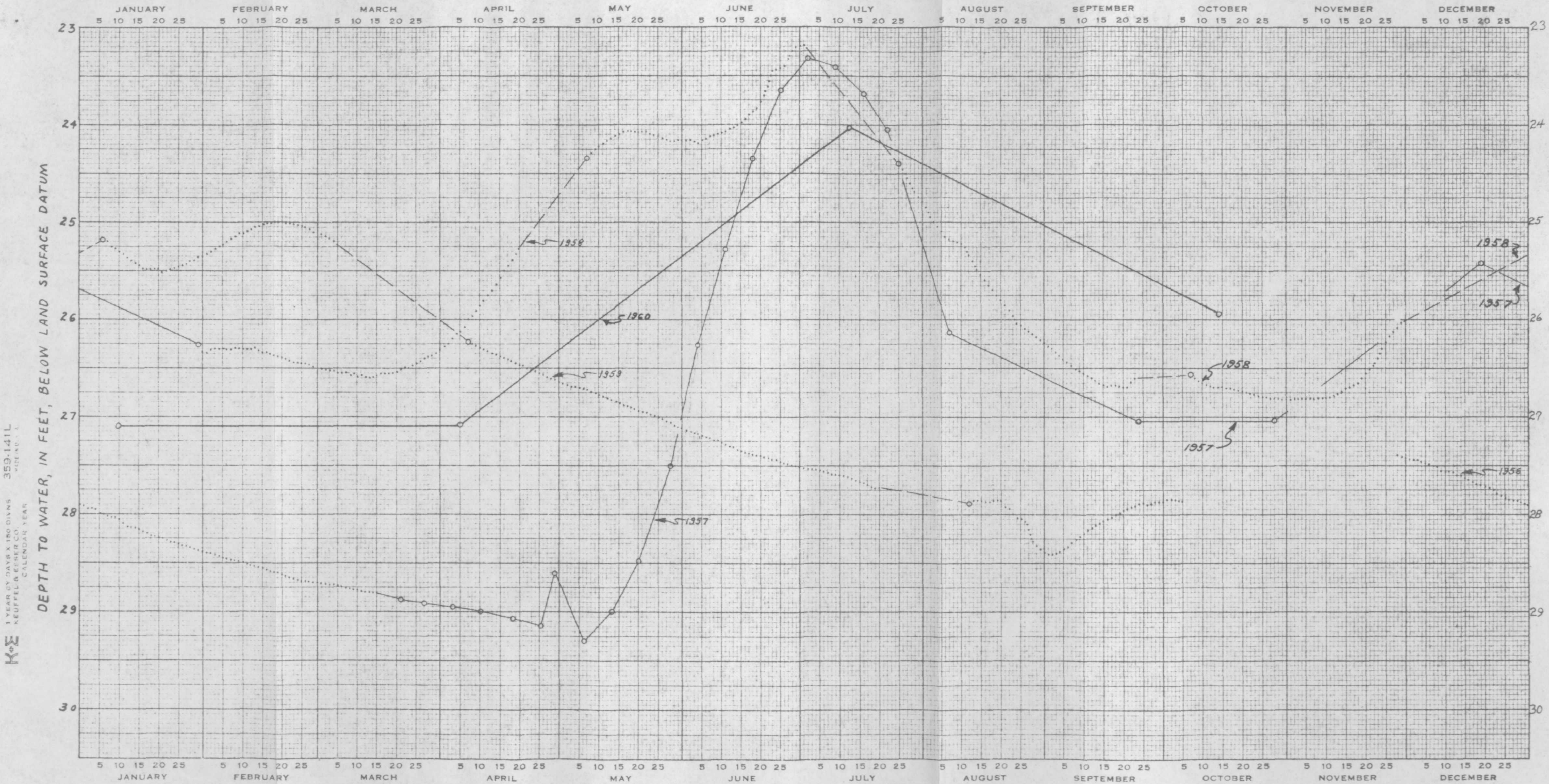
