PROGRESS REPORT ON THE GROUND-WATER HYDROLOGY OF THE EQUUS BEDS AREA, KANSAS

By

G. J. STRAMEL

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U. S. Geological Survey

Prepared by the United States Geological Survey and the State Geological Survey of Kansas with the cooperation of the Division of Sanitation of the Kansas State Board of Health, the Division of Water Resources of the Kansas State Board of Agriculture, and the City of Wichita, Kansas.

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ABSTRACT

This report describes an investigation of the availability of ground water in the well field of the city of Wichita within the area known as the Equus beds in south-central Kansas, and the general hydrology of the Equus beds area.

By January 1, 1955, the City of Wichita had pumped 330,000 acre-feet of water from the well field. As of January 1955, the water level had declined a maximum of 32 feet in the well field. The decline of the water table is small, however, compared to the thickness of the saturated deposits. In January 1955, the depth to water in the well field ranged from 5 to 47 feet. The water table is affected by the city's pumping in an area of about 100 square miles. As of January 1955, about 67 percent of the water pumped from the well field by the city of Wichita had come from recharge by precipitation. The primary source of water for recharge to the well field is local precipitation falling on the land surface, and the seasonal rise of the water levels correlates closely with precipitation.

The water-bearing materials consist of unconsolidated deposits of sand, gravel, silt, and clay of Pleistocene age. The hydraulic gradient of the water table in the well field is toward Little Arkansas River, and some water is being discharged into it, although most of the water moving across the well field is intercepted by pumping.

If the Wichita well field is expanded, a larger area will be influenced by pumping, and the perennial yield will be correspondingly larger. If the well field were expanded to include all the Equus beds area, the perennial yield would be many times larger than the amount of water pumped in 1955 by the city of Wichita.

The hydrology and geology may be favorable in parts of the well field for artificial recharge. Additional data must be collected before the best method and the economic feasibility of artificially recharging the well field can be determined.

A map of the generalized geology of the Equus beds area and figures showing the water-table contours, changes in water levels during specific periods, cross sections, pumpage charts, percipitation graphs, and hydrographs of water-level fluctuations are given in this report.

INTRODUCTION

This study of the ground-water hydrology of the Equus beds area has been made as a part of the cooperative program of ground-water investigations in Kansas by the United States Geological Survey, the State Geological Survey of Kansas, the Division of Sanitation of the Kansas State Board of Health, the Division of Water Resources of the Kansas State Board of Agriculture, and the City of Wichita, Kansas. The status of the Kansas cooperative ground-water program is shown in Figure 1.

The extent of the Equus beds area is shown in Figure 2. It includes parts of McPherson, Harvey, Reno, and Sedgwick Counties.

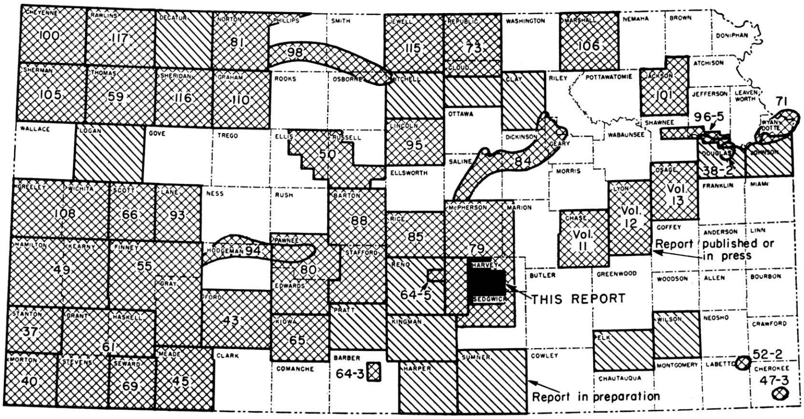

FIG. 1.—Map of Kansas showing area covered by this report and other areas for which cooperative ground-water reports have been published or are in preparation.

The area shown in Figure 2 comprises 65 townships or about 2,340 square miles. The deposits now loosely referred to as the Equus beds in this area include all Pliocene and Pleistocene deposits. The Pliocene and Pleistocene deposits are bordered by Permian and Cretaceous rocks. A smaller area comprising 10½ townships or about 378 square miles, which contains the municipal wells of the city of Wichita, is referred to in this report as the well-field area.

Williams and Lohman (1947, 1949) made an extensive study of the ground-water resources of the Equus beds area. This report presents the progress of studies to determine the effects that pumping by the city of Wichita has had on the water level in the Equus beds area, how much water has been removed from storage, how much water remains in storage, the recharge characteristics of the area, and the long-term yield of the water-bearing deposits.

ACKNOWLEDGMENTS

Appreciation and gratitude are expressed for the interest and personal assistance of R. H. Hess, Director, Water Supply and Sewage Treatment, O. K. Brandon, Water-Supply Supervisor, and S. A. Smith, Well-Field Supervisor, of the Wichita Water Department. The writer is indebted to many farmers who live in the well-field area for their courtesy in supplying information concerning the decline of the water table.

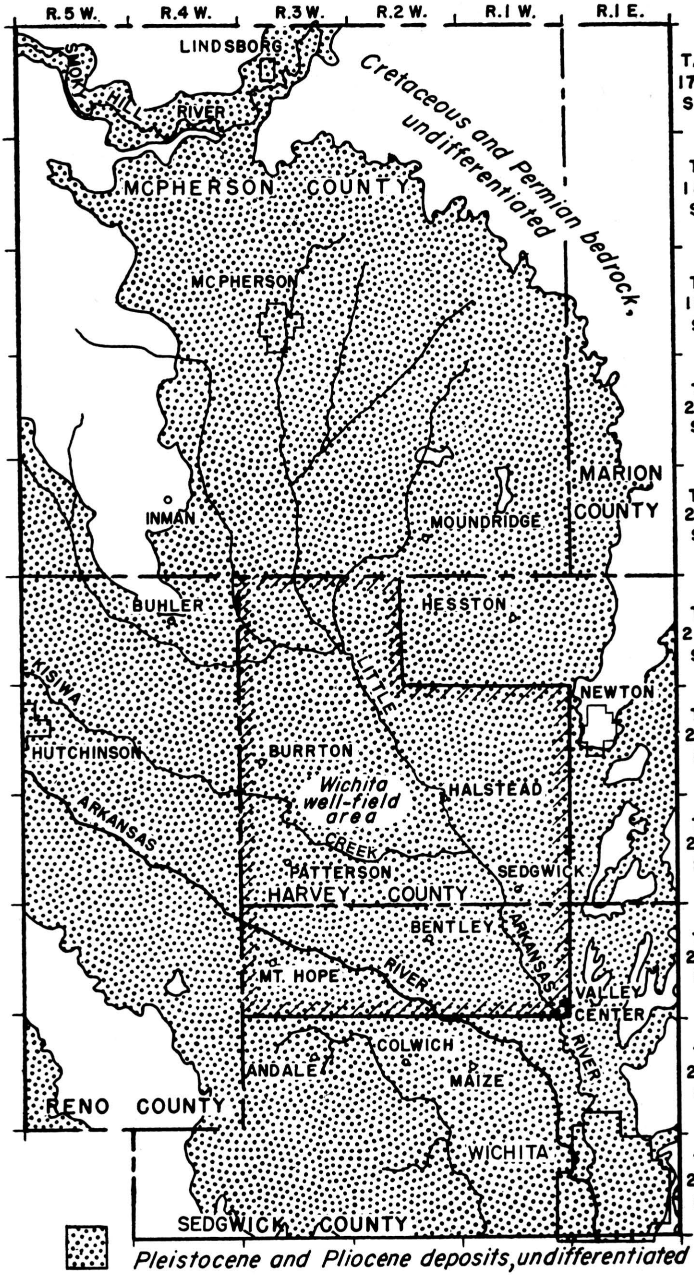

FIG. 2.—Generalized geologic map of Equus beds area and outline of well-field area. (Adapted from Williams and Lohman, 1949, pl. 1.)

The manuscript of this report has been reviewed by several members of the Federal and State Geological Surveys; by R. H. Hess, Superintendent, Water Supply and Sewage Treatment Divisions, Wichita; by Dwight Metzler, Director and Chief Engineer, and W. O. Hilton, Division of Sanitation, Kansas State Board of Health; and by R. V. Smrha, Chief Engineer, and George S. Knapp, Engineer, Division of Water Resources, Kansas State Board of Agriculture.

CLIMATE

The following climatic data are presented to provide a basis for interpreting and correlating water-level fluctuations due to weather phenomena and have been taken from the U. S. Weather Bureau records for the Wichita station. The records of the Wichita weather station have been used because they represent the average weather for the area outlined in this report, and the Wichita station is the only complete meteorological station in the area.

Wichita has a mean annual temperature of 57.0°F. The city lies in the path of masses of warm, moist air moving northward from the Gulf of Mexico, which alternate with currents of cold, dry air moving southward from the polar regions. Consequently, the weather is subject to frequent and abrupt changes. Summers are generally warm; winters are generally mild. The recorded temperatures at Wichita have ranged from 114° on July 12, 1936, to —22° on February 12, 1899. On an average, 51 days a year have temperatures of 90° or above, and 2 days a year have temperatures of 0° or lower.

Average annual precipitation based on a 67-year record is 30.06 inches, the greatest precipitation falling in the spring and summer and the least in the late fall and winter. In 1951, the wettest year on record, 50.48 inches of precipitation fell; in 1954, the driest year on record, 14.53 inches fell. Monthly and annual precipitation data for the Wichita weather station are given in Table 1.

Thunderstorms occur on an average of 52 days a year, most frequently during spring and summer. Measurable snow has fallen between October and April; the greatest average amount, 3.6 inches, falls during February. March and April are the windiest months of the year, the wind velocity averaging 14.9 and 14.7 mph, respectively. August is the least windy, the velocity averaging 11.3 mph. The average annual wind velocity is 12.8 mph. The sun shines in Wichita during 69 percent of the time possible.

Table 1.—*Monthly and annual precipitation, in inches, at Wichita, Kansas, 1888-1954*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1888							1.04	7.77	1.89	1.36	1.29	0.71	....
1889	0.82	0.57	2.41	5.18	3.88	7.89	4.72	3.79	2.10	2.14	1.14	.03	34.67
1890	2.12	.35	.14	3.36	2.17	5.05	.95	2.60	1.96	2.39	1.72	.99	24.07
1891	2.66	1.95	3.36	1.26	9.15	4.90	5.59	.40	.72	2.95	.47	1.12	34.53
1892	.31	2.62	4.03	2.05	5.83	1.70	2.75	4.06	2.12	2.52	.24	1.71	29.94
1893	.19	.80	1.09	.25	2.22	3.41	5.02	1.51	2.10	.02	.91	.67	18.19
1894	.78	1.01	.72	3.33	2.02	9.43	1.72	.94	9.72	2.10	.01	.75	32.44
1895	.57	1.19	1.81	.40	2.77	4.47	2.74	7.67	.86	.81	1.80	1.37	26.46
1896	.62	.37	1.58	3.26	3.02	7.10	3.40	.31	3.08	2.27	1.42	.63	27.06
1897	1.23	1.31	3.34	3.66	2.48	1.99	1.49	4.33	1.22	3.89	.10	.97	26.01
1898	1.97	3.04	.95	5.16	8.32	5.24	5.30	2.78	1.55	2.02	1.13	2.00	39.46
1899	.38	.20	2.53	1.58	5.72	6.81	4.62	2.45	4.75	1.55	1.09	1.81	33.49
1900	.10	2.10	.83	2.77	6.50	3.41	2.16	1.69	5.64	5.71	.21	.73	31.85
1901	.25	1.29	1.52	5.83	1.40	3.16	3.44	2.00	3.04	3.86	1.16	.52	27.47
1902	.32	.75	2.79	.87	10.33	7.11	4.12	5.28	2.69	2.02	1.76	.69	38.73
1903	.08	1.71	1.61	3.31	7.97	1.26	1.46	4.46	2.25	5.96	.75	.26	31.08
1904	.12	.04	4.23	2.65	5.74	5.69	7.46	1.42	3.10	.35	.07	.24	31.11
1905	.45	.64	3.67	2.14	4.24	5.53	5.39	1.34	6.70	1.63	2.59	.21	34.53
1906	.53	.58	1.68	3.09	3.40	1.82	6.88	3.30	4.33	2.12	2.92	.35	31.00
1907	2.97	1.53	.81	.91	4.12	3.62	3.37	5.80	1.88	4.10	.79	1.61	31.51
1908	.16	2.50	.80	1.77	9.28	5.85	2.96	6.57	3.21	2.24	2.34	.03	37.71
1909	.27	.89	1.47	1.59	3.64	5.71	3.26	1.01	1.77	2.95	6.69	1.31	30.56
1910	.55	.63	T	.96	5.11	1.94	1.24	4.52	1.56	.52	T	.69	17.72
1911	.02	4.23	.10	2.19	4.66	T	5.95	4.32	10.56	.94	.87	3.05	36.89
1912	.12	2.32	3.07	3.87	5.18	3.27	1.28	3.14	3.36	2.18	.50	.85	29.14
1913	.41	2.43	.30	1.83	.97	1.36	1.28	T	3.52	4.18	1.73	3.93	21.94
1914	T	1.58	1.13	1.70	4.31	3.83	1.60	3.68	3.39	1.38	.11	.61	23.32
1915	1.35	4.61	1.97	3.29	8.34	5.90	3.82	4.81	4.69	1.66	.39	.40	41.23
1916	1.90	.13	1.50	3.87	5.11	8.32	.10	2.12	.86	2.32	2.93	.46	29.62
1917	.41	T	.66	2.52	4.84	.32	1.41	4.69	.92	.11	.02	.21	16.11
1918	.89	1.93	2.44	4.14	5.86	1.29	2.11	5.19	1.80	5.98	3.62	3.31	38.56
1919	T	2.49	2.37	4.40	4.72	2.63	.71	1.61	.23	1.64	1.99	.14	22.98
1920	.41	.32	1.13	1.56	2.97	3.76	4.05	4.40	4.16	2.75	2.68	1.76	29.95
1921	1.30	.14	2.18	4.09	1.41	4.31	.71	4.14	4.05	.52	T	.52	23.37
1922	.88	1.38	3.39	6.12	5.60	3.99	8.46	2.12	2.00	2.59	5.35	.06	41.94
1923	.02	T	1.70	1.64	5.47	14.43	.89	.42	3.26	5.52	1.26	.67	35.28
1924	.31	.58	2.61	4.38	2.93	.36	3.64	1.70	2.51	1.70	.80	1.21	22.73
1925	.76	.10	.54	4.55	2.09	3.68	1.72	2.52	4.43	1.33	1.64	.59	23.95
1926	.80	.44	2.16	1.64	2.47	3.03	3.47	2.74	5.01	5.68	1.63	1.11	30.18
1927	.55	1.02	3.90	4.80	2.13	4.66	3.85	5.90	3.93	2.96	.32	.83	34.85
1928	.10	1.79	2.24	5.26	2.79	12.10	3.46	.70	.58	1.48	5.45	1.58	37.53
1929	2.08	.65	.88	4.04	5.84	7.13	7.08	1.30	.98	3.23	1.59	.04	34.84
1930	1.24	T	.22	1.68	5.02	2.36	1.06	2.96	5.29	2.55	3.05	.58	26.01
1931	.29	.64	2.52	2.49	2.37	5.50	.97	1.91	4.58	1.19	6.21	.69	29.36
1932	1.49	.94	.77	2.33	1.90	7.92	2.53	2.30	1.26	.40	.18	1.67	23.69
1933	.10	.34	1.72	.86	2.29	.83	2.34	8.50	1.39	.74	.85	1.85	21.81
1934	.72	1.03	1.16	3.10	4.14	1.78	1.77	.38	4.25	1.89	2.90	1.03	24.15
1935	.87	1.39	.98	1.86	11.22	7.21	.39	1.55	3.11	4.41	2.99	.25	36.23
1936	.94	.02	T	.58	3.30	1.04	.21	.04	4.84	3.77	.01	.83	15.58
1937	1.54	.73	2.80	.57	4.13	3.99	4.77	2.86	1.80	1.12	.75	.58	25.64

TABLE 1.—*Monthly and annual precipitation, in inches, at Wichita, Kansas, 1888-1954 (concluded)*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
1938	.12	2.48	1.91	2.85	8.14	4.49	2.24	5.60	2.62	.16	2.05	.15	32.81
1939	1.09	1.93	1.57	2.14	3.25	8.90	.72	5.84	.30	1.14	.81	.95	28.64
1940	1.40	1.43	.74	6.15	5.82	4.85	.94	2.87	6.14	1.05	3.82	1.56	36.77
1941	1.53	1.09	1.11	2.83	2.89	7.05	2.41	3.54	4.29	4.81	.78	.92	33.25
1942	.23	1.93	.88	7.08	1.67	8.69	2.34	4.51	7.21	3.77	.68	3.14	42.13
1943	.27	.67	1.21	1.94	6.59	3.43	6.51	1.95	3.14	1.83	.07	2.33	29.94
1944	1.01	1.34	4.55	12.42	2.04	1.60	5.49	4.77	2.20	2.20	1.93	3.98	43.53
1945	1.07	.84	1.85	6.79	1.28	4.00	5.01	4.11	10.58	.51	.05	.62	36.71
1946	2.21	1.23	1.81	1.87	2.11	2.71	.32	2.90	1.27	4.32	2.14	.78	23.67
1947	.71	.52	2.91	5.20	4.69	2.57	2.89	.82	.25	1.50	.89	2.98	25.93
1948	1.00	1.19	1.51	1.65	1.86	9.76	6.39	2.72	1.05	.67	3.30	.25	31.35
1949	6.29	1.80	2.01	3.85	6.15	3.16	6.97	1.13	3.62	1.91	.06	1.22	38.17
1950	.52	1.61	.50	.88	2.24	4.02	13.37	5.93	1.04	.48	.26	.02	30.87
1951	1.03	2.58	2.69	6.33	7.60	10.07	4.45	5.38	6.59	2.05	1.47	.24	50.48
1952	.41	.35	2.68	1.97	2.31	1.08	4.94	2.52	.28	.00	2.40	1.09	20.03
1953	.15	.82	3.35	.57	2.02	2.17	2.39	.82	.53	3.77	1.46	1.06	19.11
1954	.09	.57	1.30	1.54	4.84	.94	.19	.96	1.09	2.83	T	.18	14.53
Average	.85	1.21	1.80	3.05	4.35	4.52	3.28	3.12	3.10	2.28	1.54	1.04	30.06

T indicates trace, not enough to measure.

