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A HYDROLOGIC STUDY OF THE VALLEY-FILL DEPOSITS IN THE VENICE AREA, OHIO
TECHNICAL REPORT NO. 4
COLUMBUS 1961

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State of Ohio
Department of Natural Resources
Division of Water

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George D. Dove
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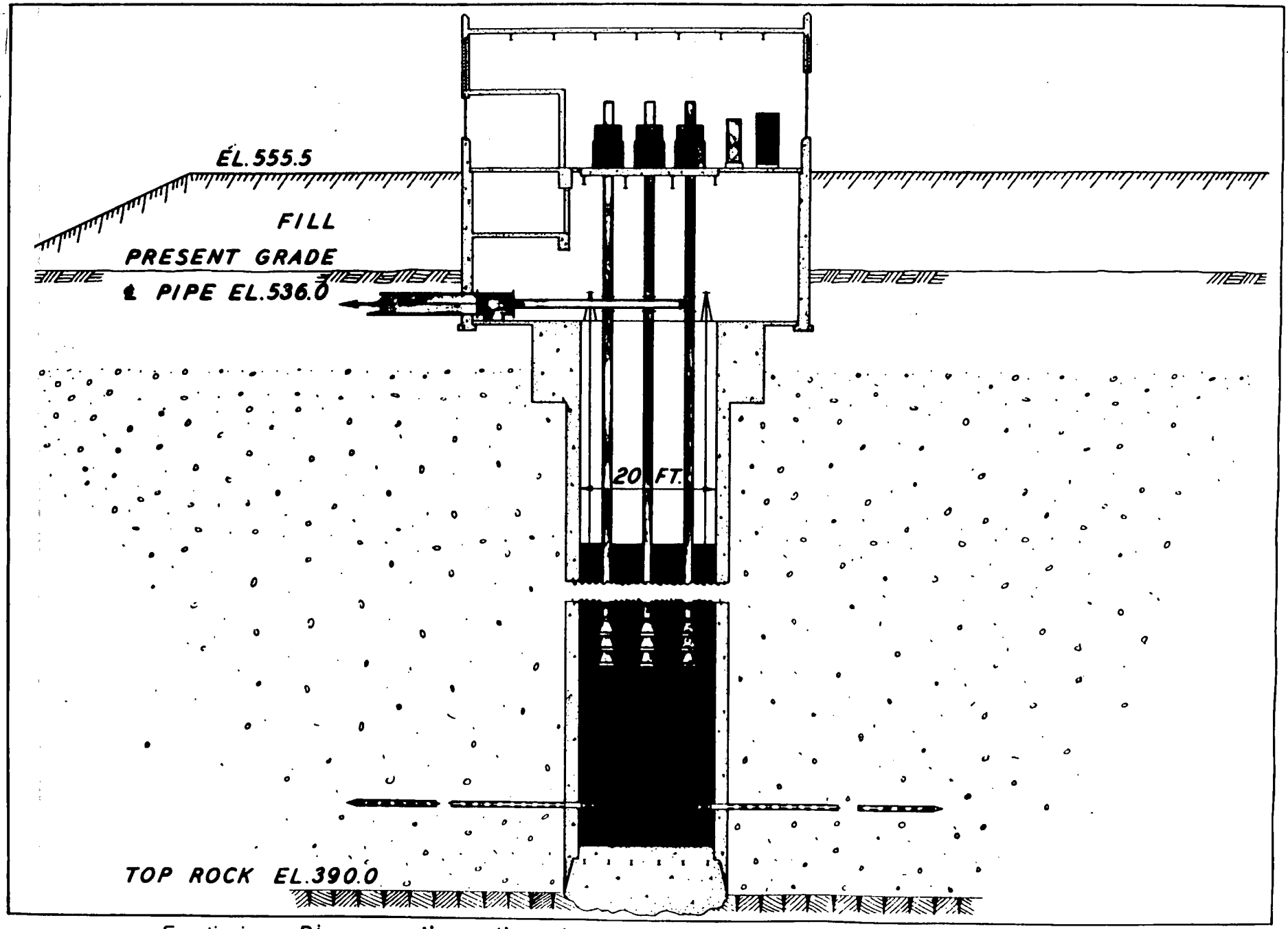

Frontispiece. Diagrammatic section showing construction of Southwestern Ohio Water Co. Collector No. 1, near Venice, Ohio.

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A HYDROLOGIC STUDY OF THE VALLEY-FILL DEPOSITS IN THE VENICE AREA, OHIO

George D. Dove

ABSTRACT

The U. S. Geological Survey in cooperation with the Board of Commissioners of Hamilton County, Ohio, and the Ohio Department of Natural Resources, Division of Water, investigated the ground-water resources in a 6-square-mile area along the Miami River near Venice, Ohio. The area is covered by glacial drift of both Illinoian and Wisconsin age. The upland areas are covered by a veneer of Illinoian till, and the valleys contain thick and extensive Wisconsin outwash deposits of sand and gravel. The consolidated rocks, which occur beneath the outwash sand and gravel and which are exposed in numerous places on the uplands, consist of shale and interbedded limestone of Ordovician age.

The Venice area lies about 12 miles northwest of Cincinnati and 7 miles southwest of Hamilton, and precipitation and temperature records are given for both of these cities. The average annual precipitation at Hamilton and Cincinnati is 39.59 and 39.51 inches, respectively. The mean annual air temperature at Hamilton is 54.0° F, and that at Cincinnati is 56.1°. The average temperature of ground water in the area is about 53.3° east of the river and 54.3° west of the river.

The principal source of ground water in the Venice area is the glacial-outwash sand and gravel in the valley of the Miami River. Test drilling shows that the saturated thickness of these outwash deposits averages about 125 feet and that ground water occurs under water-table conditions. The saturated thickness of the deposits is affected by changes in river elevation, by rainfall, and by pumping at the Southwestern Ohio Water Company, The National Lead Company of Ohio, and the Meadowbrook swimming pool. If the porosity of the outwash sand and gravel is estimated as 35 percent, the total ground-water storage in the area averages about 0.17 million acre-feet.

A controlled pumping test of the sand and gravel aquifer in the Venice area west of the Miami River was made January 27 to February 1, 1954. Adjustments were made for the effects of partial penetration of the pumped well, and the results of the test were analysed by the modified nonequilibrium formula. The coefficients of transmissibility and permeability were determined to be 374,000 gpd per foot and 3,000 gpd per square foot, respectively.

To check the results of the pumping test, the cone of depression around collector 2 was studied, and to determine the coefficient of permeability east of the Miami River, the cone of depression around collector 1 was studied. Using the formula Q = PIA, the coefficient of permeability of the aquifer west of the Miami River was found to be 3,000 gpd per square foot. This value agrees with that determined from the results of the controlled pumping test. The coefficient of permeability of the aquifer east of the Miami River was found to be 2,800 gpd per square foot.

The ground-water reservoir in the outwash deposits of the Miami River is recharged by precipitation within the area, seepage from the valley walls, and induced infiltration of water from the Miami River. Recharge from precipitation amounts to about 570,000 gpd per square mile of catchment area, or 3.42 mgd (million

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gallons per day) for the entire 6 square miles studied. The permeability of the Ordovician limestone and shale which form the valley walls is not known, but numerour well failures in the upland areas indicate that the permeability is low; it is assumed to be about 5 gpd per square foot. Therefore the total amount of water moving from the consolidated rocks into the outwash sand and gravel is about 1.2 mgd.

Under heavy pumping the outwash sand and gravel deposits will be recharged chiefly by induced infiltration of water from the Miami River. The infiltration rates for sections of the Miami River, determined by computations made using the formula Q = PIA, ranged from 113,000 to 142,000 gpd per acre per foot. Based on these figures, it was determined that infiltration supplies of 20 mgd could be developed during periods of low streamflow in the area studied. The total yield of water from the valley-train deposits, including recharge from precipitation, seepage from the valley walls, and induced infiltration that would be balanced by recharge during dry periods, is about 24.6 mgd.

INTRODUCTION

The U. S. Geological Survey, in cooperation with the Board of Commissioners of Hamilton County, Ohio and the Ohio Department of Natural Resources, Division of Water, investigated ground-water conditions and the hydraulic properties of the glacial-outwash deposits near Venice, Ohio, during the period June 1956 to June 1959. The purpose of this report is to present the results of the investigation and to discuss some of the problems of interpretation.

Venice (Ross Post Office) is in southwestern Ohio near the Hamilton-Butler County line, about 12 miles northwest of Cincinnati and 7 miles southwest of Hamilton. (See fig. 1.) The principal source of ground water in the Venice area is the glacial outwash sand and gravel in the Miami River valley. These outwash deposits are recharged by induced infiltration from the Miami River, direct precipitation, and inflow from the valley walls.

The Southwestern Ohio Water Company withdraws approximately 14 million gallons of water daily from two large radial collectors near Venice. The water is piped to manufacturing plants in the heavily industrialized Mill Creek valley north of Cincinnati. This large concentration of pumpage in an area unaffected by surface-water diversions or uncontrolled pumping affords a unique opportunity to study the effects of recharge by induced stream infiltration and the hydraulic properties of glacial-outwash deposits. The importance of determining infiltration rates is indicated by the fact that of the total ground-water pumpage in Ohio in 1955, estimated to be 500 mgd (million gallons per day), about 200 mgd was pumped in the Miami River and Mad River valleys under conditions similar to those in the Venice area.

Moreover, there is also strong Federal interest involved in an appraisal of ground-water resources in the Venice area, apart from its contribution to research studies. Much of the water pumped at Venice supplies several large industries which are, or would become, of critical importance in the event of a National emergency. It is anticipated that the withdrawal of ground water in the Venice area will increase greatly in future years, and it is essential to provide data to aid in the appraisal of this vital resource.

History of Program

In 1936, after major droughts in 1930 and 1934 had focused attention on declining water levels in the heavily industrialized Mill Creek valley, an investigation was made by the U. S. Geological Survey in cooperation with the Boards of Commissioners of Butler and Hamilton Counties. The results of the investigation were published as U. S. Geological Survey Water Supply Paper 999, entitled "Ground Water Resources of the Cincinnati Area, Butler and Hamilton Counties, Ohio," by F. H. Klaer and D. G. Thompson. This investigation revealed that the problem was not limited to the Mill Creek valley, but that a practical solution inevitably involved the Miami River valley.

As a result of the findings by Klaer and Thompson, representatives of 11 industries formed the Southwestern Ohio Water Company. This company was formed with the express intent of locating and establishing an adequate water-supply system for industries in the Mill Creek valley.

In fulfillment of this desire to locate and establish an adequate water-supply system for nearby industries, a quantitative study of the glacial-outwash

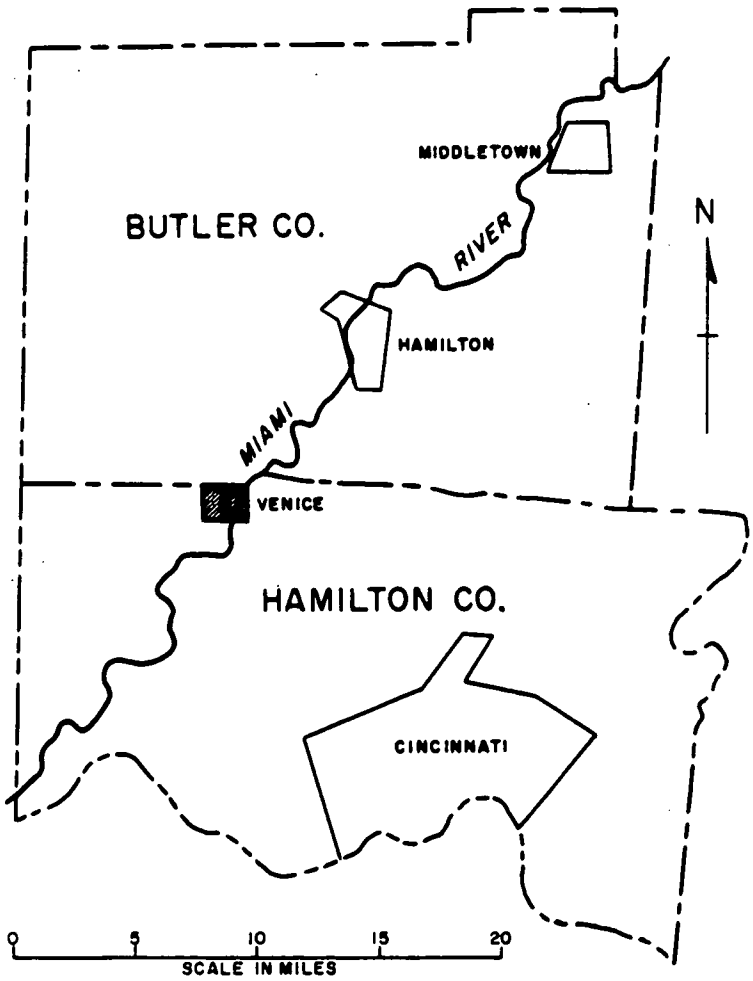

Figure 1. Map showing location of the Venice area, Ohio.

deposits in the Miami Valley was made by ground-water consultants hired by the Southwestern Ohio Water Company. The purpose of this study was to determine the feasibility of installing a large-diameter radial collector east of the Miami River near Venice. The results showed that large ground-water supplies could be obtained from the glacial-outwash deposits underlying the Miami River in this area. On July 1, 1951 radial collector 1 was completed, and almost immediately it began to supply water to industries in the Mill Creek valley.

In early 1954, in anticipation of even larger demands for water, an investigation of the glacial deposits on the west side of the Miami River was made. In the winter of 1954 the second large-diameter radial collector was installed which, in February 1955, began furnishing additional water to industries in the Mill Creek valley.

The present investigation was begun by the U. S. Geological Survey in June 1956. This study was made under the immediate supervision of S. E. Norris, district geologist, and under the general supervision of P. E. LaMoreaux, former chief, Ground Water Branch of the U. S. Geological Survey. Hamilton County is represented in this investigation by the Board of County Commissioners, consisting of James R. Clark, Jr., president, Louis J. Schneider, Jr., and Edwin J. Tepe. The Ohio Department of Natural Resources is represented by Herbert B. Eagon, director and C. V. Youngquist, chief, Division of Water.

The specific objectives of this investigation are:

1. To determine the lateral and vertical extent, and the geologic character, of the glacial-outwash deposits in the Venice area.

2. To determine the hydraulic properties of the aquifer by the collection and interpretation of pumping-test data.

3. To map the water table in the Venice area and determine the principal sources of recharge to the aquifer.

4. To maintain an observation-well program in the Venice area to determine periodic changes in ground-water storage.

5. To appraise methods for determining the recharge received directly from precipitation in the Venice area and from regional underflow and induced infiltration of streamflow.

6. To collect data on the chemical quality and temperature of ground water and surface water, and possibly the sediment load in the stream, as aids to the overall quantitative interpretation of the aquifer.

7. To collect basic records.

Previous Investigations

One of the earliest geologic reports describing the Cincinnati area was written by Leverett (1902). Leverett gave a general description of the glacial geology of the area, and also reported a few elevations on the bedrock floor of the old valley. Fuller and Clapp (1912) discussed the occurrence of ground water in the various formations underlying parts of 14 counties in southwestern Ohio and gave

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brief descriptions of ground-water conditions at specific localities and tables of well data. The geology of the region was fully described by Fenneman (1916), but only brief mention was made of the ground-water resources of the area. Stout, Ver Steeg, and Lamb (1943) discussed ground-water conditions at specific localities in southwestern Ohio and discussed in general terms the water-bearing properties of the consolidated and unconsolidated deposits. The most recent and detailed report on the water resources of the southwestern Ohio area was written by Klaer and Thompson (1948). In their report Klaer and Thompson discussed general ground-water conditions in Butler and Hamilton Counties, detailed ground-water conditions in specific localities, and also presented tables of well data and water-level elevations. Klaer and Thompson found that between 1890 and 1940 water levels in some areas in the Mill Creek valley had declined as much as 90 feet. The authors also stated (p. 61) concerning the Miami River valley south of Hamilton: "The great thickness and character of the material filling the buried valley, the relatively small amounts of clay reported, and the present small pumpage indicate that probably a moderate to large quantity of water could be pumped from wells without serious depletion of the available supply."

Acknowledgments

The author expresses his appreciation to Mr. Robert C. Lewis, general manager, and Mr. Leo Wilhelm, supervisor, The Southwestern Ohio Water Company, who provided information on the two radial collectors near Venice, Ohio. Messrs. Lewis and Wilhelm also allowed drive points to be installed in the vicinity of the collectors to aid in determining water levels in the area. Appreciation also is expressed to Mr. Fred H. Klaer, vice president, Ranney Method Water Supply Company, Columbus, Ohio, who gave the author information on a pumping test made by that company and provided logs of test wells drilled near Venice.

GEOGRAPHY

GEOLOGY

The Miami Valley is more than 2 miles wide in the Venice area. This broad lowland represents the former course of a much larger stream called the Norwood River by Stout, Ver Steeg, and Lamb (1943, p. 68). The Norwood River occupied the same course as the present Miami River from Hamilton south as far as Venice. At Venice the Norwood River turned southwestward and flowed past New Haven to Harrison near the Indiana line. This stream cut its channel into the underlying consolidated rocks to a level more than 150 feet below that of the Miami River. Glacial meltwaters filled the valley to its present level, chiefly with outwash sand and gravel deposits, called valley train, into which the Miami River has cut its present channel. A terrace prominently developed along the eastern edge of the National Lead Company of Ohio plant site marks the boundary between the floodplain of the present stream and the original level of the valley-train deposits.

The glacial-outwash deposits in the Venice area occur in the buried valley which marks the approximate course of the Norwood River. The deep channel of the Norwood River lies north of collectors 1 and 2, and it is probable that the permeability of the valley-fill deposits increases to a maximum near the deep channel, figure 2. South of the area of collectors 1 and 2, in the vicinity of well C-1 (see fig. 19), the glacial materials thin abruptly and are composed chiefly of clay. Figure 3 shows the logs of test wells in the Venice, Ohio, area.

The consolidated rocks, which occur beneath the valley-train deposits and which are exposed in numerous places on the uplands, consist of shale and interbedded limestone of Ordovician age. The bedrock surface rises rapidly east of collector 1 and southward in the vicinity of well C-1. These strata are relatively impermeable. Upland farms depend for their water supply mainly on dug wells in the overlying glacial drift, springs, and cisterns. A map of the glacial and consolidated deposits of the Venice area is shown on figure 4.

PRECIPITATION

The distribution of rainfall areally and with respect to time exercises a pronounced effect on the available water supply. For example, although the primary cause of drought is lack of precipitation, an extremely uneven distribution of rainfall throughout the year may be as disastrous as a shortage in total amount. Climatologically, the State of Ohio is divided into three sections -- northern, middle, and southern. Each section differs somewhat from the other two in the distribution of precipitation throughout the year. The Venice area is in the Southern climatological section of the State. Because of its location between the cities of Hamilton and Cincinnati, precipitation records are given for both of these cities. The average annual precipitation at Hamilton and Cincinnati is 39.59 and 39.51 inches, respectively. (See figs. 5 and 6.)

Figure 7 shows cumulative departure from the average annual precipitation at Cincinnati, Ohio. This curve represents the accumulated excesses and deficiencies in precipitation above or below the mean or average amount for the period of record. When precipitation is in excess of the average during a particular year, the curve rises; when less than average, the curve falls. For example, in 1920 the precipitation was 40.13 inches, or 0.59 inches more than average; the curve therefore is drawn above the average precipitation line. During 1921, precipitation was 45.45

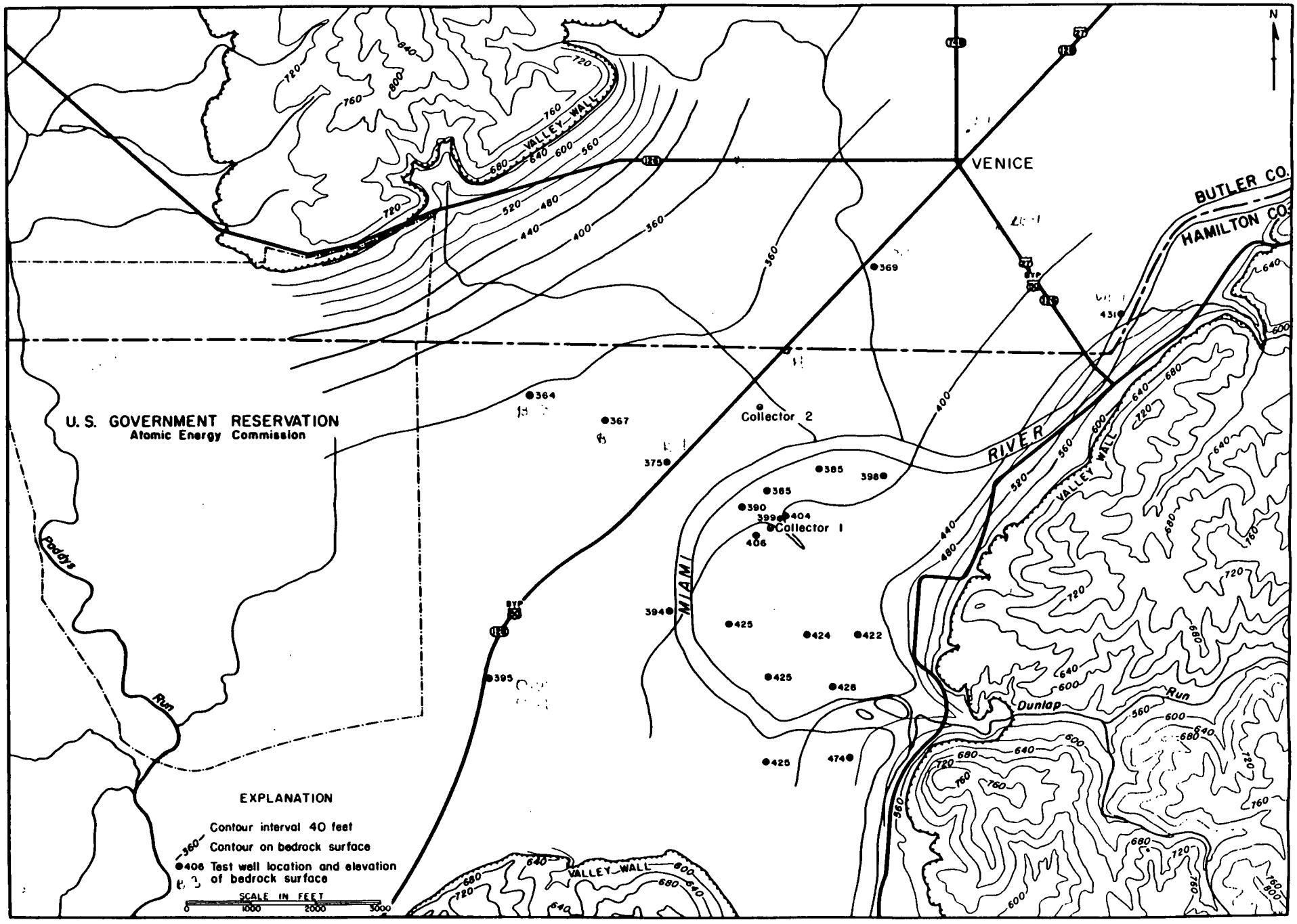


Figure 2. Map showing approximate contours on the bedrock surface and locations of test wells in the Venice area.

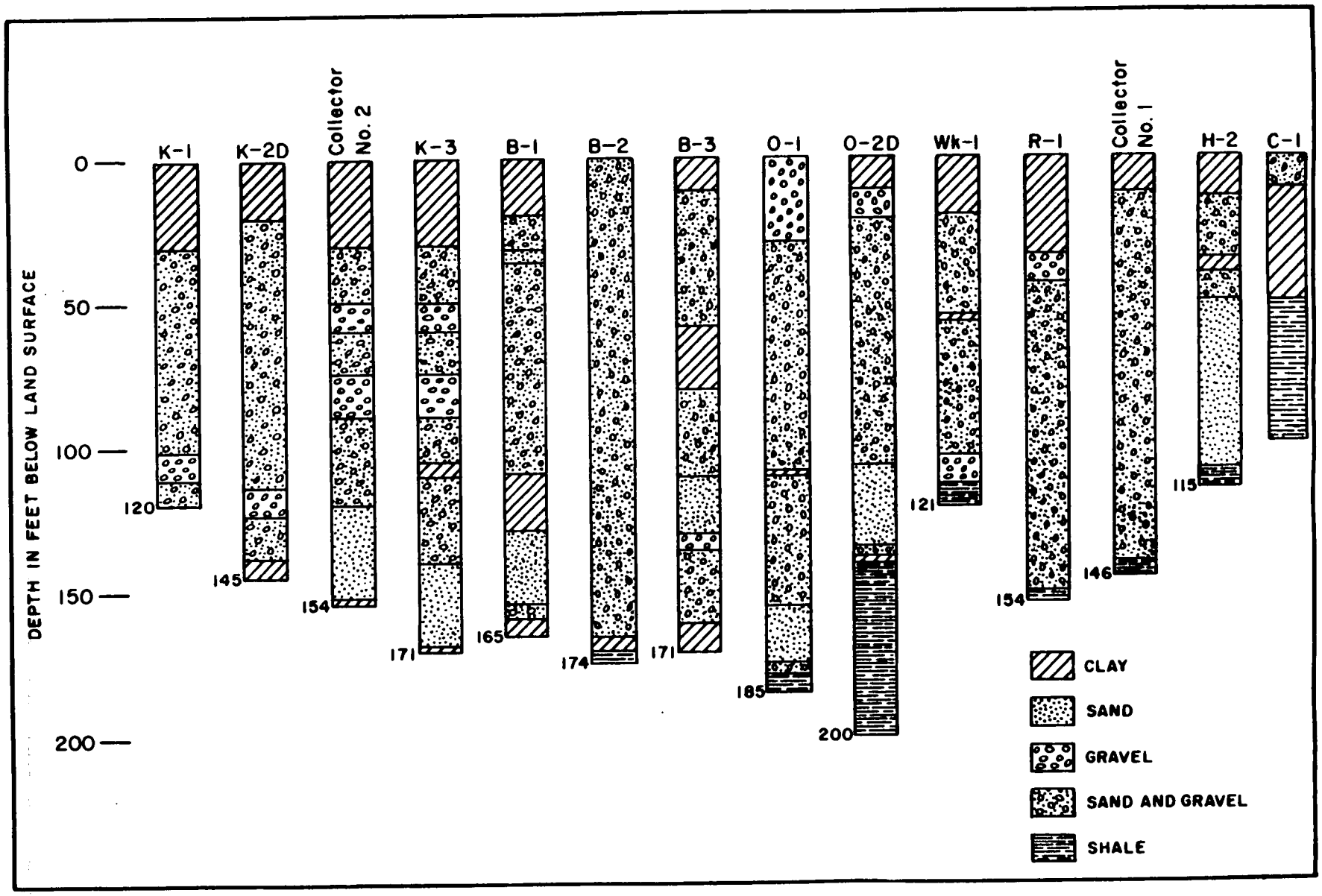


Figure 3. Logs of test wells in the Venice, Ohio. area.

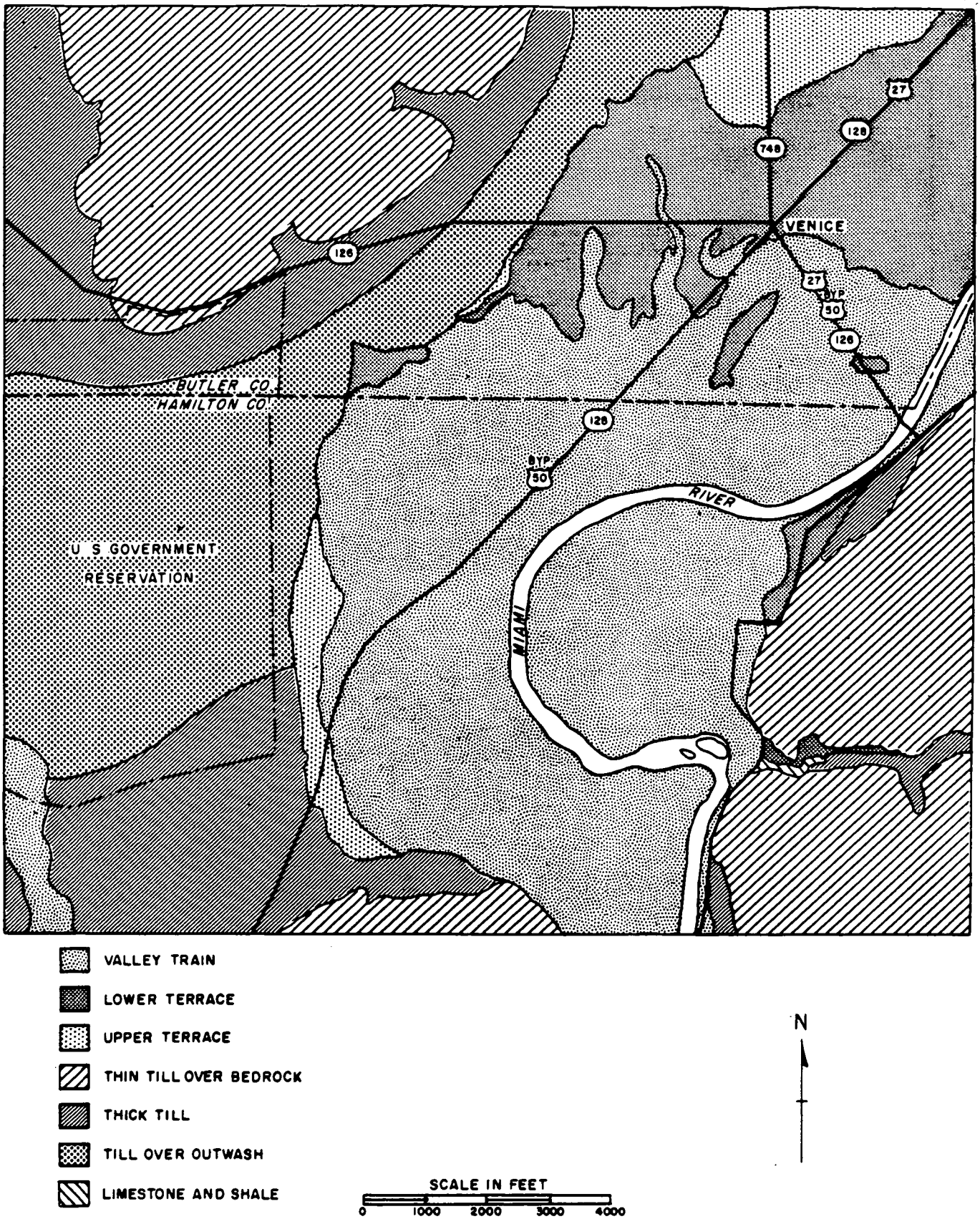


Figure 4. Map of the glacial and consolidated deposits of the Venice area.