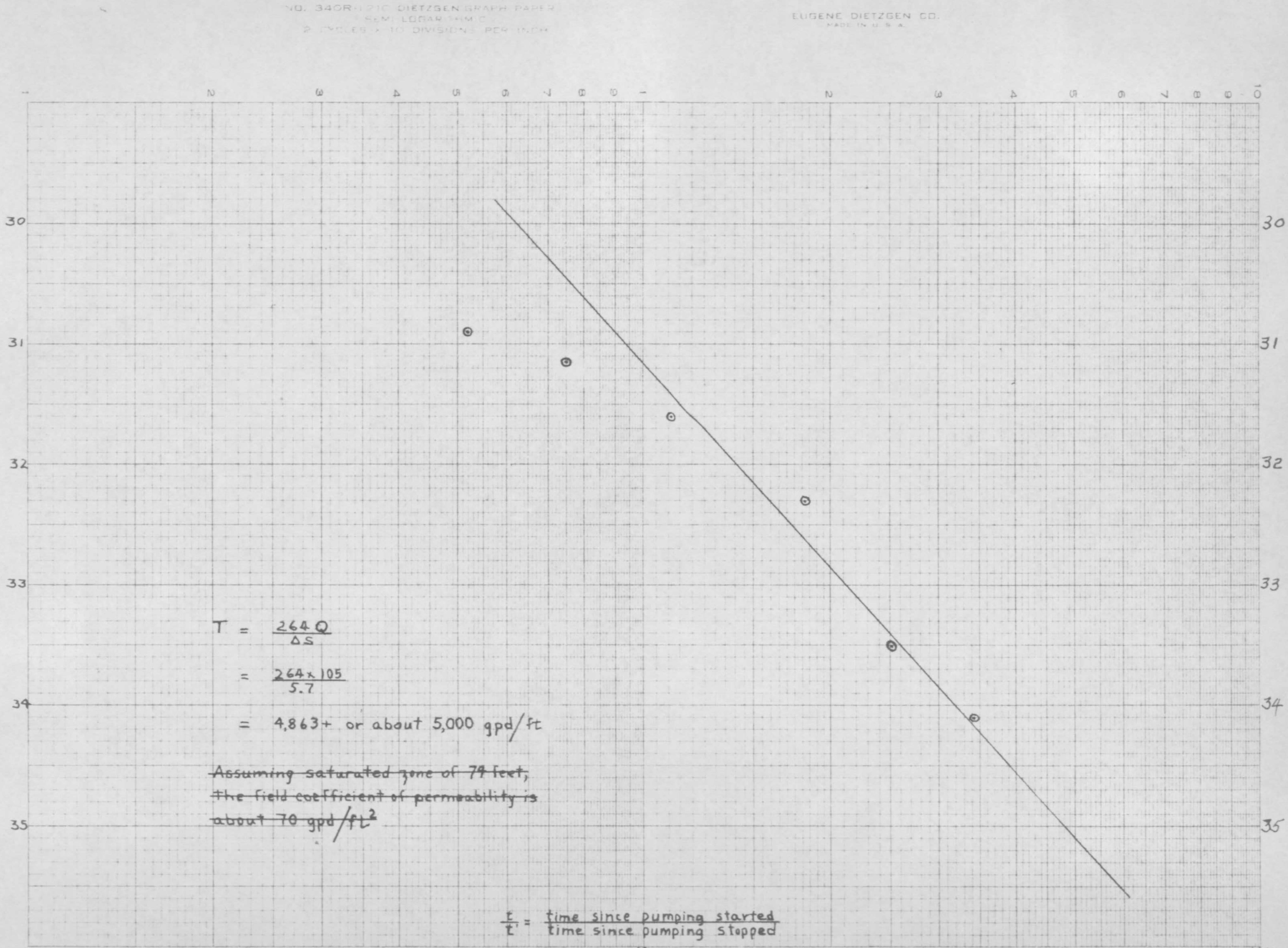