PUMPAGE

City of Wichita.—Prior to 1940, the city of Wichita obtained its water supply from wells in the Arkansas River valley near the filtration plant. The city began pumping from the well field in the Equus beds area on September 1, 1940. At that time water was pumped from 25 wells. In 1949, 10 more wells were added to the system. The water from these wells flows through a 48-inch pipeline to the treatment plant at Wichita. The city of Wichita is by far the largest user of water in or near the well field.

A considerable increase in water consumption by the city of Wichita has resulted in a corresponding increase in withdrawal from the well field. From 1940 through 1954 a small quantity of water was pumped from wells near the city filtration plant. The water from these wells is of poor quality, but by mixing this water with water of good quality from the well field, a water of acceptable quality is obtained. Water is pumped from the wells near the filtration plant mostly during the summer when the water demand in Wichita is greater than the quantity of water that can be pumped through the 48-inch pipeline.

The quantity of water pumped from the wells near the filtration plant increased greatly from 1952 through 1954. Figure 3 shows the amount of pumpage by the city of Wichita from the well field, the amount obtained from wells near the filtration plant, and the total amount of pumpage. The quantity of water pumped from the well field is given by months also in Table 2. The quantity of water pumped from each well in the well field during the period 1940-1954 is shown in Figure 4. The largest quantities of water have been pumped from the wells that were put in operation in 1940.

Other municipal pumpage.—Six municipalities other than Wichita use ground water from the area designated on Figure 2 as the well field. These cities are Burrton, Halstead, Mount Hope, Newton, Sedgwick, and Valley Center. During 1954, the average daily consumption by each municipality was: Burrton, 74,000 gallons; Halstead, 300,000 gallons; Mount Hope, 55,000 gallons; Newton, 2,200,000 gallons; Sedgwick, 250,000 gallons; and Valley

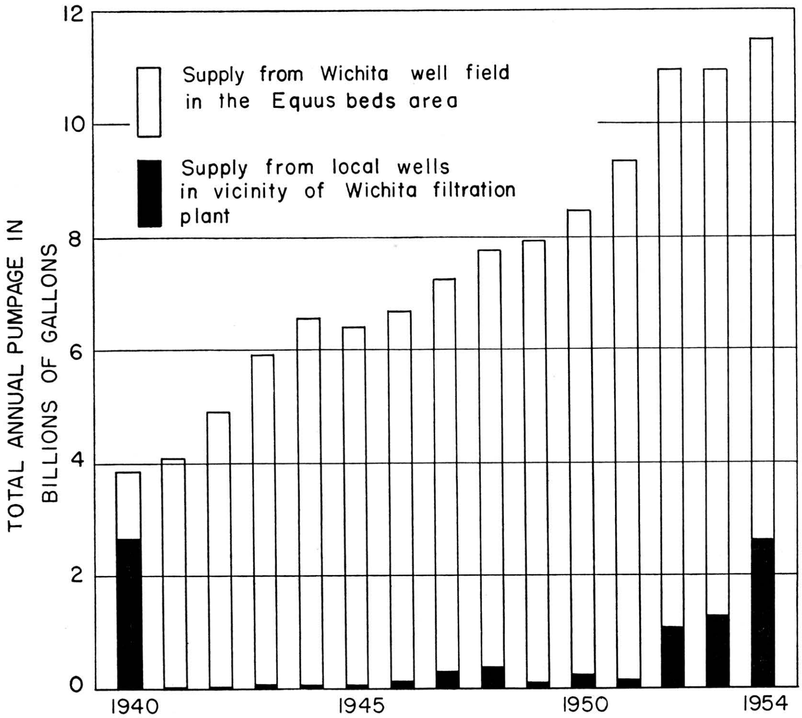

FIG. 3.—Annual pumpage of water by city of Wichita, 1940-54.

TABLE 2.—*Pumpage by city of Wichita from well field, in million gallons, 1940-54*

Year	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954
Jan.	....	277.4	317.9	393.4	542.2	505.0	498.8	510.7	592.8	641.3	670.1	674.7	805.1	733.1	656.8
Feb.	....	247.9	349.9	388.5	493.2	444.2	451.4	472.6	511.8	559.3	615.4	655.9	744.0	665.7	635.8
Mar.	....	269.7	337.5	422.6	516.3	514.8	489.0	507.3	521.6	507.2	630.6	732.0	794.9	722.0	653.5
Apr.	....	320.6	361.1	484.7	534.3	476.0	493.0	476.3	458.1	575.9	674.2	672.8	732.3	747.0	747.2
May	....	336.4	381.5	495.9	570.1	578.5	496.9	567.8	696.2	669.9	752.0	772.9	914.7	921.8	705.6
June	....	415.4	444.1	543.3	597.2	566.9	623.1	880.6	686.1	745.0	819.4	806.2	897.6	941.7	788.0
July	....	459.6	459.9	653.6	629.7	654.6	805.4	737.8	744.3	833.5	730.5	920.4	1,077.3	1,034.8	993.9
Aug.	....	483.3	625.9	643.3	652.9	665.7	723.7	835.2	749.4	821.0	758.5	993.8	1,102.7	1,027.4	975.7
Sept.	297.6	447.5	455.7	555.1	586.1	570.4	559.6	741.4	754.9	672.4	736.2	841.9	1,068.3	1,001.5	866.6
Oct.	378.7	336.0	435.8	539.2	524.7	552.4	588.4	644.1	643.3	657.0	720.5	869.7	955.1	863.8	800.9
Nov.	316.6	345.7	384.6	517.8	496.5	479.5	494.7	549.4	562.2	617.8	693.0	779.0	1,059.3	809.0	713.8
Dec.	286.4	320.9	408.6	510.4	498.3	490.2	514.1	459.1	504.0	576.3	730.6	832.1	672.3	755.0	708.6
Annual pumpage	1,279.3	4,260.4	4,962.5	6,149.8	6,641.5	6,498.3	6,738.1	7,382.3	7,424.7	7,876.6	8,531.0	9,551.4	10,823.6	10,222.3	9,246.4
Average daily pumpage	10.5	11.7	13.6	16.9	18.2	17.8	18.5	20.2	20.3	21.6	23.4	26.2	29.7	28.0	25.3
Annual pumpage, in thousand acre-feet	3.9	13.1	15.2	18.9	20.4	20.0	20.7	22.7	22.8	24.2	26.2	29.3	33.2	31.4	28.4

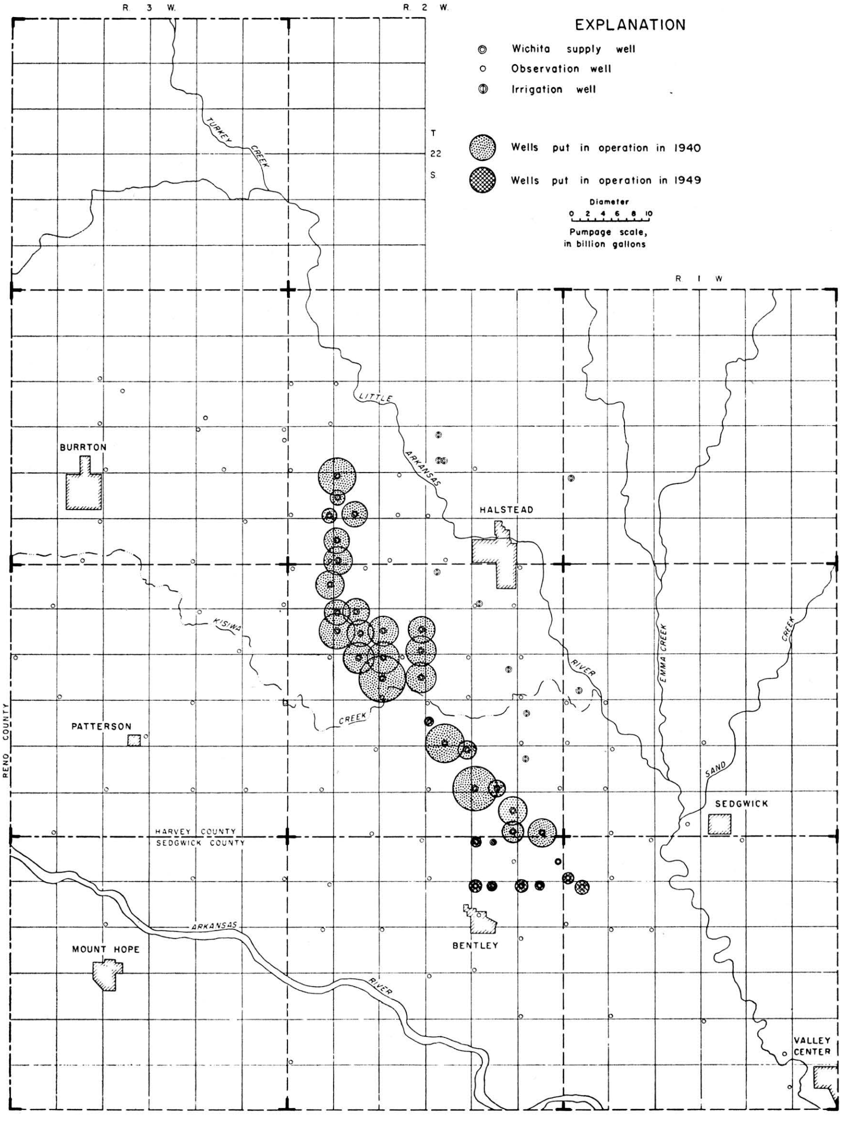

FIG. 4.—Water pumped from each well in well field by city of Wichita, 1940-54.

Center, 200,000 gallons. The total average use of water by these six municipalities was 3,079,000 gallons per day, or 1,122,000,000 gallons per year (3,460 acre-feet).

The daily use by these cities increased substantially during the decade preceding 1955. The increase in use in these cities was caused by increased domestic and commercial use. In Newton, which is just east of the well field as shown in Figure 2, use of water for ordinary purposes has increased but total usage has increased very little because the Atchison, Topeka and Santa Fe Railway is now using diesel locomotives and does not need the large quantities of water formerly used for the operation of steam locomotives.

Domestic and irrigation pumpage.—About 175,000 gallons of ground water a day, or a total of 64 million gallons, was used during 1954 for rural domestic and stock use in the well-field area.

By the end of 1954, 10 irrigation wells in the well field were in operation or under construction. About 900 acres was being irrigated with water from wells. Based on estimates by the owners, tenants, and the Soil Conservation Service, the amount of irrigation water pumped from wells during 1954 was about 700 acre-feet (228 million gallons). Some irrigation wells were completed late in 1954 and used only small quantities of water in that year. Three irrigators southeast of Halstead use surface water from Little Arkansas River to irrigate about 120 acres. The quantity of water used in 1954 from the river was about 100 acre-feet.

OBSERVATION-WELL PROGRAM

An observation-well program was started in the Equus beds area in 1937. Some original observation wells have been replaced, and many new wells have been added since 1937. As of January 1955, there were 223 observation wells in the well-field area, most of which are measured monthly. Some wells are measured more frequently than monthly, but others, only quarterly. Three wells are equipped with automatic water-stage recorders, which furnish a continuous record of water-level fluctuations.

The records obtained from these observation wells are published annually by the U. S. Geological Survey in the series of water-supply papers entitled "Water levels and artesian pressures in observation wells in the United States." The numbers of these water-supply papers are as follows:

Year	Water-Supply Paper No.	Year	Water-Supply Paper No.
1935	777	1944	1018
1936	817	1945	1025
1937	840	1946	1073
1938	845	1947	1098
1939	886	1948	1128
1940	908	1949	1158
1941	938	1950	1167
1942	946	1951	1193
1943	988	1952	1223
		1953	1267

The locations of wells for which data are being collected are shown on Plate 1. These wells include Wichita supply wells, observation wells, and irrigation wells. Data pertaining to the many domestic and stock wells in the area have not been included in this report.

The observation wells, except for the pumped wells of the city of Wichita, are chiefly 1¼-inch drive-point wells and are used only for measuring water levels. Near each Wichita supply well are two 1¼-inch observation wells, at distances of 100 and 500 feet, respectively.

Excepting 12 wells, the well numbers on Plate 1 are numbers that were originally assigned in the field. These numbers are the same numbers that are used in the annual series of water level reports issued by the U. S. Geological Survey. The numbers of 12 wells have been changed to agree with the numbers used by the city of Wichita. The 12 well numbers formerly used in the annual series of water-level reports and the numbers as changed in this report are as follows:

Number formerly used in water-supply papers	Number used by city of Wichita and in this report
M-4	3
M-3	4
M-8	7
M-9	8
M-11	9
M-20	11
M-7	15
M-15	16
M-16	17
M-17	18
M-18	19
M-19	20

Table 3 correlates the numbers used in this report with the numbers used by Williams and Lohman (1949). On Plate 1, a line below a well symbol indicates that there are 2 or 3 observation wells screened at different depths at that location.

TABLE 3.—*Correlation of well numbers used in this report with well numbers used in Bulletin 79, and depths of wells*

Well No. in this report	Well No. used in Bull. 79	Location	Depth of well, feet
*1	311	NW NW sec. 29-23-2	222
1a	312	do	71
1b	313	do	69
*2	314	NW SW sec. 29-23-2	234
2a	315	do	67
2b	316	do	68
*3	322	SE SE sec. 30-23-2	234
3a	323	do	69
3b	324	do	69
*4	317	SE SW sec. 29-23-2	238
4a	318	do	66
4b	319	do	97
*5	330	NW SW sec. 32-23-2	237
5a	331	do	71
5b	332	do	59
*6	333	SW SW sec. 32-23-2	257
6a	334	do	51
6b	335	do	51
*7	415	SE NE sec. 6-24-2	257
7a	416	do	51
7b	417	do	54
*8	423	NW NW sec. 8-24-2	248
8a	424	do	51
8b	425	do	51
*9	429	SW NW sec. 8-24-2	227
9a	430	do	48
9b	431	do	48
*10	419	NE NW sec. 8-24-2	259
10a	420	do	51
10b	421	do	51
*11	426	NW SE sec. 8-24-2	248
11a	427	do	51
11b	428	do	51
*12	436	NW SW sec. 9-24-2	236
12a	437	do	69
12b	438	do	69
*13	459	NW NE sec. 17-24-2	245
13a	460	do	51
13b	461	do	51
*14	450	NW NW sec. 16-24-2	102
14a	451	do	50
14b	439	SW SW sec. 9-24-2	57
*15	455	NW SW sec. 16-24-2	122
15a	456	do	51
15b	457	SW NW sec. 16-24-2	51
*16	433	SE NE sec. 9-24-2	193
16a	434	do	67
16b	435	do	62
*17	440	SE SE sec. 29-24-2	193
17a	441	do	57
17b	442	do	56
*18	452	NE SE sec. 16-24-2	185
18a	453	do	51

TABLE 3.—*Correlation of well numbers used in this report with well numbers used in Bulletin 79, and depths of wells (continued)*

Well No. in this report	Well No. used in Bull. 79	Location	Depth of well, feet
18b	454	do	51
*19	465	SE SW sec. 22-24-2	158
19a	466	do	72
19b	467	do	63
*20	479	NE NE sec. 27-24-2	145
20a	480	do	60
20b	481	do	51
*21	473	SW SW sec. 26-24-2	80
21a	474	do	51
21b	475	do	51
*22	476	SW SE sec. 26-24-2	82
22a	477	do	51
22b	478	SE SW sec. 26-24-2	50
*23	487	SE NE sec. 35-24-2	204
23a	488	do	51
23b	489	do	51
*24	491	SE SE sec. 35-24-2	97
24a	492	do	54
24b	493	do	51
*25	494	SW SE sec. 36-24-2	189
25a	495	do	50
25b	567	NE NW sec. 1-25-2	51
*26	‡	SW NE sec. 22-24-2	195
26a	‡	SW NW sec. 22-24-2	81
26b	‡	do	79
*27	‡	NW NW sec. 2-25-2	215
27a	‡	NW NW 2-25-2	82
27b	‡	NE NE sec. 3-25-2	80
*28	‡	NE NW sec. 2-25-2	220
28a	‡	do	80
28b	‡	NW NE sec. 2-25-2	82
*29	‡	NW NW sec. 11-25-2	225
29a	‡	do	97
29b	‡	do	103
*30	‡	NE NW sec. 11-25-2	225
30a	‡	do	72
30b	‡	NW NE sec. 11-25-2	61
*31	‡	NW NW sec. 12-25-2	197
31a	‡	do	87
31b	‡	do	62
*32	‡	NE NW sec. 16-25-2	185
32a	‡	do	71
32b	‡	do	71
*33	‡	NE SE sec. 1-25-2	170
33a	‡	do	54
33b	‡	SE NE sec. 1-25-2	75
*34	‡	SW SW sec. 6-25-1	150
34a	‡	do	85
34b	‡	do	85
*35	‡	NE NW sec. 7-25-1	130
35a	‡	do	85
35b	‡	SE SW sec. 6-25-1	86
101	‡	NW cor. 18-23-2	75
102	‡	NE 24-23-3	68
103	‡	SW cor. sec. 19-23-2	72
104	‡	NW cor. sec. 23-23-3	81