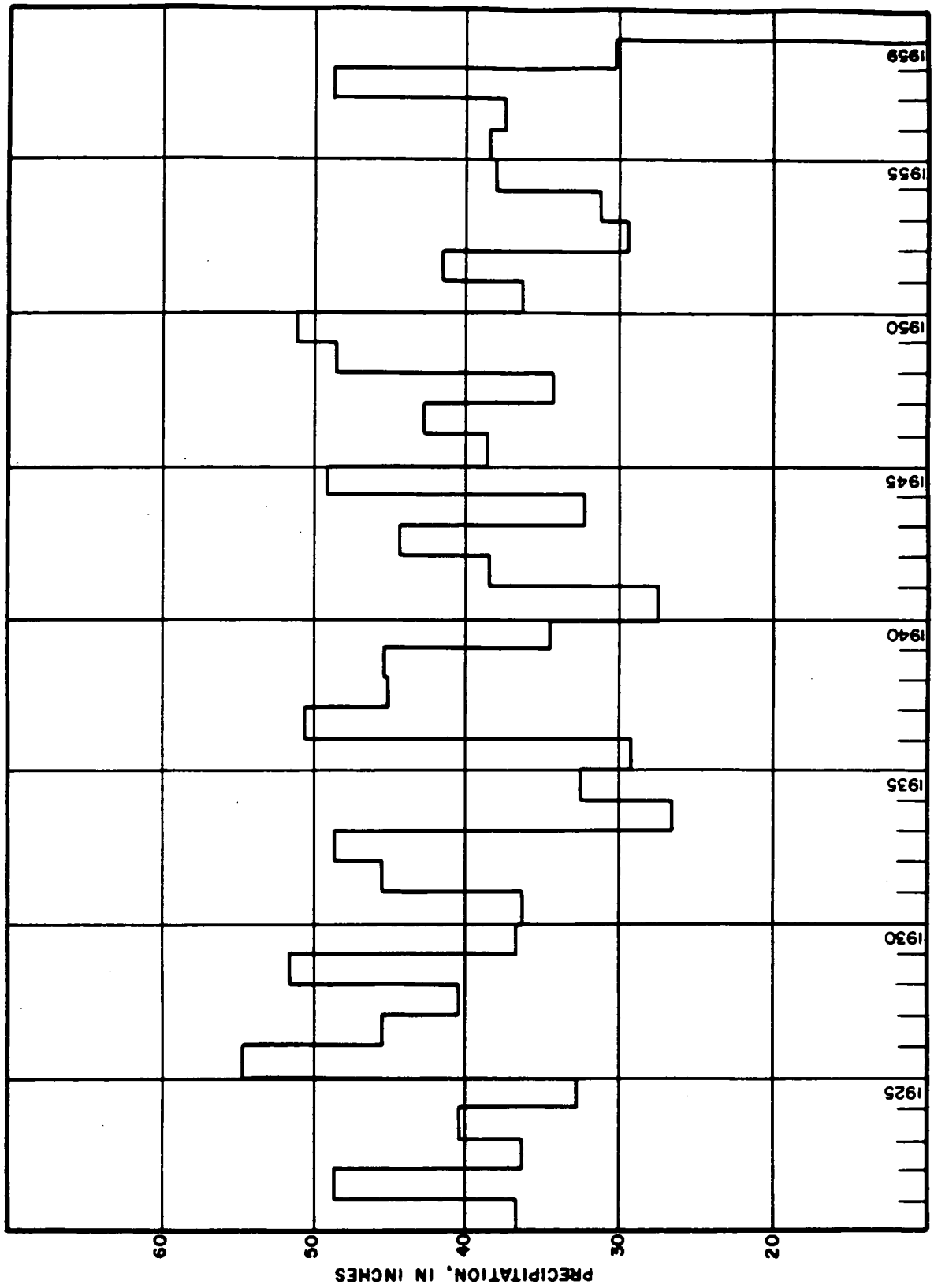


Figure 5. Graph showing the yearly precipitation at Hamilton, Ohio.

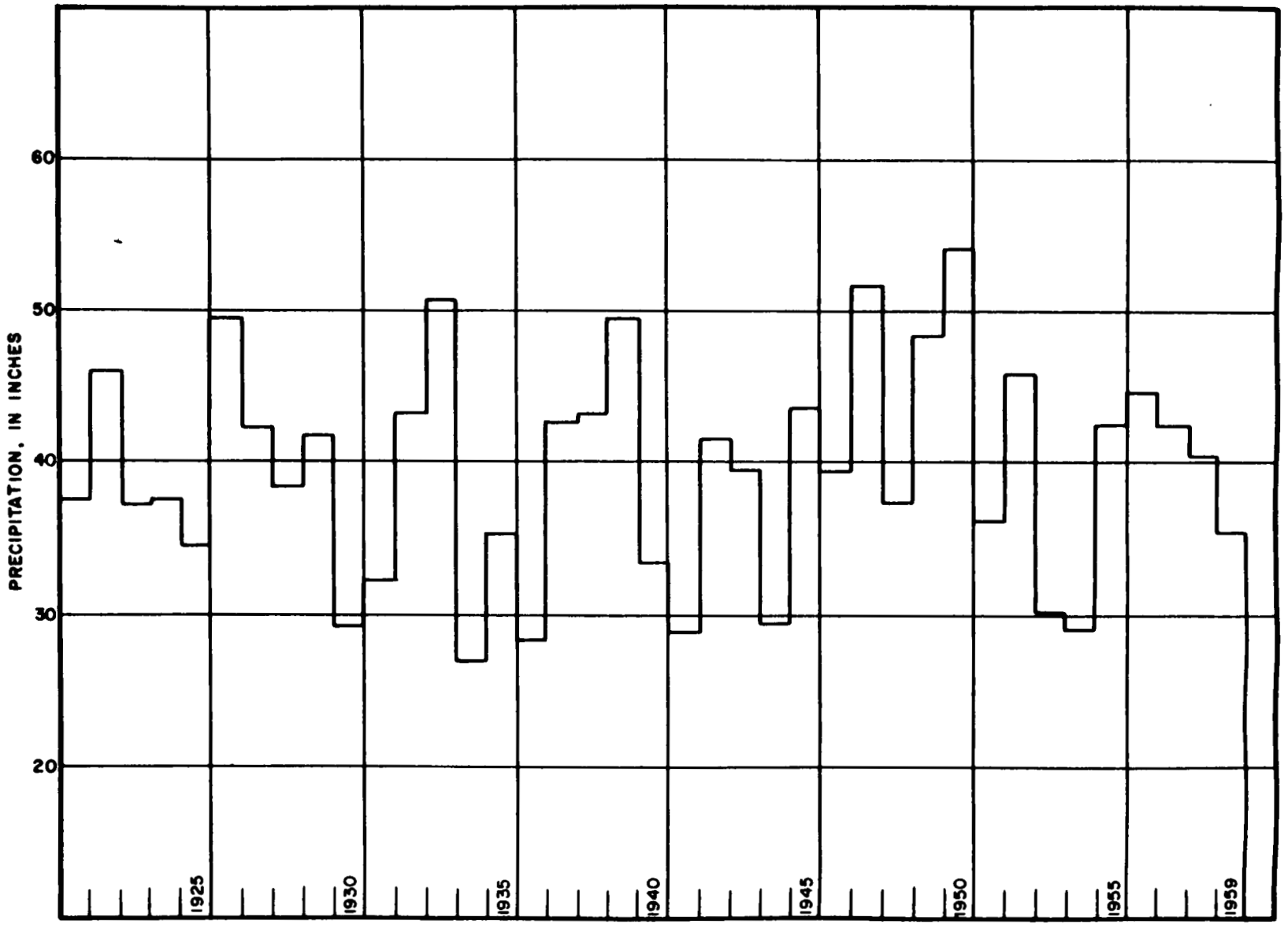


Figure 6. Graph showing the yearly precipitation at Cincinnati, Ohio.

inches, 5.94 inches greater than average. This excess added to the excess for 1920 gives an accumulated departure of 6.53 inches greater than the average. As figure 7 shows, the cumulative departure from the mean annual precipitation at Cincinnati was below average from 1934 to 1957, the lowest year on record being 1944. It was during this period (1940-45) that water became of vital concern to industries in the Mill Creek valley engaged in the production of essential war materials. As shown by figure 7, the cumulative departure from the mean annual precipitation at Cincinnati between the years 1920-59 is 6.39 inches.

Precipitation might be considered to be the primary influence in determining the available water resources in a given area. There is, however, no simple relation between rainfall, streamflow, and ground water, as is shown by figures 8 and 9. These figures show, respectively, the relation of flow in the Miami River to precipitation at selected stations in the headwaters area of the Miami River and that at Hamilton. Modifying influences are temperature, evaporation, and transpiration. The graphs shown in figures 8 and 9, however, show that runoff in the winter generally is greater in proportion to the total precipitation than it is in the summer. This is to be expected, largely on account of evapotranspiration losses in summer. The graphs also suggest a seasonal distribution of flows, which may be of significance in that it relates to storage conditions in the aquifer. That is, during periods when ground-water levels are high, greater amounts of water seep from the ground and sustain a higher flow of the river.

TEMPERATURE

The mean annual air temperature at Hamilton and Cincinnati is 54.0° F and 56.1° F, respectively. July and August are the hottest months and January is the coldest. A graph showing the mean monthly temperature is given in figure 10. Maximum temperatures of 111° F and 108° F were recorded on July 21, 1934 at Hamilton and Cincinnati, respectively. A minimum temperature of -20° F was recorded at Hamilton on January 19, 1918, and a minimum temperature of -17° F was recorded at Cincinnati on February 9, 1934.

STREAMFLOW

The Miami River drains a total of 5,385 square miles, of which 1,437 square miles is in Indiana. The entire basin is in the Till Plains section of the central lowlands physiographic province (Fenneman, 1938). Discharge measurements in the Miami River were recorded at Venice during the period 1919 to 1927. In 1927 the station was moved to Hamilton, where it has remained in constant operation. The maximum and minimum flows of the Miami River at Hamilton and the dates they were recorded are:

Maximum daily discharge, 73,900 cfs (cubic feet per second), January 22, 1959.
Minimum daily discharge, 155 cfs, September 27, 1941.
Mean discharge (October 30, 1931 to September 30, 1960), 3,214 cfs.
Maximum recorded discharge, 108,000 cfs, January 21, 1959.
Minimum recorded discharge 100 cfs, September 26, 27, 1941.

The maximum and minimum flows of the Miami River at Hamilton for the period 1951-1957 are shown on figure 11.

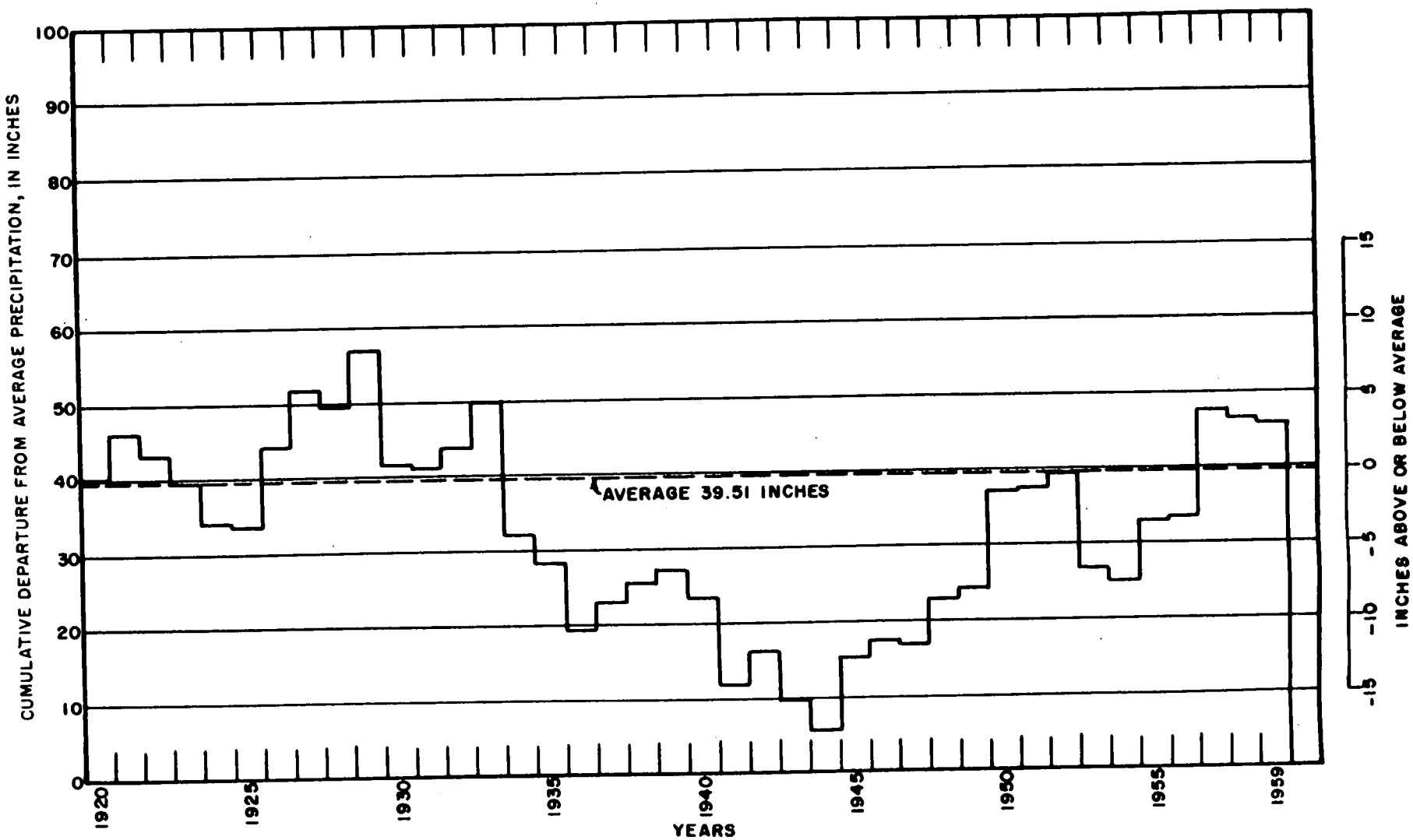


Figure 7. Cumulative departure from average annual precipitation at Cincinnati, Ohio.

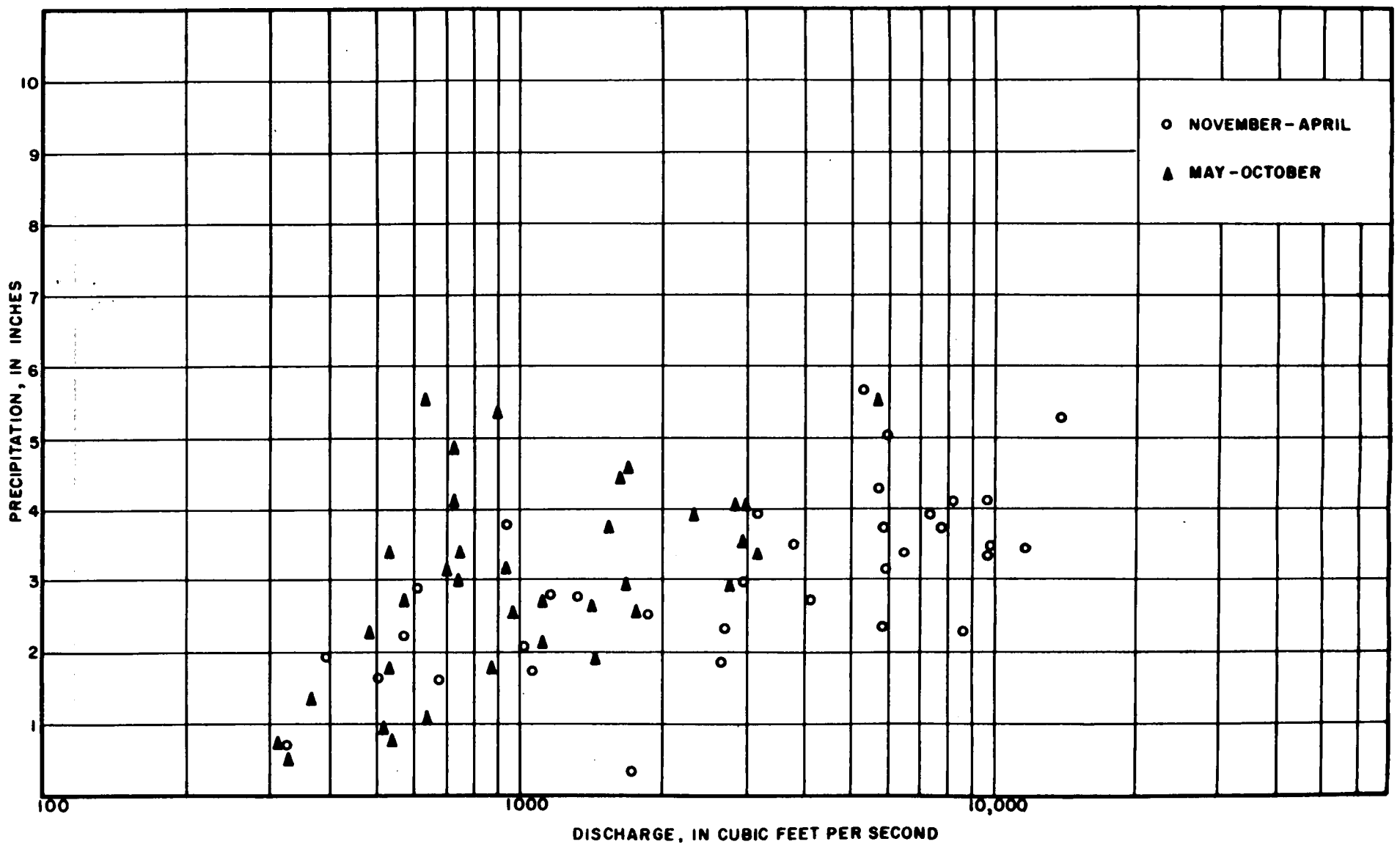


Figure 8. Graph showing the relationship of flow of the Miami River at Hamilton, Ohio, to the average monthly precipitation at selected stations (Lakeview, Sidney, Varsailles, Dayton) in the headwater areas of the river between the years 1951 and 1956.

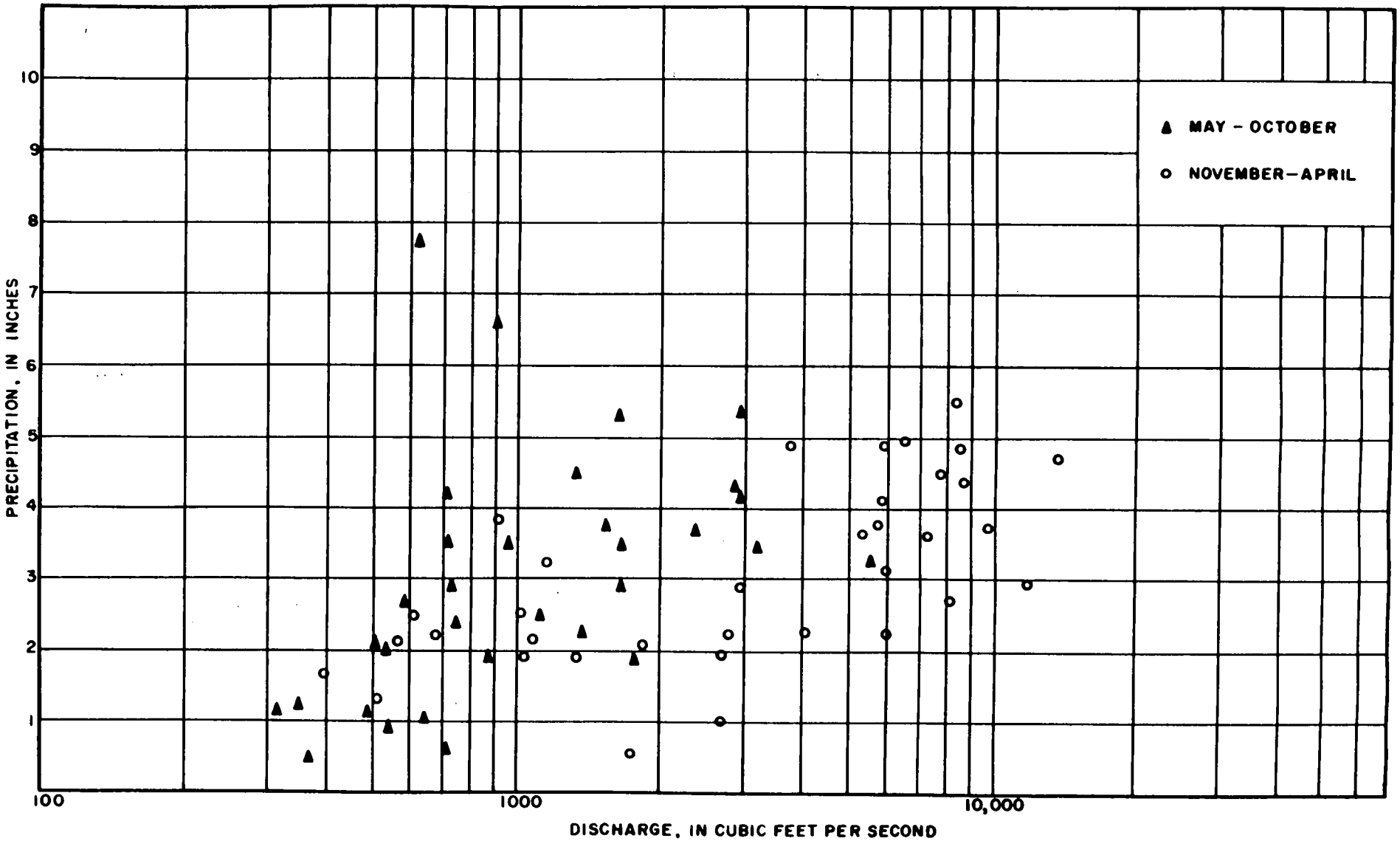


Figure 9. Graph showing the relationship of flow of the Miami River at Hamilton, Ohio, to the average monthly precipitation at Hamilton between the years 1951 and 1956.

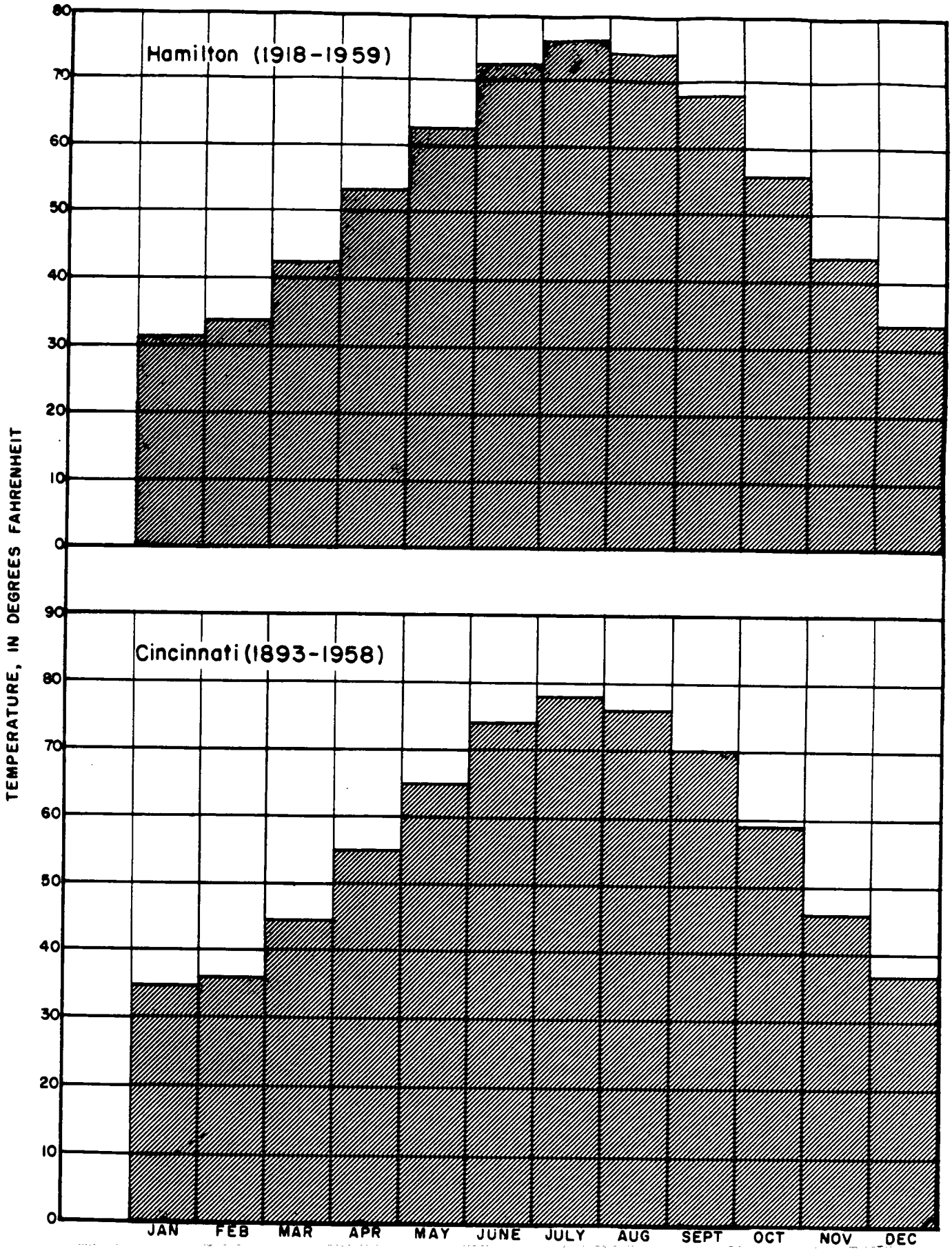


Figure 10. Mean monthly temperatures recorded at Hamilton and Cincinnati, Ohio.

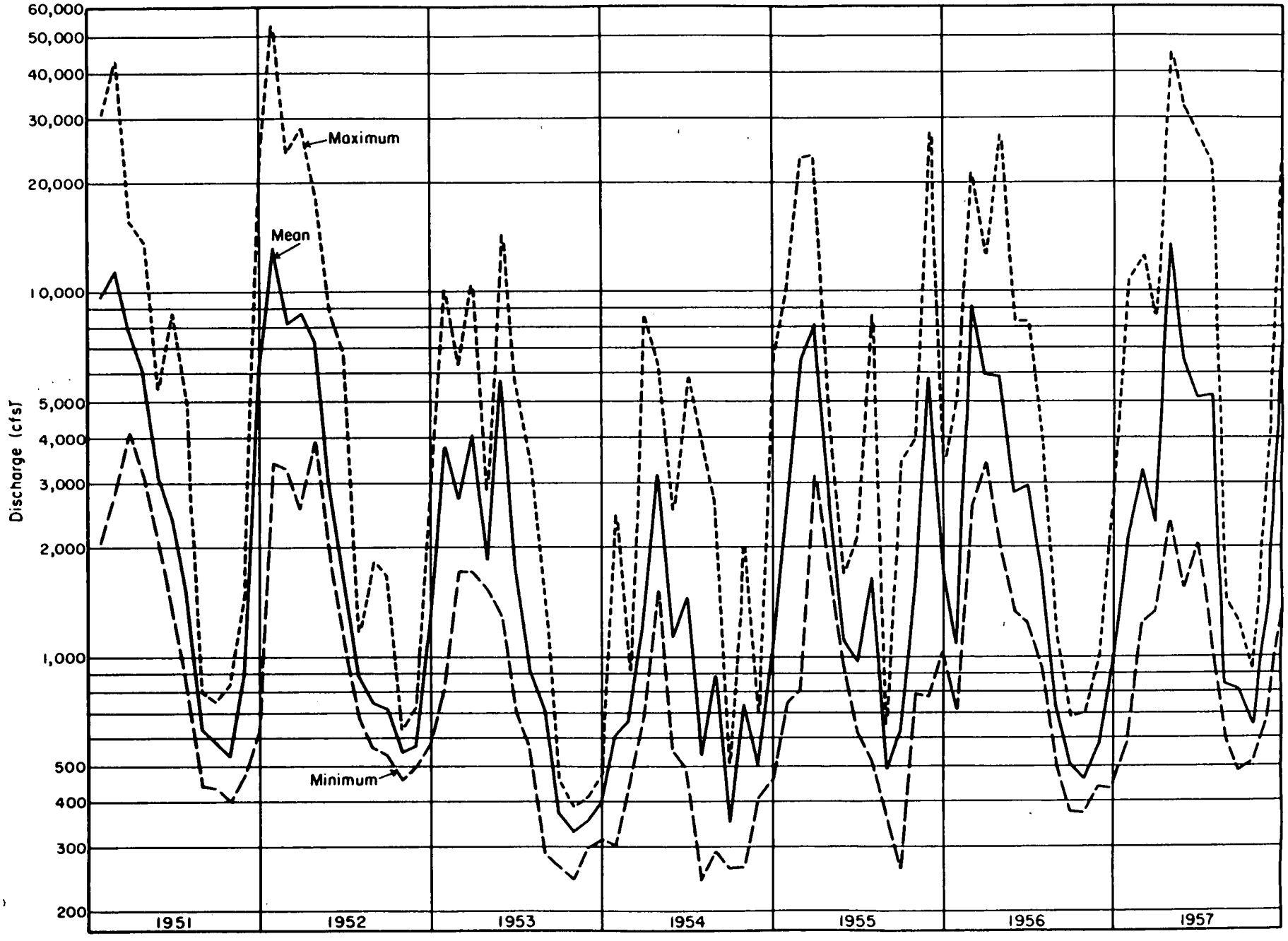


Figure 11. Hydrograph showing the maximum, mean, and minimum daily flows of the Miami River at Hamilton, Ohio, 1951-1957.

In studying the flow of a stream there are several types of curves that may be used in the analysis of streamflow records. The flow-duration curve is perhaps the best for comparing flow characteristics of different streams. Flow-duration curves show the frequency of occurrence of various rates of flow. This is a cumulative curve and is prepared by tabulating all discharges of record in order of magnitude and arranging them according to percentage of time during which these specific flows are equaled or exceeded. The shape of the duration curve is an index of the natural storage within a basin, including ground water storage; the more nearly horizontal the curve the greater is the storage effect. Figure 12 is a flow-duration curve for the Miami River at Hamilton.

The Miami River valley is subject to frequent floods. Since 1805, the date of the first recorded flood, numerous damaging floods have occurred in the valley. These floods have taken hundreds of lives and destroyed millions of dollars worth of property. By far the worst flood on record in Ohio occurred in March, 1913. During this flood more than 400 lives were lost and more than 100 million dollars worth of property was destroyed. To prevent the recurrence of major floods such as that in 1913, engineers constructed five detention dams in the Miami River basin. (See table 1.) These dams are maintained by the Miami Conservancy District.

Since the completion of the five detention dams in the Miami River basin, no floods have approached in magnitude that of 1913. Fairly large floods occurred however in 1922, 1929, 1937, 1943, 1952, and 1959. Figure 13 shows the inundated area near Venice during the flood of January 1959. During the flood of January 1959, collector 1 was pumped at approximately 10 mgd, yet the water in the collector rose about 30 feet to an elevation of 520 feet, or 1 foot below the pump floor.

Table 1.--Detention dams in the Miami River basin

Reservoir	Stream	Drainage area in miles	Total storage in acre-feet
Englewood	Stillwater River	646	312,000
Germantown	Twin Creek	275	106,000
Huffman	Mad River	632	167,000
Lockington	Loramie Creek	261	70,000
Taylorsville	Miami River	1,155	186,000

Above Dayton the sustained flow of the Miami River is relatively high. From Dayton to Hamilton there is a general decrease in the dry-weather-flow indices of tributaries to the Miami River except at Miamisburg, where the effects of diversion at Dayton of municipal and industrial water from the Mad River valley is noticeable (Cross and Hedges, 1959). Flow-duration curves adjusted to base period 1921-45 for the Miami River at Taylorsville, Dayton, Miamisburg, and Hamilton are shown in figures 14 and 15. The location of these stations is shown on figure 16. The decrease in dry-weather flow below Dayton probably results from less natural storage in the tributary streams below Dayton. These streams drain the Ordovician shale terrane and flow in relatively shallow, narrow valleys. Above Dayton the streams flow over limestone and, moreover, they generally occupy relatively wide valleys filled with permeable outwash deposits.