Figure 17.--Hydrograph of the Foley test hole (11.10.7.234), 1956-60, Three Rivers area, Otero County, N. Mex.



$$T = \frac{264\,Q}{\Delta s}$$

$$= \frac{264 \times 105}{5.7}$$

$$= 4{,}863+ \text{ or about } 5{,}000 \text{ gpd/ft}$$

~~Assuming saturated zone of 74 feet, the field coefficient of permeability is about 70 gpd/ft^2~~

$$\frac{t}{t'} = \frac{\text{time since pumping started}}{\text{time since pumping stopped}}$$

Figure 18. -- Recovery data from pumping test at Foley test hole (11.10.7.234), Three Rivers area, Otero County, N. Mex., February 7, 1956

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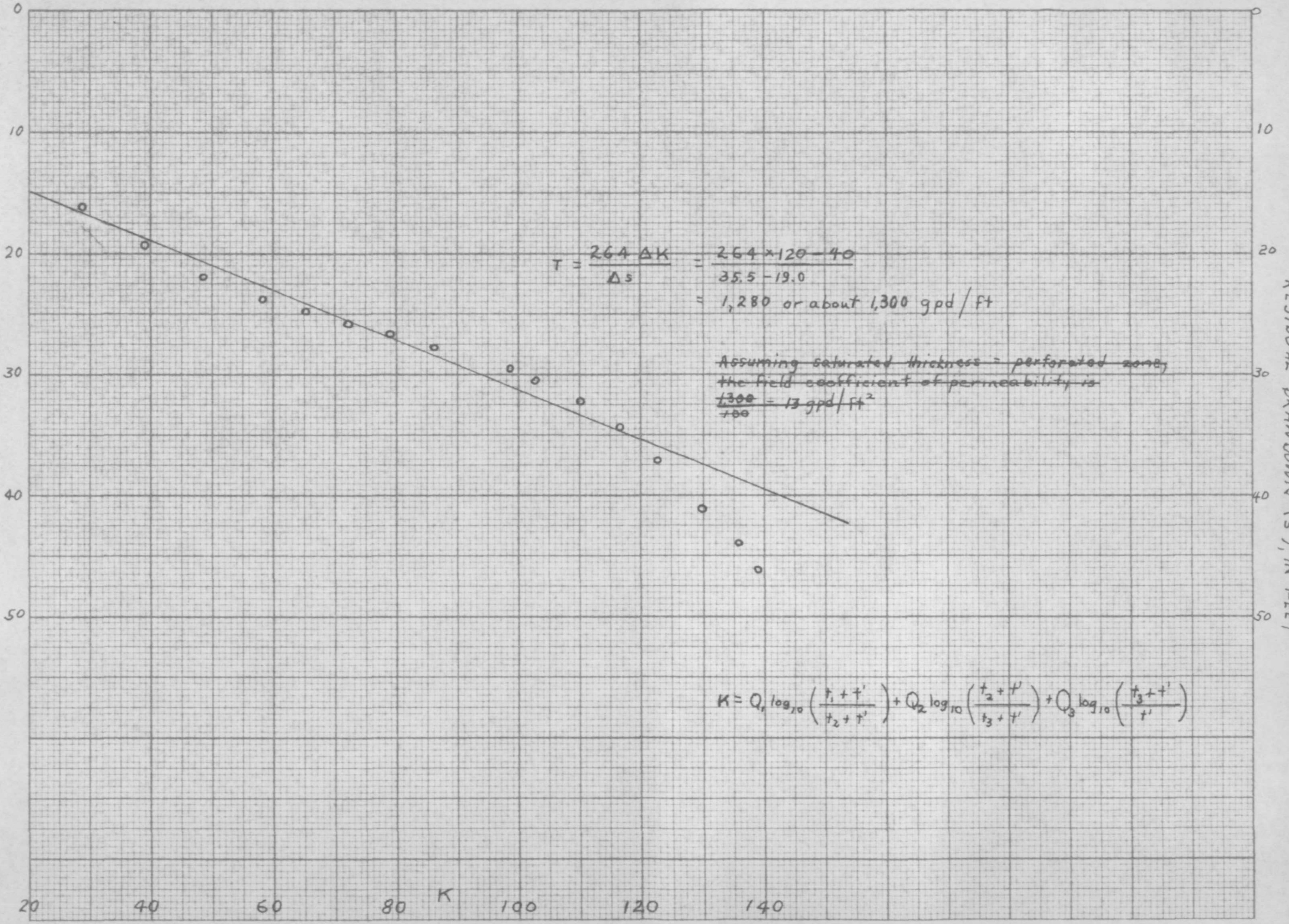

Figure 19.--Recovery data from step-pumping test at test hole T-1 (10.10.32.334), Three Rivers area, Lincoln County, N. Mex., January 2, 1957.