TABLE 3.—*Correlation of well numbers used in this report with well numbers used in Bulletin 79, and depths of wells (continued)*

Well No. in this report	Well No. used in Bull. 79	Location	Depth of well, feet
105	‡	SE cor. sec. 18-23-2	60
106	‡	NW cor. sec. 36-23-3	62
107	‡	NW SW sec. 3-24-2	66
108	‡	NW cor. sec. 11-24-3	38
109	‡	NE cor. sec. 22-24-3	38
110	‡	SW cor. sec. 25-24-3	37
111	‡	SE cor. sec. 2-24-2	42
112	‡	SE cor. sec. 25-24-2	40
113	‡	NW cor. sec. 29-24-1	29
114	‡	NE cor. sec. 7-25-2	32
115	‡	NW cor. sec. 22-25-2	32
116	‡	NW cor. sec. 17-25-1	30
117	‡	SW cor. sec. 20-25-1	38
12	557	NW SE sec. 26-25-1	54
307	568	NW SW sec. 1-25-2	91
506	309	NW NE sec. 28-23-2	44
507	310	do	139
810	563	NE SE sec. 35-25-1	25
812	558	NW cor. sec. 27-25-1	25
815	549	NE cor. sec. 17-25-1	31
816	544	SW cor. sec. 7-25-1	31
817	411	NW cor. sec. 1-24-2	31
821	414	NW cor. sec. 6-24-2	19
824	404	SE cor. sec. 22-24-1	42
825	538	NE cor. sec. 3-25-1	25
826	540	NE cor. sec. 5-25-1	18
830	582	SW cor. sec. 30-25-2	57
832	401	NE cor. sec. 19-24-1	129
833	403	SW cor. sec. 19-24-1	57
834	583	SW cor. sec. 9-25-3	18
839	486	NE cor. sec. 35-24-2	27
840	572	NE cor. sec. 9-25-2	61
842	575	NW cor. sec. 16-25-2	15
853	445	NW cor. sec. 13-24-2	37
854	305	SW cor. sec. 23-23-2	32
870	578	NW NE NE sec. 18-25-2	19
872	327	SE cor. sec. 31-23-2	50
873	328	SE cor. sec. 31-23-2	63
874	329	do	201
875	354	SE cor. sec. 17-23-3	13
876	355	do	246
877	356	do	47
878	496	SE cor. sec. 1-24-3	45
879	497	do	241
880	502	SE cor. sec. 11-24-3	15
881	503		57
883	470	NW cor. sec. 26-24-2	38
884	471	NW cor. sec. 26-24-2	60
885	472	do	99
886	886	NE NE NW sec. 16-24-2	57
887	887	NE NE NW sec. 16-24-2	111
888	299	NW cor. sec. 17-23-2	12
889	300	NW cor. sec. 17-23-2	151
890	511	NE SE SE sec. 21-24-3	......
891	516	SE cor. sec. 31-24-3	7
892	517	do	106

TABLE 3.—*Correlation of well numbers used in this report with well numbers used in Bulletin 79, and depths of wells (concluded)*

Well No. in this report	Well No. used in Bull. 79	Location	Depth of well feet
893	518	do	163
894	462	NE cor. sec. 18-24-2	59
895	463	do	238
1053 B	353	SW NE NW sec. 16-23-3	37
1171	570	NE cor. sec. 4-25-2	20
1172	482	SW cor. sec. 27-24-2	32
1173	483	NE cor. sec. 29-24-2	26
1174	407	SW cor. sec. 32-24-1	32
1175	406	SE cor. sec. 30-24-1	32
1176	541	SW cor. sec. 5-25-1	32
1179	408	SE NW SE sec. 33-24-1	32
1186	446	SW cor. sec. 13-24-2	21
1187	402	NW cor. 19-24-1	39
1188	464	NE cor. sec. 21-24-2	21
1189	458	SW cor. sec. 16-24-2	21
1190	444	NE cor. sec. 15-24-2	60
1191	308	SW cor. sec. 27-23-2	27
1193	363	SE NE NE sec. 24-23-3	23
1194		NE SW SW sec. 14-23-3	21
1196	514	SE cor. sec. 27-24-3	19
2072		NE NW sec. 5-24-2	46
2084	447	SE cor. sec. 15-24-2	30
2088	‡	NW cor. sec. 22-24-2	......
3001	‡	SW cor. sec. 30-23-2	47
3002	‡	SW SE SE sec. 30-24-2	20
3003	‡	SW SE SE sec. 32-24-2	20
3004	‡	SE cor. sec. 1-25-3	20
3005	‡	SE SW sec. 28-23-2	68
3030	‡	SW NW SW sec. 11-25-2	30
3031	‡	NE cor. sec. 24-24-3	26
3032	‡	SW cor. sec. 24-24-2	48
3033	‡	SW cor. sec. 2-24-2	44
3034	‡	SW cor. sec. 28-24-3	20
3035	‡	SE cor. sec. 34-23-3	28
3036	‡	SE SW SE sec. 23-23-3	40
3037	‡	NE NW NE sec. 5-24-2	70
3038	‡	SE SW SW sec. 33-23-2	70
3039	‡	SW SE sec. 34-23-2	37
3041	‡	SE cor. sec. 3-25-3	17
3044	‡	SW cor. sec. 14-25-2	20
3045	‡	SW NW NW sec. 13-25-2	65
3050	‡	SW cor. sec. 24-25-2	20
P27	509	NW cor. sec. 18-24-3	71
P27a	510	do	157
P28	500	SE cor. sec. 6-24-3	61
P28a	501	do	97
P29	369	SW SE sec. 32-23-3	42
P29a	370	SW SE sec. 32-23-3	100
P30	367	NE cor. sec. 32-23-3	88
P30a	368	do	128
P31	360	SW cor. sec. 21-23-3	40
P31a	361	do	66
P32	347	SE cor. sec. 8-23-3	35
P32a	348	do	86
P34	344	NW cor. sec. 4-23-3	79
P34a	345	do	127
P35	507	SW cor. sec. 17-24-3	62
P35a	508	do	136

*Wichita supply well.
‡Constructed since well tabulation in Bulletin 79.

SUMMARY OF GEOLOGY*

The geology of the Equus beds area has been described by Haworth and Beede (1897), Lohman and Frye (1940), Williams and Lohman (1949), and Frye and Leonard (1952). Adjoining areas in which the geology has been described include the vicinity of Hutchinson (Williams, 1946), Rice County (Fent, 1950), and Reno County (Bayne, report in preparation). The reader is referred to the published reports for further discussion of the geology. A generalized geologic map of the Equus beds area is shown in Figure 2.

The bedrock underlying the Equus beds area comprises the Wellington formation and Ninnescah shale, of Permian age, and the Kiowa shale of Cretaceous age. The part of the Wellington formation that crops out in this area consists dominantly of soft calcareous gray and bluish-gray shale containing several thin beds of argillaceous limestone and gypsum (Williams and Lohman, 1949, p. 40). Some beds of maroon and green shale occur near the top of the formation. Salt is not exposed in this area, but it is known to underlie the western part. The Wellington formation yields small quantities of water to wells in the area southeast of Lindsborg, near Newton, and east and northeast of Wichita. No large supplies of water are available from the Wellington formation, owing to the physical character of the rocks comprising it.

In the northwestern part of the Equus beds area the Wellington formation is overlain by the Ninnescah shale. The Ninnescah shale is a soft to hard brick-red shale (Williams and Lohman, 1949, p. 43). It has a maximum thickness of about 275 feet and contains some thin beds of gray and green shale, thin argillaceous limestone, and gypsum. The Ninnescah shale yields meager supplies of strongly mineralized water to farm wells.

In the northeastern part of the Equus beds area the Wellington formation and Ninnescah shale are overlain by Kiowa shale. The Kiowa shale has a maximum thickness of about 120 feet and consists of dark-gray to black gypsiferous shale, gray to buff sandy shale, soft crossbedded sandstone, and thin fossiliferous limestones. The Kiowa shale yields small supplies of hard water to domestic and stock wells and to small springs.

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*This report is a cooperative product of the U. S. Geological Survey and the State Geological Survey of Kansas. The classification and nomenclature of the rock units accord for the most part with those of the two surveys, but it differs somewhat from that of the U. S. Geological Survey.

During early Pleistocene time, a stream flowing from a point near Lindsborg southward past McPherson and Wichita incised a wide, deep valley in the Cretaceous and Permian rocks and in the Pliocene Ogallala formation (Frye and Leonard, 1952, p. 94). This valley was referred to as the McPherson Valley by Williams and Lohman (1949, p. 59). The McPherson Valley was joined at a point southwest of the Wichita well field by a large tributary valley, which paralleled the present Arkansas River. The McPherson Valley was filled during Pleistocene time with gravel, sand, silt, clay, and some volcanic ash. These deposits are a part of the Pleistocene Blanco, Meade, and Sanborn formations (Fig. 5).

The Ogallala formation (called the Delmore formation by Williams and Lohman, 1949, p. 40, pl. 1) crops out in a small area in the northeastern part of the Equus beds area. The material comprising the Ogallala formation is fine grained and poorly sorted compared with other unconsolidated deposits in this area, and only comparatively small quantities of moderately hard water are available from the formation.

Although not shown in Figure 5, some of the coarse gravel and sand overlying the Permian Wellington formation in the deeper

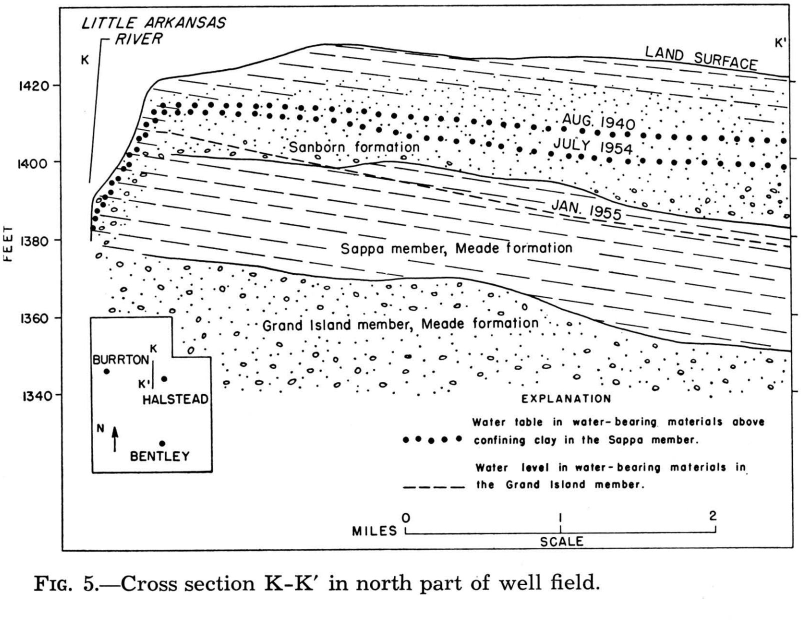


FIG. 5.—Cross section K-K′ in north part of well field.

channels probably represents the Blanco formation. The Blanco formation, if present, is overlain by the Meade formation (Frye and Leonard, 1952, p. 99), which consists of two members—the Grand Island member, which overlies the Blanco formation, and the Sappa member, which overlies the Grand Island member in part of the area. The Grand Island member is composed of gravel, sand, silt, and clay and yields most of the ground water obtained from the Equus beds area. The Sappa member is composed chiefly of silt and clay, and in the northern part of the well field the Sappa member confines the ground water in the underlying Grand Island member. The approximate boundary of the Sappa member in the well field is shown in Figure 6. The Sappa member yields no water to wells.

The Meade formation is overlain in much of the area by the Sanborn formation. The Sanborn formation has the Crete sand and gravel member at the base and Peoria silt member at the top. The Crete sand and gravel member yields moderate supplies of water to wells, and in the northern part of the Wichita well field the water body in the Sanborn formation is semiperched above the Sappa member of the Meade formation.

Recent alluvium and Wisconsinan deposits occur in the Arkansas River valley and in the Little Arkansas River valley. In the Arkansas River valley the deposits are composed of unconsolidated gravel, sand, and silt and have a high permeability. The deposits in the Little Arkansas River valley are composed of silt, clay, sand, and gravel. In general, these deposits are thin and have a low to medium permeability.

Sand dunes, probably Wisconsinan and Recent in age, extend over a wide belt northwestward from Little Arkansas River northeast of Burrton. These sand dunes are in the northwest part of the well field and form the only prominent topographic relief in this part of the Equus beds area (Williams and Lohman, 1949, p. 70). The sand dunes have a high permeability, and they absorb large amounts of precipitation. No large supplies of ground water have been developed in the area underlain by sand dunes, but they unquestionably help to recharge the deposits below.

GROUND-WATER HYDROLOGY

Before water was discharged from wells in the Equus beds area, the average rate of natural discharge of ground water was equal to

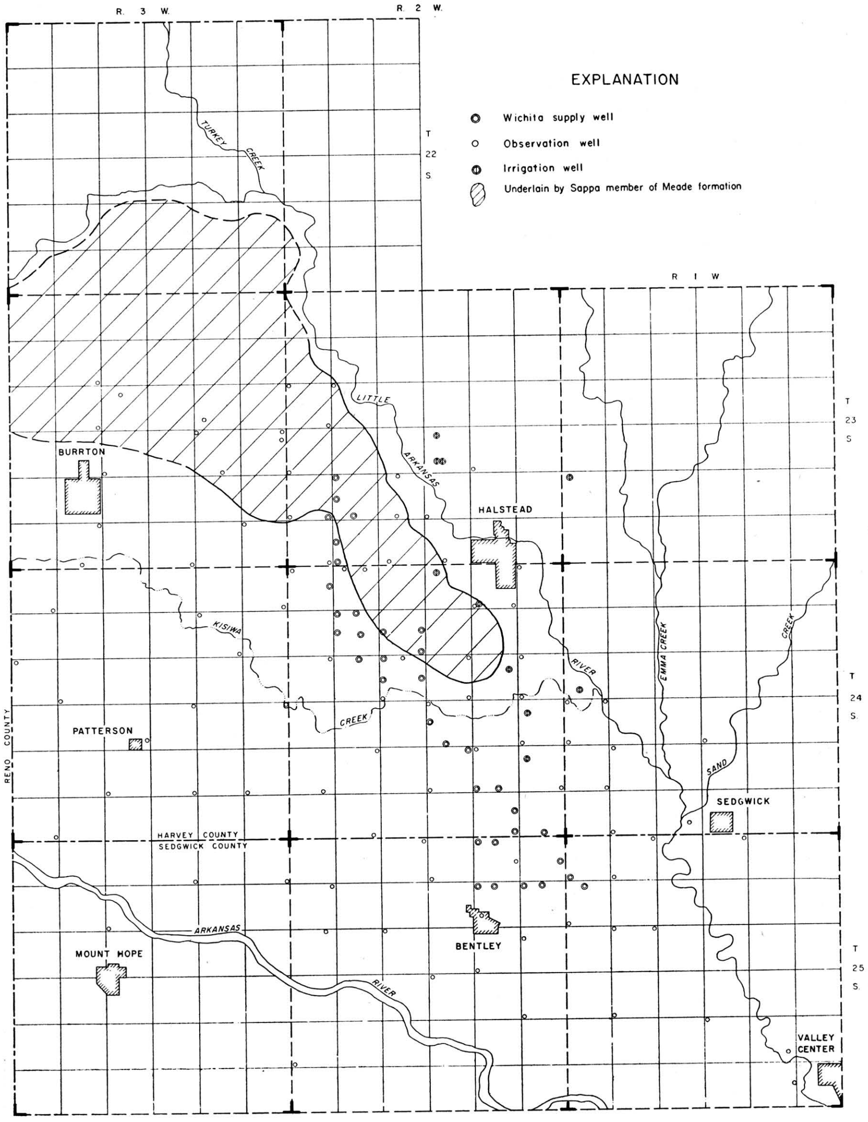


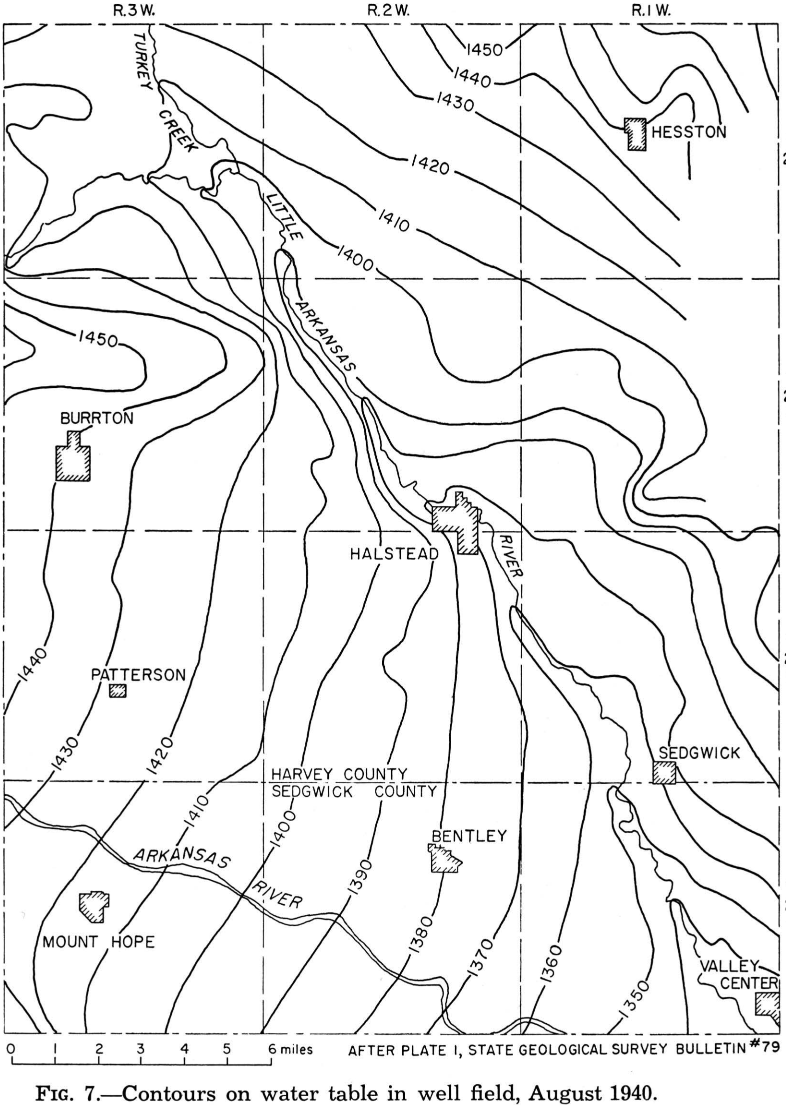
FIG. 6.—Map of well field showing area underlain by Sappa member of Meade formation.

the average rate of recharge. Small changes in the quantity of water in an aquifer, and accompanying changes in water level, occur as the result of temporary unbalance between discharge by natural processes and recharge, but such fluctuations balance each other over a period of years and the water table under such conditions is in a state of approximate equilibrium. Discharge by wells is a new discharge superimposed upon a previously stable system, and it must be balanced by an increase in the recharge to the ground-water reservoir, by a decrease in natural discharge, by a reduction of storage, or by a combination of these. Pumping from wells generally diverts ground water that otherwise would discharge elsewhere. Whether the diversion results in a higher beneficial use of the water depends on the purpose served by the water under natural conditions.