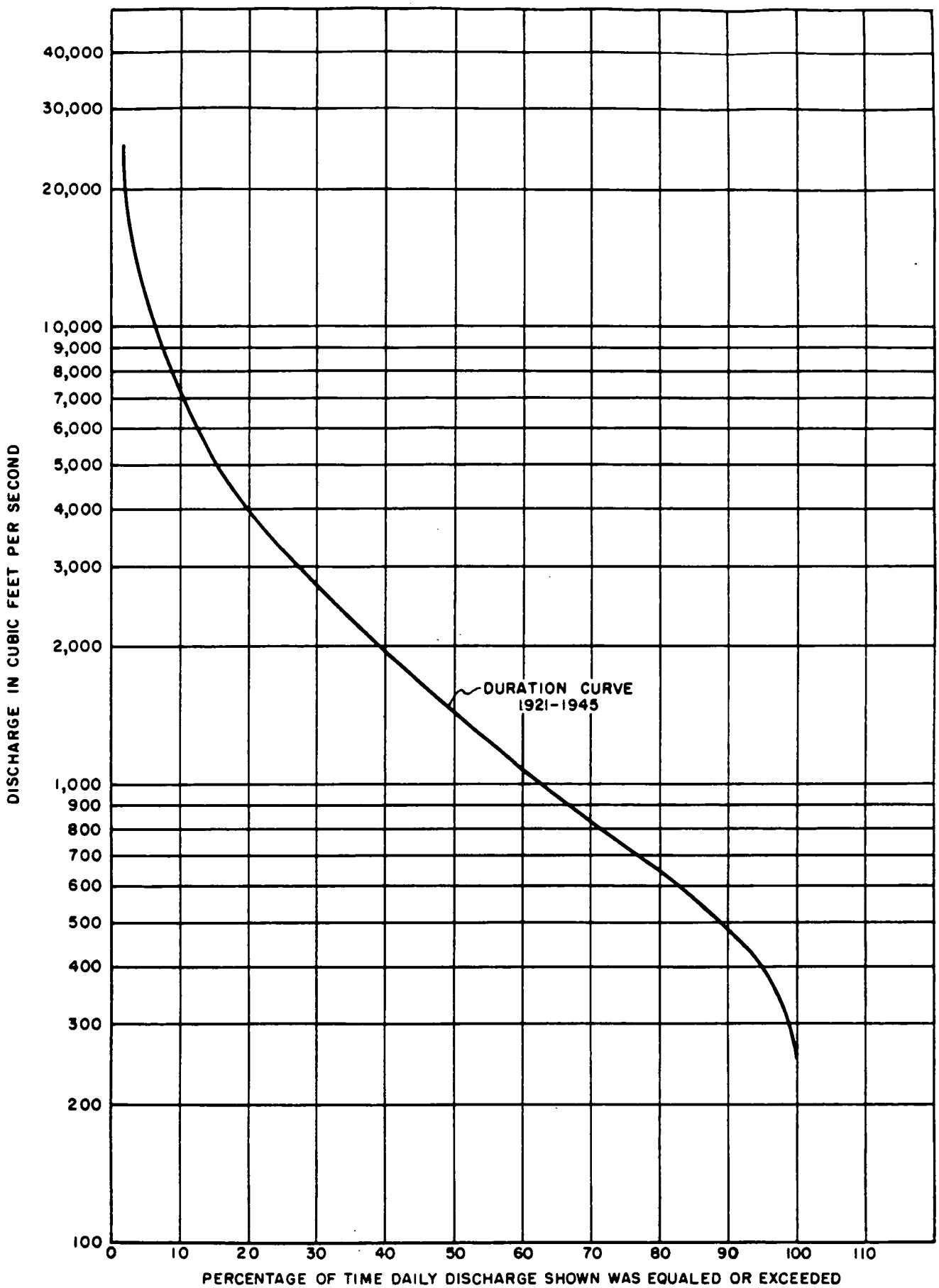


Figure 12. Flow-duration curve for Miami River at Hamilton, Ohio.

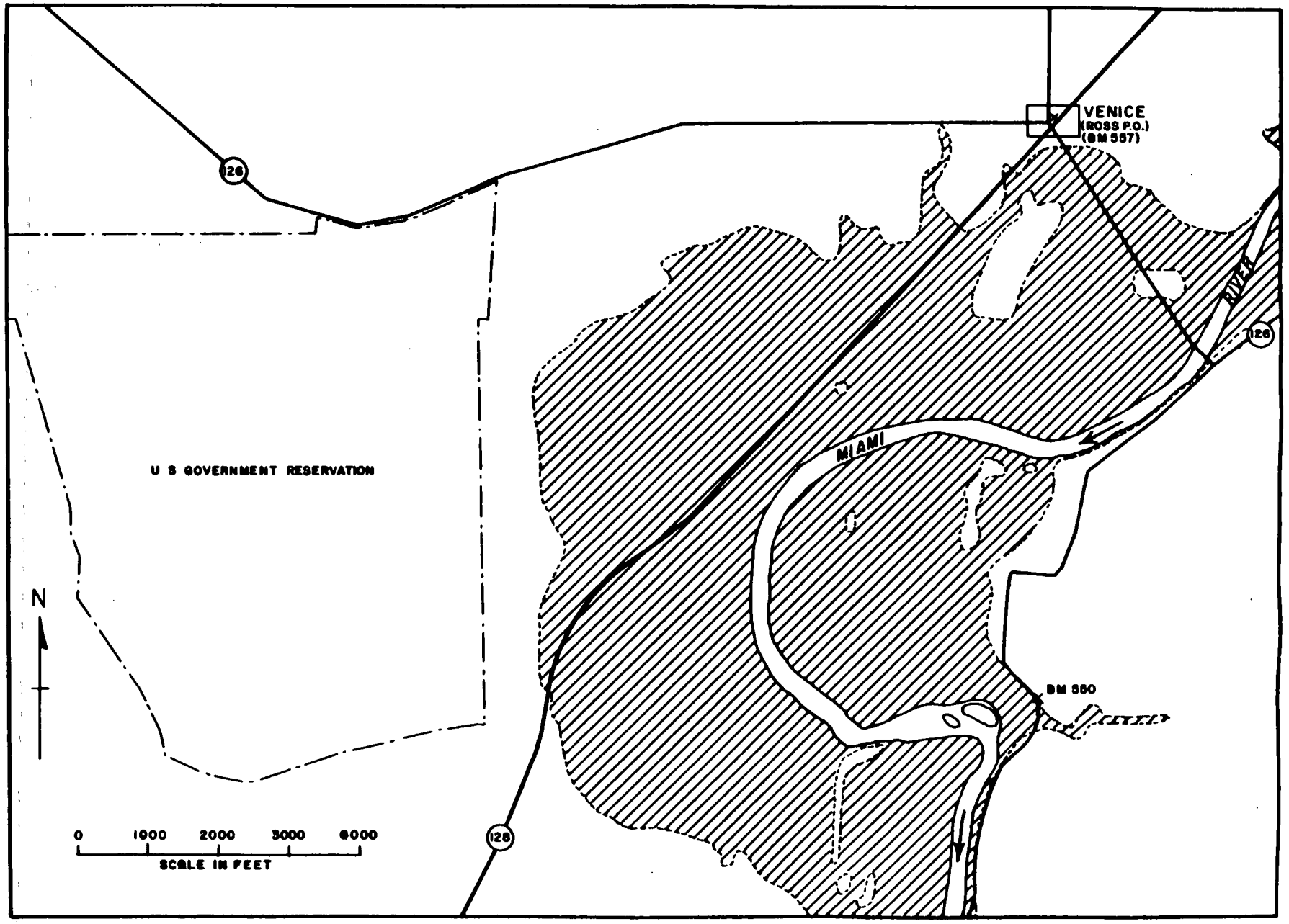


Figure 13. Map showing area inundated by the flood of January 21-23, 1959.

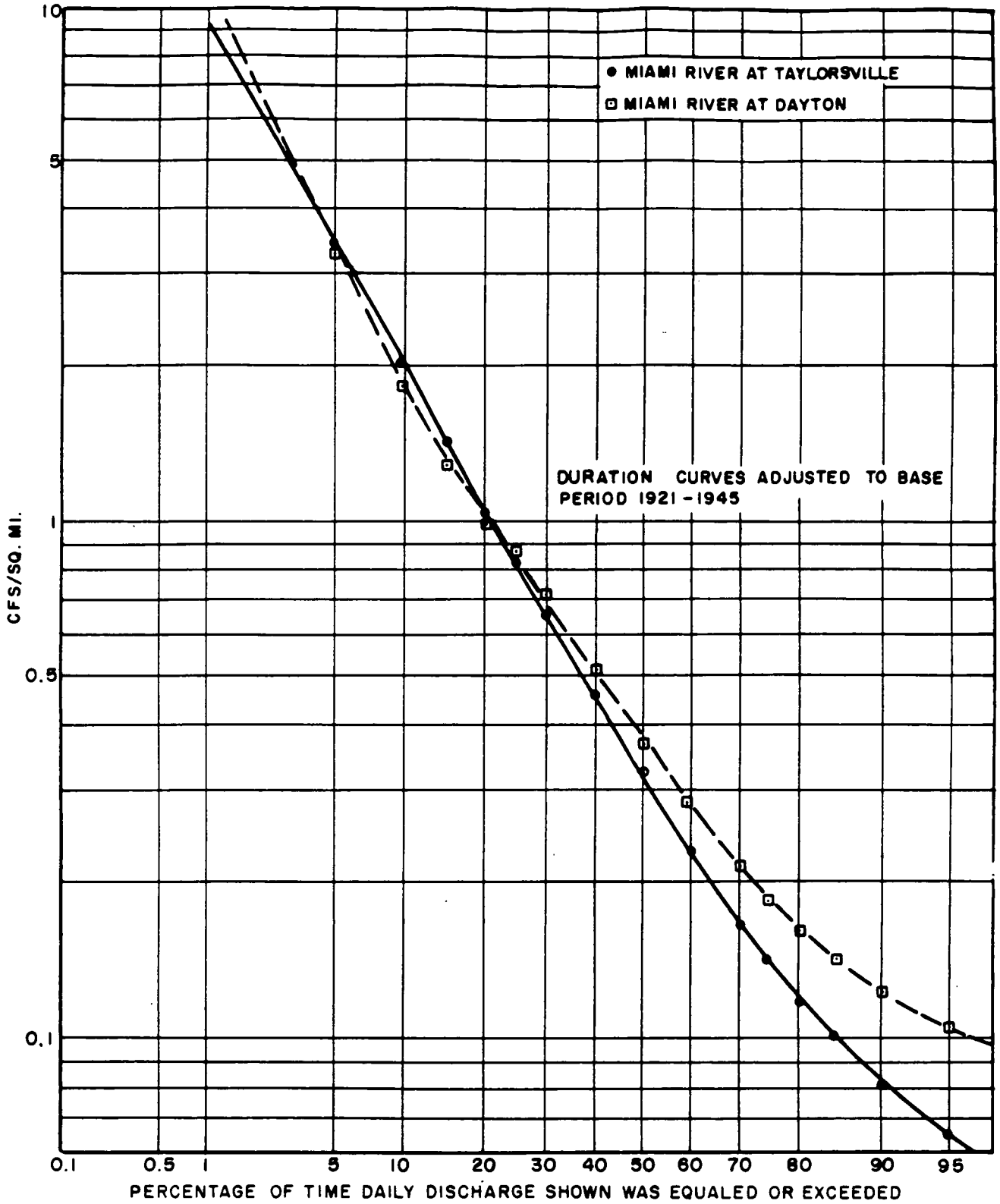


Figure 14. Flow-duration curve, Miami River at Taylorsville and Dayton, 1921-1945.

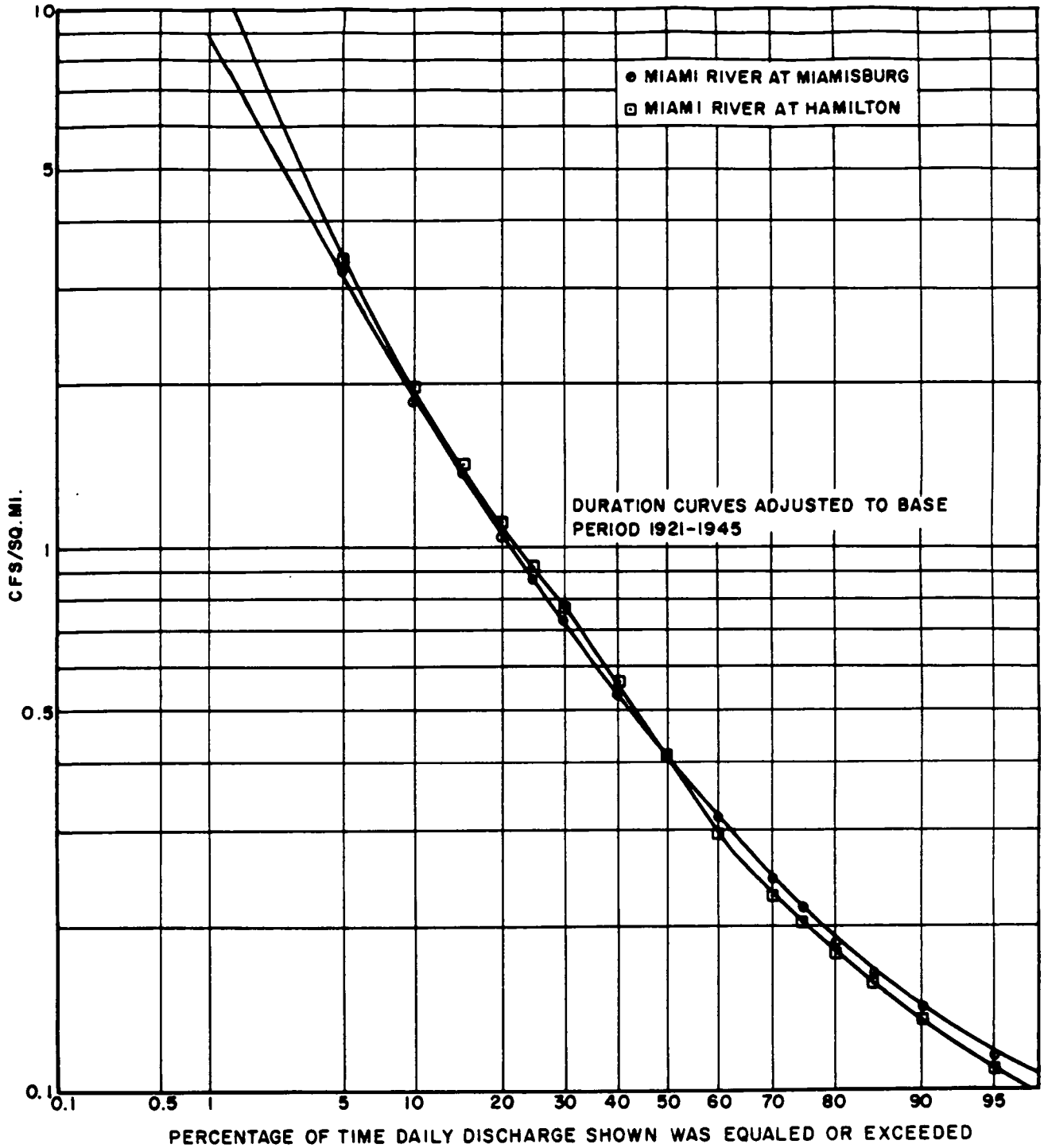


Figure 15. Flow-duration curve, Miami River at Miamisburg and Hamilton, 1921-1945

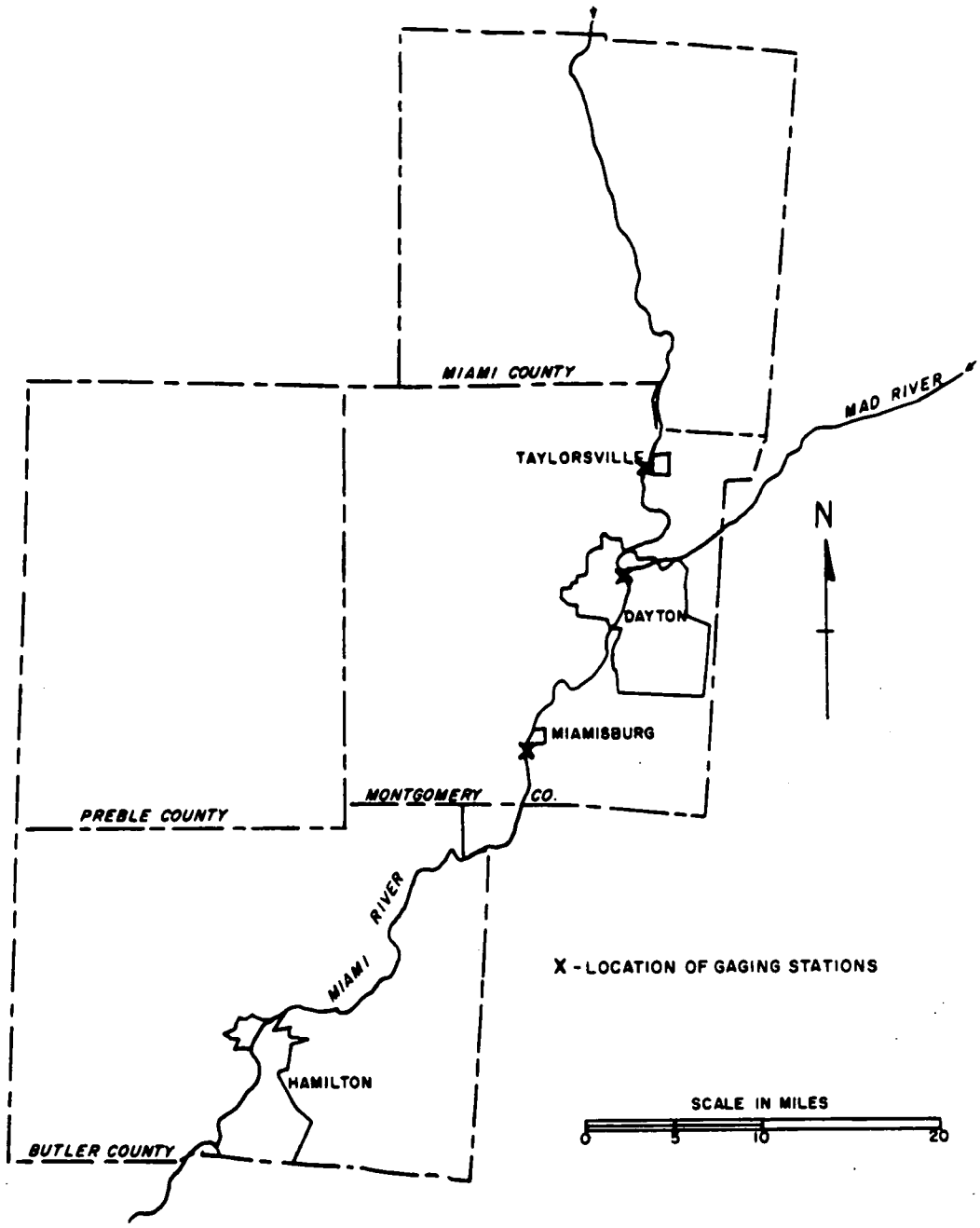


Figure 16. Map of Miami River north of Hamilton, showing locations of stream-gaging stations.

GROUND-WATER OCCURRENCE AND STORAGE

Ground water in outwash deposits, such as those in the Miami River valley near Venice, occurs in the irregular openings between the individual particles of sand and gravel. The water in these openings is controlled principally by two forces, gravity and molecular attraction. Gravity is the force that causes water to flow from springs or to enter wells, and the molecular forces tend to resist motion. The most productive water-bearing deposit is coarse well-sorted gravel in which the spaces between adjacent particles are large and interconnected so that they readily absorb water, store it in large quantities, and yield it freely to wells.

Water in the openings between sand and gravel particles may occur under water-table or artesian conditions. The water may be bounded above and below by an impervious layer, when it is said to be under confined or artesian conditions, or the upper surface of the ground water may be unconfined, when it is said to be under water-table conditions. Ground water in the outwash deposits of the Miami River valley in the Venice area is under water-table conditions.

The saturated thickness of the valley-train deposits in the Venice area averages about 125 feet, and the porosity (the ratio of the interstitial volume of a rock to its total volume) of these deposits is estimated to be about 35 percent. The quantity of water in storage, therefore is about 0.17 million acre-feet (55 billion gallons). However, not all the water in the pore spaces will drain into wells, a part being retained by the forces of cohesion and adhesion. The amount of water that is free to drain by gravity from the aquifer is indicated by its specific yield. The specific yield is the volume of water that is free to drain by gravity from a saturated rock, expressed as a percentage of the total volume of the rock. From a study of the water-bearing properties of the aquifer at Venice, and based on computations for the sand and gravel aquifer at Louisville, Ky. (Stuart, 1944), the average specific yield of the valley-train deposits near Venice is estimated to be about 0.2. If the average specific yield of the aquifer is assumed to be 20 percent, about 95,000 acre feet (31 billion gallons) of water could be made available from storage in the Venice area by completely dewatering the aquifer.

PUMPAGE

The users of the largest amounts of ground water in the Venice area are the Southwestern Ohio Water Company, National Lead Company of Ohio, and the Meadowbrook Swimming Pool. The Southwestern Ohio Water Company pumps 14 to 15 mgd, the National Lead Company of Ohio pumps an average of 2 mgd and the Meadowbrook Swimming Pool pumps about half a million gallons of water once a week during the summer. (See table 2.) This report is concerned primarily with the pumpage of the Southwestern Ohio Water Company.

Ground water for the Southwestern Ohio Water Company is supplied by two radial collectors. Figure 17 and 18 are diagrams of the collectors, designated 1 and 2, respectively. Water pumped from the collectors is piped about 24 miles through a 36-inch-diameter main to a reservoir in the Mill Creek valley, whence it flows by gravity to the industries served by this system. The monthly rates of pumpage from the two Southwestern Ohio Water Company collectors are shown in table 2.

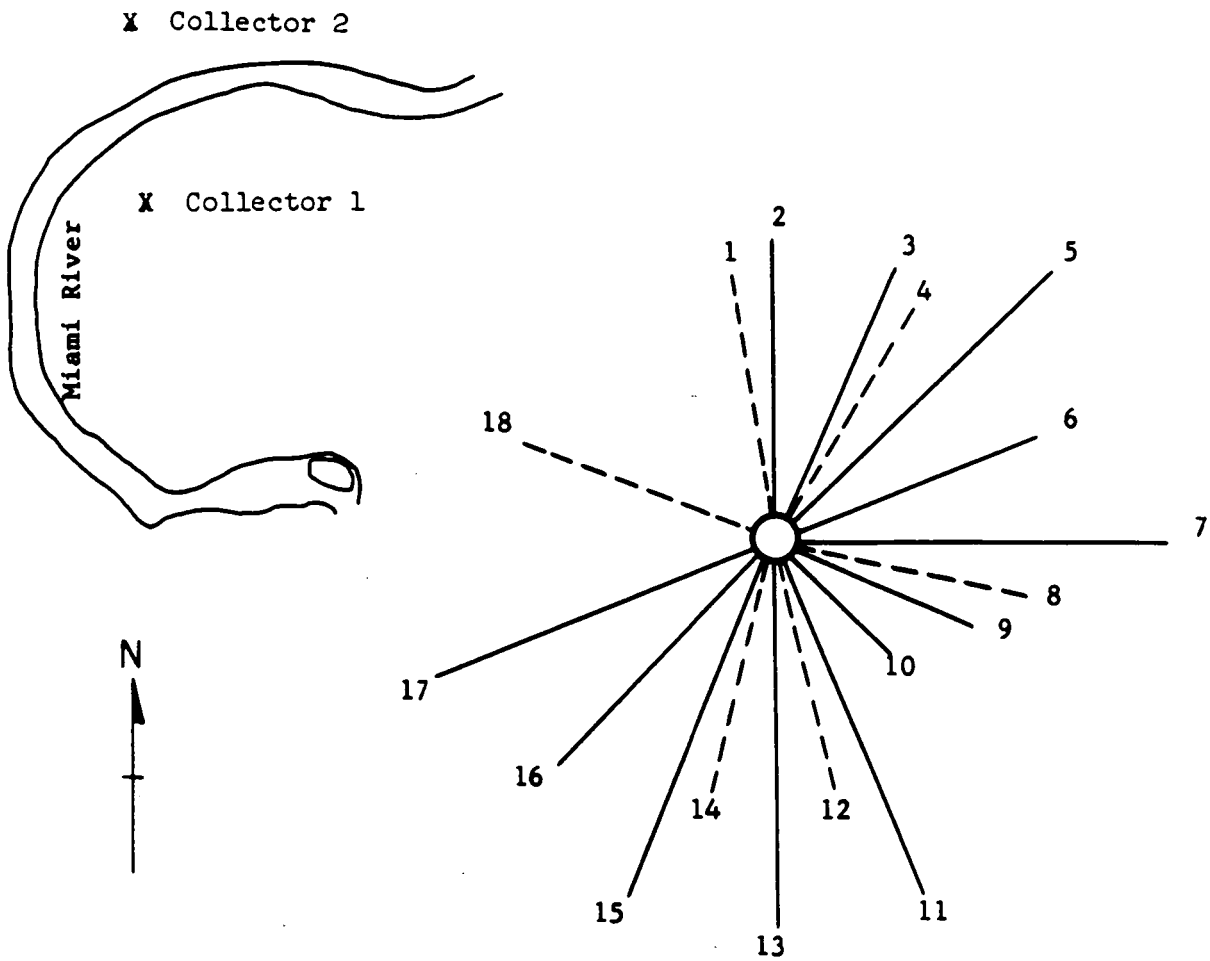
Table 2.--Monthly pumpage in millions of gallons at Southwestern Ohio Water Company collectors.

Collector 1

	1952	1953	1954	1955	1956	1957	1958
Jan.		384 588	339.800	392.500	175.880	197.718	207.559
Feb.		362.784	309.367	396.369	159.517	257.132	200.222
Mar.		353.693	365.702	309.180	182.837	288.196	148.200
Apr.		342.415	339.527	259.148	170.228	256.787	197.503
May		362.964	362.162	208.798	183.503	230.075	191.582
June	156.492	385.585	350.750	185.979	167.534	245.510	201.549
July	170.093	342.065	337.316	144.313	172.350	209.482	195.779
Aug.	329.302	408.736	344.181	145.542	175.523	219.191	235.821
Sept.	349.136	365.904	346.225	171.372	173.215	196.318	213.294
Oct.	368.494	390.845	354.168	146.083	171.625	193.178	204.013
Nov.	354.480	313.124	355.979	239.697	186.953	179.460	187.063
Dec.	326.817	316 687	351.606	247.404	167.412	208.237	193.013
Daily Avg.	9.60	11.86	11.39	7.80	5.72	7.35	6.51

Collector 2

Jan.					224.707	255.405	211.037
Feb.				11.567	218.166	177.683	163.432
Mar.				132.994	218.721	189.553	244.835
Apr.				165.047	237.101	222.058	210.921
May				250.595	248.349	258.861	207.231
June				289.975	233.916	246.016	191.191
July				234.710	201.633	214.557	171.551
Aug.				313.673	275.931	232.051	192.988
Sept.				239.802	211.410	236.115	176.781
Oct.				278.697	258.553	251.561	206.961
Nov.				191.702	220.693	207.301	185.189
Dec.				188.097	246.843	193.343	224.060
Daily Avg.				7.39	7.63	7.37	6.54

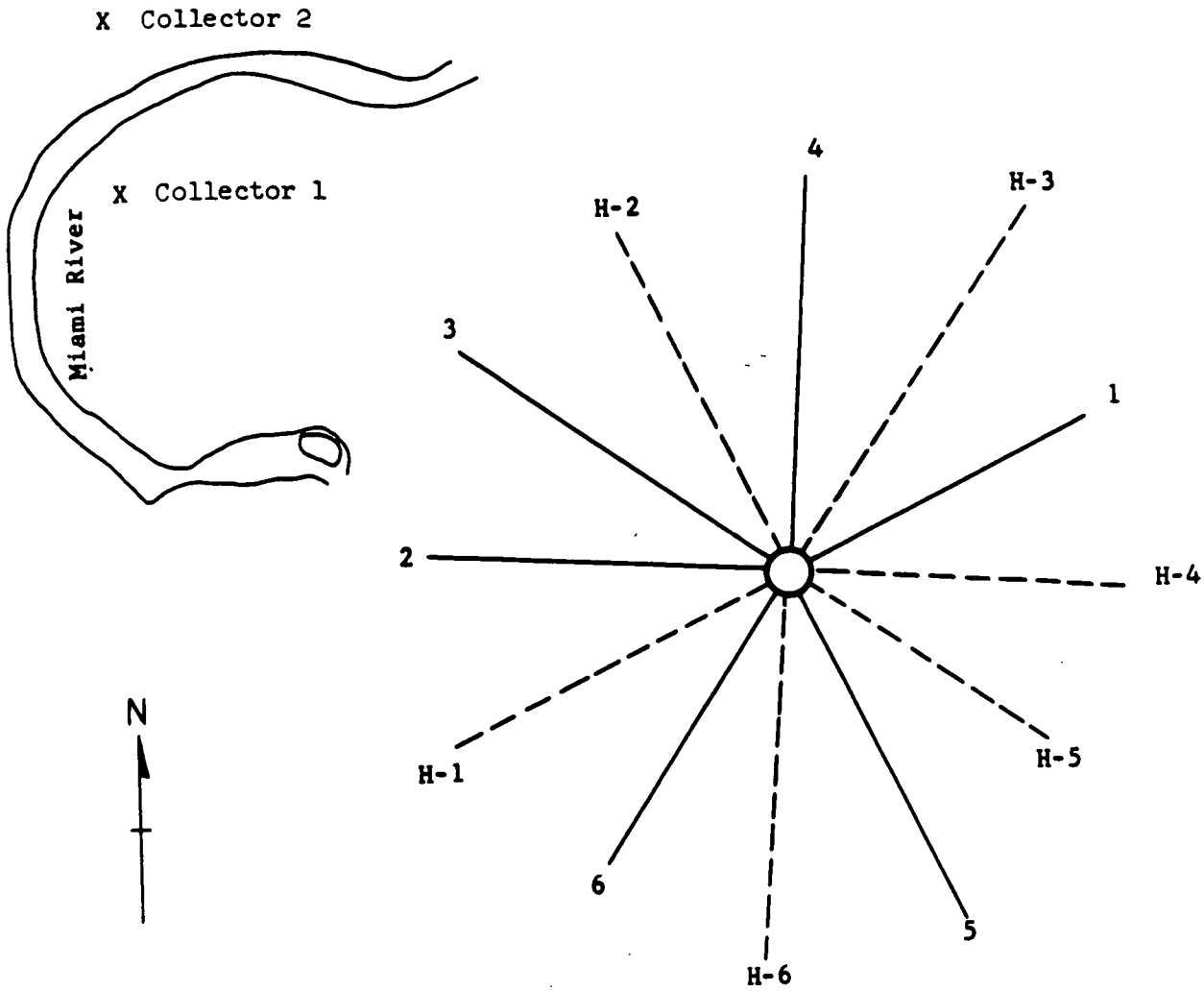


Elevations: LOWER TIER - 409.7 ft. UPPER TIER - 433 ft.