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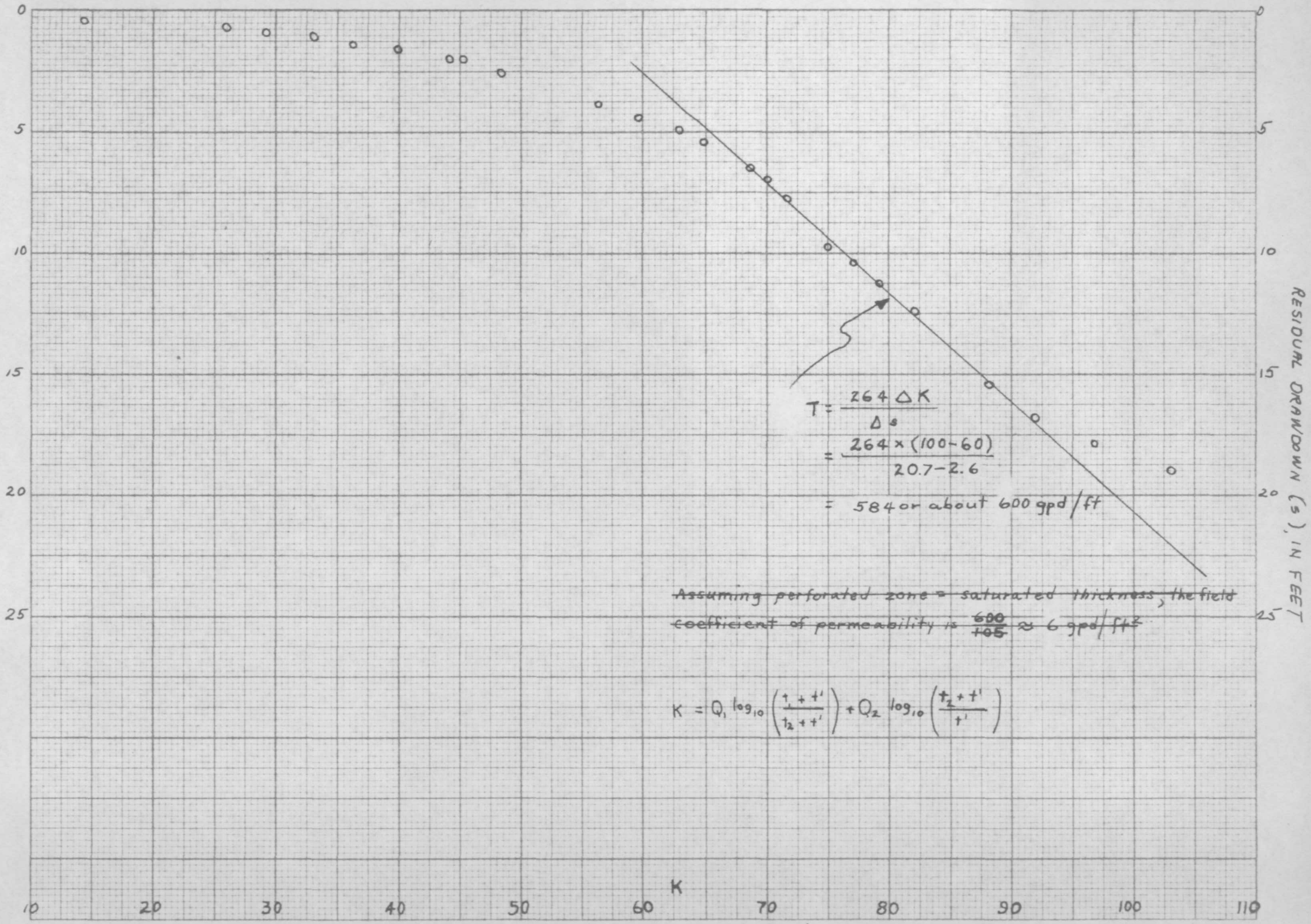

Figure 20.-- Recovery data from step-pumping test at test hole T-2 (11.10.6.333), Three Rivers area, Otero County, N. Mex., March 4, 1957.