MOVEMENT OF GROUND WATER

Ground water in the Equus beds area is a transient resource. The water is derived from precipitation falling on the land surface, and, if the water is not used, it slowly moves out of the area and is replaced by new ground water. Before pumping started in 1940, the ground water in the well field was moving east toward Little Arkansas River, as shown in the water-table contour map in Figure 7. At any point on such a map, the water moves down the gradient, perpendicular to the adjacent contour. Water-table contours as of January 1, 1955, are shown in Figure 8. As of January 1, 1955, the water was still moving toward Little Arkansas River, but the contours in the areas of heavy pumping have been deflected by the lowering of the water table.

The average rate of movement of the ground water through the well field is about 2 feet a day. Williams and Lohman (1949, p. 214) estimated that prior to 1940 about 5.3 million gallons a day was moving across the boundary of the well field. The part of the ground water moving to the east that is not discharged through wells or by evaporation and transpiration is discharged as base flow into Little Arkansas River. The seepage of ground water into the river constitutes the streamflow during drought periods. The water-table contours in Figure 8 are not in sufficient detail to measure the difference in the amount of water moving into and out



AFTER PLATE I, STATE GEOLOGICAL SURVEY BULLETIN #79

FIG. 7.—Contours on water table in well field, August 1940.

of the well field or the amount of ground water that would have been discharged by seepage into Little Arkansas River had it not been intercepted by pumping. Also, the extent to which reduction of seepage into the stream has affected the discharge of Little Arkansas River is not apparent from a hydrograph of the stream. A

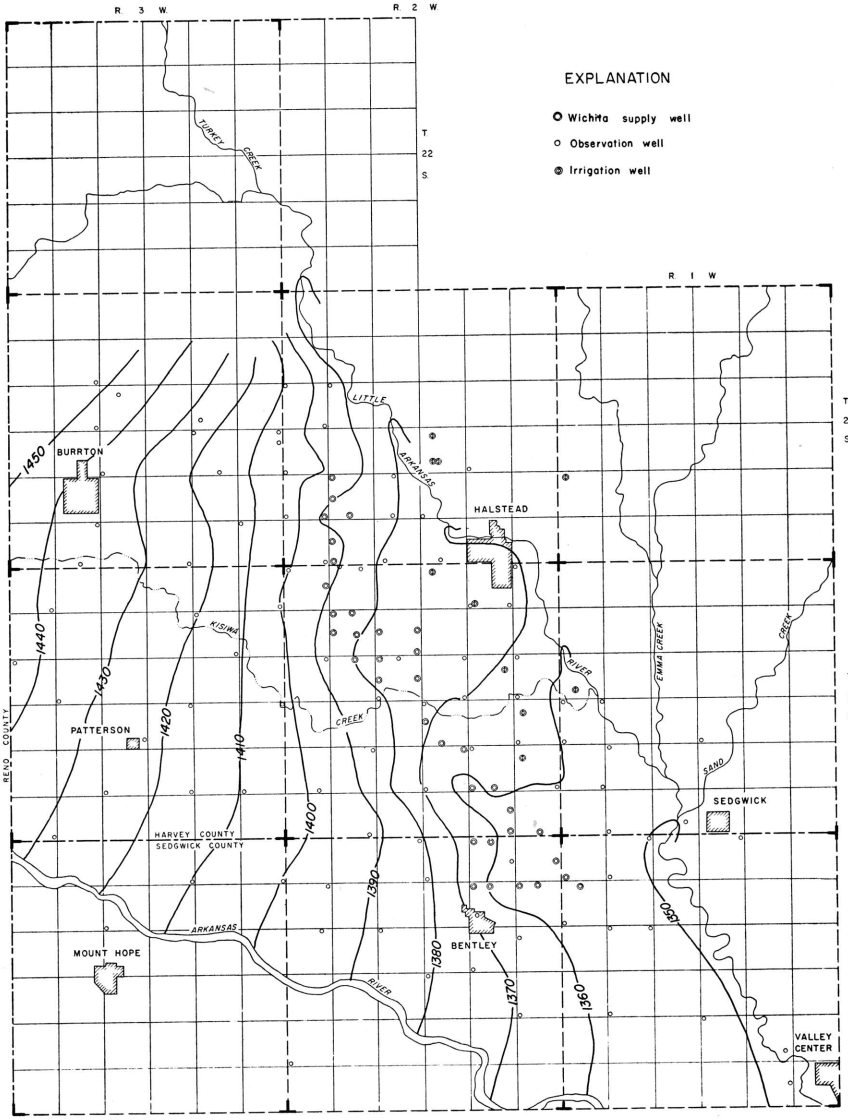


FIG. 8.—Contours on water table in well field, January 1, 1955.

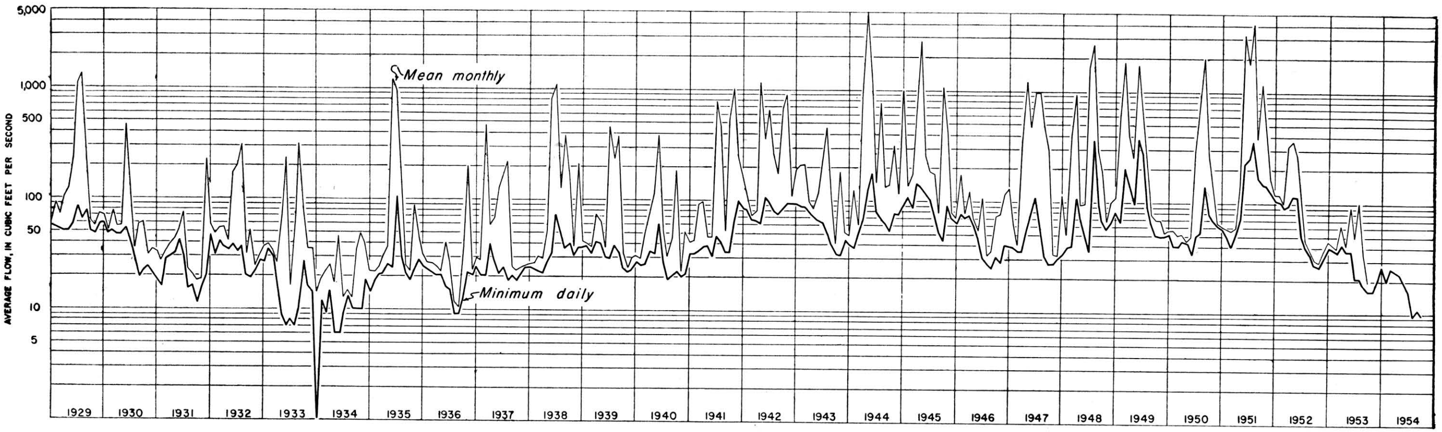


FIG. 9.—Hydrograph of discharge of Little Arkansas River at Valley Center, 1929-1954.

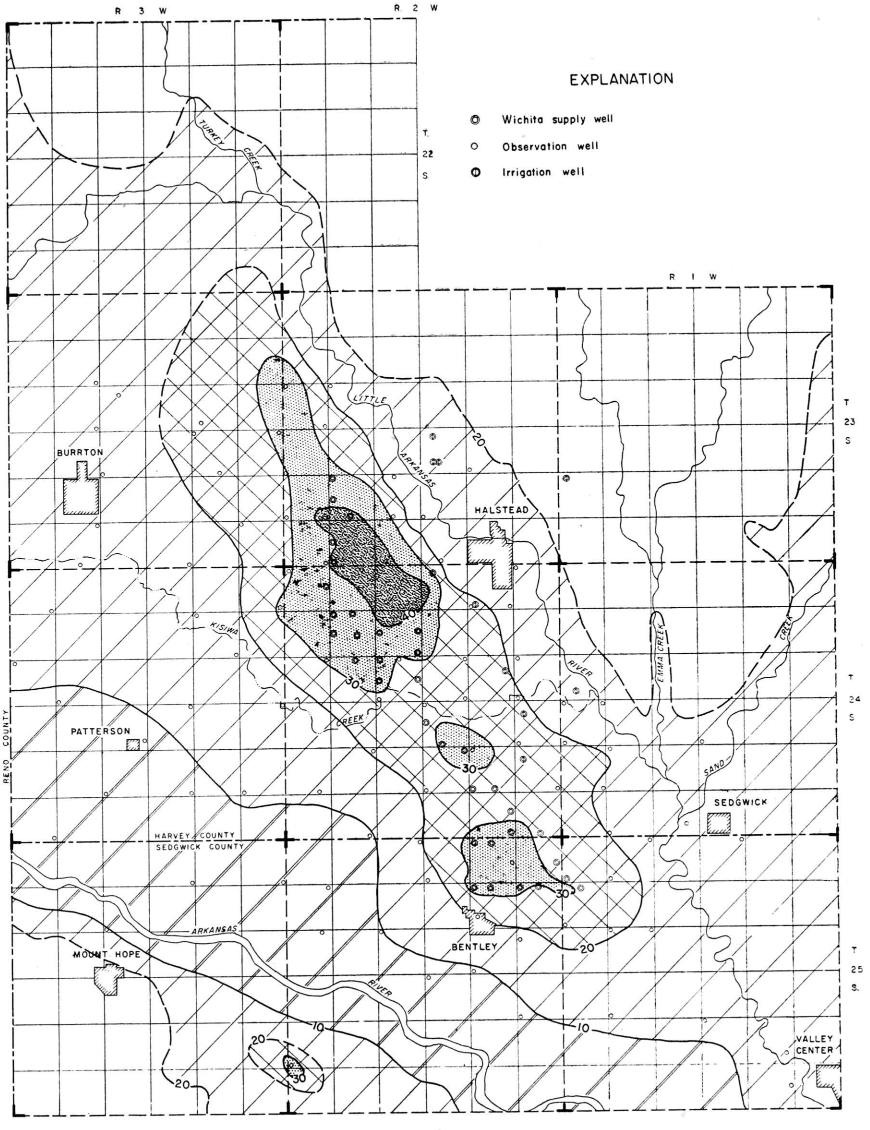


Fig. 10.—Depth to water in well-field area, January 1, 1955.

hydrograph of the discharge of the river is shown in Figure 9 for the period 1929 through October 1954. The hydrograph does show that there were periods prior to 1940 in which the discharge was lower than it was at the end of October 1954.

DEPTH TO WATER LEVEL

In 1940, before pumping started, the depth to water level in most of the well field ranged from 5 to 20 feet below the land surface (Williams and Lohman, 1949, pl. 5). By January 1, 1955, the depth to water level ranged from 5 to 47 feet (Fig. 10). The maximum lowering of the water table since 1940 has been 32 feet. The amount of lowering of the water table along profiles E-E′ and G-G′ is shown in Figure 11.

The unconsolidated water-bearing deposits of sand, gravel, clay, and silt in the well field are stratified in most places, and water levels in wells vary with the depth of the wells. Figure 12 shows the hydrographs of three wells (875, 876, and 877) at the

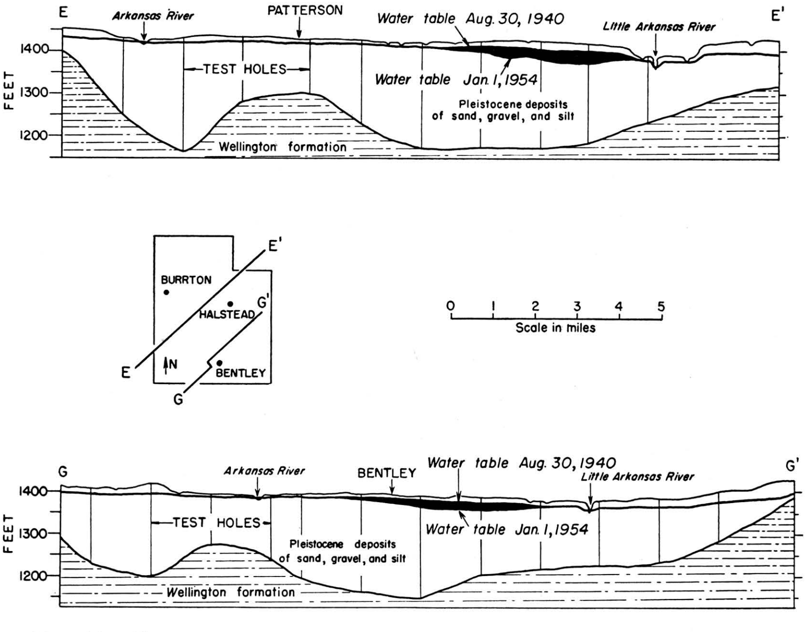


FIG. 11.—Cross sections E-E′, and G-G′, showing decline of water table from August 30, 1940, to January 1, 1955. Modified from Williams and Lohman, 1949.

same location screened at different depths. In these wells, the deeper the well, the lower the water level. In some other parts of the well field, the water levels in wells screened at different depths stand at about the same level. Wells 886 and 887, which are 57 and 111 feet deep, respectively, have about the same depth to water level.

In the well field, clay and silt zones occur throughout the water-bearing reservoir. Generally these interbedded layers of

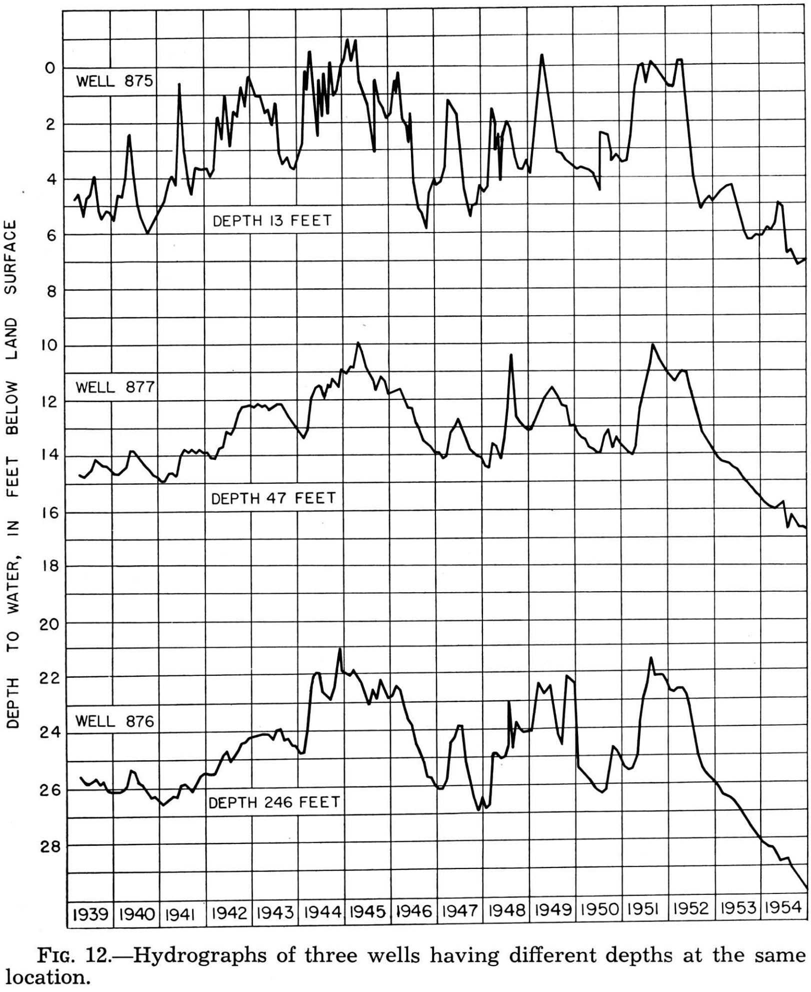


FIG. 12.—Hydrographs of three wells having different depths at the same location.

clay and silt are not extensive, and semiperched water is of local extent.

In the northern part of the well field, as shown in Figure 5, the Sappa member of the Meade formation acts as a leaky confining bed to the water contained below it. Water levels in wells terminated above and below the Sappa member stand at different levels. The static head of the water in the Grand Island member of the Meade formation is lower than that of the semiperched water in the Sanborn formation above it.

Observation wells must be carefully selected in the northern part of the well field if they are to show the effects of the Wichita pumping. The water levels in wells terminating in the Sanborn formation have declined only a small amount, whereas the water levels in deeper wells penetrating the Grand Island member have been directly affected by the Wichita pumping and have declined many feet. The water-table contour map for 1940 prepared by Williams and Lohman (1949, pl. 1) was based partly on data collected from wells terminating in the Sanborn formation. Hence, a map showing water-level change based on the original map gives an erroneous picture in the northern part of the well field. The maximum error in the original water-level-change map caused by using the wells in the Sanborn formation is about 10 feet.