Line No.	length	Line No.	length
1	132'	2	150'
4	132'	3	152'
8	132'	5	197'
12	132'	6	144'
14	132'	7	200'
18	132'	9	112'
		10	88'
		11	200'
		13	200'
		15	200'
		16	168'
		17	192'

Scale 1 in. = 100 ft.

Figure 17. Diagram showing the position and length of the horizontal screens in Southwestern Ohio Water Company Collector 1.



Elevations:

LOWER TIER - 413 ft. Line No.	length	UPPER TIER - 417 ft. Line No.	length
1	166'	H-1	192'
2	186'	H-2	192'
3	200'	H-3	224'
4	200'	H-4	176'
5	200'	H-5	155'
6	176'	H-6	200'

Scale 1 in. = 100 ft.

Figure 18. Diagram showing the position and length of the horizontal screens in Southwestern Ohio Water Company Collector 2.

WATER-LEVEL TRENDS

A quantitative study of the ground water supply in an area must be based in part on water-level fluctuations over a considerable period of time. This is necessary to determine the effects of variable precipitation, streamflow, pumping rates, and other factors that influence the amount of water available. During the present investigation, water levels in 35 observation wells have been measured periodically or continuously. The locations of these wells are shown on figure 19. Water-level fluctuations in the wells are shown on figures 20 to 30. Water-level fluctuations and monthly pumpage from collectors 1 and 2, respectively, are shown on figures 31 and 32.

Figures 21 and 23 show the effect, in wells R-6 and K-1, of river stage on ground-water levels in the area. Well R-6 is about 300 feet east of the Miami River, and well K-1 is about 25 feet west of the river. (See fig. 19.) The hydrographs show that during typical high discharge periods (usually in April, May, and June) and during low discharge periods (usually in September and October) corresponding high and low water levels were recorded in the wells.

The graph of the water level in well B-2, figure 22, is not affected by pumpage from collector 2 or by the stage of the Miami River. The water level in this well generally declines during the summer as a result of greater loss of water by evaporation and by transpiration from plants, and it rises during the winter, when these losses are at a minimum. The high and low points of the annual cycle, however, may be reached at different times as a result of many variable factors, such as the depth to the water table, the seasonal and areal distribution of rainfall, and the freezing of the ground in winter.

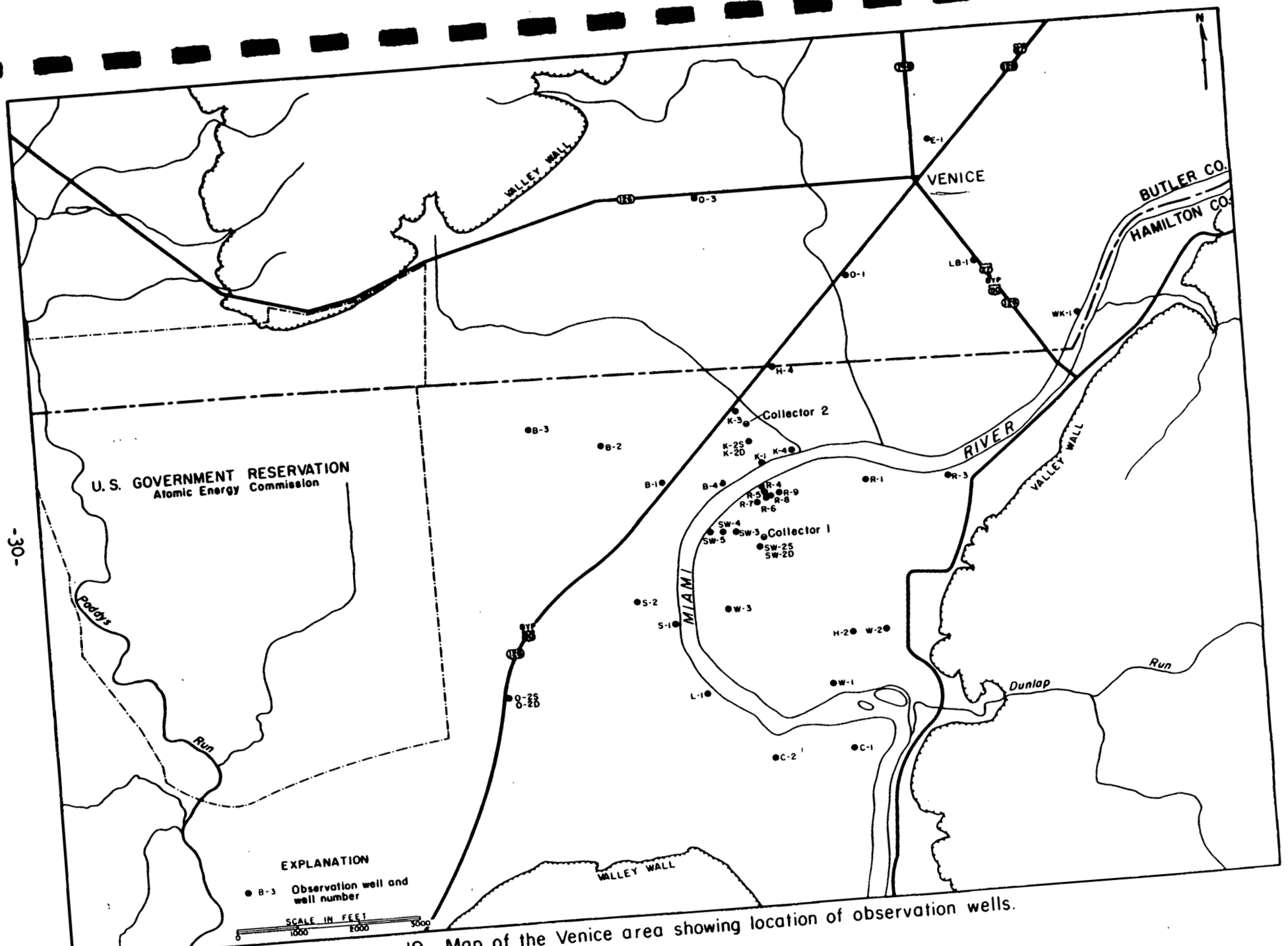


Figure 19. Map of the Venice area showing location of observation wells.

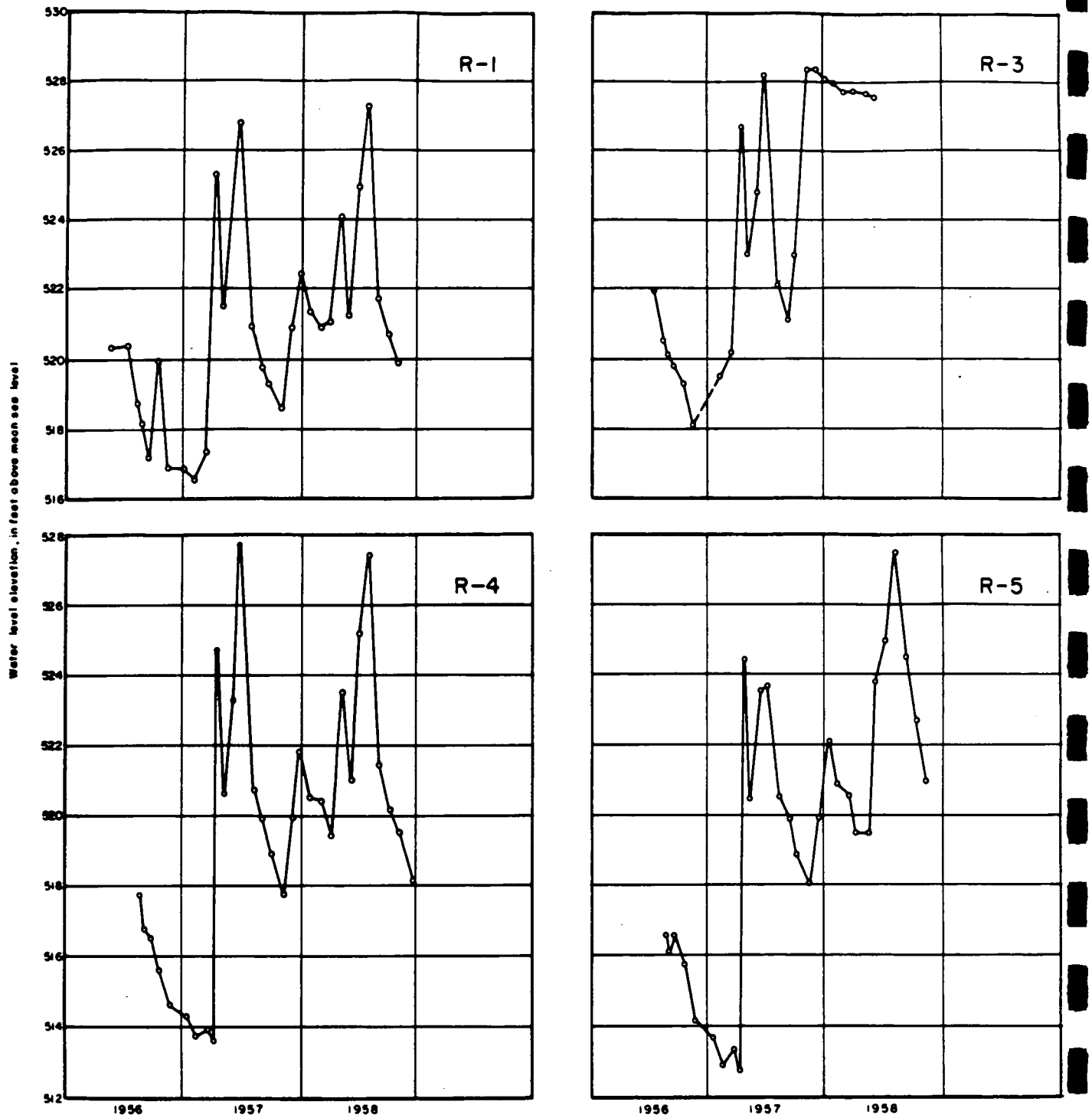


Figure 20. Hydrograph showing fluctuations of the water levels in wells R-1, R-3, R-4 and R-5.

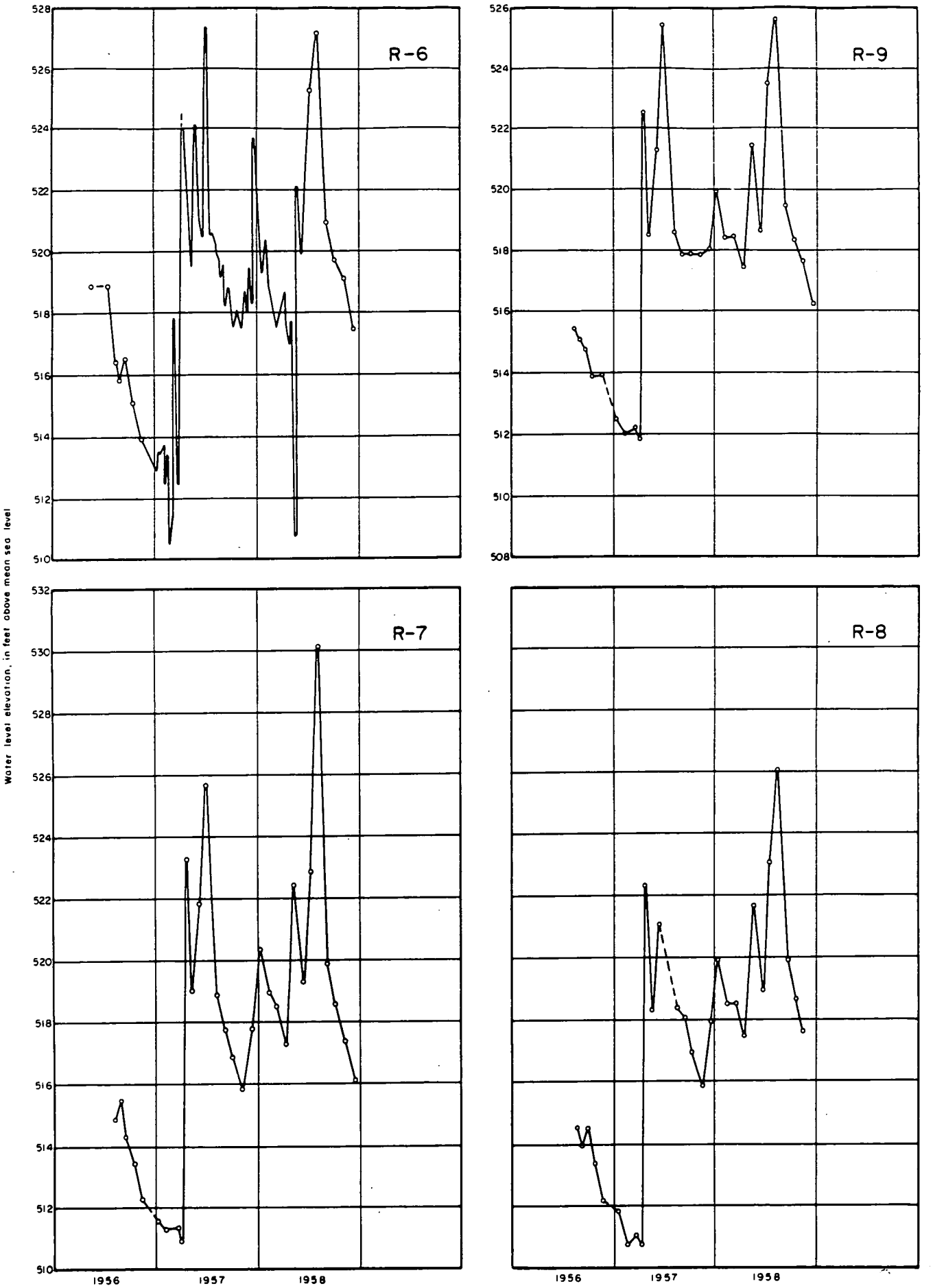


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Figure 21. Hydrograph showing fluctuations of the water levels in wells R-6, R-7, R-8 and R-9.

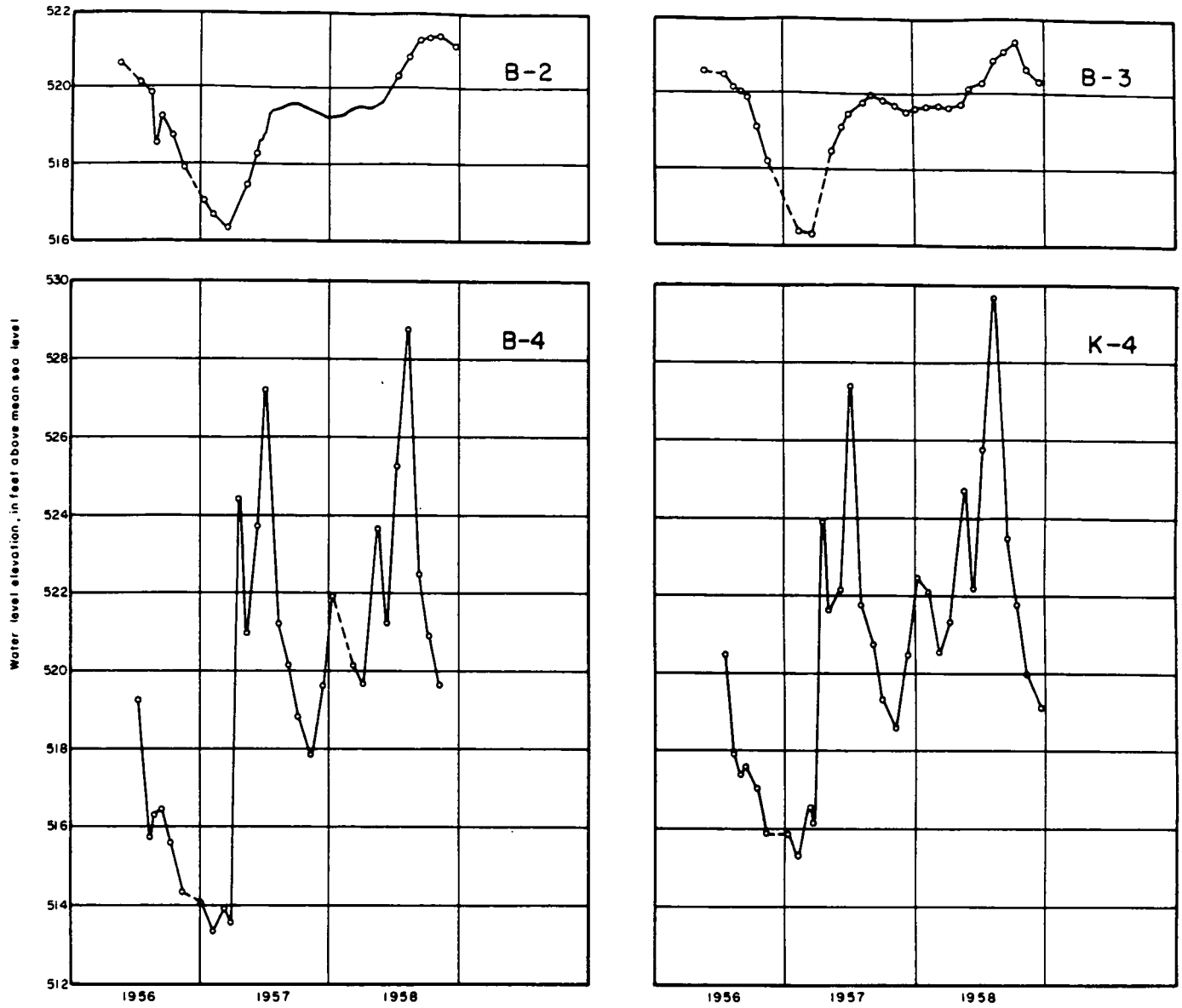

Figure 22. Hydrograph showing fluctuations of the water levels in wells B-2, B-3, B-4 and K-4.

41

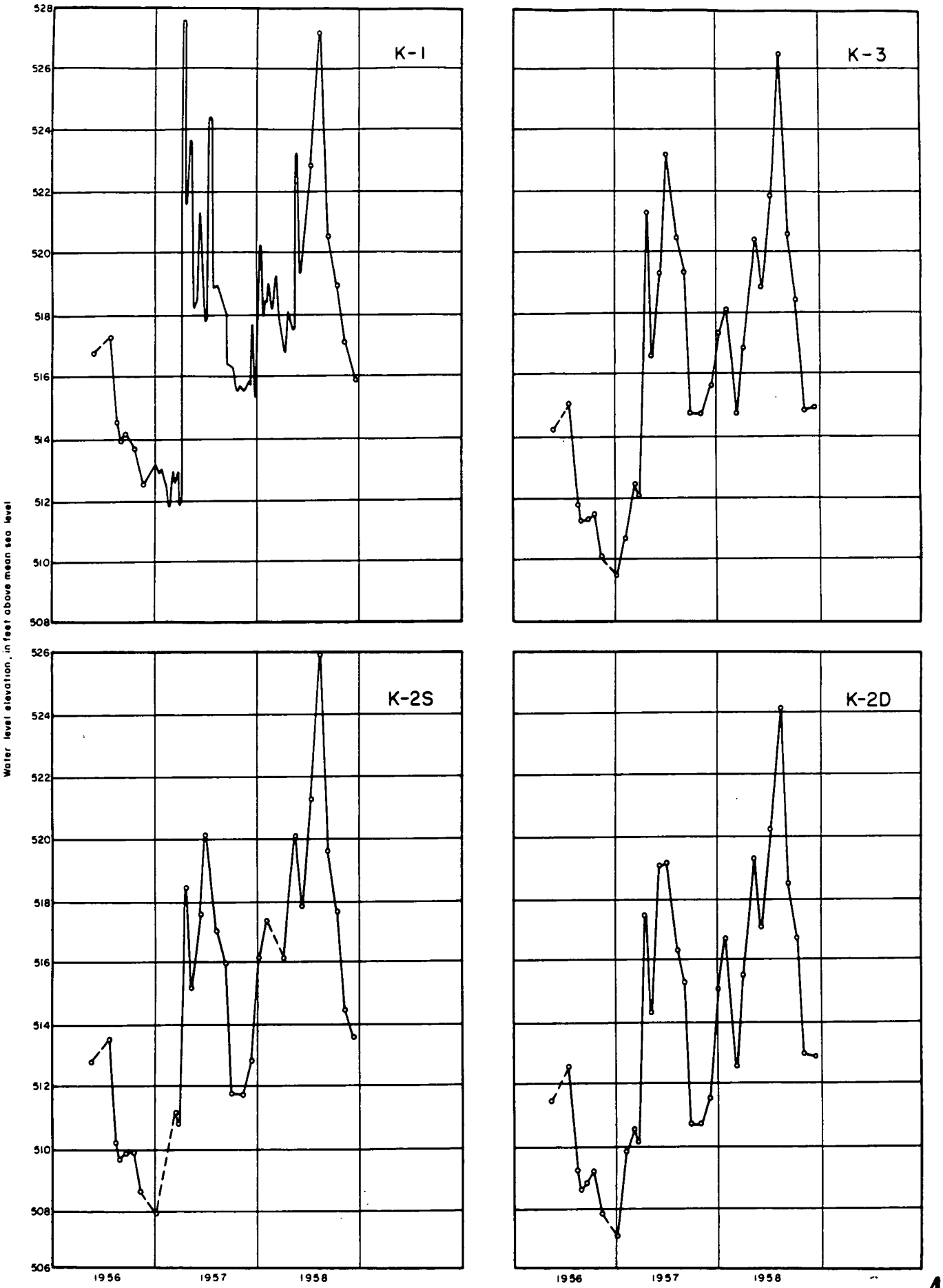

Figure 23. Hydrograph showing fluctuations of the water levels in wells K-1, K-2S, K-2D and K-3.

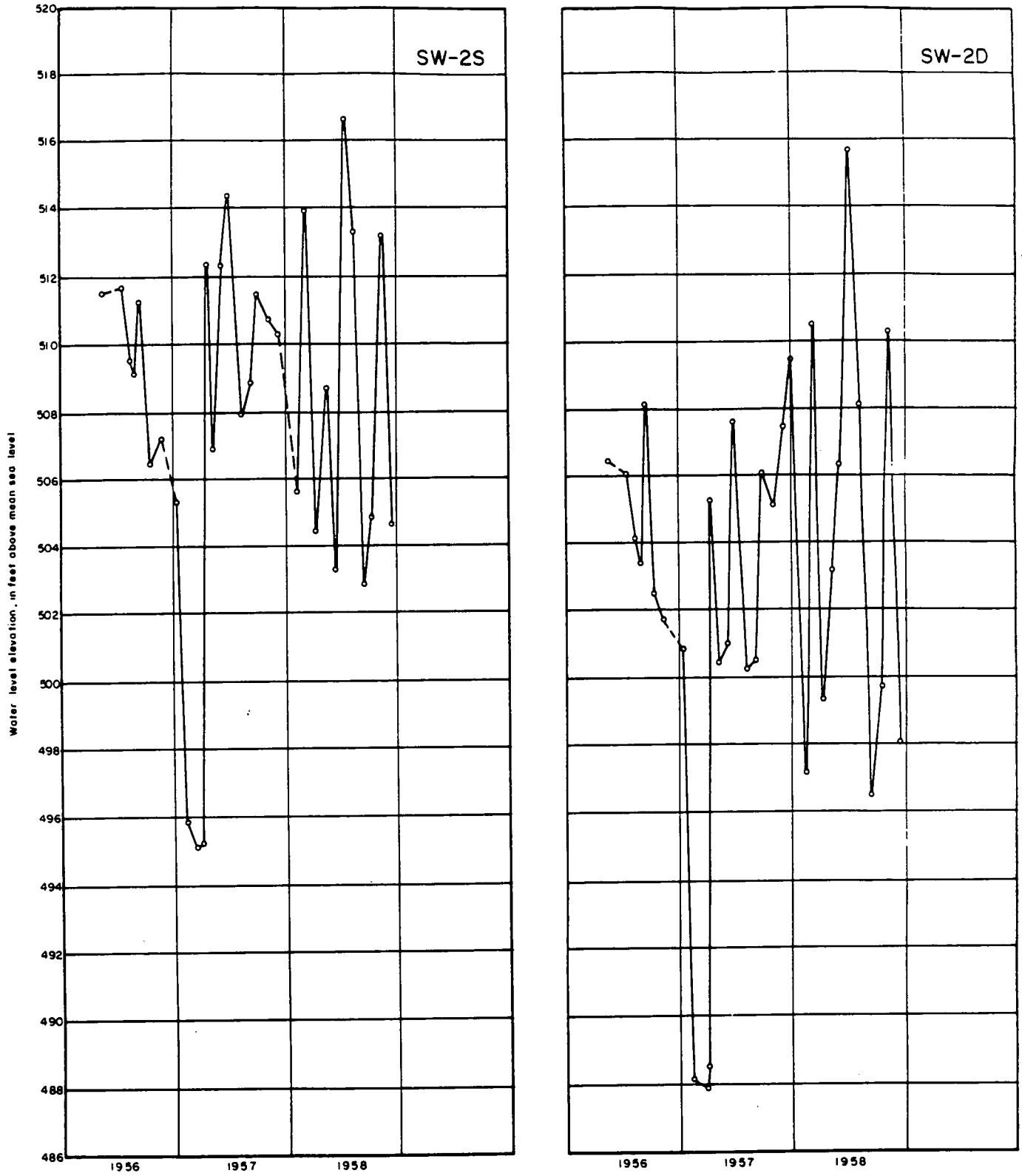

Figure 24. Hydrograph showing fluctuations of the water levels in wells SW-2S and SW-2D.

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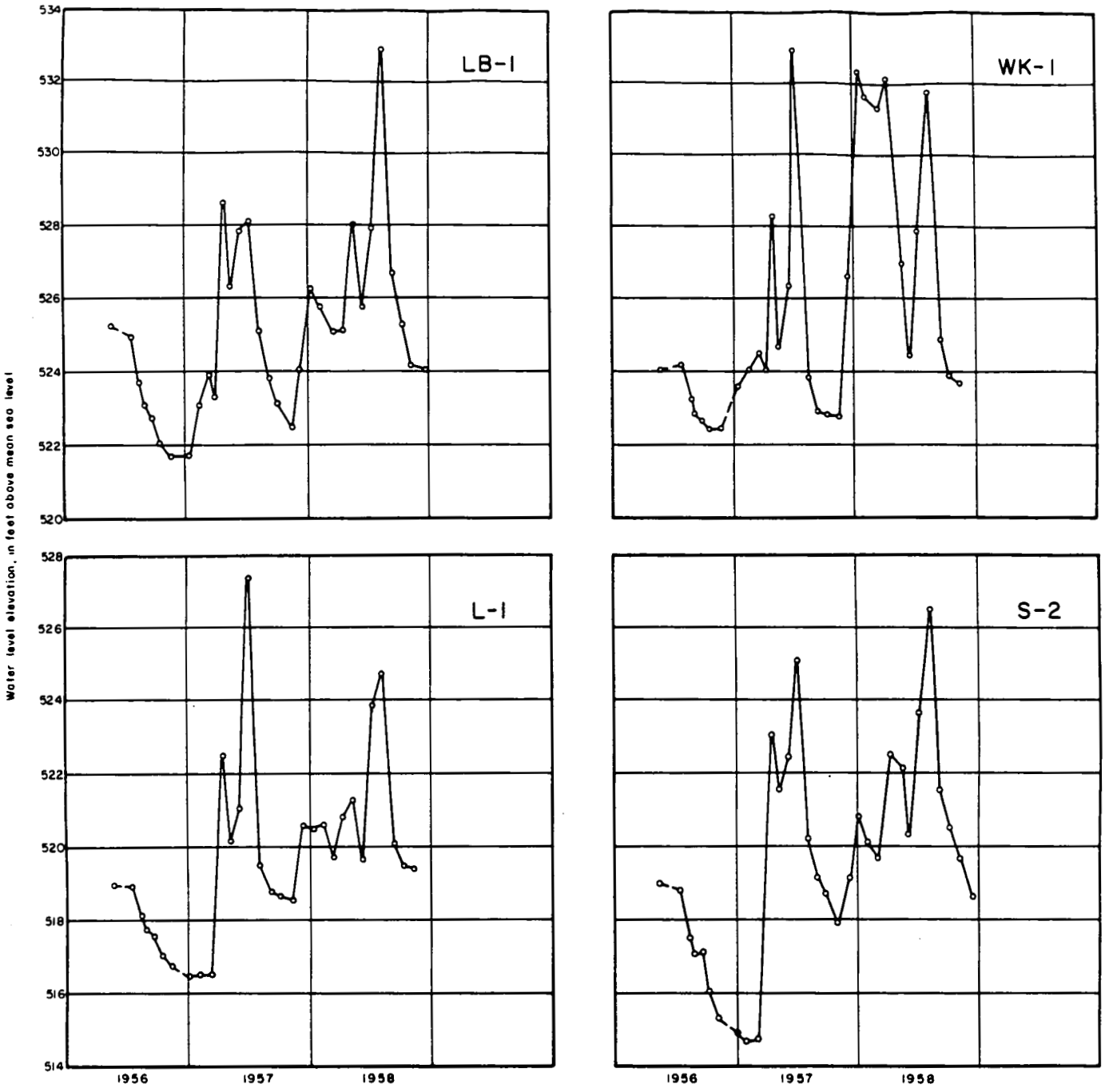

Figure 25. Hydrograph showing fluctuations of the water levels in wells LB-1, L-1, WK-1 and S-2.