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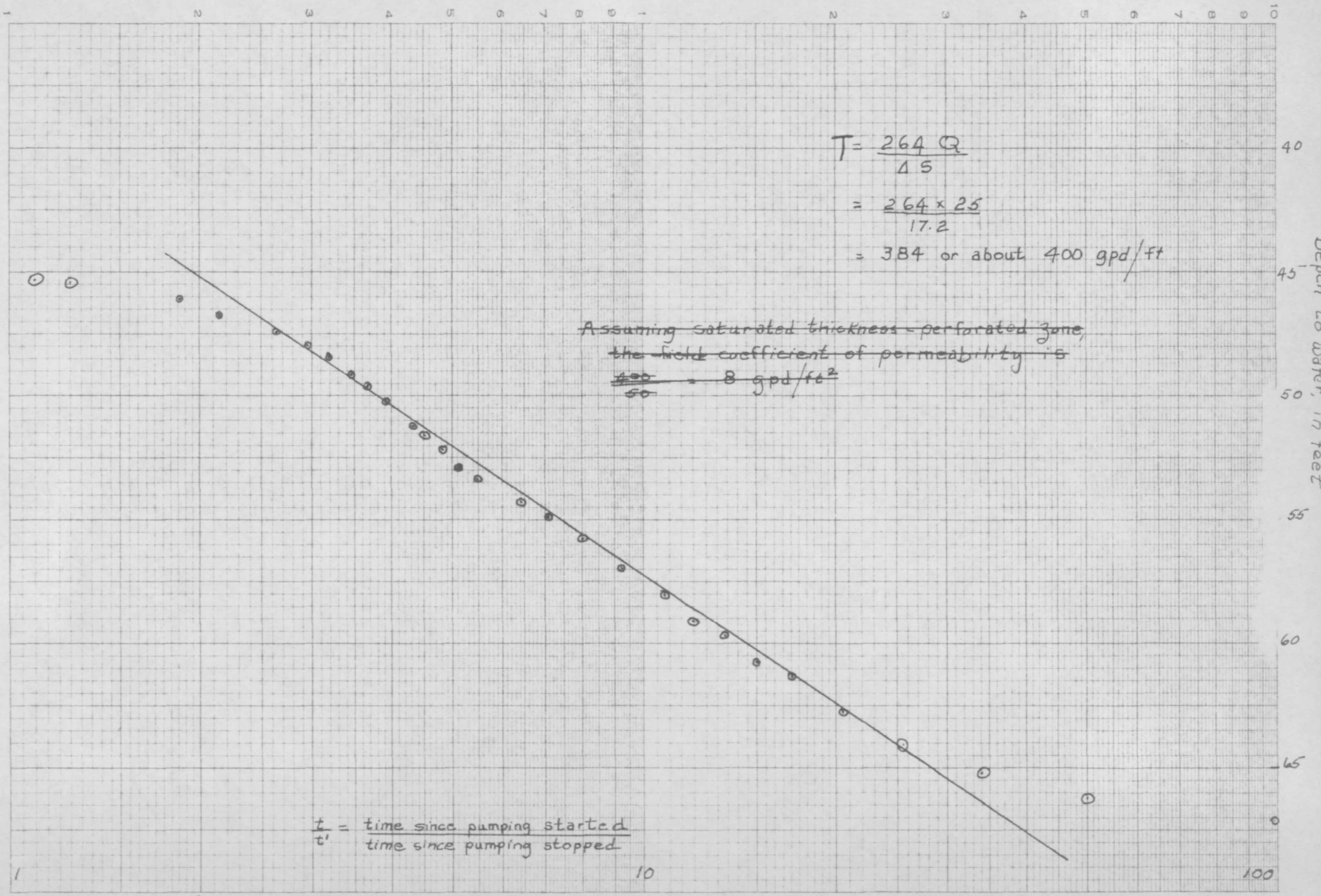