FLUCTUATIONS OF THE WATER TABLE

General Considerations

The water table, shown by means of contours in Figures 7 and 8, does not remain static but fluctuates much like the water level of a surface reservoir. Whether the water table rises or declines depends upon the amount of recharge into the ground-water reservoir and the amount of discharge from it. When the inflow exceeds the draft, the water table rises; conversely, when the draft exceeds the inflow into the ground-water reservoir the water table declines. The amount of precipitation that descends to the zone of saturation is the principal factor that controls the rise of the water table. Pumping from wells, discharge from seeps and springs, and evaporation and transpiration are the principal factors that cause a decline in the water table. The fluctuations of the water table in the Equus beds area were determined by observing the water levels in wells.

Relation to Precipitation

Of the total precipitation, a part runs off directly at the land surface to streams, a part is dissipated by evaporation, a part is transpired by plants from the zone of soil moisture, and a part percolates downward to the zone of saturation. The fluctuations of water levels in nine wells not affected by pumping are shown by Figures 13 and 14. From 1940 to 1951, precipitation in the Wichita area was above average and the trend of the water levels was generally upward during that period. During the years of greatest precipitation the water levels rose sharply to high levels, and during dry periods they declined sharply. From 1952 to 1955, precipitation was below normal, and, accordingly, the water levels declined during that period.

In Figures 15 and 16 are shown precipitation, cumulative departure from average precipitation, and hydrographs of well 877 for 1951 and 1952. In 1951 the precipitation was considerably above normal, and as a result the water level in well 877 was about 2.5 feet higher at the end of the year than at the beginning of the year. In 1952 the precipitation was below normal, and the water level declined to a level slightly lower than at the beginning of 1951. The fluctuations of well 877 were not affected by pumping and represented only natural fluctuations.

Relation to Pumping

When water is pumped from a well, the water level in and around the well is lowered, the greatest amount of lowering being at the pumped well. The lowering of the water level by pumping is called drawdown. The area in which drawdown occurs is called the cone of depression. The greater the pumping rate in a given well, the greater the drawdown. A simplified cross section of a cone of depression is shown in Figure 17. The shape of the cone is determined principally by how easily water flows through the water-bearing formation. A well pumping a given quantity of water from a very permeable formation will have less drawdown than a well pumping from a less permeable formation. Continued pumping gradually lowers the water level, and the effects of the pumping can be observed at increasingly greater distances. The cone of depression must expand because the water level in the formation

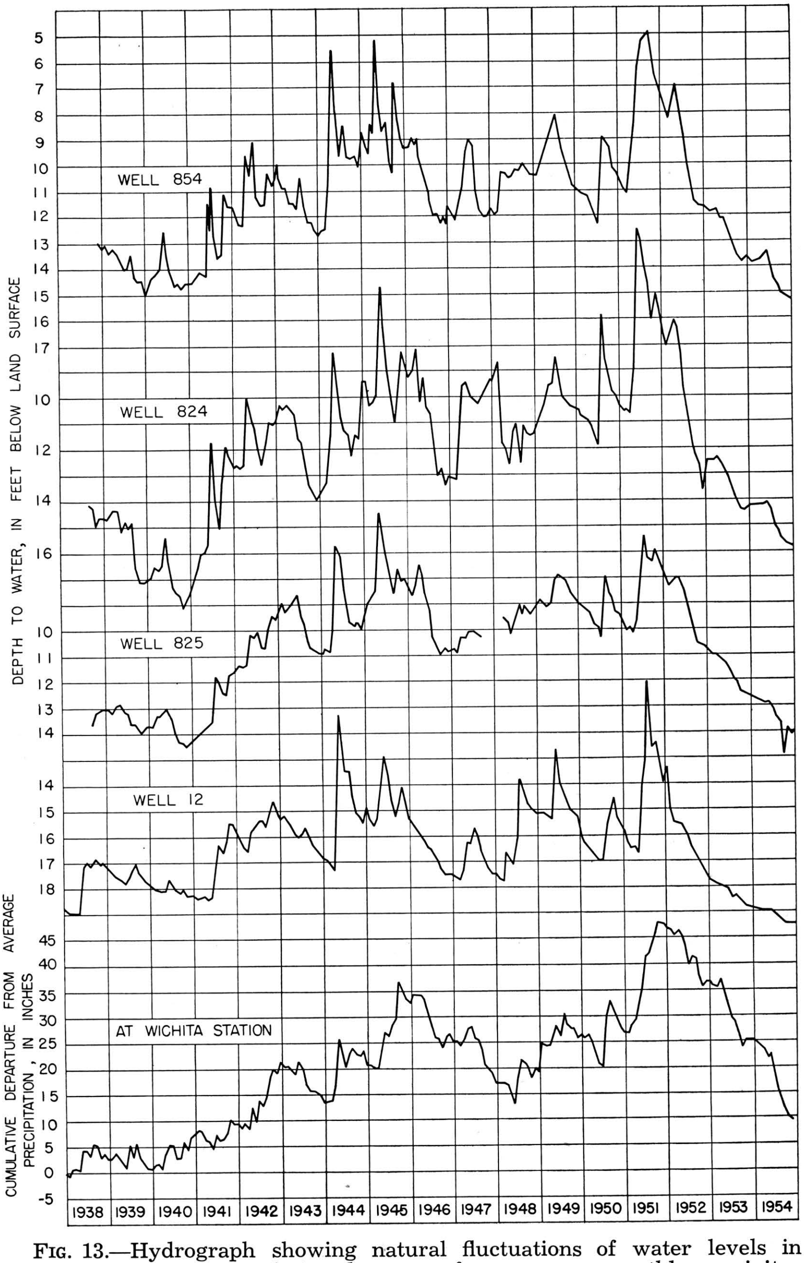


FIG. 13.—Hydrograph showing natural fluctuations of water levels in well-field area and cumulative departure from average monthly precipitation at Wichita.

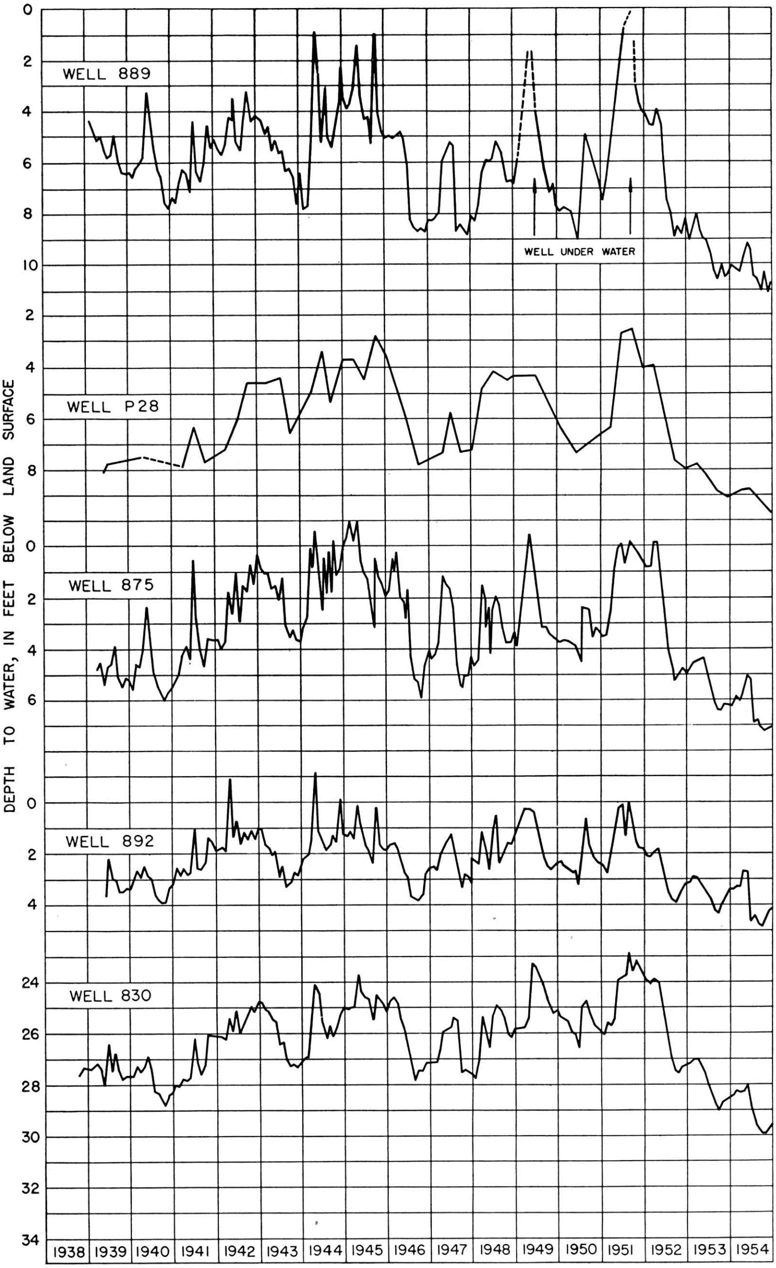


FIG. 14.—Hydrographs showing natural fluctuations of water levels in well -field.

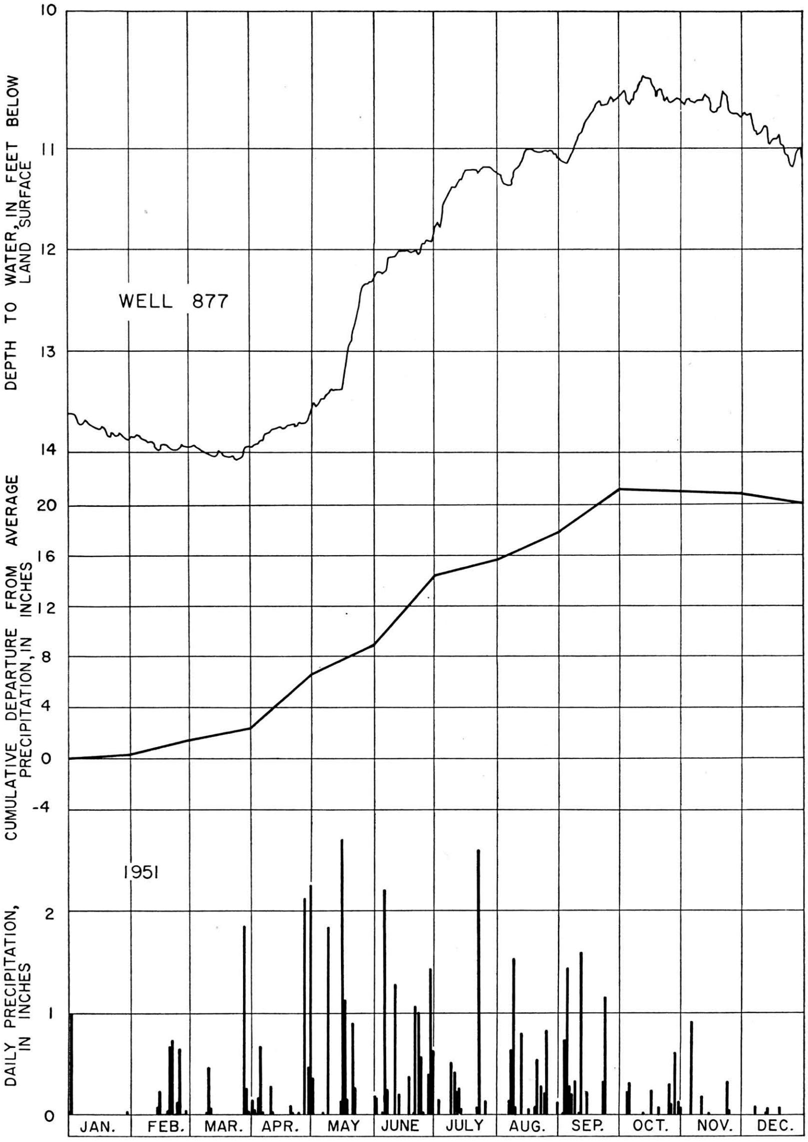


FIG. 15.—Hydrograph of well 877, daily precipitation at Wichita, and cumulative departure from average precipitation, 1951.

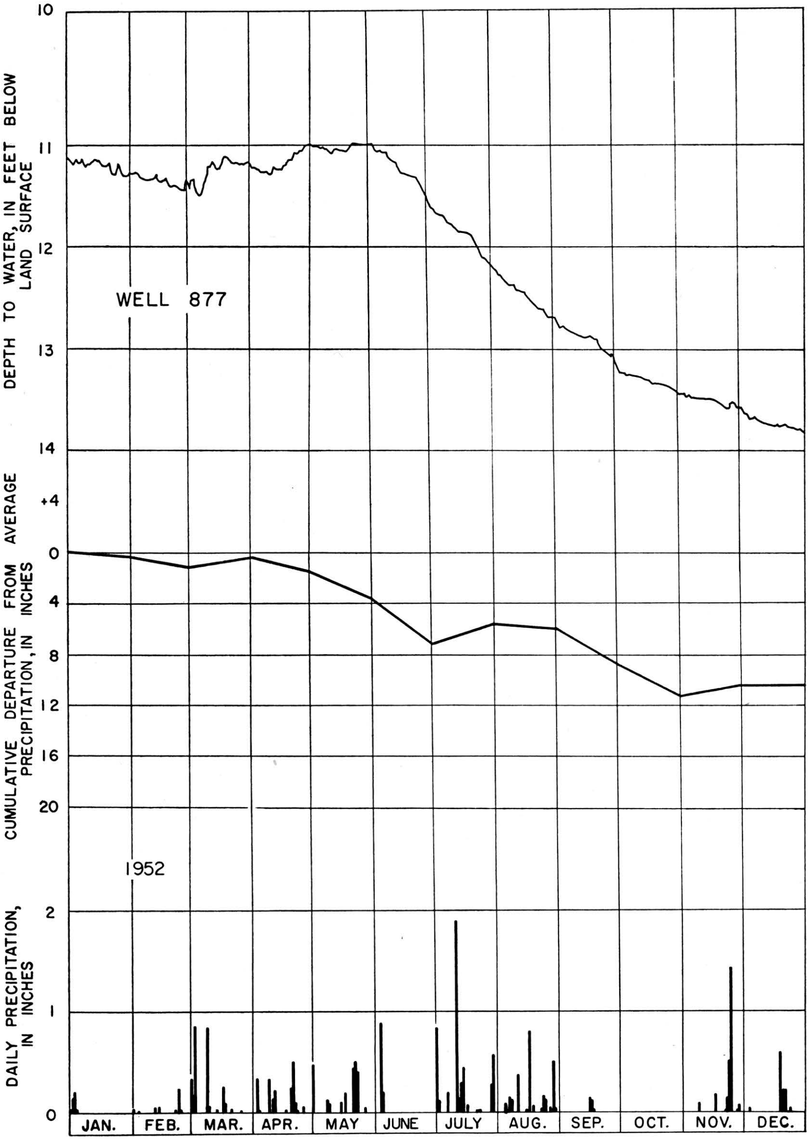


FIG. 16.—Hydrograph of well 877, daily precipitation at Wichita, and cumulative departure from average precipitation, 1952.

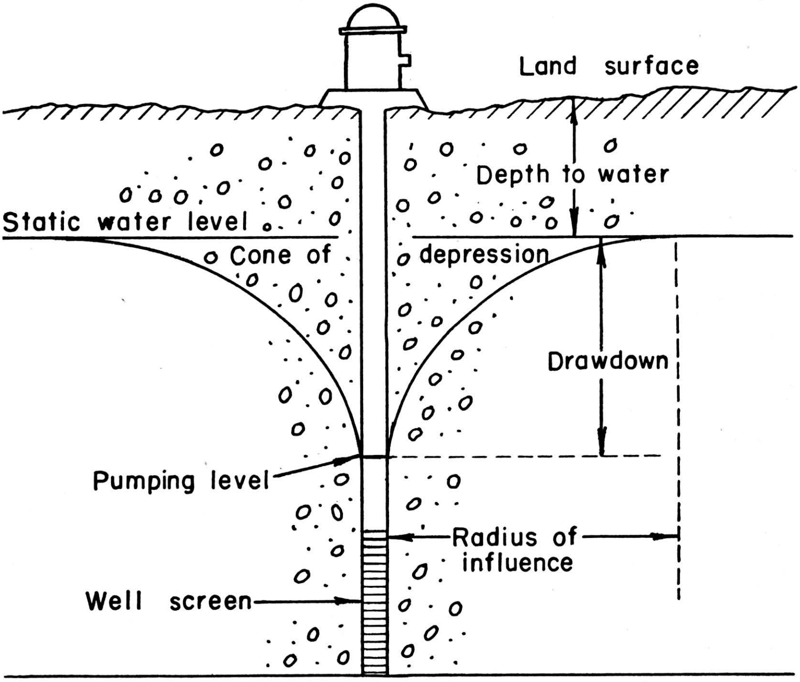


FIG. 17.—Schematic cross section through a cone of depression.

must slope so that water can move toward the well. If the water is coming from storage in the formation, the water level declines steadily, though at a decreasing rate. If the water begins to come from an area of replenishment, the water level may stop declining and approach equilibrium. Before the water level can reach a state of near equilibrium, it must decline so that an amount of water equal to that being pumped can move to the well from the area of recharge. When pumping by the city of Wichita began in 1940, the water level declined rapidly in and near the pumped wells. At that time most of the water was pumped from storage. As pumping continued, the rate of decline of the water level became slower, and in some periods of heavy recharge the water level rose. In part of the area, however, water was still being taken from storage during the periods that water was being replenished by infiltration of water from precipitation.