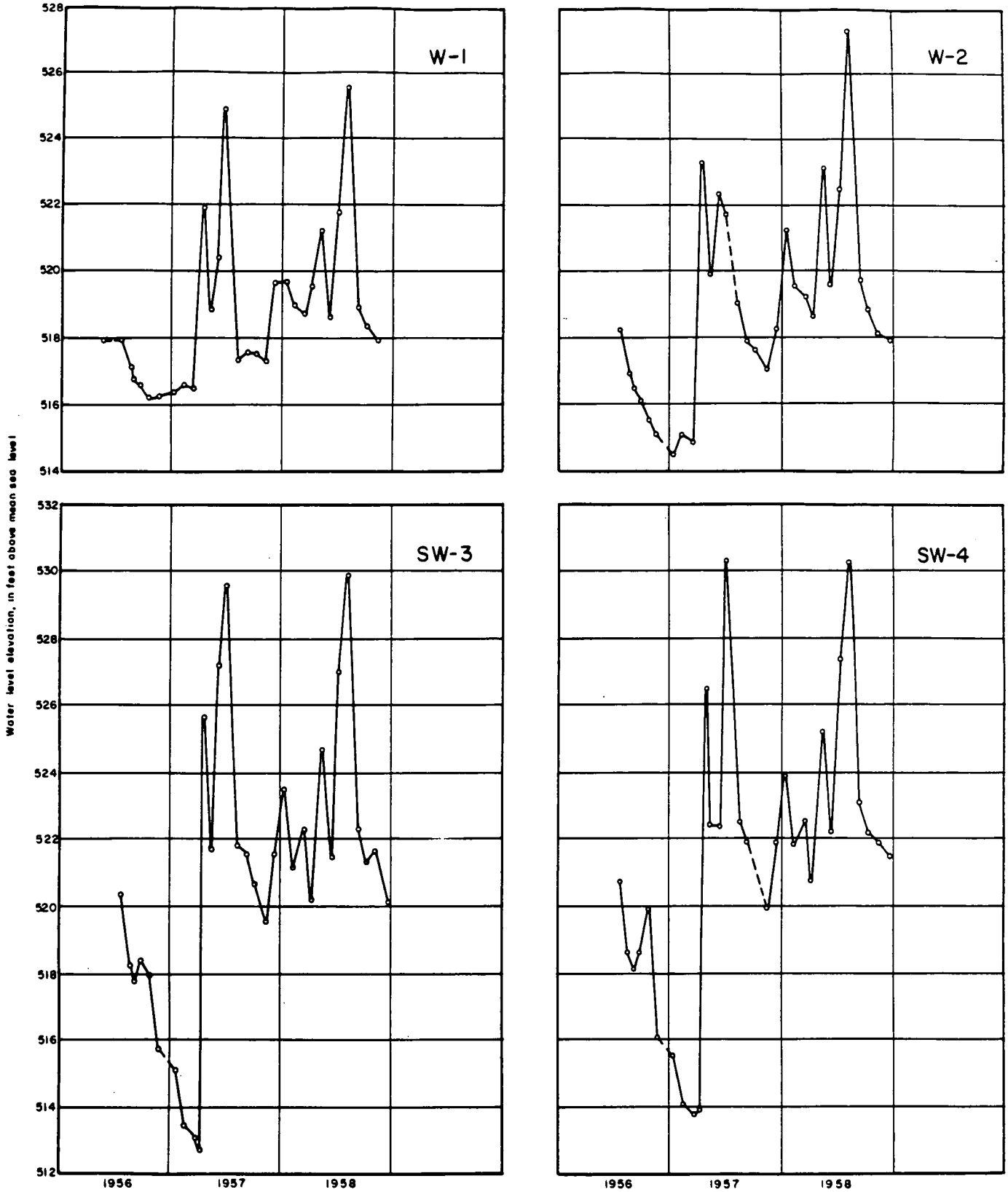

Figure 26. Hydrograph showing fluctuations of the water levels in wells W-1, W-2, SW-3 and SW-4

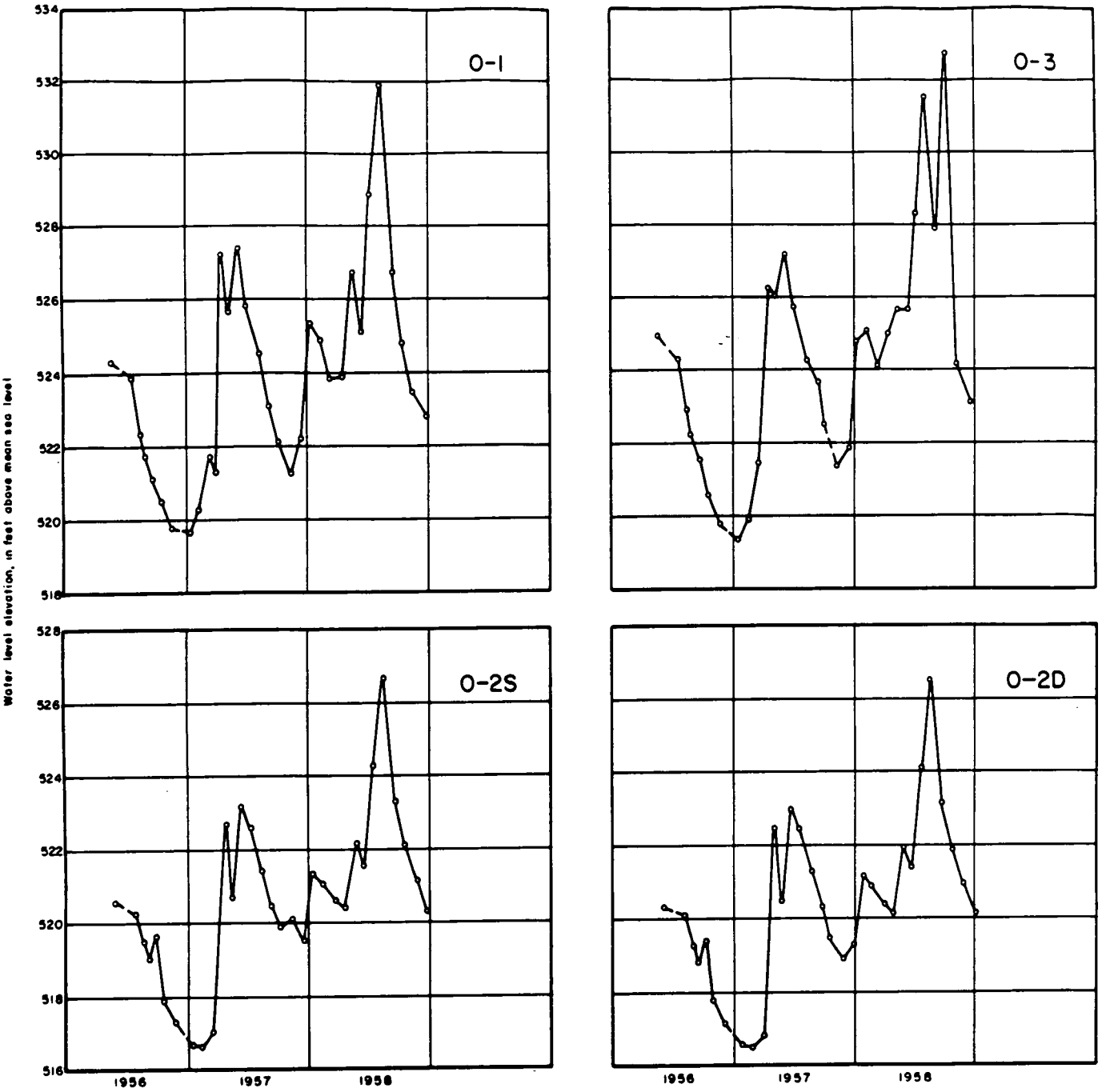

Figure 27. Hydrograph showing fluctuations of the water levels in wells O-1, O-2S, O-2D and O-3.

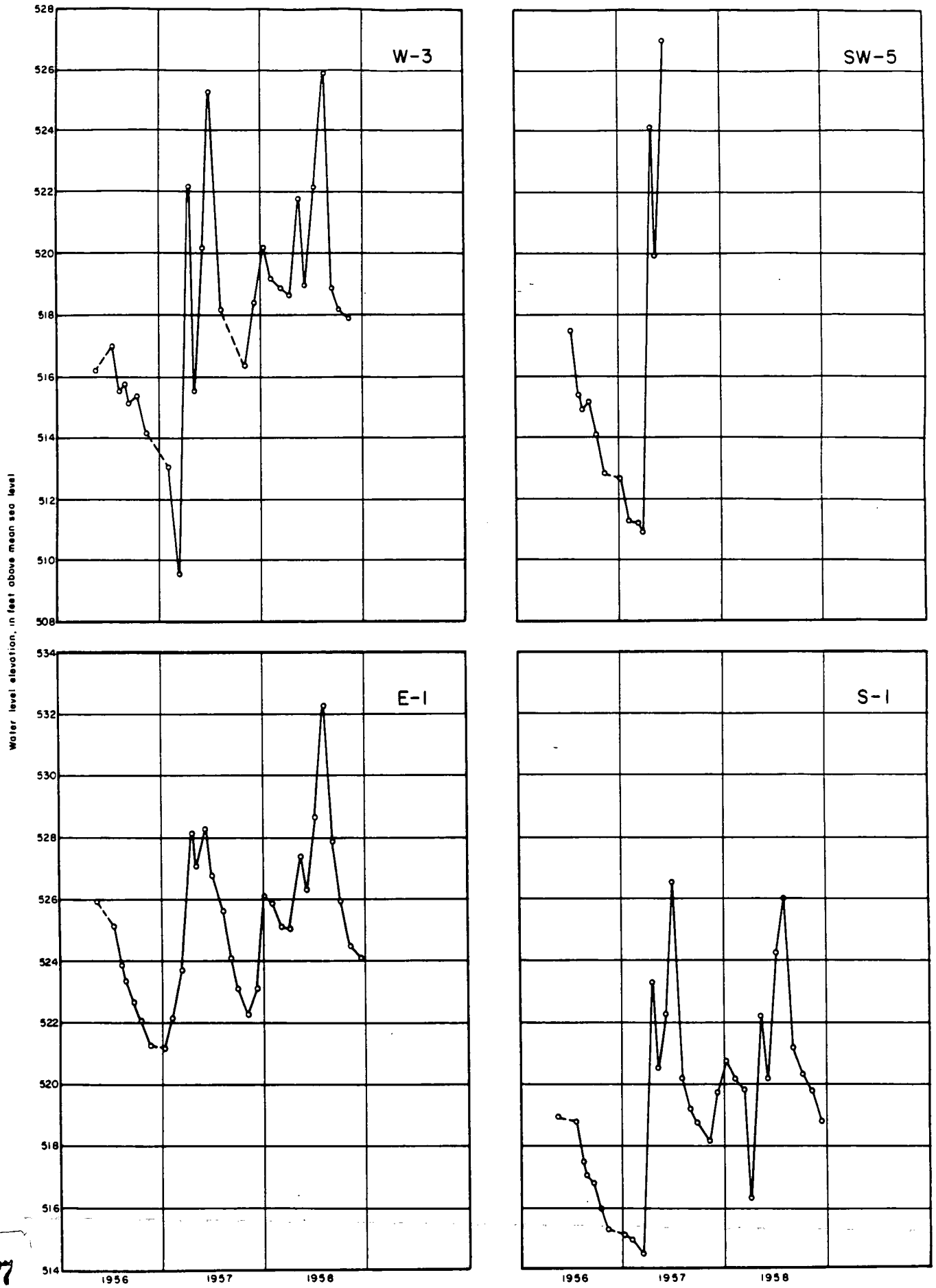

Figure 28. Hydrograph showing fluctuations of the water levels in wells W-3, E-1, SW-5 and S-1.

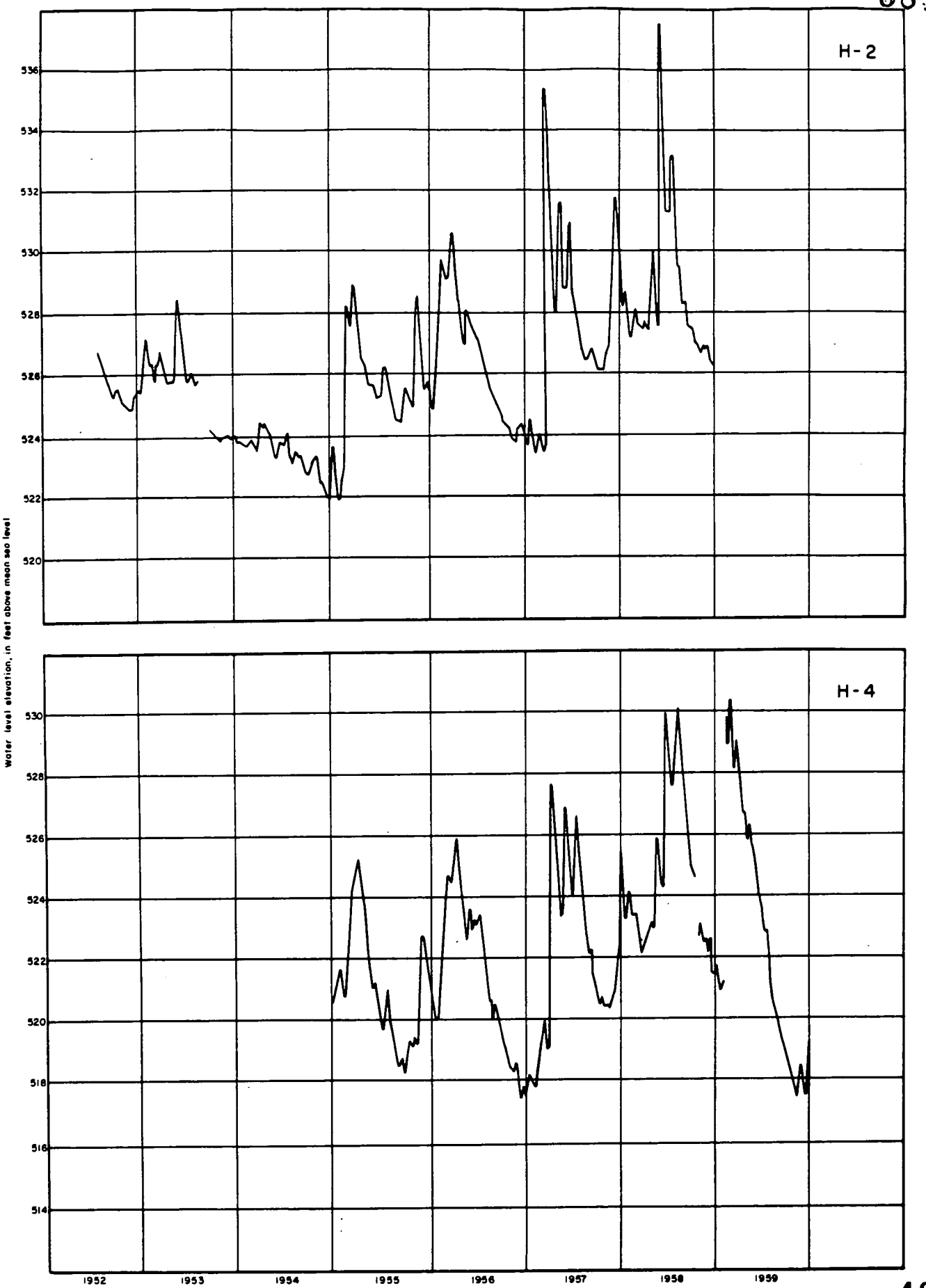

Figure 29. Hydrograph showing fluctuations in the water levels in wells H-2 and H-4.

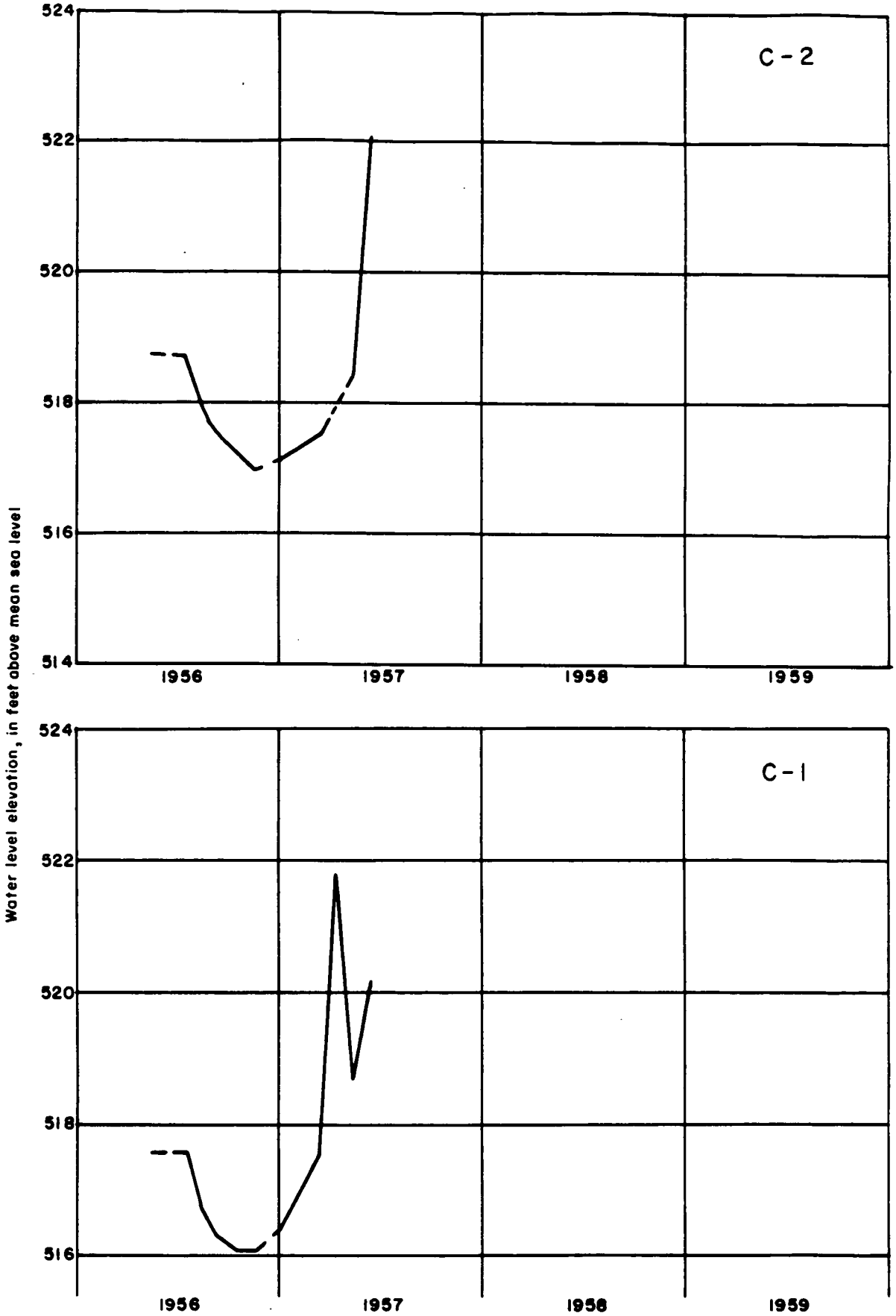

Figure 30. Hydrograph showing fluctuation of the water levels in wells C-1 and C-2.

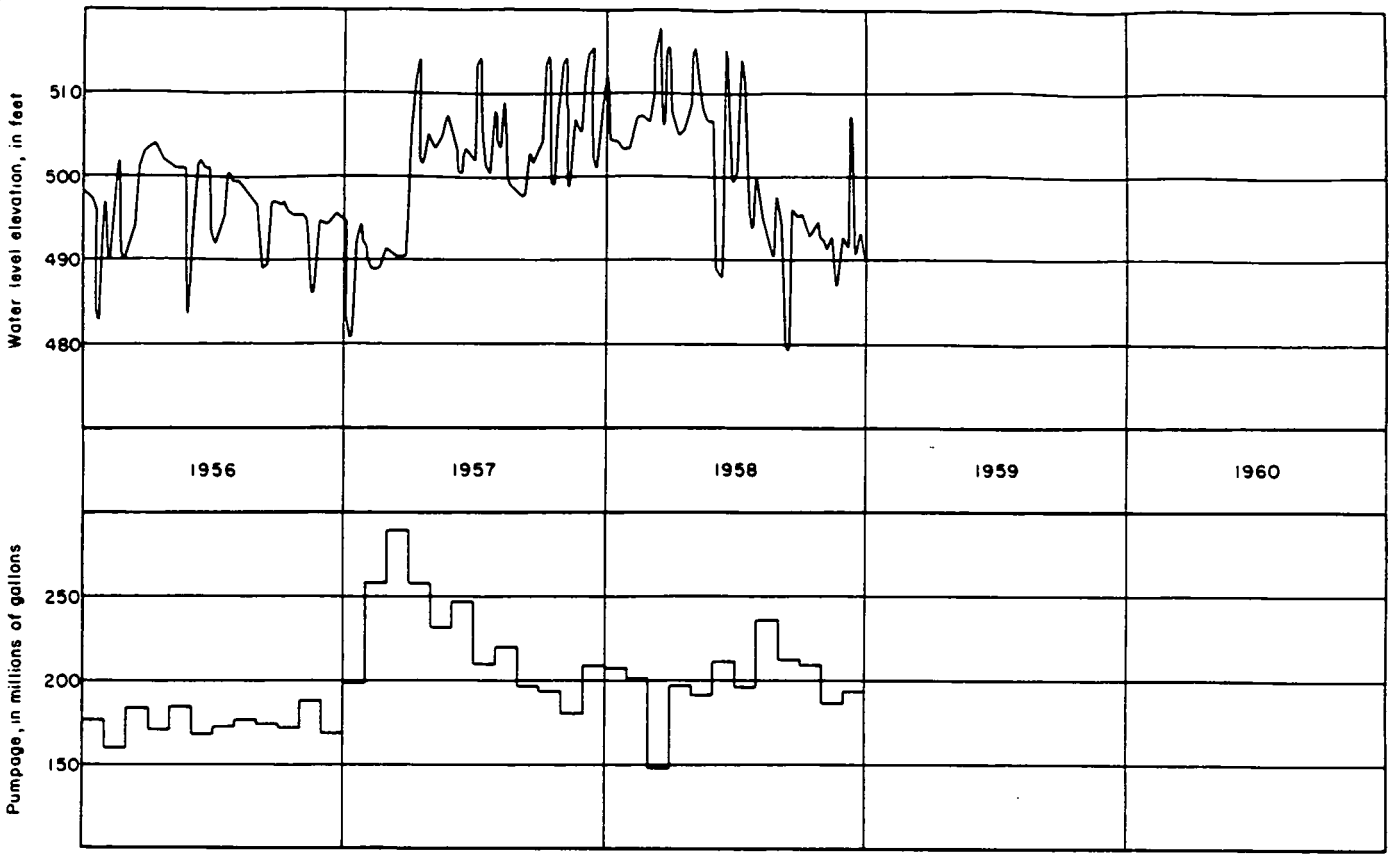

Figure 31. Water-level trends and monthly pumping rates of Southwestern Ohio Water Company collector 1.

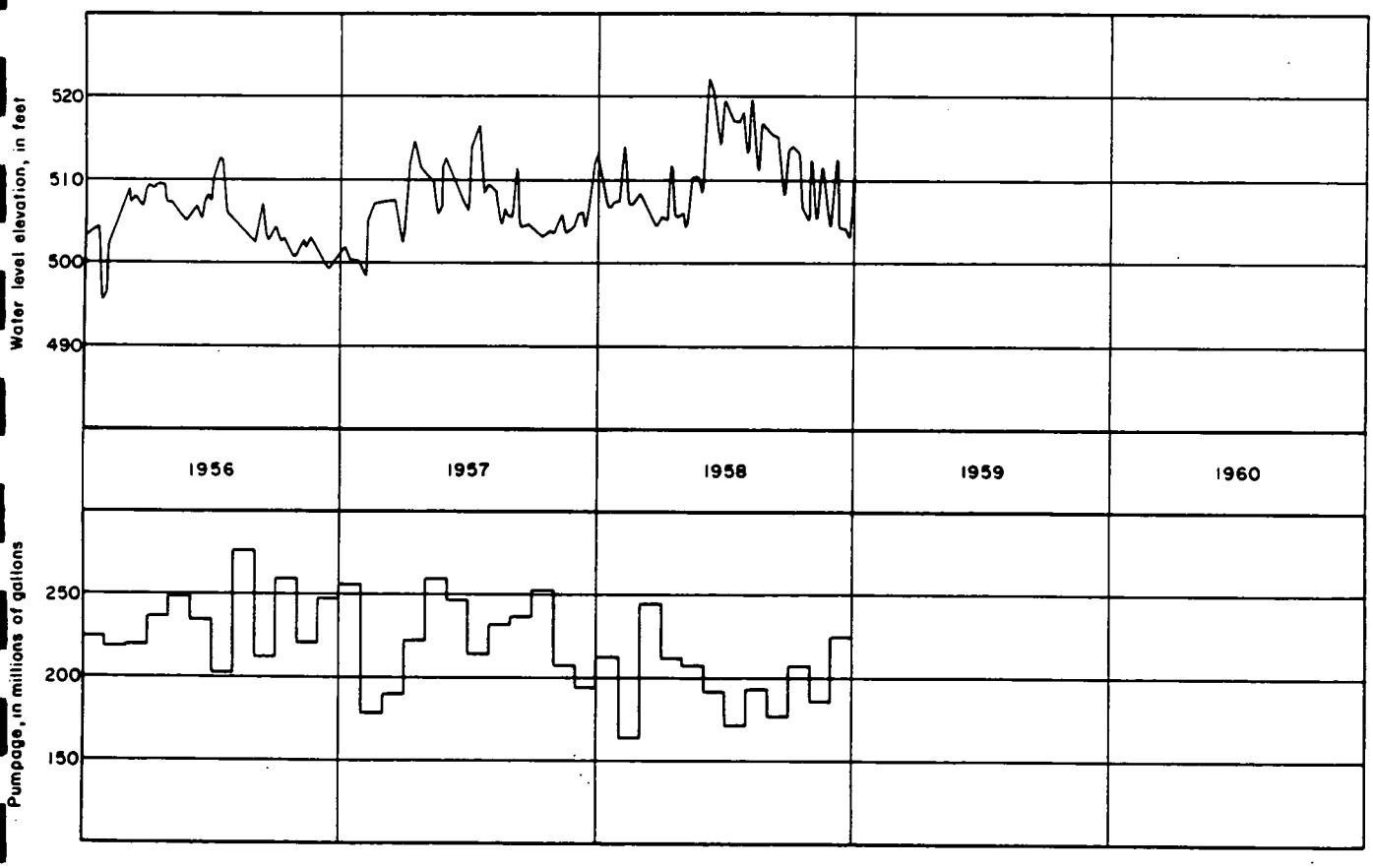

Figure 32. Water-level trends and monthly pumping rates of Southwestern Ohio Water Company collector 2.

PUMPING-TEST METHODS

Field methods used for determining and comparing the water-yielding properties of aquifers are grouped under the general term pumping tests. Pumping tests commonly are further divided into specific-capacity and aquifer-test methods.

The specific-capacity method, though generally inadequate and subject to much criticism, is the oldest and still the most widely used pumping-test method. This method does not take into account the effect of time, turbulent flow through the screen and discharge pipe, or the effect of other pumping wells. Nevertheless, if these limitations are recognized and considered, the specific-capacity method is very useful in analyzing hydrologic problems. In determining the specific capacity a well is pumped and its rate of discharge and the accompanying drawdown are observed. The specific capacity of the well is then computed as the rate of discharge per unit drawdown of water level. It is assumed that this ratio of discharge to drawdown holds for all discharges and drawdowns. For example, if a well is pumped at 50 gpm and has a drawdown of 5 feet, the specific capacity of the well is 10 gpm per foot of drawdown. Therefore a well with a drawdown of 100 feet, and a specific capacity of 10 gpm per foot of drawdown, would yield (10 gpm/ft x 100 ft) 1,000 gpm.

Drawdown against rate of pumping in collectors 1 and 2 is plotted on figure 33. The problem of properly evaluating the specific capacity of a well or collector affected by the water-surface altitude of a nearby stream is shown by the wide scattering of the points. If, however, the specific capacities of the collectors are plotted opposite river discharge during the particular period of pumping used in determining the specific capacity, the points fall in a much narrower range, showing that the specific capacity is related to the discharge of the stream. (See figs. 34 and 35.)

In the controlled pumping-test method, the rate of discharge is held constant or different discharge rates are held constant for specific intervals. Drawdown is measured in the pumped well and in one or more observation wells. Generally, the recovery of water level also is measured after pumping stops. The results of the test are analysed by methods given in numerous U. S. Geological Survey publications and other publications (Brown, 1953). The hydraulic properties of an aquifer -- permeability, transmissibility, and storage capacity -- thus are defined.

Explanation of Terms

The coefficient of permeability is the rate, in gallons per day, at which water at a temperature of 60° F will flow through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent (Wenzel, 1942, p. 7). Because the temperature of ground water in a given region remains nearly constant, the coefficient of permeability is generally determined at the prevailing temperature of the ground water. This determination of the permeability is called the field coefficient.

The coefficient of transmissibility (Theis, 1935, p. 520) is defined as the number of gallons of water that will move in 1 day through a verticle strip of the aquifer 1 foot wide, having a height equal to the full thickness of the aquifer under a hydraulic gradient of 1 foot per foot. The coefficient of transmissibility is equal to the average field coefficient of permeability multiplied by the thickness of the aquifer in feet.

The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit

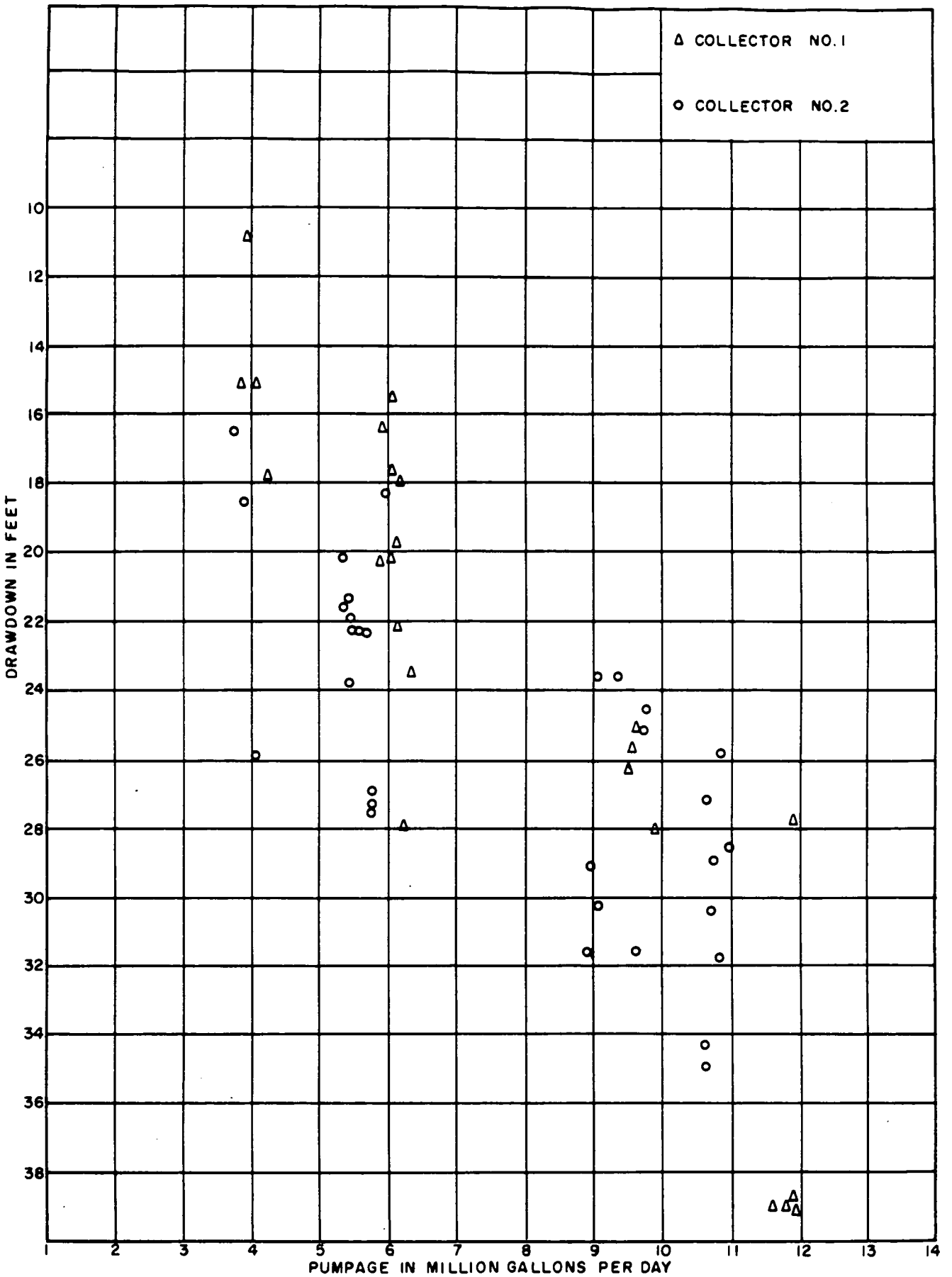

Figure 33. Graph showing specific capacities in Collectors 1. and 2.