Figure 21.-- Recovery data from pumping test at test hole T-3 (11.10.6.433), Three Rivers area, Otero County, N. Mex., March 11, 1957

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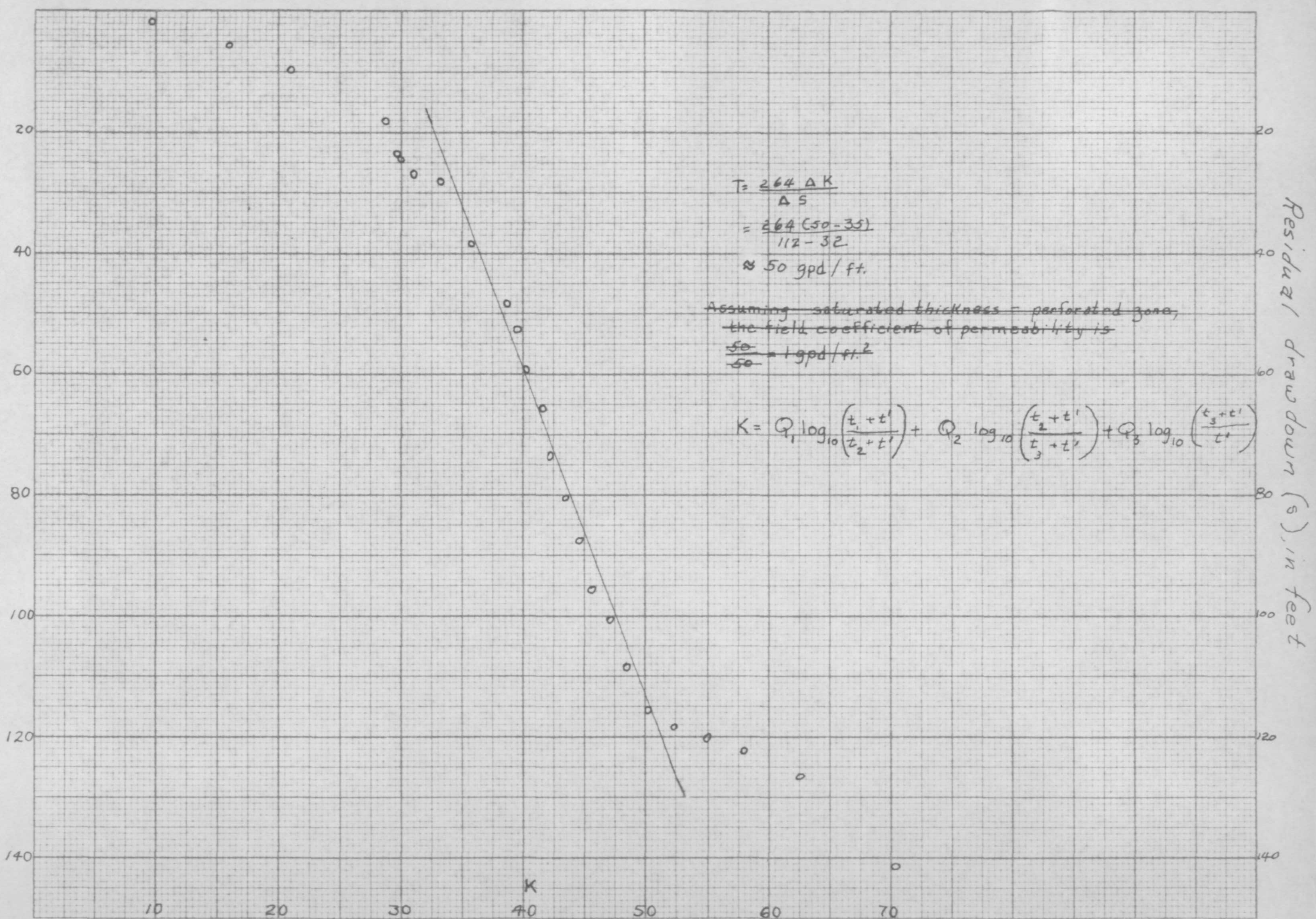

Figure 22. -- Recovery data from step-pumping test at test hole T-6 (11.9½.13.234), Three Rivers area, Otero County, N.Mex., March 28, 1957