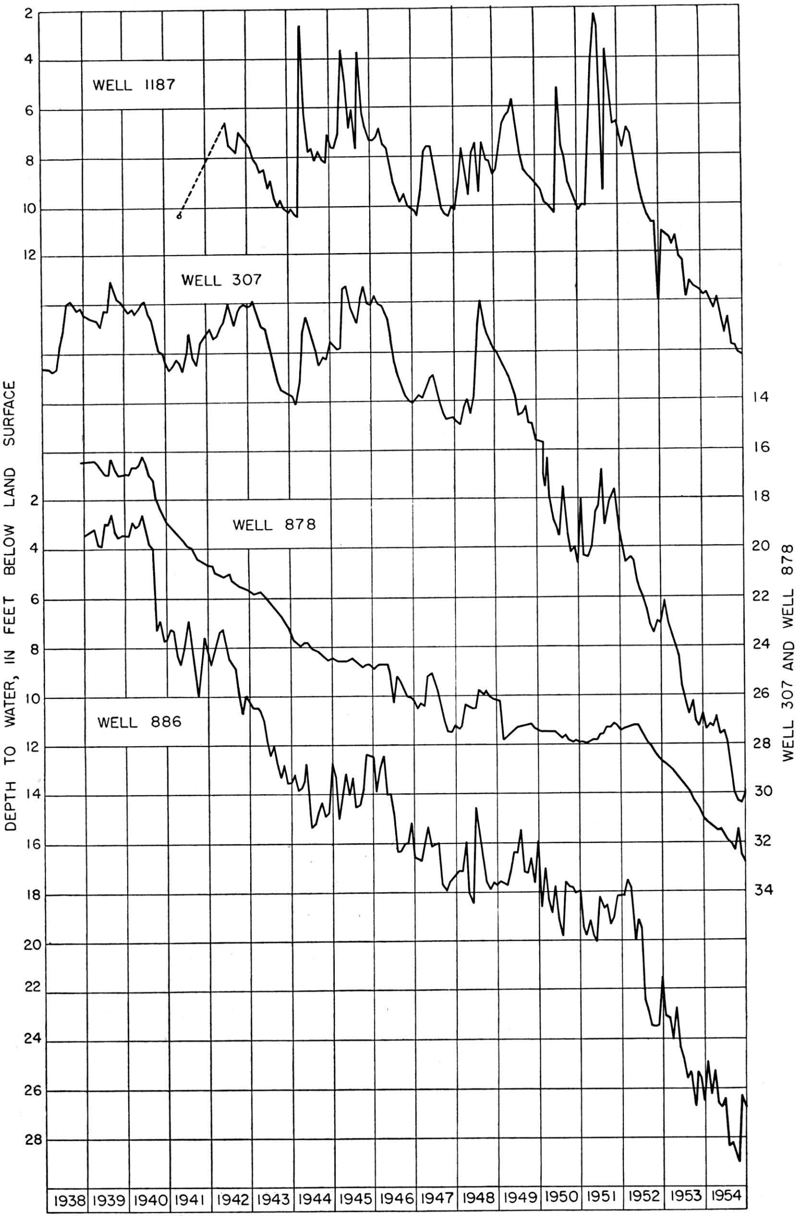


FIG. 18.—Hydrographs of wells at different distances from pumped wells.

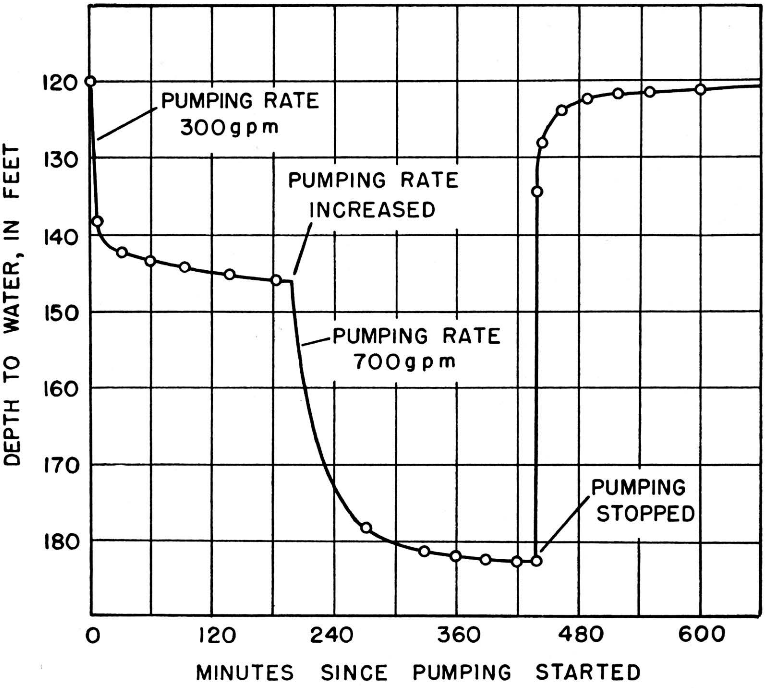


FIG. 19.—Drawdown and recovery of water level in pumped well.

Hydrographs of wells at different distances from the pumped wells are shown in Figure 18. The graphs are arranged so that those showing the least drawdown are near the top. This is in the order of their distance from the nearest pumped well. The rate of decline in a well due to a given rate of pumping becomes progressively slower, as shown in Figure 19. If the pumping rate is increased, the rate of decline also will increase. If two pumped wells are near each other, the cones of depression of the two wells will overlap. Consequently, the drawdown in both wells will be more than if only one well had been pumping. Mutual interference between two wells is shown in Figure 20.

When a well is turned off, water continues to flow toward the well because of the hydraulic gradient in that direction, and after pumping ceases, the water level in the well recovers. The rate of recovery becomes progressively slower. In time, the water levels

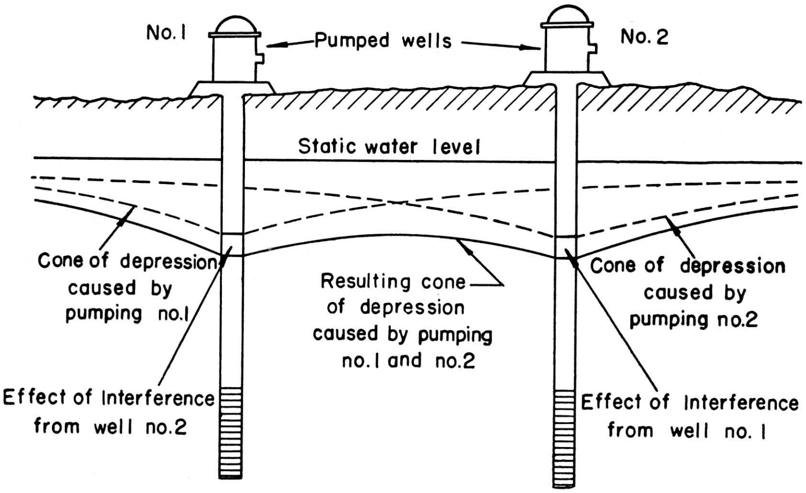


FIG. 20.—Schematic diagram of mutual interference between two wells.

equalize over the area affected by pumping, and the water table tends to assume its original position, but it may be lower than before water was withdrawn. If the water level after recovery is lower than it was prior to pumping, there was a net withdrawal of water from storage that was not replenished by recharge.

In the Wichita well field, the effect of pumping from many wells is a large, complex cone of influence, and the water levels in observation wells are perpetually fluctuating. Wells in the field are turned on and off periodically to distribute the pumping effect over the field. The fluctuations of water levels in three observation wells centrally located in the three heavily pumped areas of the well field are shown in Figure 21. The wells are respectively in the northern (6b), central (14b), and southern (24b) parts of the well field. These three hydrographs show a general decline of the water level. The water level in well M14b has shown the greatest decline of any well in the well field. In addition to the pumping effects shown in these hydrographs, there are changes in the rate of decline caused by recharge. Had there been no recharge, the drawdown curves would have been steeper. The effects from recharge are not easily distinguished from normal recovery due to the shutdown of wells.

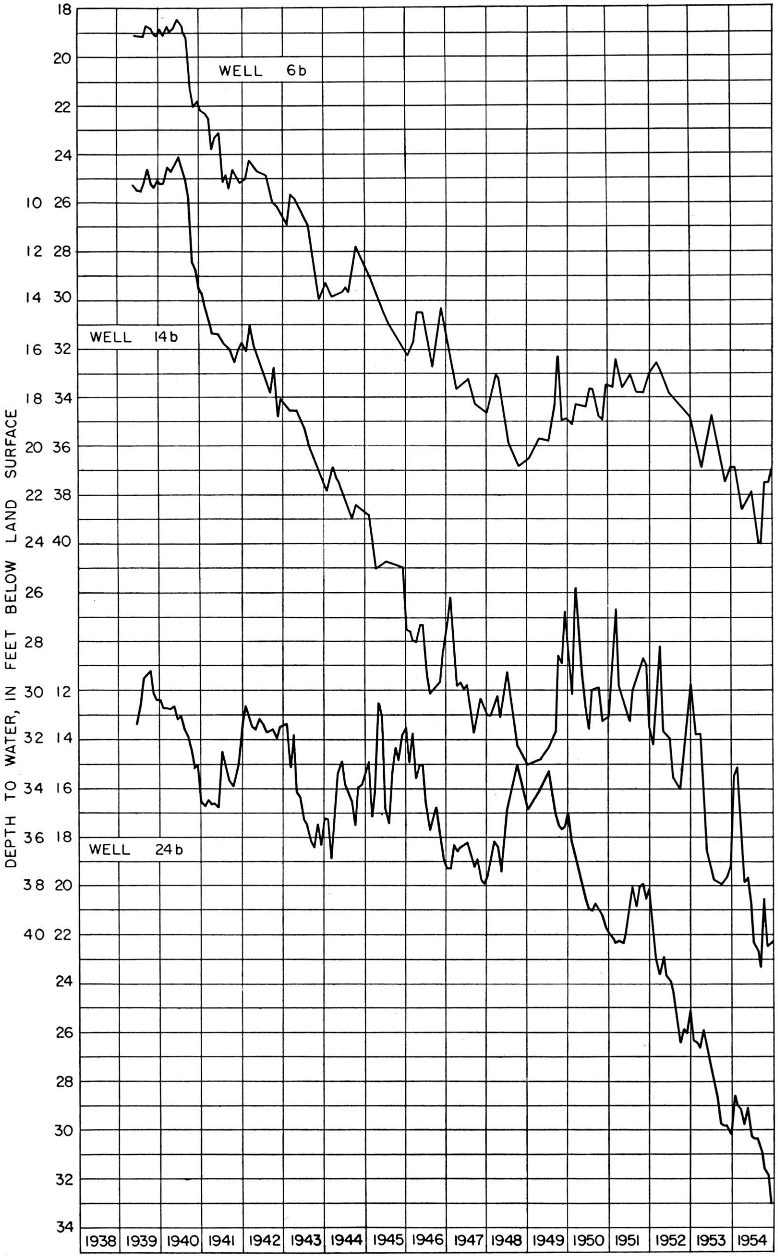


FIG. 21.—Hydrographs of wells in the centers of pumping, showing decline in water level due to pumping.

GROUND-WATER RECHARGE

Recharge is the term used to denote the addition of water to the ground-water reservoir, and it may be accomplished in several ways. The ultimate source of all ground water of quality suitable for ordinary uses in this area is precipitation on the area or in nearby areas. Once the water becomes a part of the ground-water body, it moves in the direction of the slope of the water table, later to be discharged at some point downgradient. Of the total precipitation, a part runs off directly at the land surface to streams, a part is dissipated by evaporation, a part is transpired by plants from the zone of soil moisture, and a part percolates downward to the zone of saturation.

Figures 12 and 13 show that the well-field area is recharged by precipitation. Abundant precipitation during the 1940's produced large amounts of recharge. Since 1952, precipitation has been deficient and water levels have declined steadily. During the period September 1940 to January 1, 1955, 330,000 acre-feet of water was pumped from the well field by the city of Wichita, and about 111,000 acre-feet of water was removed from storage in the well-field area. Thus, during that same period, about 33 percent of the water pumped by the city of Wichita came from storage and about 67 percent must have come from recharge (Table 4).

TABLE 4.—*Summary of changes in storage in well field*

Period from Aug. 30, 1940, to:	Area affected by pumping (acres)	Net reduction in storage (acre-feet)	Quantity of water discharged by pumping (acre-feet)	Percentage of total water pumped that has come from storage within well-field area
Jan. 1, 1944	32,300	33,390	51,600	66
Jan. 1, 1948	34,700	49,800	135,800	37
Jan. 1, 1952	32,400	50,200	239,000	21
Jan. 1, 1955	66,000	111,000	330,000	33

The amount of annual recharge has varied since 1940 and will continue to vary from year to year in response to precipitation and drought. The average rate of recharge in the well-field area from 1938 to 1943 was estimated by Williams and Lohman (1949, p. 129) to be about 20 percent of the precipitation, or a rate of 320 acre-feet per year per square mile. Before pumping by the city of Wichita began, much of this recharge was returned to the atmosphere by evaporation and transpiration or moved out of the area as base flow in streams. After pumping by the city of Wichita began, some water that would have been discharged by natural processes was diverted to the pumped wells. The amount of water diverted is the effective rate of recharge as far as the well field is concerned. The average effective rate of recharge during the period September 1, 1940, to January 1, 1948, was about 200 acre-feet per square mile per year. (See data in Table 4.) By January 1, 1952, the average rate of effective recharge for the whole period of record had increased to about 285 acre-feet. By January 1, 1955, the average for the whole period had decreased to about 147 acre-feet. During the period of abundant precipitation, January 1, 1948, to January 1, 1952, the effective average rate of recharge was about 470 acre-feet. The effective rates of recharge for the 15-year period are lower than the average recharge rate (320 acre-feet per square mile per year) because a part of the water that recharges the ground-water reservoir is being discharged by natural processes. When sufficient water is removed from storage, possibly water can be diverted from streamflow or from evaporation and transpiration and salvaged by wells. During wet periods, the ground-water reservoir may become full and potential recharge may be rejected. As a result of the high water table in 1951, ditches were excavated to drain the excess ground water in parts of the well field.

Where the water table stands at or near the surface, large quantities of water may be discharged by evaporation and transpiration. Where this condition prevails, removal of ground water by wells can increase the effective rate of recharge by lowering the water level beyond the influences of evaporation and transpiration.

Ultimately, the perennial yield of the Equus beds area and the well field will depend on the average annual recharge. The perennial yield of the Equus bed area is not known, but it is known to be much larger than the present use of water.

ARTIFICIAL RECHARGE

The use of ground-water reservoirs can be augmented by artificially increasing the rate of recharge; if the normal rate of recharge can be increased by artificial means, the perennial yield can be increased. A large quantity of water is available in storage in the well field to provide a perennial supply of water during drought periods. During periods of abundant precipitation, the well field probably could be recharged with runoff water.

Artificial recharge increases the rate of recharge into the underground reservoir by some method of artificially changing natural conditions. Four major methods of artificially recharging a groundwater reservoir are:

1. Water spreading or flooding
2. Recharge through pits and other excavations
3. Recharge through wells
4. Induced recharge by pumping

Artificial recharging can be done by one or more methods or by a combination of all methods. Each method has advantages and disadvantages dependent upon local conditions of climate, surface and subsurface geology, and quality of water available for recharging. The geology of some parts of the well field is most suitable for water spreading or for recharge through pits and other excavations. The geology of other parts of the well field is more suitable for induced recharge from streams. The local geology must be analyzed in order to select the best method.

An aquifer can be recharged by surface application of water only where the material above the aquifer is permeable and the water may move readily downward to the zone of saturation. The area least suitable geologically for water spreading or flooding coincides with the distribution of the Sappa member of the Meade formation, which underlies the north end of the well field (Fig. 6).

Three sources of water may be available for artificially recharging the Equus beds area—Arkansas River, Little Arkansas River, and Kisiwa Creek. The availability of water from Arkansas River and Little Arkansas River will depend on the quality of the water in the rivers.

The average daily discharge of Arkansas River at Wichita during the period 1934 through 1951 was 1,203 cfs. The maximum discharge during the period was 27,600 cfs on July 1, 1951. The minimum discharge during this same period was 3 cfs on September 3, 1934.

The water in Arkansas River is, in general, of poor quality. At low stages the water is hard and high in chloride and sulfate. Little is known about the quality of the water at high stages, but although it contains large quantities of sediment it is assumed to be of much better chemical quality than at low stages. The relation between stage and quality should be determined. Should the water at high stages be *of acceptable quality,* it could be used for artificially recharging the well-field.

Data collected by the State Board of Health and the City of Wichita water department indicate that the quality of the water in Little Arkansas River may be suitable for recharging, but the quality is inferior to that of the water in the Equus beds.

A hydrograph of the monthly mean and minimum daily discharge of Little Arkansas River is shown in Figure 9. A hydrograph of the annual discharge of Little Arkansas River at Valley Center is shown in Figure 22. The daily discharge of Little Arkansas River is often equal to the daily use of water by the city of Wichita. During the period of record, the minimum daily discharge of the river has been less than 10cfs (6,463,000 gallons a day) at only a few times. The ground-water profile across the well field as of January 1, 1955, was toward Little Arkansas River (Fig. 8 and 26), and water was being discharged into Little Arkansas River from the well field. The gradient from the well field has been reduced since pumping began (Fig. 26), and, accordingly, the discharge of ground water into the stream has been reduced. No water has moved yet from the river toward the well field, but when the water table in the well field declines about 10 feet more, the hydraulic gradient will be from rather than to the river, and water will then move from the river westward to the well field.

Data are not available for determining the rate at which influent seepage from Little Arkansas River may occur. The effect on observation well 506 in sec. 28, T. 23 S., R. 2 W., of pumping the Harvey Hensley irrigation well in sec. 22, T. 23 S., R. 2 W., indicates that the stream bed at low stages is relatively impervious. Little Arkansas River flows between these two wells. Well 506 is equipped with an automatic water-stage recorder. When the Hensley well is pumped the water level in well 506 declines. If the stream bed were highly permeable, stream water would flow through it to the expanding cone of depression and the cone would not expand beyond the river. The extension of the cone of depression beyond the river indicates that, at least during low stages of the river, little leakage occurs. During flood stage, the stream bed probably is scoured enough to permit some infiltration—perhaps a large amount.