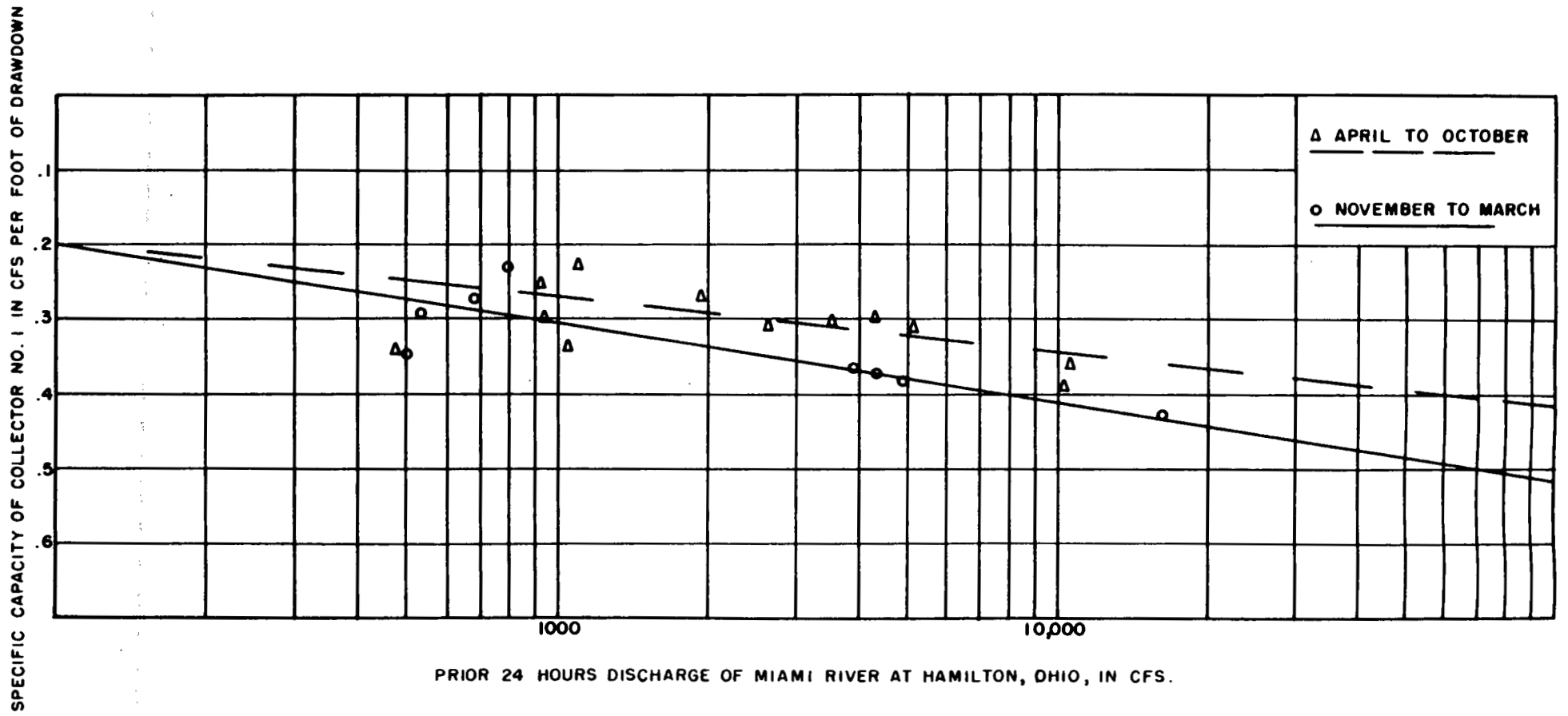

Figure 34. Graph showing the relationship between the specific capacity in collector I and river discharge.

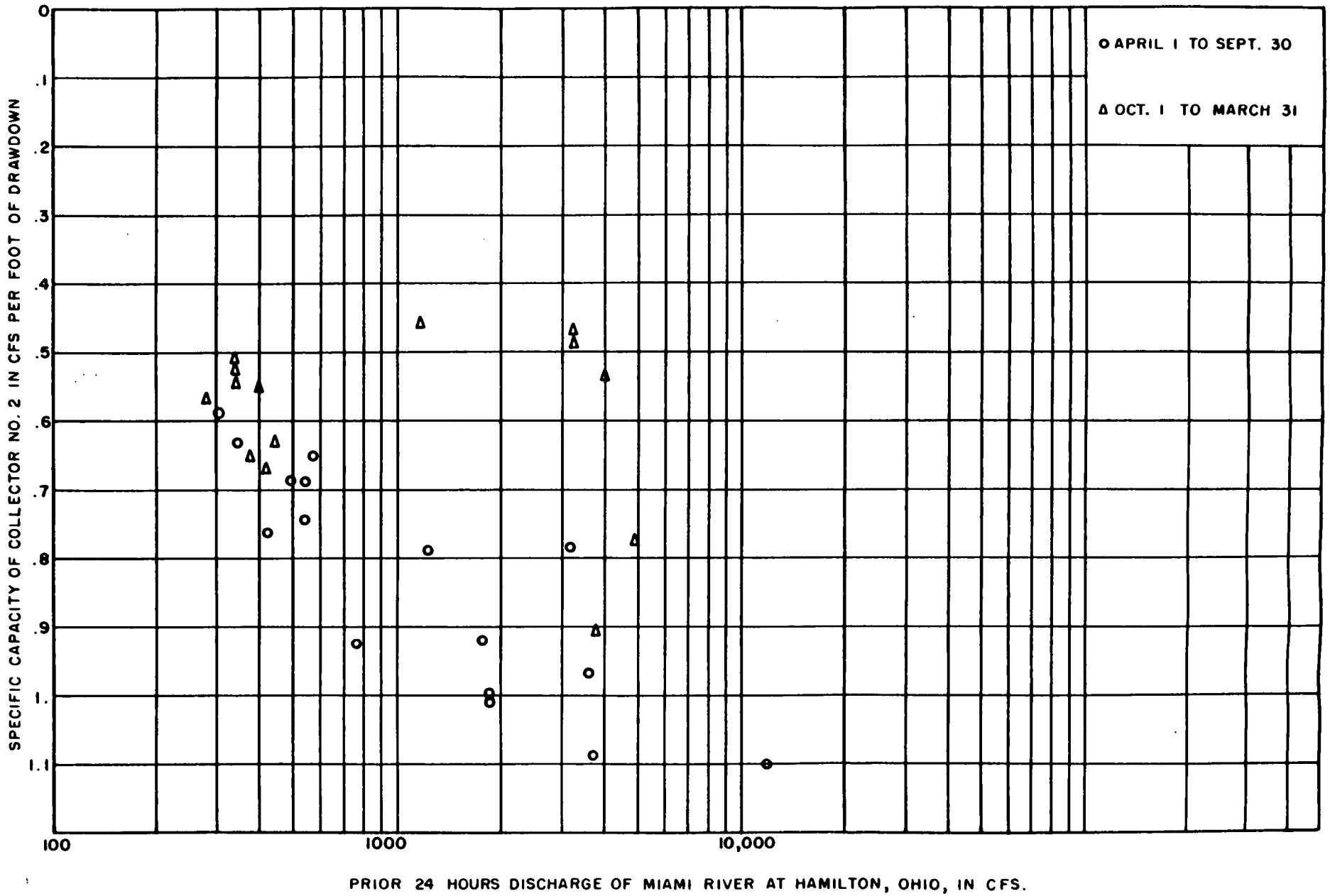

Figure 35. Graph showing the relationship between the specific capacity in collector 2 and river discharge.

change in the component of head normal to that surface. In a water-table aquifer, such as that at Venice, when the water table is lowered by pumping, ground water is derived from storage by the gravity drainage of the pore spaces in that part of the aquifer unwatered by the pumping.

Pumping Tests

A controlled pumping test of the sand and gravel aquifer in the Venice area was made January 27 to February 1, 1954. The sand and gravel is about 150 feet thick; however, only about 125 feet of the sand and gravel is saturated, the water occurring under water-table conditions. The aquifer is recharged chiefly by precipitation and infiltration from the Miami River.

Pumping was begun at 12:45 p.m. on January 27 and was continued at a relatively constant rate of 1,175 gpm until 3:09 p.m., February 1, 1954. The pumping well was 12 inches in diameter and was equipped with 40 feet of iron screen set at the bottom of the aquifer. Recording gages were installed on nine 6-inch observation wells to ascertain the effects of pumping on water levels at other points in the aquifer. The location and arrangement of the wells used in the test are shown on figure 36. The effects of water levels in the observation wells caused by starting and stopping the pump in the pumped well are shown in figures 37 to 39.

Drawdown in the observation wells was determined by comparing the extrapolated graphs of nonpumping water levels with those made during the pumping periods. The results of the test were analysed by the modified nonequilibrium formula described by Cooper and Jacob (1946). The computed average coefficients of transmissibility and permeability were 360,000 gpd per ft and 2,900 gpd per square foot. (See figures 40 to 42.) Wells W-2, N-2 and S-1d were not used in computing these average coefficients because measurements were not accurately obtained before infiltration effects from the nearby river were observed.

Outwash sand and gravel generally is highly stratified and consequently is less permeable vertically than it is horizontally. Because of this directional difference in permeability, water entering wells that only partly penetrate the aquifer must percolate vertically downward or upward in a less permeable path than water entering the wells in a horizontal direction. The vertical component of groundwater flow thus produced is not in accordance with the horizontal component on which the modified nonequilibrium formula is based, and the effect will be reflected in an increase in drawdowns in the well. The observed drawdowns in the wells must therefore be adjusted for the effect of partial penetration of the pumped well. The adjustments for the partial penetration of a pumped well are discussed by Wenzel (1942) and outlined by Jacob[1] (written communication). Using the adjusted values of drawdown due to the effects of partial penetration of the pumped well, the corrected coefficients of transmissibility and permeability of the aquifer were found to be 370,000 gpd per ft. and 3,000 gpd per square ft., respectively. (See figure 43.)

On December 2, 1956, ground-water pumpage in collector 1 was 6.318 mgd and ground-water pumpage in collector 2 was 2.487 mgd. At 10:00 p.m. on December 2, pumpage in collector 2 was increased to 10.605 mgd, an increase of 8.118 mgd. The

1/ Jacob, C. E., 1945, Partial penetration of pumping well, adjustments for: U. S. Geol. Survey Water Resources Bull., p. 169-175, August.

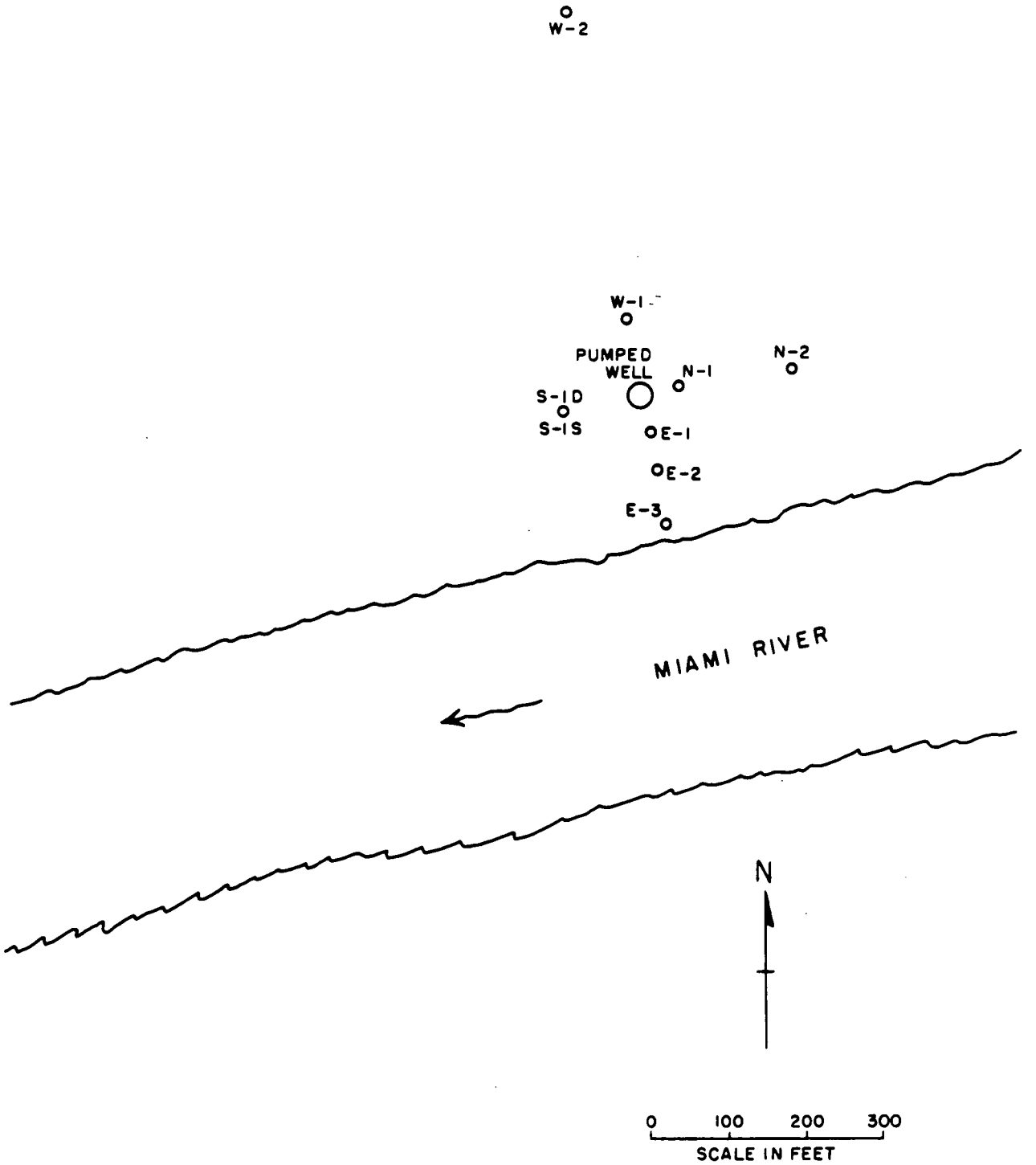

Figure 36. Map showing locations of wells used during controlled pumping test from January 27 to February 1, 1954.

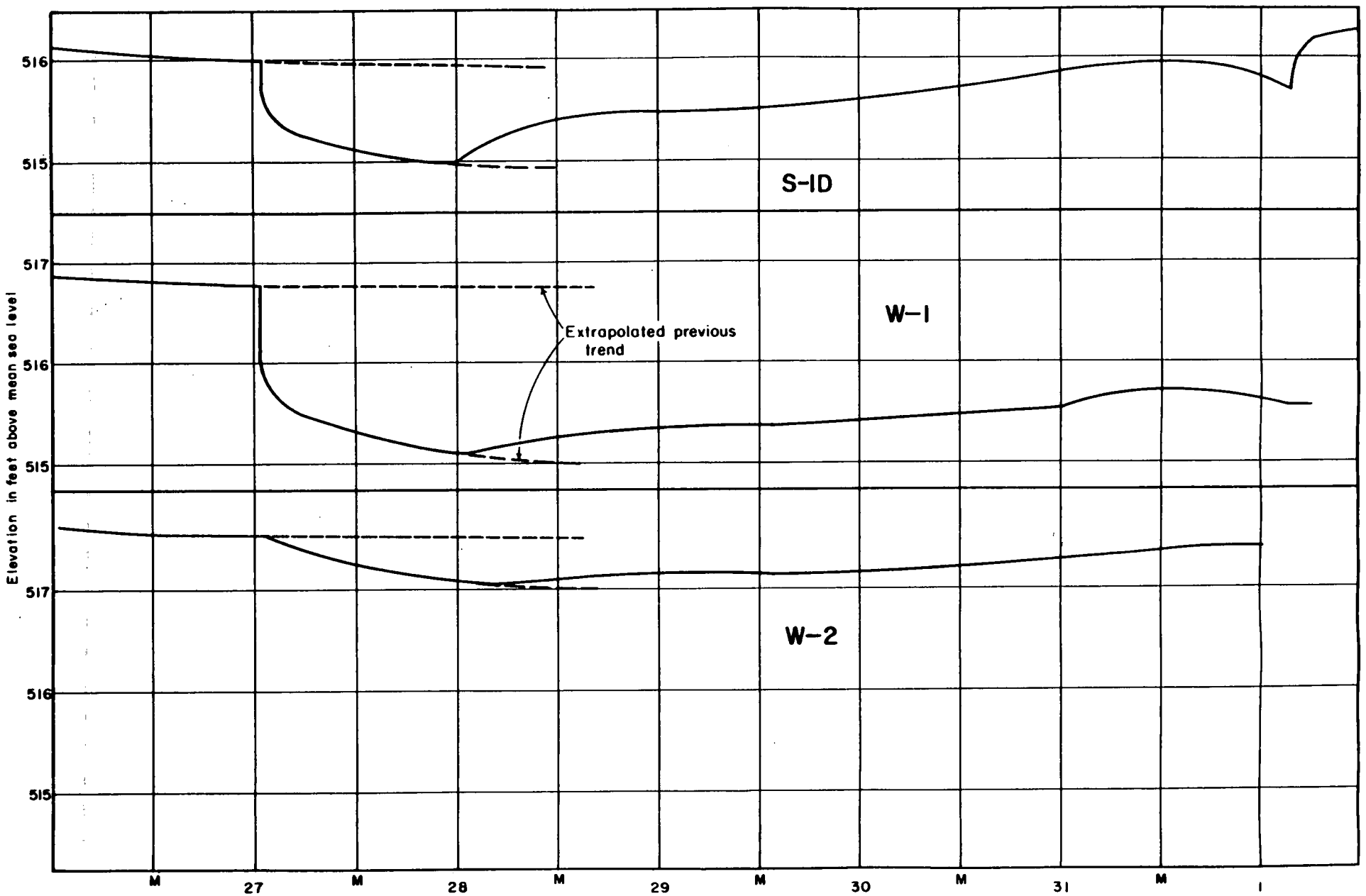

Figure 37. Effect on water levels in observation wells caused by pumping test well, January 27 to February 1, 1954.

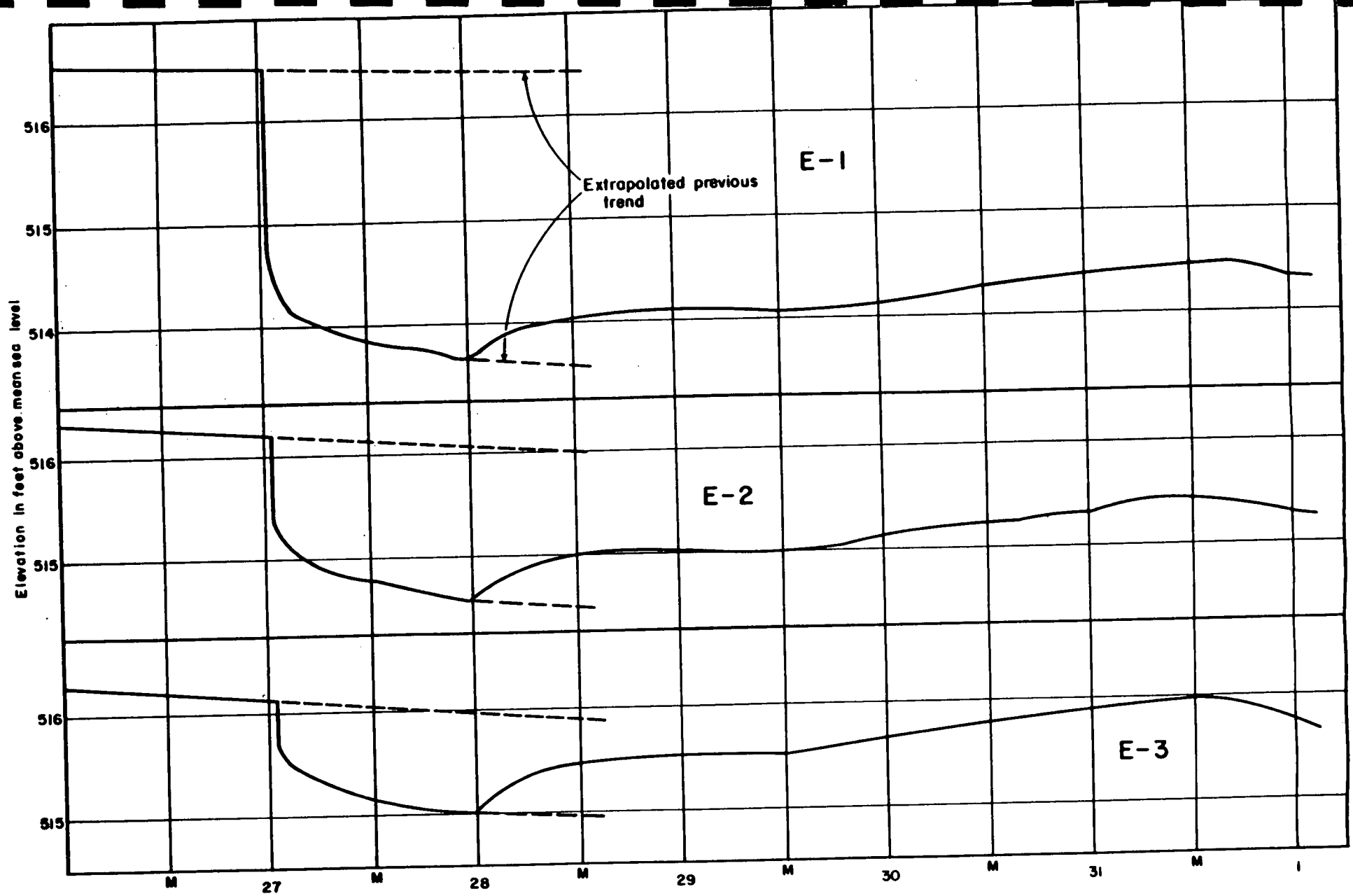

Figure 38. Effect on water levels in observation wells caused by pumping test well, January 27 to February 1, 1954.

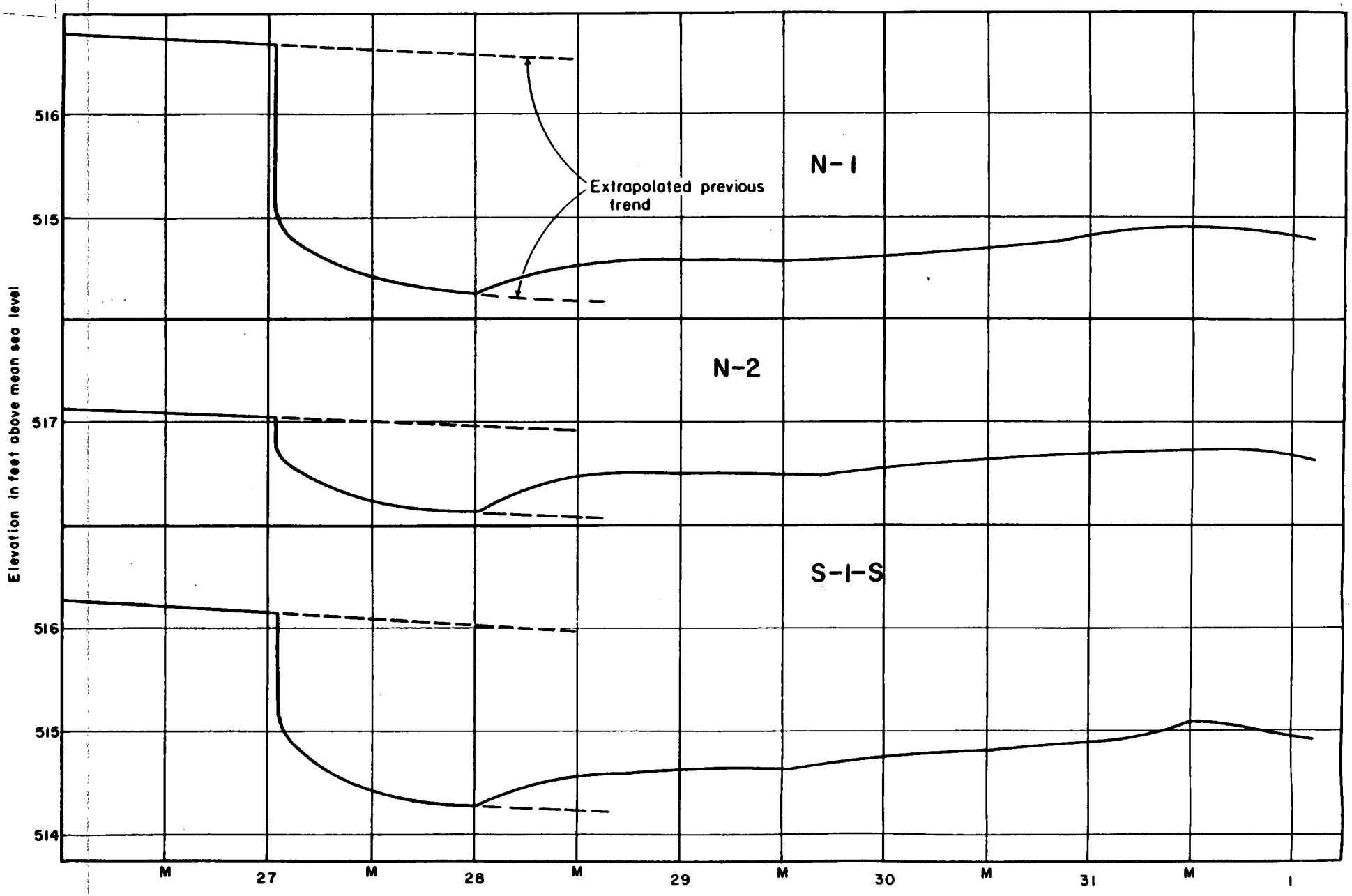

Figure 39. Effect on water levels in observation wells caused by pumping test well, January 27 to February 1, 1954.

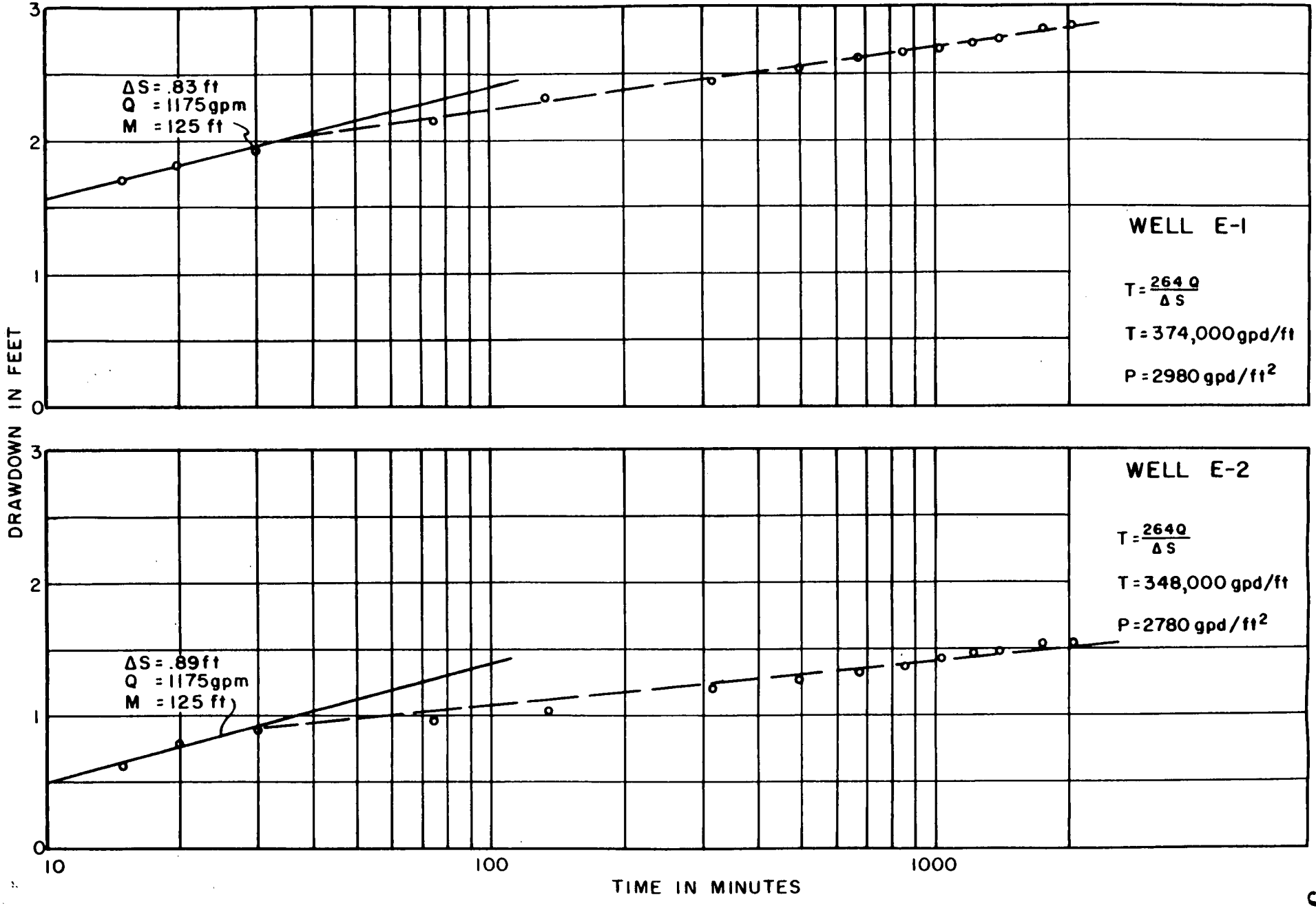

Figure 40. Time-drawdown semilog arithmic graph for wells E-1 and E-2.

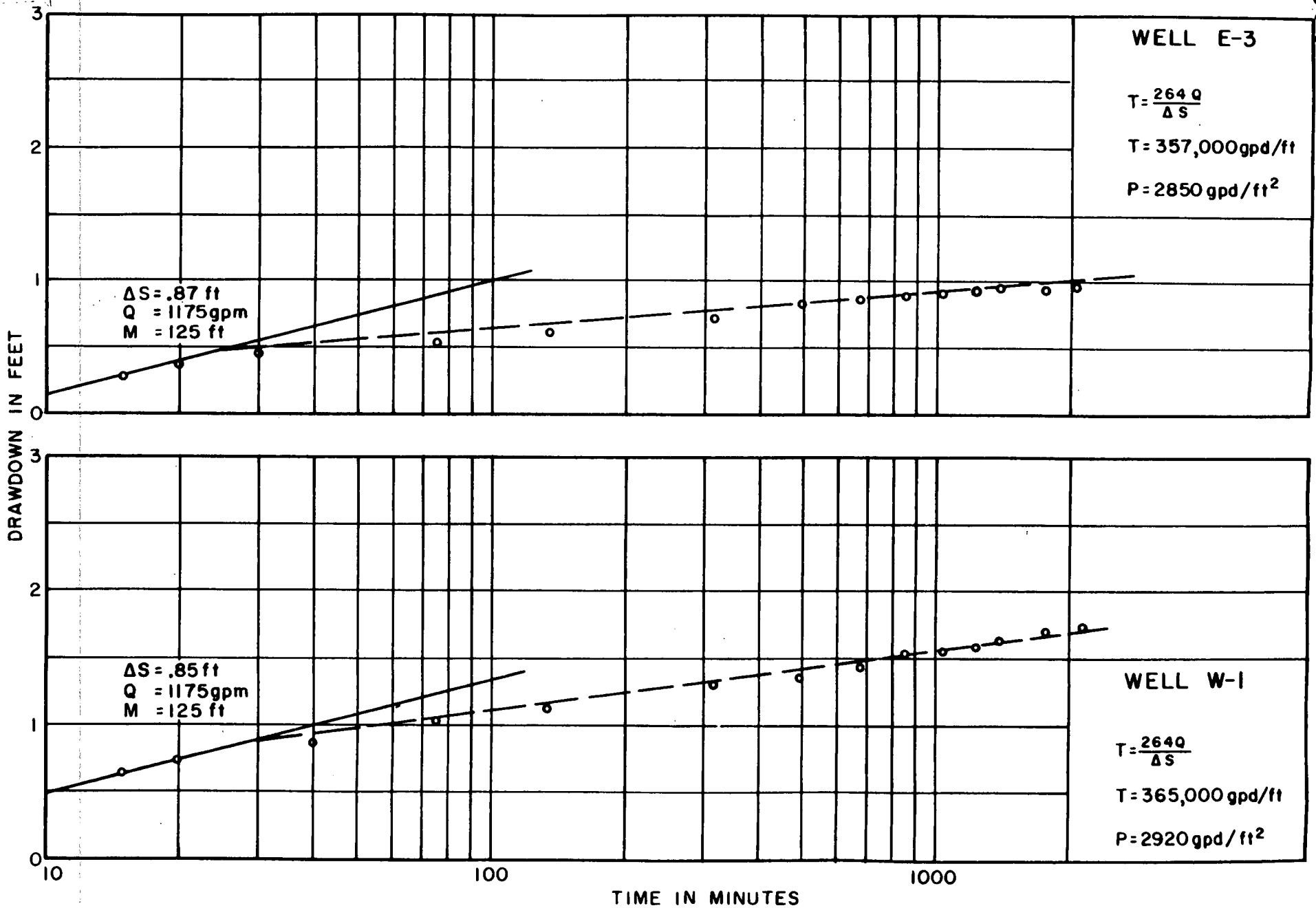

Figure 41. Time-drawdown semilog arithmic graph for wells E-3 and W-1.