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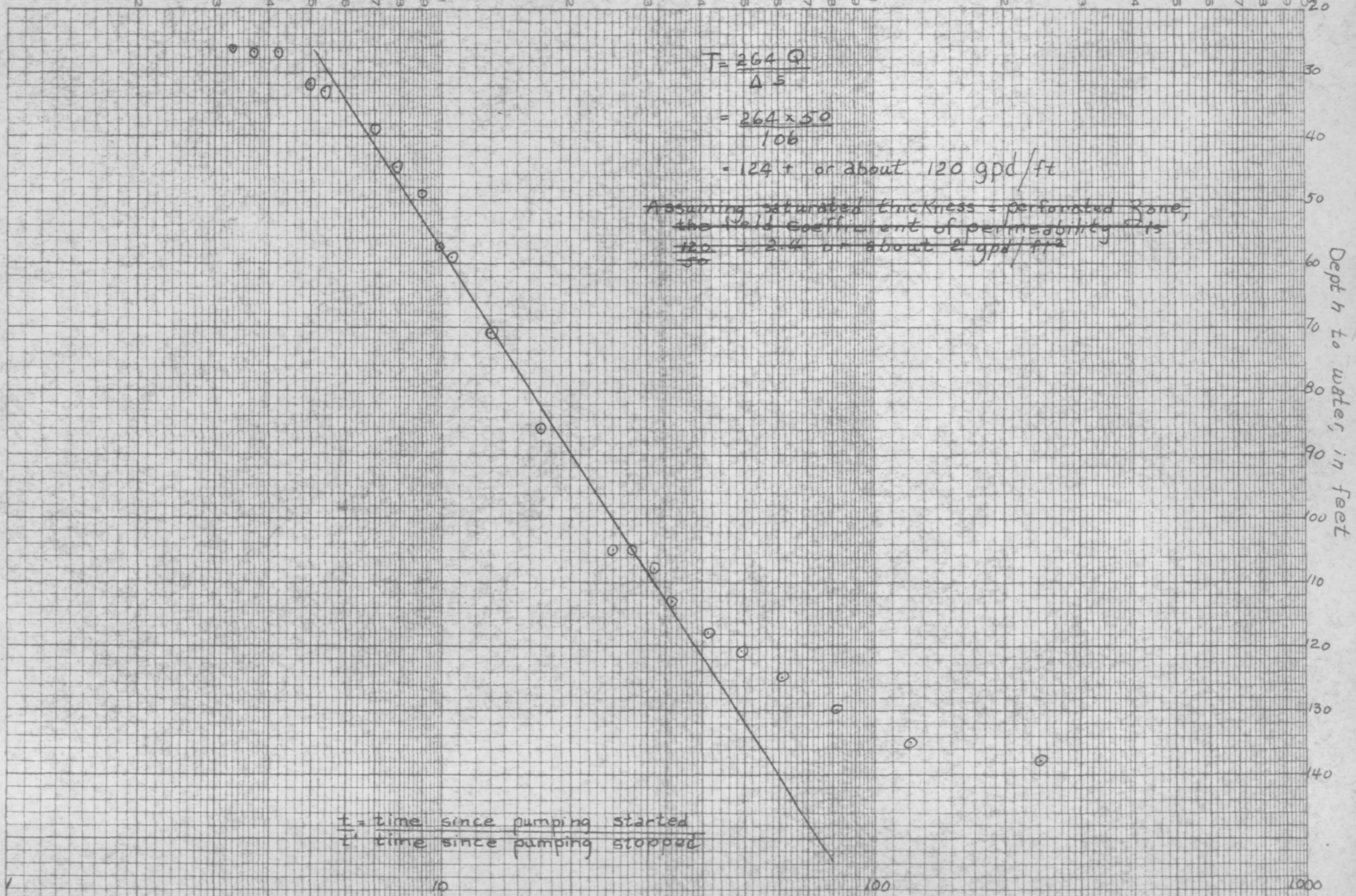

Figure 23.-- Recovery data from pumping test at Test hole T-8 (11.9½.23.124), Three Rivers area, Otero County, N. Mex., October 16, 1957.