The relation of the stage of Little Arkansas River to the water level in well 506 is shown in Figure 23. During low stages of the

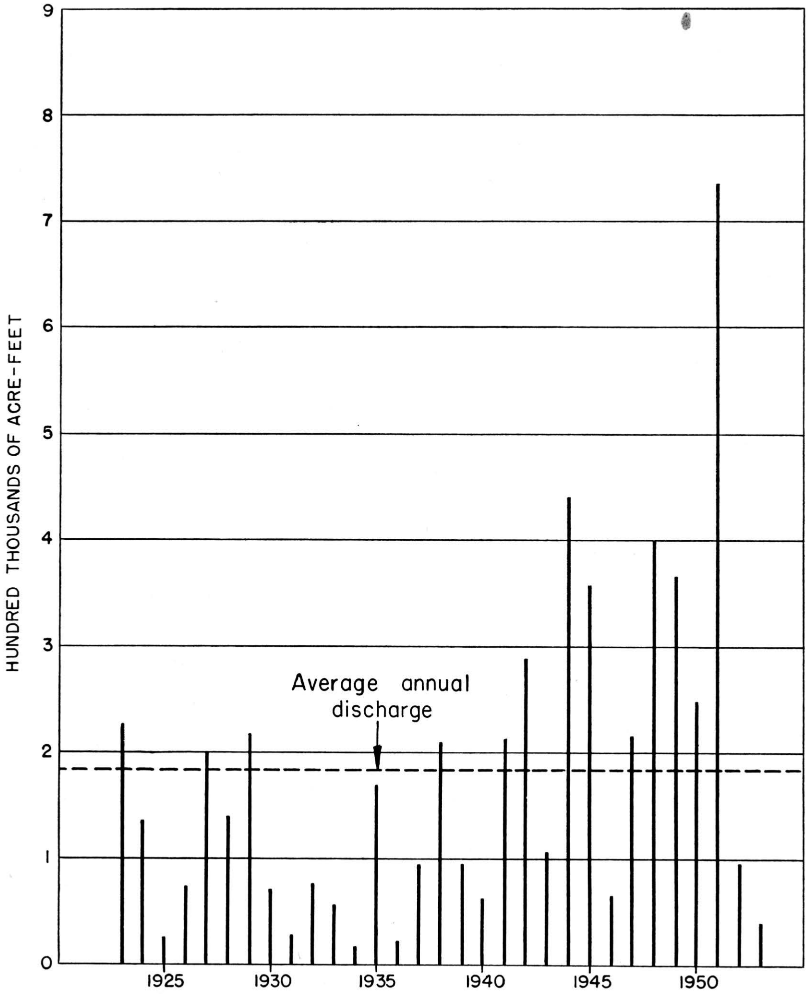


FIG. 22.—Annual discharge of Little Arkansas River at Valley Center, 1923-53.

river, ground water moves eastward toward the river. During high stages of the river, water moves from the river to the ground-water reservoir (bank storage), but, as the stage of the river declines, the gradient is reversed and most of the bank storage is slowly discharged back into the river.

Kisiwa Creek is a source of recharge to the well field. The creek is dry during drought periods, but, during periods of high precipi-

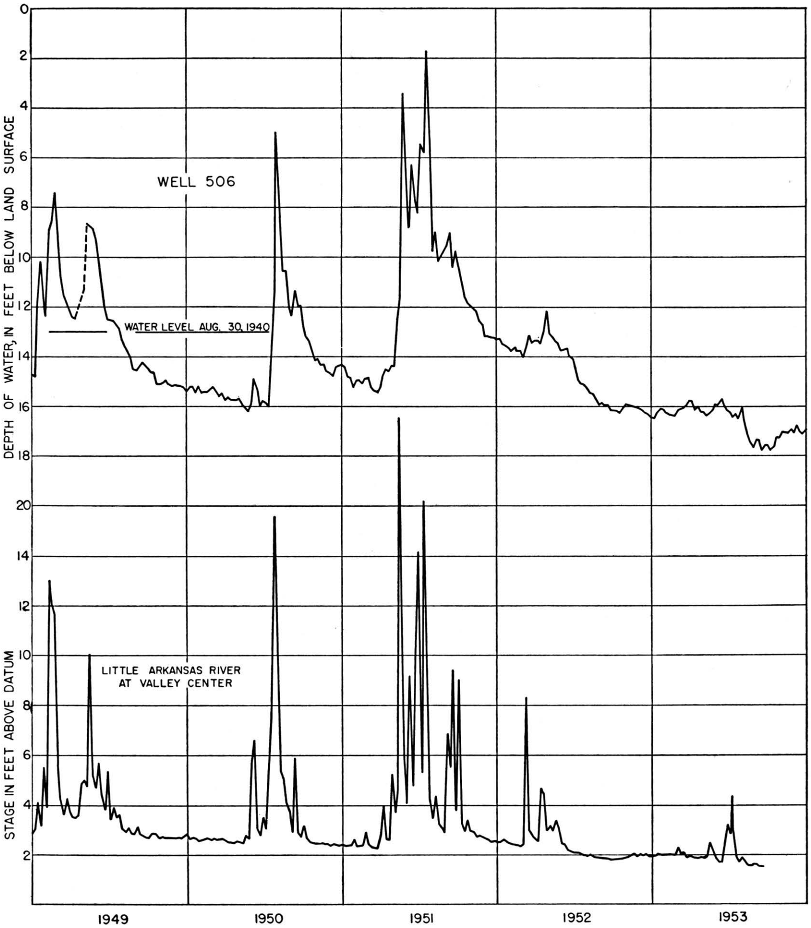


FIG. 23.—Relation between stage of Little Arkansas River and water-level in well 506, 1949-53.

tation, overland runoff flows down the creek and helps recharge the dewatered section that lies below and adjacent to the creek. Maximum use could be made of the flow of Kisiwa Creek by developing it so that no water flows out of the well field.

WATER IN STORAGE

Quantity

Ground-water storage depends on the saturated thickness of the water-bearing material and the specific yield of the material. Water in storage is available for use during drought periods.

Figure 24 is a saturated-thickness map of the Equus beds area. The map was prepared by superimposing the water-table contour map prepared by Williams and Lohman for 1940 on the bedrock contour map and drawing contours through points of equal thickness. The contour showing zero thickness represents the line of contact where the water table passes from the unconsolidated deposits and abuts on the underlying Permian rocks. The total volume of water in the saturated water-bearing materials in the Equus beds area is about 75 million acre-feet. If the material has a specific yield of 20 percent, a total of 15 million acre-feet of water theoretically is available from storage. From a practical standpoint, when less than half the 15 million acre-feet has been pumped from storage, the yields of wells will diminish and further pumping may be economically unfeasible. Hence, probably not more than about 6 to 8 million acre-feet of water can be pumped economically from storage in the Equus beds area.

A small part of the quantity of water in storage is of poor quality, principally owing to the presence of chloride salts, and must be subtracted from the total supply available. The principal areas where the water is of poor quality are near Burrton and in the Arkansas River valley. The water at relatively shallow depths is generally of satisfactory quality for most uses, but the quality becomes progressively worse with depth. The Burrton area is upgradient from the Wichita wells, and if the mineralized water at Burrton moves downgradient it will have a serious effect on the Wichita water supply. A chloride-sampling program to detect any movement of the poor-quality water from the Burrton area has been carried out since Wichita began pumping from the well field.

At the present rate of pumping by the city of Wichita, the water in storage alone, not considering recharge, would furnish the needs of the city for 200 years or more. However, the rate of use by the city undoubtedly will expand greatly. Black and Veatch (1952) stated that the city should anticipate an average daily use of 73 million gallons by 1985. At that rate, the water in storage would furnish the needs of the city for something like 100 years.

Since September 1940, approximately 111,000 acre-feet of water has been removed from storage by pumping by the city of Wichita. This is between 1 and 2 percent of the total volume in storage in the Equus beds area that is theoretically available for pumping. Profiles through the well field (Fig. 11) show the amount of water

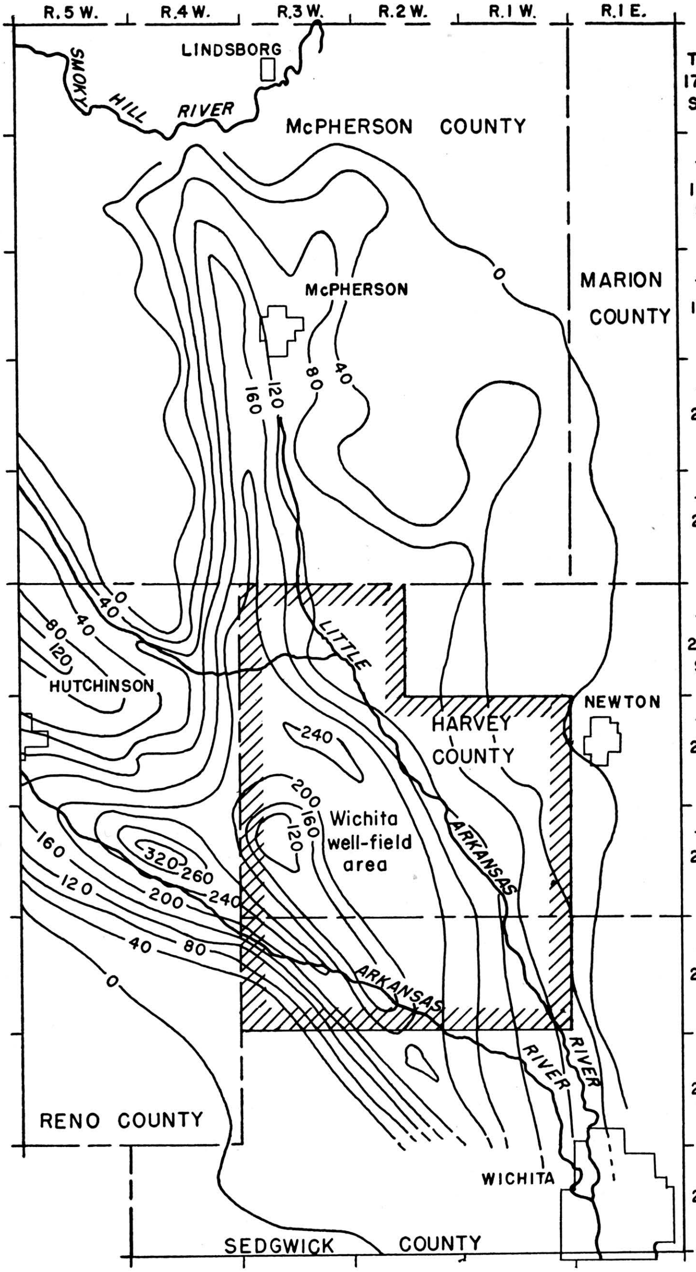


FIG. 24.—Map showing saturated thickness of Pliocene and Pleistocene deposits in Equus beds area (prepared by C. K. Bayne).

that has been taken out of storage since 1940 and that it has been relatively small compared to the total in storage. The saturated water-bearing materials (Fig. 24) have a maximum thickness of about 240 feet in the well field. In the channel entering from the west in Reno County the deposits have a saturated thickness of 320 feet.

Depletion

A water-table contour map was prepared by Williams and Lohman (1949, pl. 1) for the well-field area for 1940. Since 1940, contour maps have been made periodically to measure the effects of Wichita's pumping on the water table. In recent years these contour maps have been made quarterly. Pumping by the city of Wichita since 1940 has produced a large cone of depression. As pumping continued the cone of depression became deeper and covered a larger area. The areal extent and depth of the cone of depression have been determined from maps of water-level change made by comparing the water levels in wells for any given time with the water levels in 1940 .

In an area of about 6 square miles the water table has declined more than 20 feet, and in an area of about 76 square miles it has declined more than 4 feet. The amount of areal decline of the water table since 1940 is shown in Figure 25. The boundary of the area affected by pumping is difficult to determine precisely. In Figure 25 the area affected by a given amount of decline is plotted against the decline. The curve defined by the known points is projected to the line of no drawdown, and the area obtained for the point of no drawdown is 100 square miles. (Table 5) Outside the area known to be affected by pumping, the water level on January 1, 1955, was 3 or 4 feet lower than it was in September 1940, presumably owing to drought. The decline of the water level along two cross sections through the well field from 1940 to 1955 is shown in Figures 26 and 27.

Figures 28, 29, 30, and 31 show lines of equal decline of water level in the well field from August 30, 1940, to the following dates: January 1, 1944; January 1, 1948; January 1, 1952, and January 1, 1955. From these maps the volumes of dewatered material were determined. To these volumes a value of 20 percent for specific yield was applied. The specific yield is the amount of water that will drain out of the saturated material when the water level is

TABLE 5.—*Decline of water table in well field from August 1940 to January 1, 1955*

Area, in square miles, within contours of equal decline	Contours of equal decline on Figure 31
0.1	30
.3	28
.6	26
1.6	24
3.4	22
6.0	20
12.5	18
18.0	16
24.8	14
31.8	12
40.0	10
51.0	8
64.2	6
76.0	4

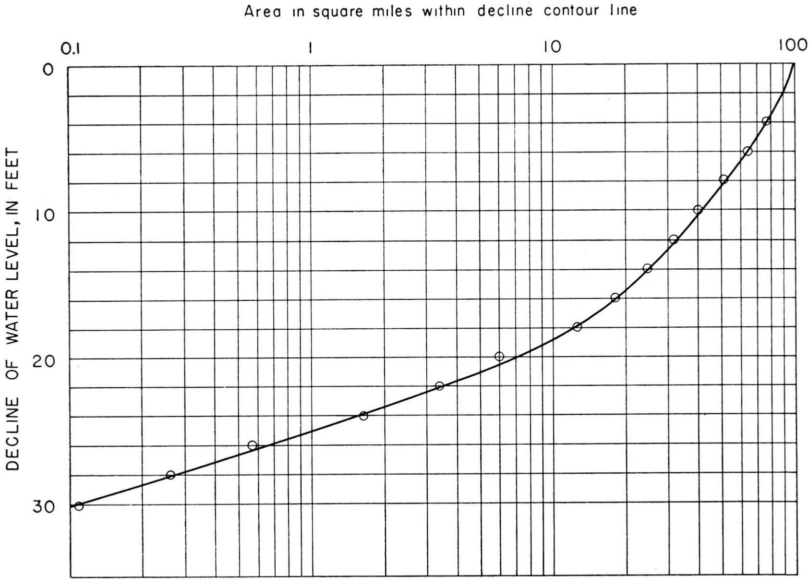


FIG. 25.—Areal decline of water table in well-field area from September 1940 to January 1, 1955.

lowered. Williams and Lohman (1949) used a value of 25 percent for the specific yield. This value was based principally on laboratory determinations. The materials tested in the laboratory for specific yield consisted predominantly of gravel and sand. Because

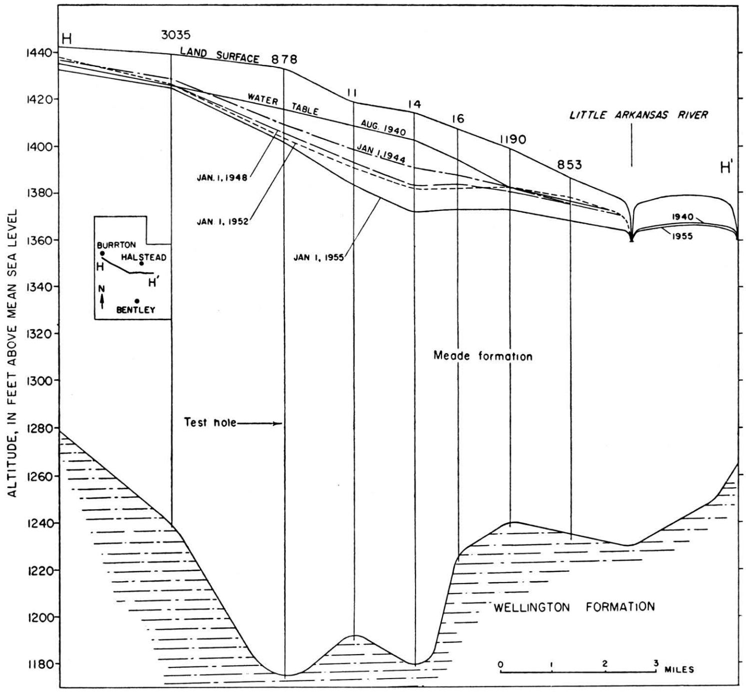


FIG. 26.—Cross section H-H′ through well-field area, showing ground-water levels and thickness of saturated water-bearing materials.

the ground-water reservoir is heterogeneous and stratified with zones of clay, a specific yield of 25 percent seems too high, and a lower value of 20 percent has been used in this report. The value of 20 percent was obtained by comparing change in storage with pumping. During October, November, and December, 1954, the monthly precipitation at Wichita was reported as 2.83 inches, a trace, and 0.18 inch, respectively. Hydrographs of wells not affected by pumping indicate that there was no recharge to the ground-water body during the 3-month period. The city of Wichita pumped 6,830 acre-feet of water from the well field during this same period. Using the water-level-change maps for October 1, 1954, and January 1, 1955, and a value of 20 percent for specific yield, it was determined that 7,250 acre-feet of water was removed from storage. The 420 acre-feet of water unaccounted for can be attributed to errors in the assumptions and to natural discharge.