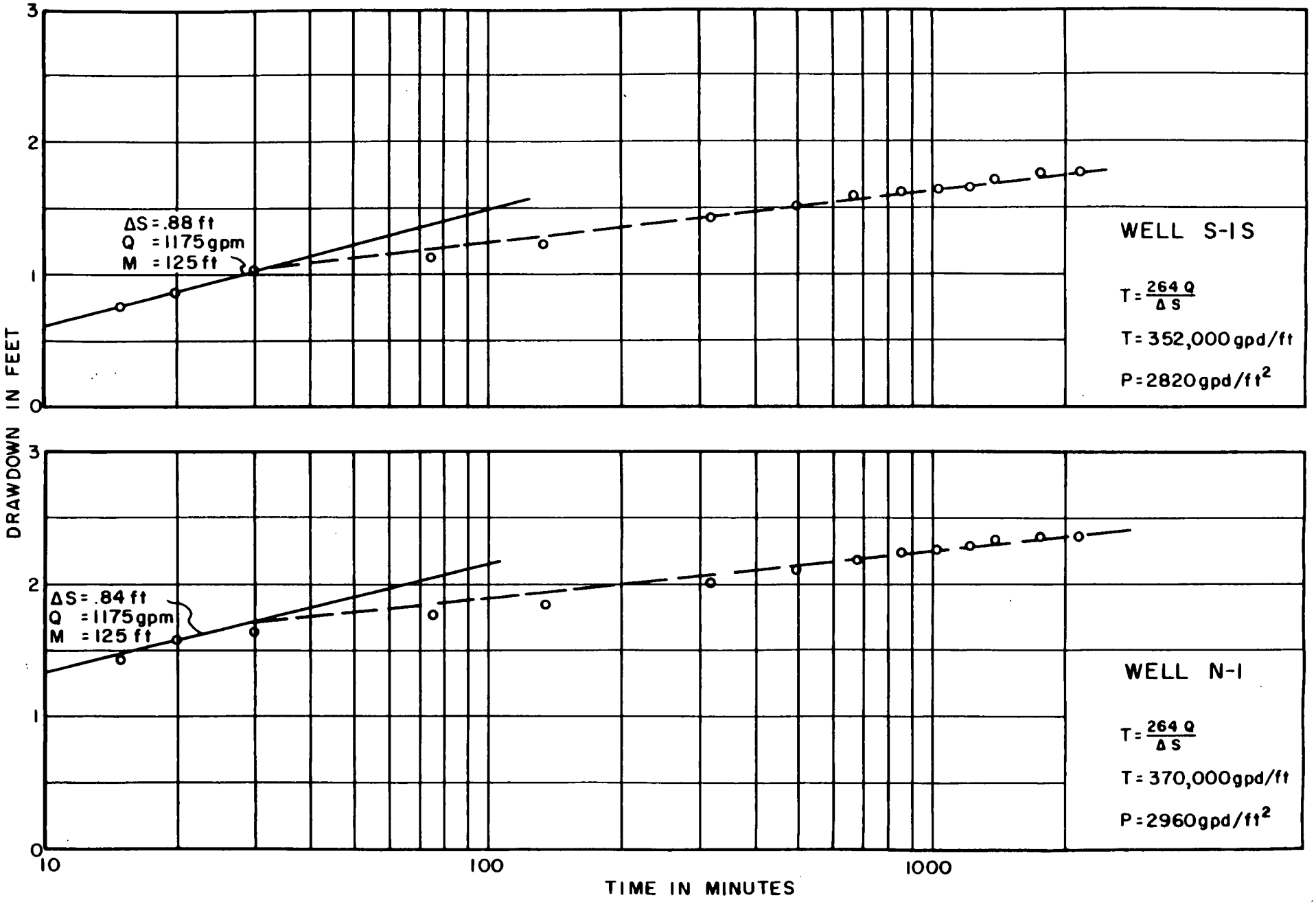

Figure 42. Time-drawdown semilog arithmic graph for wells S-1S and N-1.

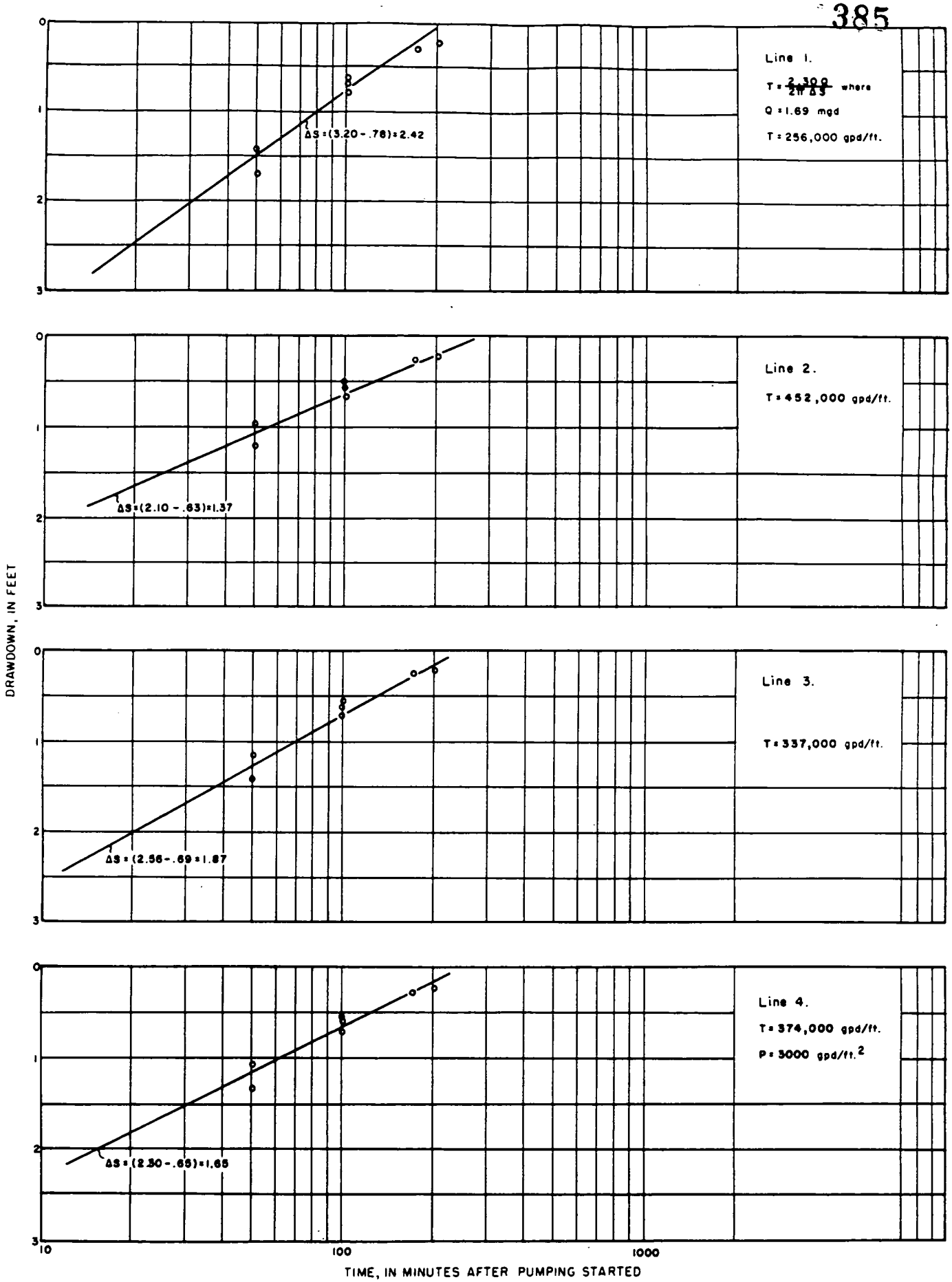

Figure 43. Adjustments for partial penetration of pumping well.

pumpage was held constant at about 6.318 and 10.605 mgd in collectors 1 and 2, respectively, until midnight, December 7, 1956. Figure 44 and 45 are maps showing the position of the water table on December 2 and December 7, 1956. Figure 46 is a graph of elevations on the Miami River during the period of the pumping test.

The cone of depression around collector 2 was analyzed to check the coefficient of permeability computed from the results of the controlled pumping test made January 27 to February 1, 1954, and the cone around collector 1 was analyzed to determine the coefficient of permeability of the materials east of the Miami River. The 509- and 510- foot water-table contours around collector 1 and the 510- and 511-foot water-table contours around collector 2 were selected for analysis because they do not intercept the river, and they are not in the zone of the projected laterals of the collectors.

All the water pumped from the collectors moved through the areas encumpassed by the 509- and 510- foot and the 510- and 511- foot water-table contours of collectors 1 and 2, respectively, in accordance with Darcy's law, which may be expressed in the form Q= PIA (Ferris, 1949, p. 226). Q is the discharge of the collector in gallons per day, P is the coefficient of permeability of the aquifer in gallons per day per square foot, I is the hydraulic gradient of feet per foot, and A is the cross section of the area of flow in square feet.

The hydraulic gradient (I) governing the movement of water through the aquifer was computed by using the formula $I = \frac{c}{A'/L}$ where:

c = the water-table-contour interval in feet (1 foot).

A' = the area in square feet between the 509- and 510- foot water-table contour of collector 1 (1,130,000 square feet) and the 510- and 511- foot water-table contour of collector 2 (2,580,000 square feet).

L = the average length of the 509- and 510- foot water-table contour of collector 1 (4,600 feet) and the 510- and 511-foot water-table contour of collector 2 (8,530 feet).

I = .0040 (collector 1)

= .0033 (collector 2)

The cross section of the area of flow, A, was computed by using the formula A = Lm;

where:

L = the average length of the water-table contours in feet.

(See above.)

m = the average saturated thickness of the aquifer midway between the 509- and 510- foot and 510- and 511- foot water-table contours of collectors 1 and 2, respectively (125 feet).

A = 575,000 square feet (collector 1)

= 1,064,000 square feet (collector 2)

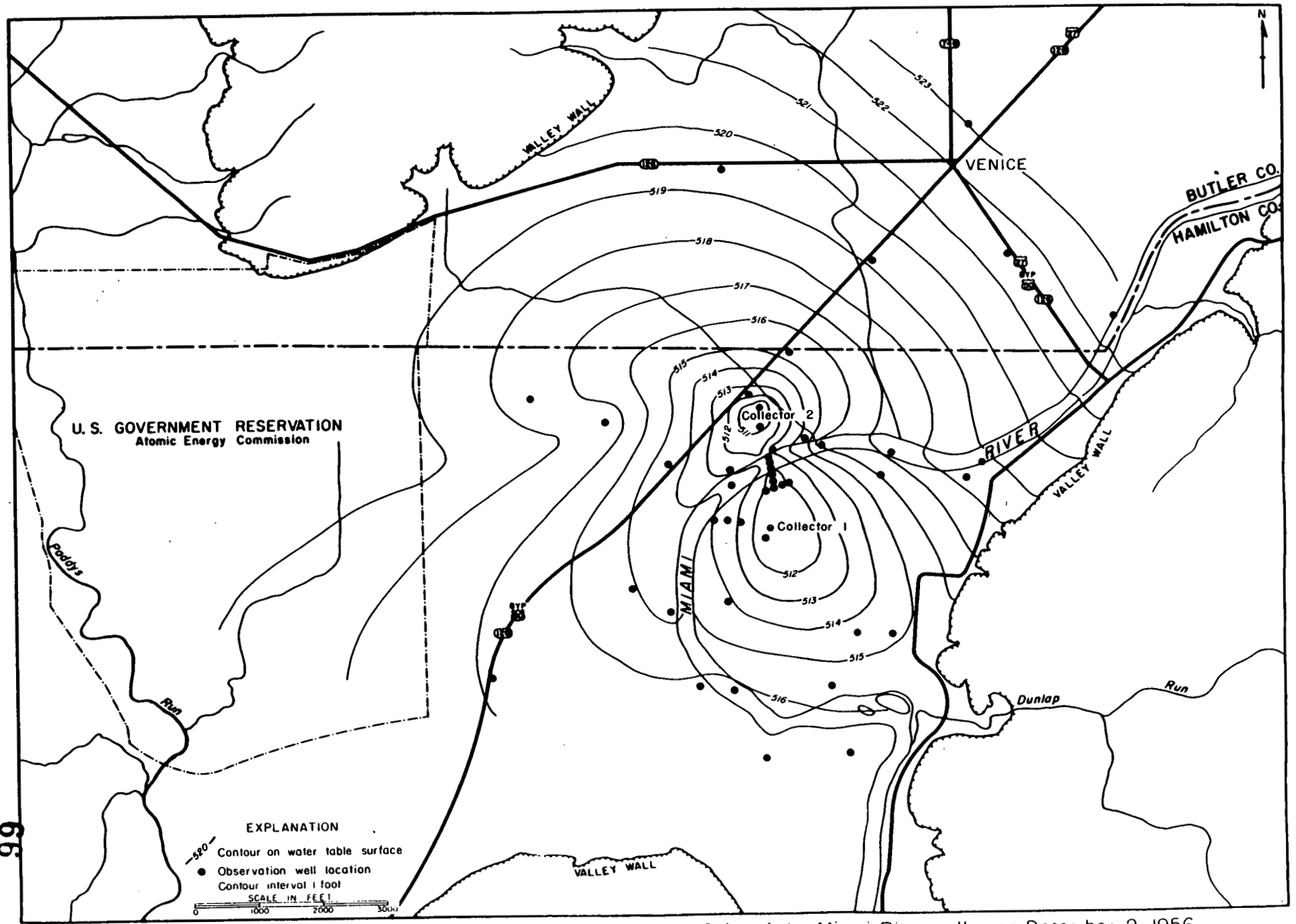

Figure 44. Map showing the water table in the Venice area, Ohio, of the Miami River valley on December 2, 1956

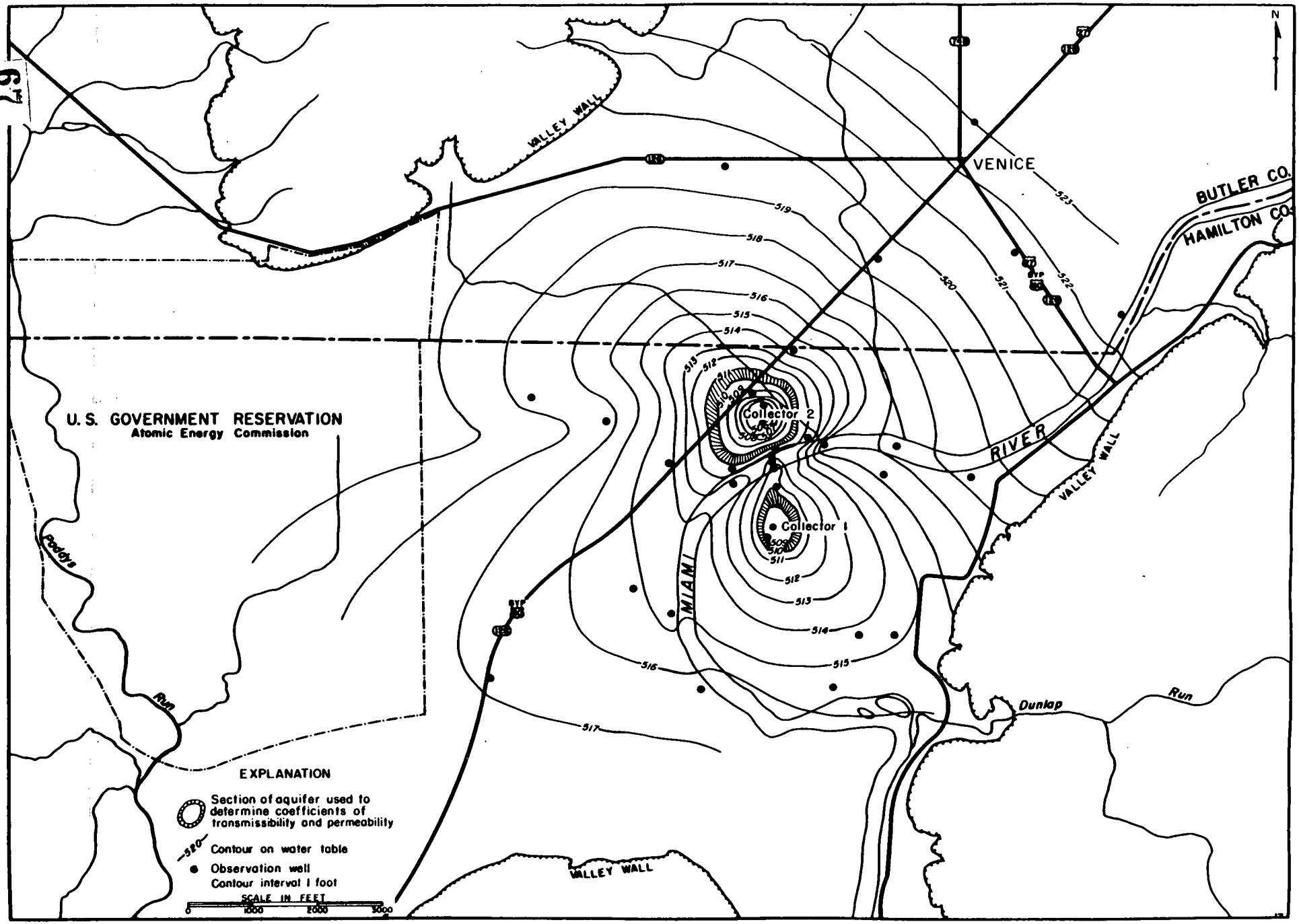

Figure 45. Map showing the water table in the Venice area, Ohio, of the Miami River valley on December 7, 1956.

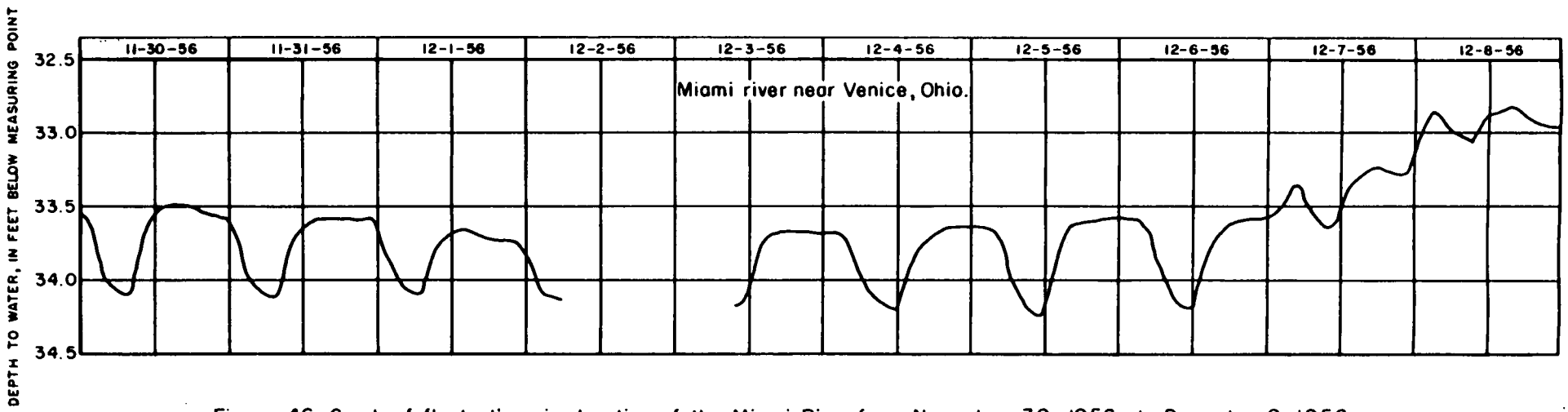

Figure 46. Graph of fluctuations in elevation of the Miami River from November 30, 1956, to December 8, 1956.

Substituting the figures I = 0.004 and 0.0033 ft per ft, A = 575,000 and 1,064,000 square feet, and Q = 6.318 mgd and 10.605 mgd for collectors 1 and 2, respectively; in the formula Q = PIA, the coefficient of permeability of the aquifer in the vicinity of collector 1 was determined to be 2,800 gpd per square ft, and the permeability near collector 2 was determined to be 3,000 gpd per square ft.

The coefficient of permeability of the outwash deposits near collector 1 is slightly less than that determined at collector 2, indicating that the permeability of the aquifer may increase to the northwest toward the deep channel of the Norwood River. (See p. 7). The coefficient of permeability of the deposits determined near collector 2 agrees with that determined from the results of the controlled pumping test (p. 47).

RECHARGE

Precipitation and Subsurface Inflow

The principal sources of recharge to an aquifer are the infiltration of rain and snow falling on the intake area, seepage from streams, subsurface inflow from adjacent areas, and vertical leakage from other aquifers through relatively impermeable confining beds.

When rain and snow falls on the land some of the water flows directly into streams, some evaporates, some is transpired by plants, and the remainder seeps into the ground. The amount of precipitation that seeps into the ground and reaches the water table, depends upon such factors as: (1) character of soil and underlying materials; (2) topography; (3) vegetal cover; (4) soil moisture; (5) land use; (6) depth to water table; (7) intensity, duration, and seasonal distribution of rainfall; and (8) the air temperature.

The area (6 square miles) used to compute recharge to the valley-train deposits from precipitation is shown in figure 4. Contours of the water table north of the Colerain Pike bridge (5,000 feet north of collector 2) and near the south end of the oxbow bend in the Miami River show that ground water is discharging into the Miami River north and south of these areas (see fig. 45). The surface soil in the area is a flood-plain deposit consisting chiefly of a silty, sandy loam underlain by coarse sand and gravel. The area is level, and, as shown by the lack of flow during the most of the year in Dry Run and other small streams in the area, there is little or no surface-water runoff. The loss from transpiration is chiefly from agricultural crops consisting almost entirely of corn, wheat, and hay. Based on unpublished studies by L. T. Pierce[1] under conditions similar to those at Venice, these crops have an average evapotranspiration rate of 26 inches during the growing season. The average total precipitation between April and September, the growing season, is 20.67 inches; therefore, evapotranspiration generally exceeds precipitation by about 5 inches. The depth of the water table averages more than 20 feet below the land surface in most of the area, and for all practical purposes there is no evapotranspiration of ground water. This means there is a soil-moisture deficiency created during the growing season that must be replenished before ground-water recharge can occur.

From a study of the hydrology of the valley-train deposits in the Mad River valley near Fairborn made by Walton (1960, p. 35), annual recharge from precipitation was estimated to be about 12 inches. The topographic relief, vegetal cover, land use, and air temperature, at Fairborn is very similar to that in the Venice area. The average annual precipitation is about 2 inches less, and the permeability of the underlying sand and gravel deposits is slightly greater near Fairborn than at Venice. The smaller annual precipitation and the greater permeability of the underlying materials at Fairborn, however, tend to compensate for the larger annual precipitation and the smaller permeability at Venice, so that an estimate of recharge of 12 inches of precipitation per year in the Venice area is not unreasonable. During the year of normal precipitation, the 12 inches of recharge, therefore, amounts to about 570,000 gpd per square mile of catchment area, or 3.42 mgd for the 6 square miles in the Venice area.

[1]Weather Bureau State Climatologist, U. S. Weather Bureau, Columbus, Ohio

Besides recharge derived locally from precipitation, subsurface inflow from adjacent areas may contribute to the ground-water supply. Subsurface inflow to the sand and gravel deposits in the Miami River valley is primarily from the Ordovician limestone and shale along the valley walls. The permeability of the limestone and shale is not known, but, in view of the number of well failures in the upland areas, the permeability probably is low, perhaps 5 gpd per square foot. Under these conditions, the amount of water moving from the limestone and shale into the buried Miami River valley should be about 200,000 gpd per mile or 1.2 mgd for the entire 6 miles of valley wall in the area.

Induced Infiltration from the Miami River

When a well is pumped, water is withdrawn from storage in the aquifer, and the water level in the vicinity of the well is drawn down in the shape of an inverted cone called the cone of depression. As pumping continues the cone expands, all the while drawing water from storage in the aquifer until either a hydraulic gradient is established between the pumped well and an area of recharge sufficient to replenish the amount of water being pumped or sufficient water is diverted from some area of discharge to balance the pumpage. If the well is placed near a surface source such as the Miami River, and the cone of depression expands until it intercepts the bed of the river, the water being pumped from the well will be replaced in part by water entering the aquifer from the river. This method of induced infiltration of surface water is a major source of recharge to ground-water reservoirs in Ohio, and particularly is this true in the Miami River valley.

The rate at which water enters an aquifer from a surface source will depend on several factors; such as, the position of the water table, the permeability of the stream bed and the underlying aquifer, the depth and width of water in the stream, and the temperature of the water. In addition a stream bed does not remain stable over a long period of time, consequently its permeability may be increased by the scouring action of the waters during high flow and decreased by the deposition of fine materials on the river bottom during periods of low flow.

The shape of the water-table contours caused by pumping from the collectors on each side of the stream indicates a ground-water mound beneath the bed of the Miami River in the oxbow bend near Venice. The shape of the cone of depression is distorted so that gradients between the river and the collectors are steeper than those on the landward side of the collectors. The cone of depression is distorted because the aquifer receives large amounts of recharge from the river. All other factors being equal, the flow toward the collectors will be greatest on the side nearest the source, where the gradients are steepest.

Contours of the water table north of the oxbow area of the Miami River bend upstream, and those south of the oxbow roughly parallel the river, indicating that ground water is moving toward and discharging into the river in those areas. Recharge to the two radial collectors by the induced infiltration of surface water, therefore, is confined to the reach of the river encompassed between the dashed lines shown on figure 47.

The dashed lines that cross the water-table contours shown on figure 47, drawn from the river toward the collectors, are called flow lines. These flow lines are the paths that typical particles of water would follow in moving from the river through the aquifer in the direction of decreasing head. Under ideal conditions, flow lines cross the water-table contours at right angles, which is the direction of

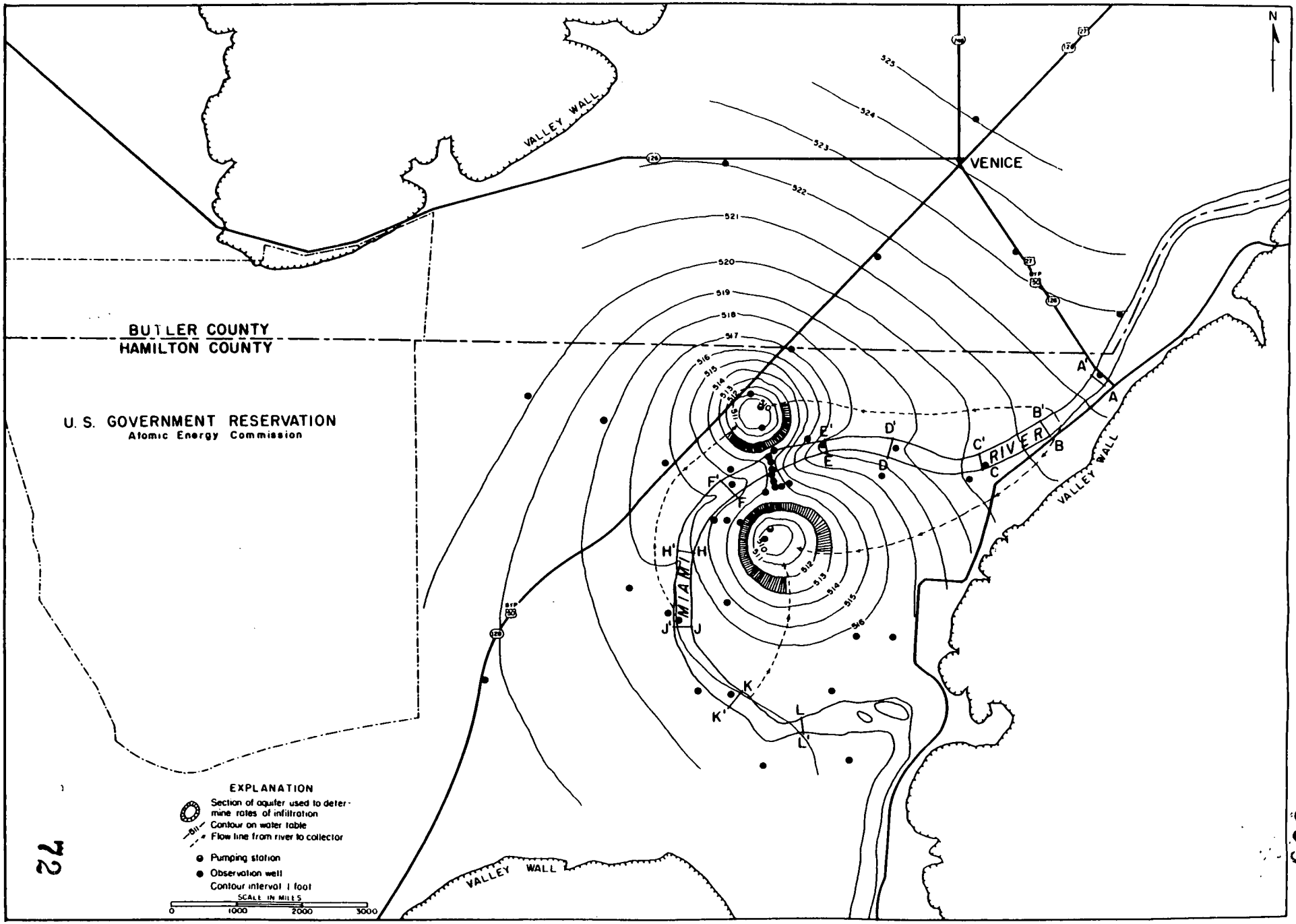

Figure 47. Map showing the water table in the Venice area, Ohio, of the Miami River valley on August 31, 1956.

maximum gradient. The four limiting flow lines shown on figure 47 delimit the sections of the aquifer through which all the infiltrated water from the Miami River moved towards the areas of withdrawal.