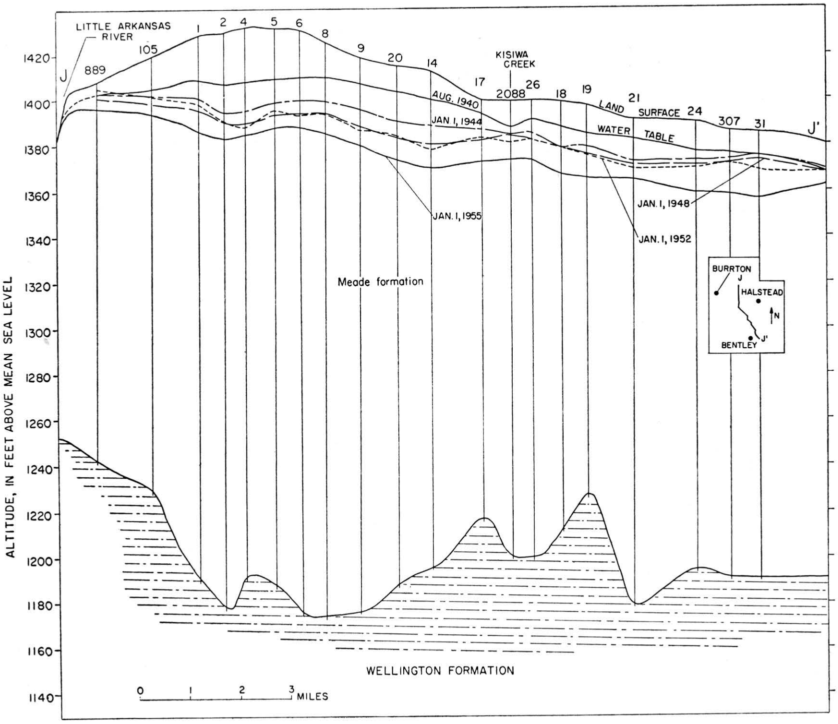


FIG. 27.—Cross section J-J′ through well-field area, showing ground-water levels and thickness of saturated water-bearing materials.

During the period September 1, 1940, to January 1, 1955, about 555,000 acre-feet of saturated material was dewatered in the well field. The decline of the water table in the well field during the period August 1940 to January 1, 1955, is given in Table 5 and shown graphically in Figure 25.

Table 4 summarizes the data contained in Figures 28, 29, 30, and 31.

Through the period August 30, 1940, to January 1, 1952, 21 percent of the water pumped by the city of Wichita came out of storage and 79 percent came from recharge. In contrast, during the drought years 1953 and 1954, most of the water pumped was from storage, and, as a result, the average percentage of water pumped from storage during the entire period up to January 1, 1955, by the city of Wichita was about 33.

Two cross sections showing the original water level and the water level as of January 1, 1955, are shown in Figures 26 and 27.

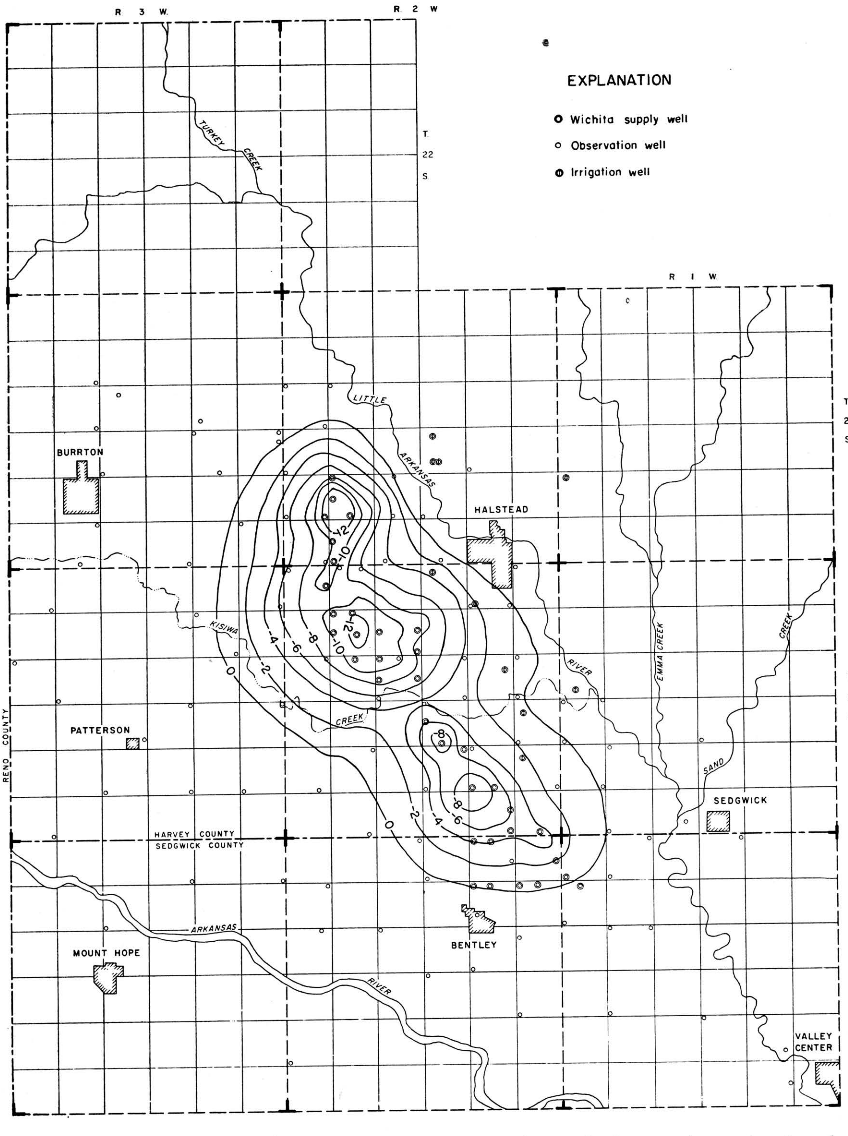


FIG. 28.—Map of well field showing lines of equal change in water level from August 30, 1940, to January 1, 1944.

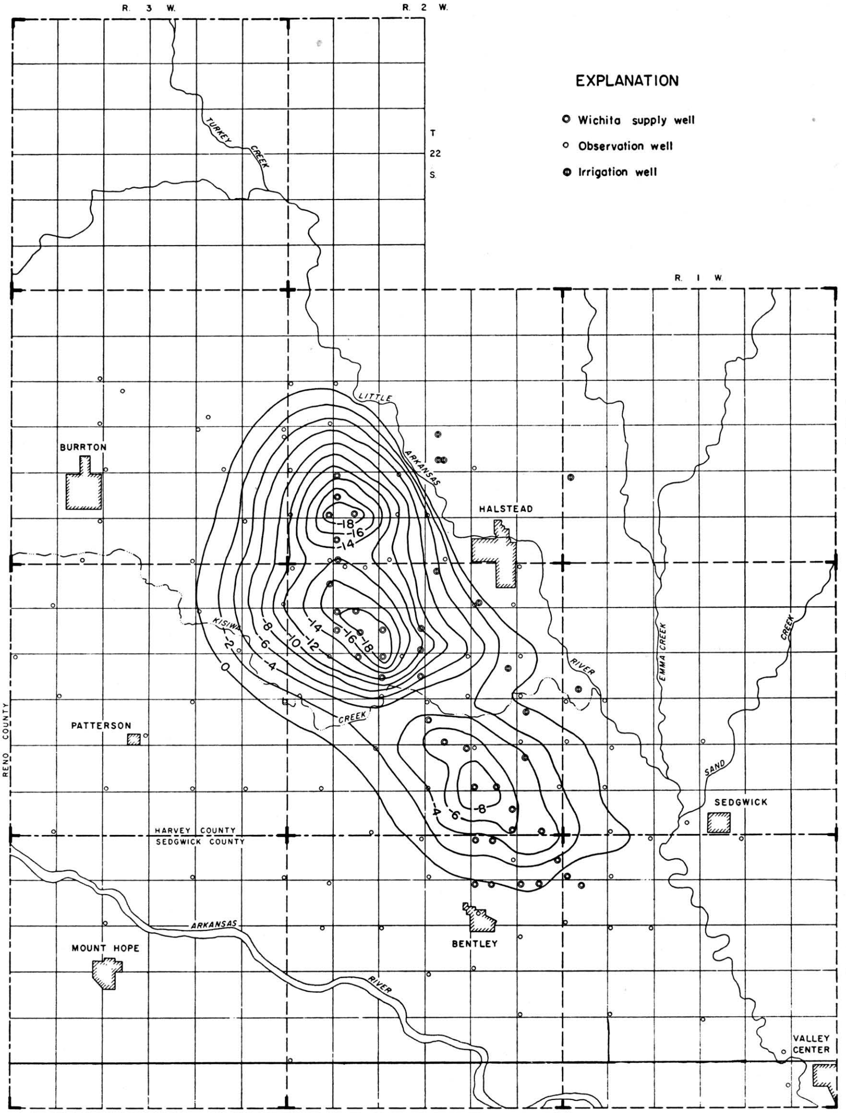


FIG. 29.—Map of well field showing lines of equal change in water level from August 30, 1940 to January 1, 1948.

Figure 26 is a section in an east-west direction through the deepest part of the area of decline. Figure 27 is a section in a general north-south direction through the area of greatest decline. The cross sections show that the quantity of water discharged from storage is small in comparison with the quantity still in storage.

Figure 21 shows that the decline in the well field has not ceased. During the drought period of the last 3 years, the rate of decline of water level has accelerated, reflecting the reduction in recharge during this period. In the future, during periods of excess precipitation, recharge should add some water to storage and cause a rise in water level. However, in the well field and vicinity the checking of the water-level decline by recharge may be only temporary. If the present rate of pumping is maintained, the water level in the well field eventually will stabilize, but if pumping continues to increase, the water level will continue to decline. The quantity of water in storage will continue to fluctuate in response to changes in precipitation and pumping.

SUMMARY

The potential perennial yield of the well field is larger than the present withdrawal by the city of Wichita. Only a part of the natural discharge in the well field is being intercepted by wells; some water is still moving past the well field toward Little Arkansas River. When the water table is lowered below the stream level of Little Arkansas River so that the hydraulic gradient slopes from the river to the well field, the direction of movement of the water will be reversed, and water will move toward the well field and become a source of recharge to it. The average annual recharge has been estimated to be about 320 acre-feet per square mile in the well field.

By January 1, 1955, the city of Wichita had pumped 330,000 acre-feet of water from the well field. This pumpage had resulted in a maximum decline in water level of 32 feet. The total area in which the water table is affected by the Wichita pumping is difficult to determine, but it is about 100 square miles. As of January 1, 1955, about 67 percent of the water pumped by the city of Wichita since pumping began in 1940 had been derived from recharge and the other 33 percent had been pumped from storage. The decline of the water table caused by pumping is small in comparison with the thickness of the saturated deposits.

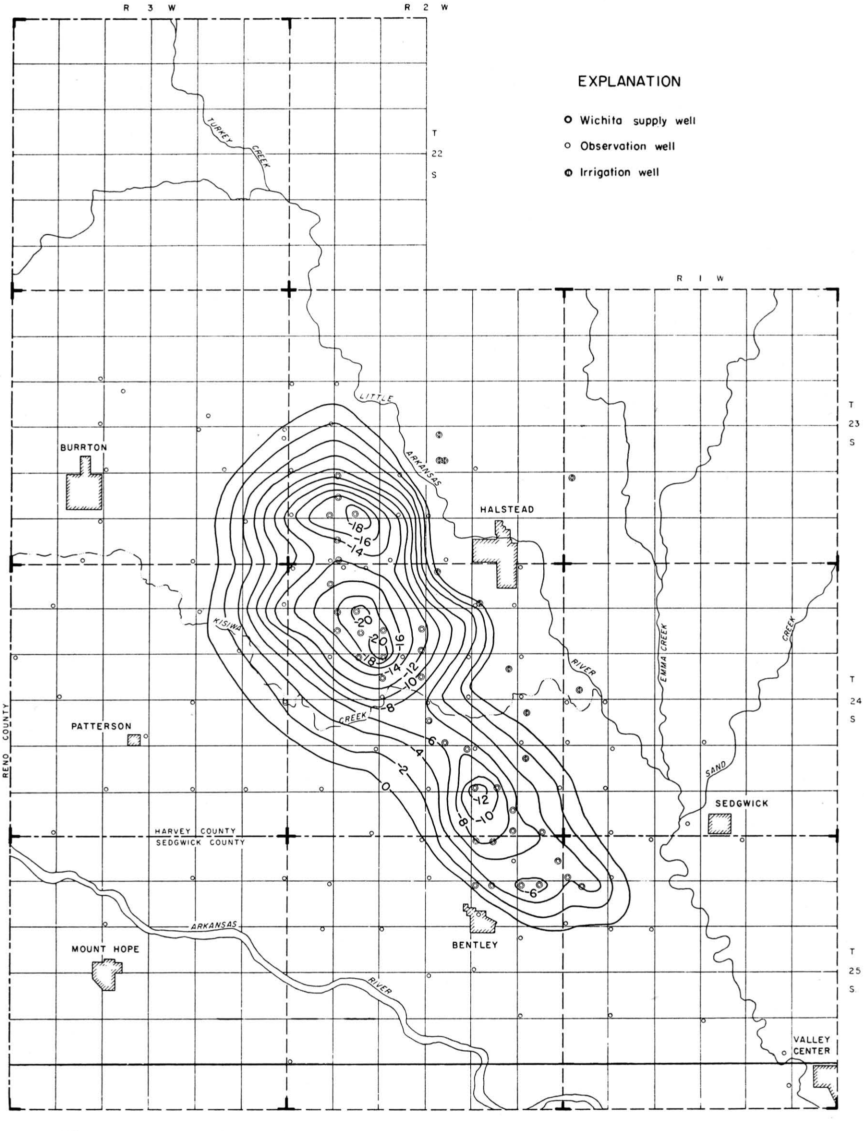


FIG. 30.—Map of well field showing lines of equal change in water level from August 30, 1940, to January 1, 1952.

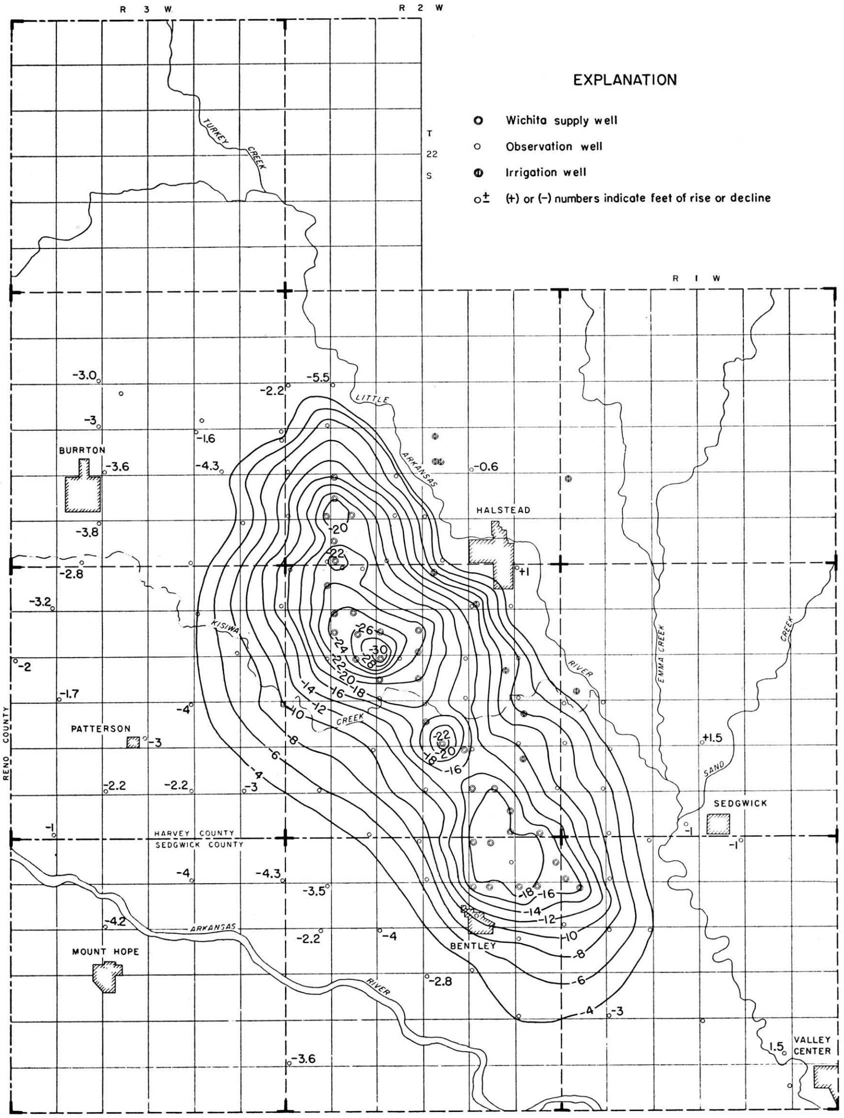


FIG. 31.—Map of well field showing lines of equal change in water level from August 30, 1940, to January 1, 1955.

The primary source of water for recharge to the Equus beds area is the local precipitation falling on the land surface, and physical conditions for recharge are excellent in most of the well field. Ultimately, the perennial yield will be dependent on the average annual recharge. Water in storage in the well field is available for use during drought periods. The water-bearing formation cannot be developed without some decline in water level. The higher the rate of withdrawal, the greater the lowering of the water table will be. Decline alone does not determine whether a water-bearing formation has been overdeveloped. Estimates of availability of water in the Equus beds area will necessarily be revised as the hydrology of the area becomes better understood.

Physical conditions in the well field seem to be excellent for some forms of artificial recharge. Additional data are needed before the best methods of artificial recharge and the suitability of the water for recharging can be determined.

If the present well field is expanded, a larger area will be influenced, and the perennial yield will be correspondingly larger. Additional supplies of water can be developed from the Equus beds area without depleting the supply, and the perennial yield is many times larger than the present use.

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