The two sections of the aquifer included between the four limiting flow lines and the 512- and 513- foot water-table contours were used to determine the amount of induced infiltration from the river. The equation Q = PIA was used to arrive at the amount of water infiltrated from the Miami River on August 31, 1956. The hydraulic gradients (I) and the areas (A) were computed for that part of the aquifer lying between the limiting flow lines and the 512- and 513- foot water-table contours. The permeabilities, previously determined, and the hydraulic gradients and areas computed for August 31, 1956, were substituted in the equation. The amount of water being infiltrated from the Miami River on August 31, 1956, was 10 mgd, or about 60 percent of the water being pumped from collectors 1 and 2. Pumpage at collector 1 averaged 6.2 mgd, and pumpage at collector 2 averaged 10.7 mgd, or a total of 16.9 mgd.

The average rate of infiltration from the Miami River determined from the study of the infiltration between the four limiting flow lines on August 31, 1956, was 240,000 gpd per acre. This rate was derived by using the average width of the river (200 feet) and assuming that infiltration was uniform over the entire river bed. The infiltration rate, however, varies across the river, most of the flow during dry periods being concentrated in the deeper part of the channel. (See figure 48.)

Flow lines also were drawn towards the collectors from the river at stream bed profiles B - B' and E - E', E - E' and F - F', F - F' and K - K'. Determinations similar to those previously outlined show that recharge by induced infiltration from the Miami River on August 31, 1956, included between profiles B - B' and E - E', was 2.35 mgd; that between E - E' and F - F' was 4.08 mgd, and recharge between F - F' and K - K' was 3.57 mgd.

During the summer of 1956, ten 2-inch-diameter observation wells were driven about 6 inches into the bed of the Miami River to determine water levels beneath the bed of the river. (See fig. 47.) The head loss, and difference between the surface elevation of the river and the water level inside the river well is given on table 3. The average width of the river and the length of the river between profiles were then determined. Using the average head loss between profiles, the infiltration rate of the river bed was determined to be 113,000 gpd per acre per foot between sections B - B' and E - E', 142,000 gpd per acre per foot between sections E - E' and F - F', and 117,000 gpd per acre per foot between sections F - F' and K - K'.

The average infiltration rate of the river bed determined from a study of the infiltration between sections B - B' and K - K' varies from one location to another. This variation may be explained in part by two natural dams formed when the flow of the river changed from a high to a low velocity. (Riffles occur in the vicinity of D - D' and J - J', fig. 47.) In adjacent areas upstream from these dams, the water is ponded, and silt and clay settle to the bottom and reduce the permeability of the river bed.

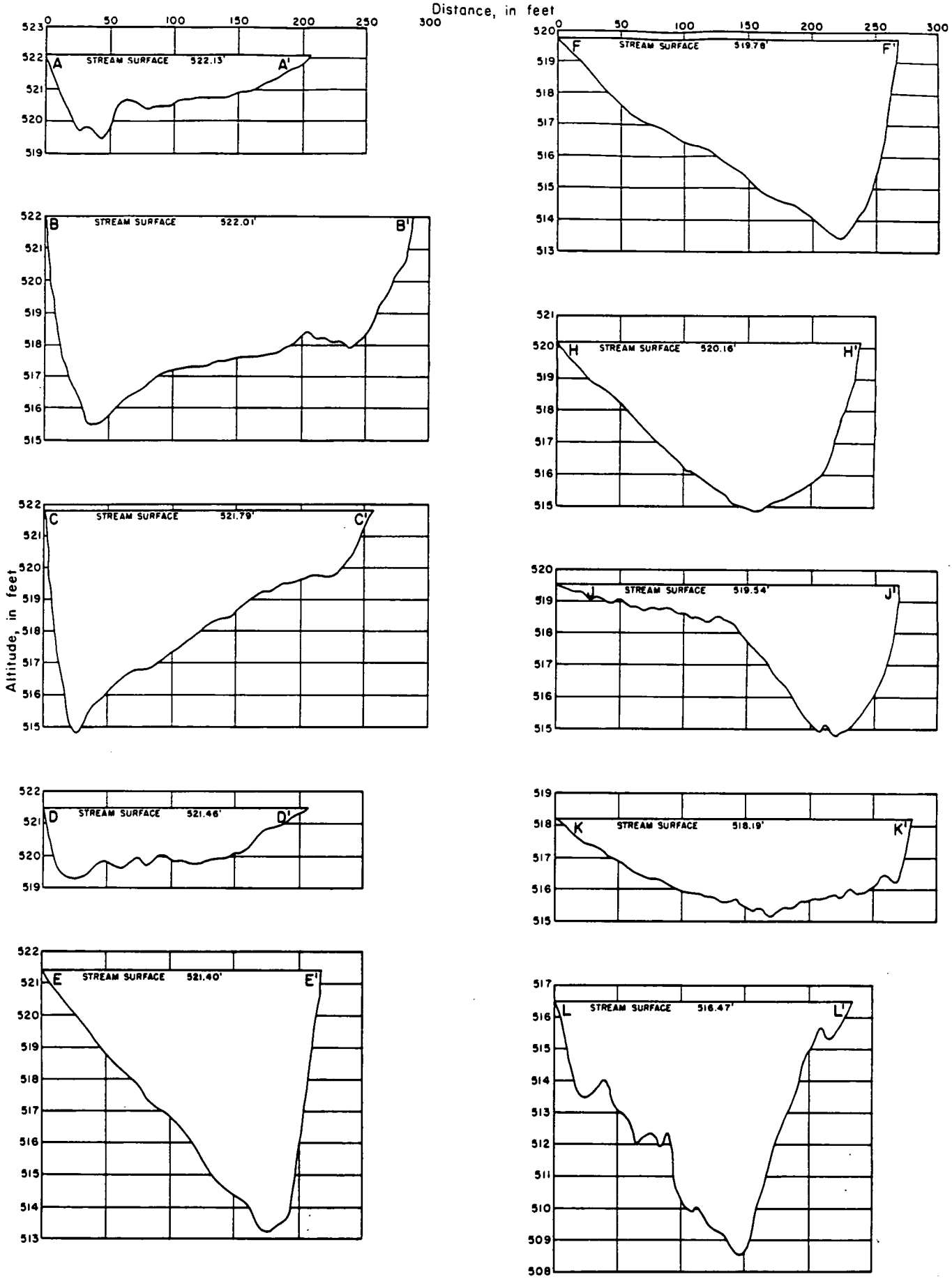

Figure 48. Cross sections showing the configuration of the Miami River bed in the Big Bend area.

Table 3.--Head loss in river wells Rw-1 to Rw-10 caused by infiltration from the Miami River on August 31, 1956.

Well No.	Elevation of well	Depth to water in well	Depth to river	Head loss
Rw-1	524.28	2.10	2.15	+.05
Rw-2	523.51	3.66	2.88	-.78
Rw-3	523.38	4.57	1.92	-2.65
Rw-4	522.21	4.16	2.08	-2.08
Rw-5	521.71	3.90	1.99	-1.91
Rw-6	522.17	-	-	-
Rw-7	522.06	8.02	1.65	-6.37
Rw-8	522.47	6.86	2.57	-4.29
Rw-9	522.30	5.47	2.76	-2.71
Rw-10	520.73	2.95	2.54	-.41

SILTING OF THE RIVER BED

During dry periods, most of the flow of the Miami River in the Venice area is concentrated in a deep channel about 100 feet wide. The velocity of the river, recorded at Hamilton, during periods of low flow (100 cfs) is about 0.3 feet per second. The flow at Venice is restricted to a narrower channel than that at Hamilton, and the velocity in the deep channel is approximately 0.5 feet per second during comparable low-flow periods. This velocity is probably great enough to prevent large amounts of silt from settling from the moving waters. However, in the shallow part of the river at Venice, which is about 100 feet wide also, the flow is very sluggish, and silt and clay undoubtedly settle from these slow-moving waters, reducing the permeability of this part of the river bed. Cross sections of the river channel made during periods of low streamflow are shown on figure 48.

The average mean discharge of the Miami River at Hamilton is 3,214 cfs. Because the river has a fairly high velocity during part of the year (7 or more feet per second during periods of high flow at Hamilton) the effects of silting of the river bed probably are confined to short periods of low-velocity flow in the late summer and early fall. Funds for this investigation unfortunately did not provide for a long-term sediment-sampling program to aid in determining the effect of siltation of the river bed on the rate of infiltration. Table 4, however, gives particle-size analyses, date collected, discharge, and total suspended sediment load of the Miami River at Dayton at selected times. In addition, figure 49 shows the configuration of the bed of the Miami River at different dates at Hamilton, Ohio.

Table 4.--Particle-size analyses of suspended sediment, Miami River at Dayton, Ohio.

Date of collection	Instantaneous discharge (cfs)	Concentration of sample (ppm)	Tons per day	Sediment load by percent		
				clay	silt	sand
January 26. 1952	20,500	1,360	75,300	51	47	2
March 11, 1952	17,900	568	27,400	83	14	3
March 12, 1952	18,700	459	23,200	83	15	2
January 19, 1953	7,260	228	4,470	90	10	0
March 4, 1953	10,700	644	18,600	88	12	0
March 19, 1953	6,700	308	5,570	82	18	0
May 9, 1953	2,930	184	1,460	84	16	0
May 15, 1953	5,700	230	3,540	68	31	1
May 20, 1953	5,810	93	1,460	74	25	1
May 22, 1953	11,400	1,040	32,000	79	18	3
May 23, 1953	16,900	259	11,800	92	7	1
June 11, 1953	6,560	1,580	28,000	84	16	-

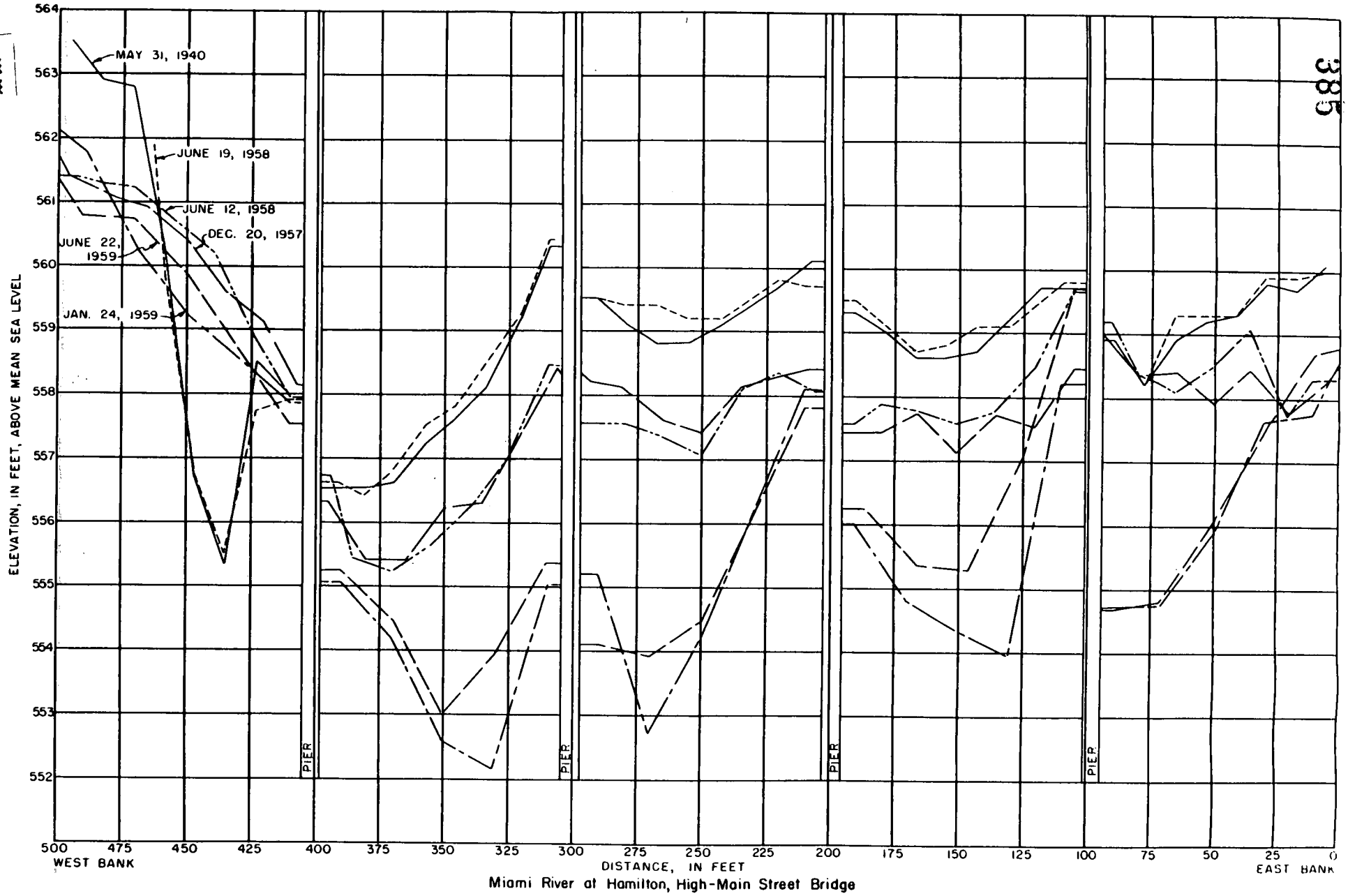

Figure 49. Configuration of the bed of the Miami River at Hamilton, Ohio, on May 31, 1940, December 20, 1957, June 12, 1958, June 19, 1958, January 22, 1959 and January 24, 1959.

TEMPERATURE OF WATER

In addition to silting of the river bed infiltration rates vary with the temperature of the water being infiltrated, the viscosity of the water being directly related to its temperature. A decrease in the temperature of the water increases its viscosity and decreases infiltration rates. For conditions of laminar flow, which usually prevail in ground-water movement, the viscosity of water changes about 1.5 percent per degree (Fahrenheit) change of temperature. Records of temperature of both surface water and ground water therefore are necessary to any infiltration study. Figure 50 is a graph showing the relationship between the temperature of water and its viscosity.

The temperature of the water withdrawn from a river infiltration system such as that at Venice is controlled by several variables. These variables are: temperature of river water, distance of well or collector from river, spacing of wells or collector, volume of aquifer, amount and temperature of ground-water flow from the land side, and the specific heat of the material composing the aquifer. At a given time the water flows to the pumping unit by various paths and at different rates. Water entering from the riverward side, where gradients are steepest, travels to the unit in a relatively short time compared to water entering from the landward side or from more distant points upstream or downstream. Consequently, the water pumped at any given time is made up of water which entered the aquifer at different points and at different times.

Temperatures have been measured monthly in the two radial collectors at Venice since September 1956. Temperatures also were measured at 5-foot intervals of depth in the other wells by means of an electric-resistance thermometer. The monthly variations of temperature with depth in selected wells are shown on figures 51 to 53.

The temperatures measured in many of the wells from June 1956 to June 1959 show a wide vertical range, suggestive of the effects of horizontal layers of widely different permeability of the aquifer.

In areas comparatively far from the river, the average ground-water temperature is about 53.3° F east of the river and about 54.3° west of the river. In these areas the annual temperature change is only a degree or less above or below the average. In wells K-1 and R-4, figure 19, the temperature close to the river, ranges from 50.2° to 67.5° and 49.3° to 68.8° respectively. River water entering the aquifer has a temperature range from 34.2° to 82.8°. (See figure 54.)

From September 1956 to December 1958, the temperature of the water in collector 1 ranged from 56.9° to 58.9°, and the temperature of the water in collector 2 ranged from 53.7° to 57.4°. The average temperature of the water in collectors 1 and 2 was 57.8° and 54.9°, respectively. The lower average temperature of water in collector 2 probably is due to the fact that it is made up of a smaller proportion of river water and a larger proportion of ground water than that in collector 1. The fact that the valley wall is a greater distance from collector 2 also has a bearing on the lower water temperature in that unit.

Because the viscosity of the water varies with its temperature it is necessary to decide what point in the aquifer should be selected to determine changes in the rate of infiltration caused by variations in the water temperature. If a point immediately adjacent to the river is selected, the change in the ground-water temperature would be about 48°, as the temperature of the river water ranges from 34.2° to 82.8°. If a point about 30 feet from the river is chosen, the temperature change

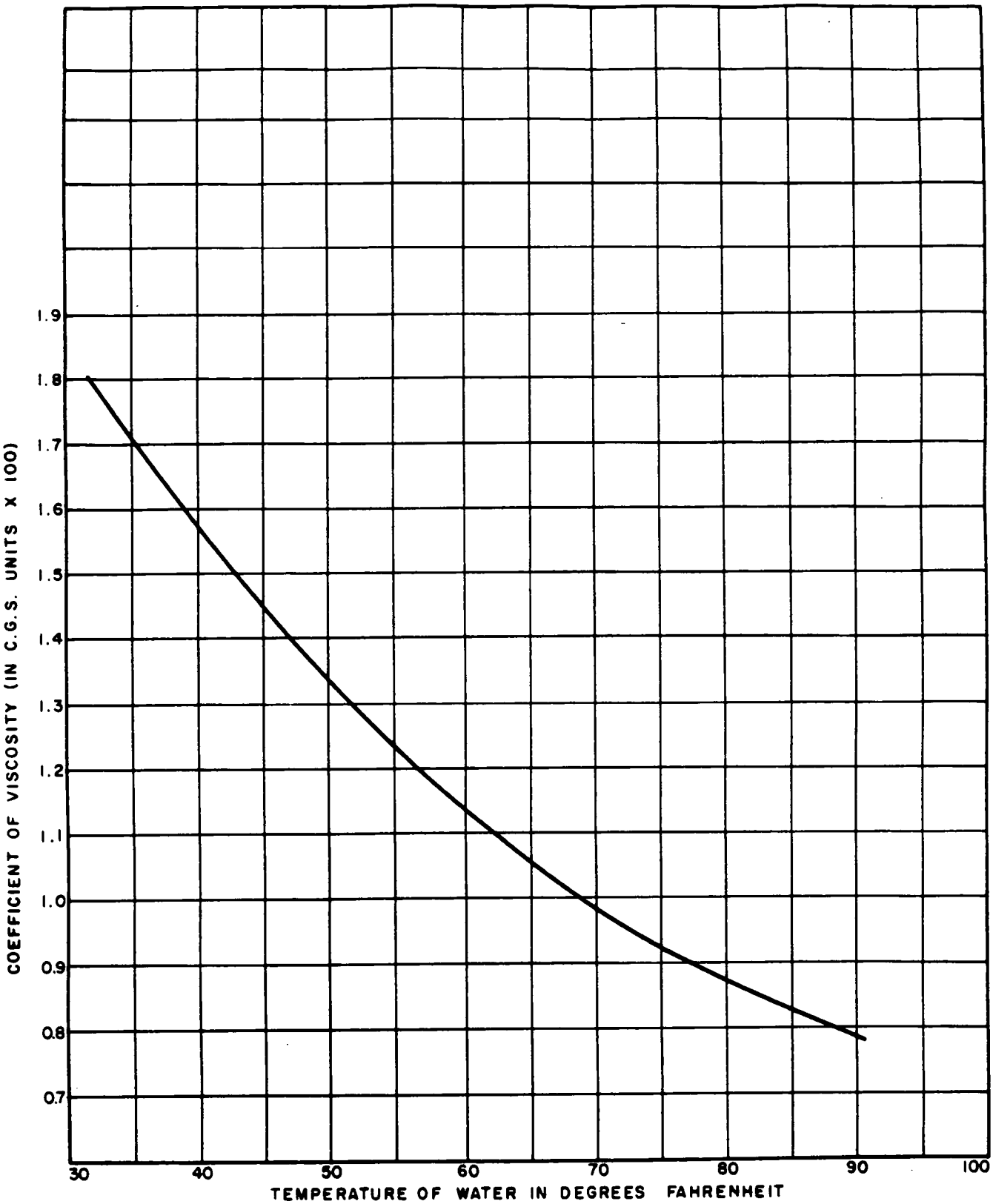

Figure 50. Graph showing the relationship between the temperature of water and its viscosity.

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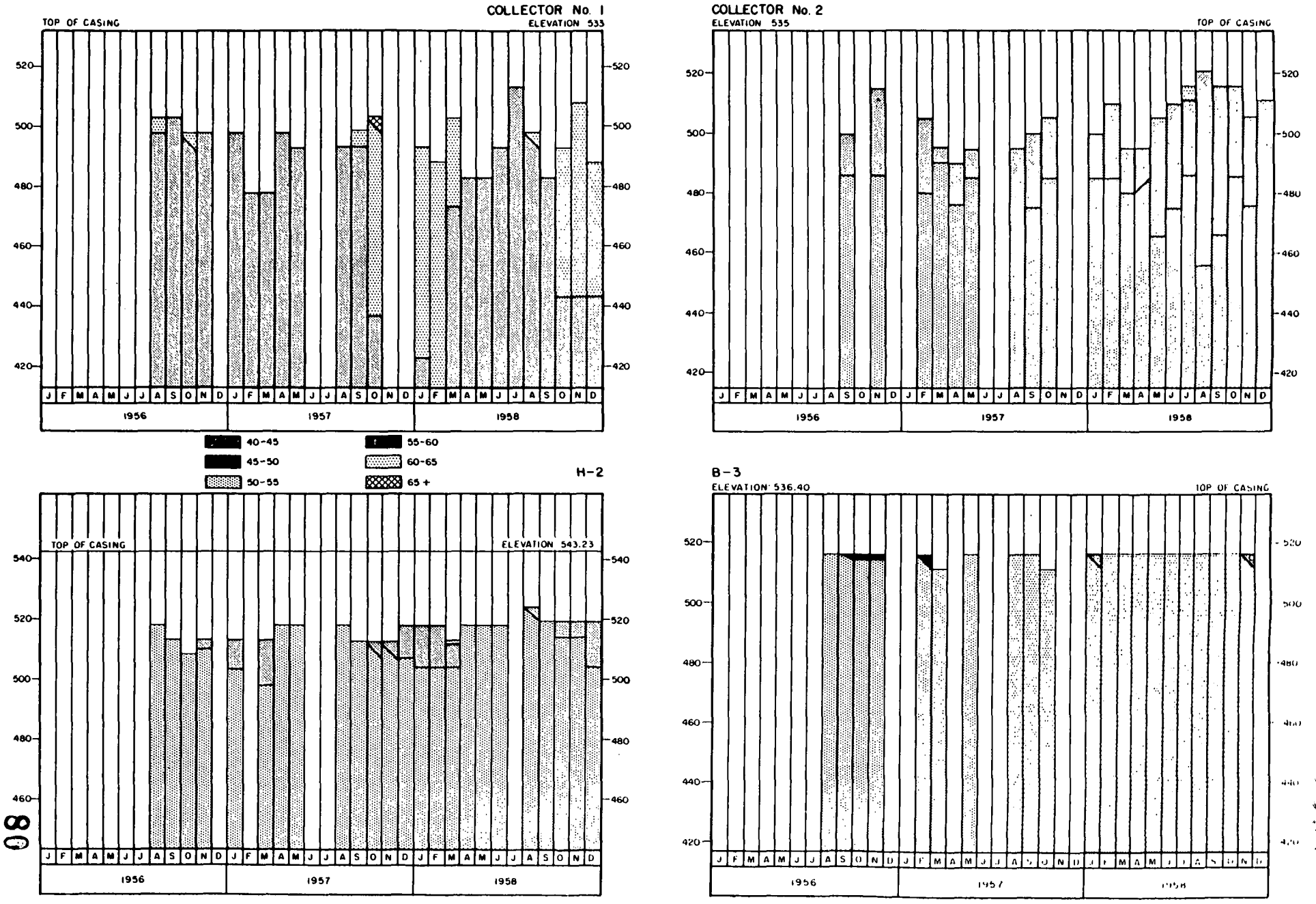

Figure 51. Graph showing monthly variations of water temperature, in degrees Fahrenheit, in wells H-2, B-3, Collector I and Collector 2

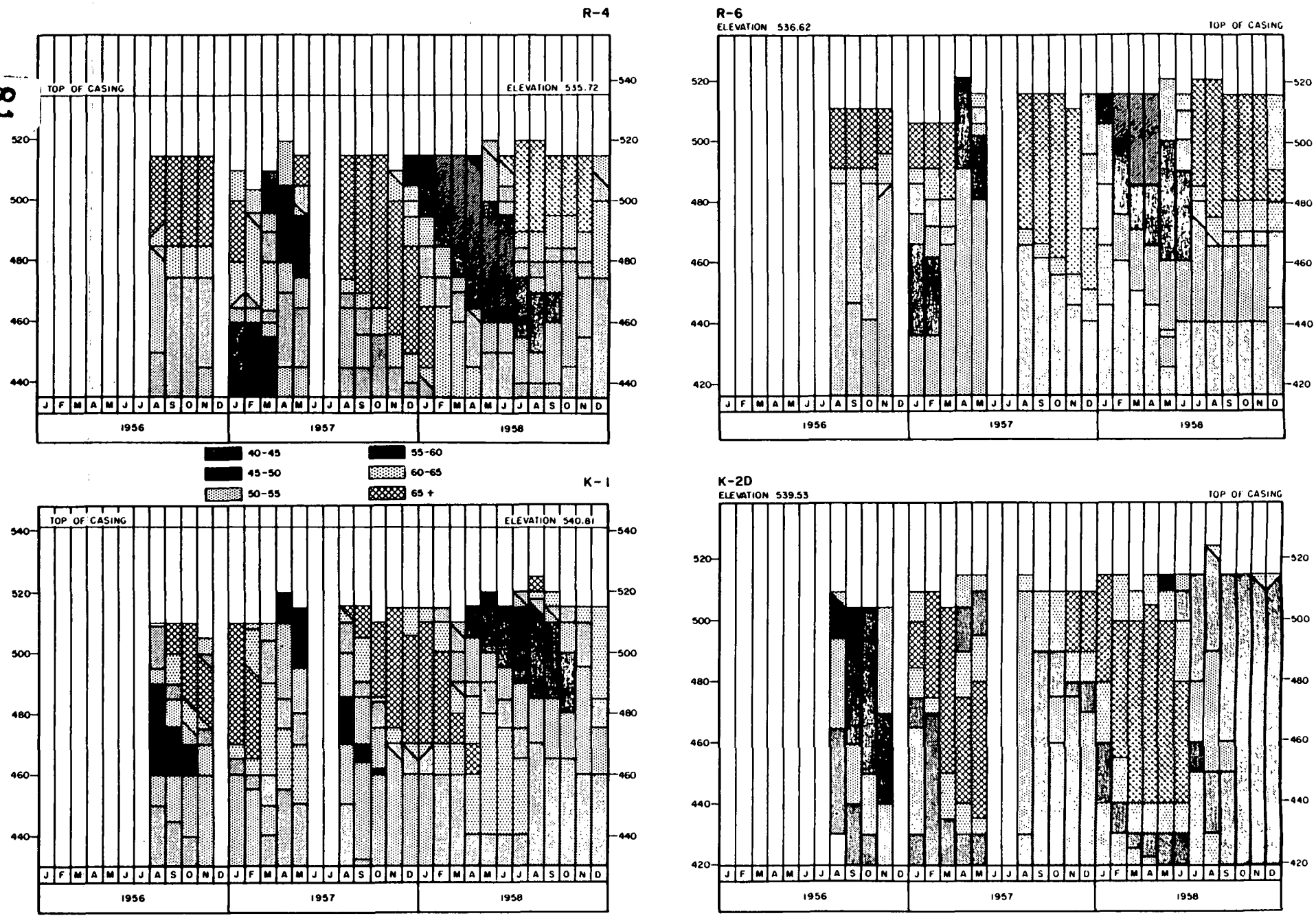

Figure 52. Graph showing monthly variations of water temperature, in degrees Fahrenheit, in wells R-4, R-6, K-1 and K-2d.

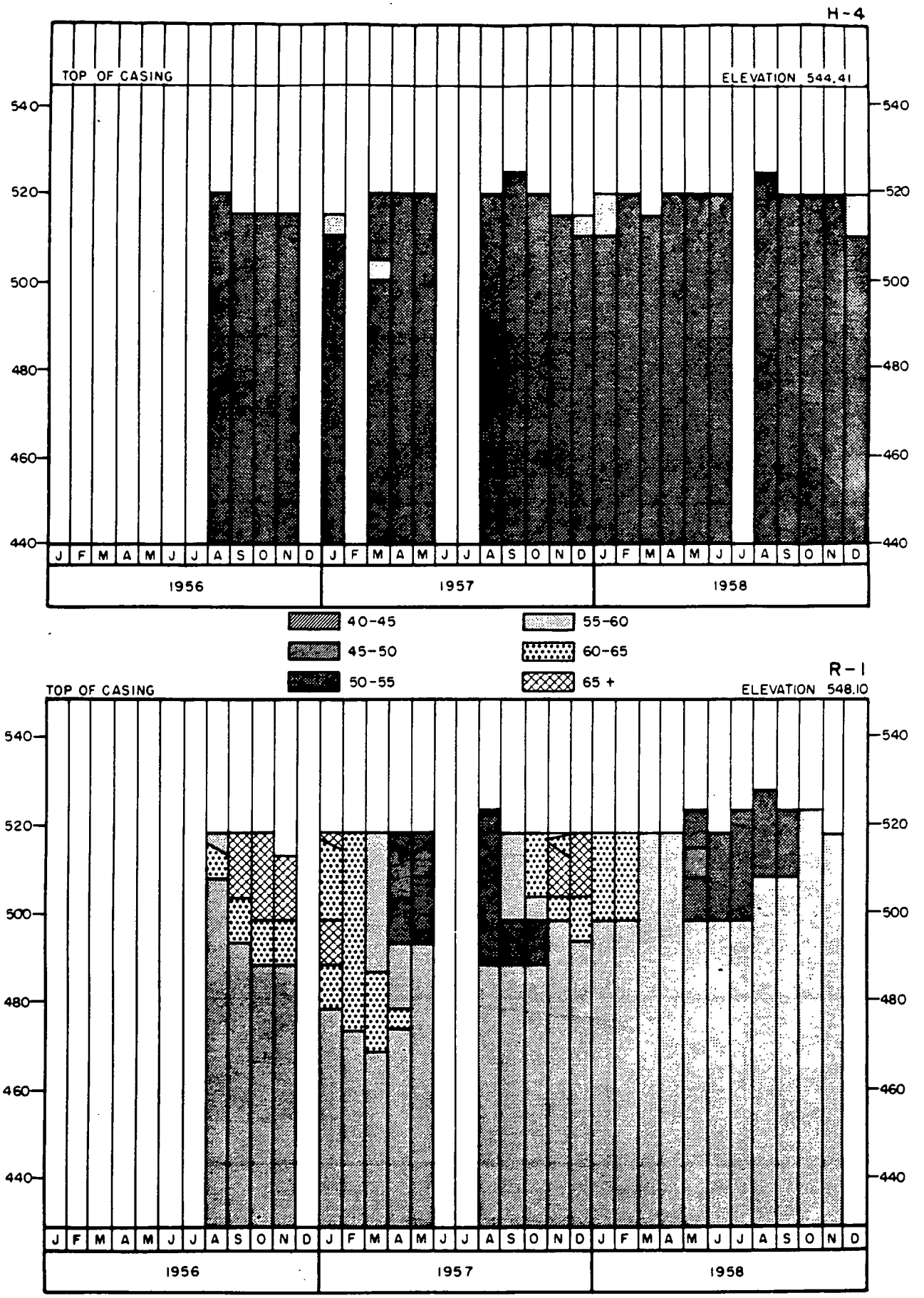

Figure 53. Graph showing monthly variations of water temperature, in degrees Fahrenheit, in wells H-4 and R-1.

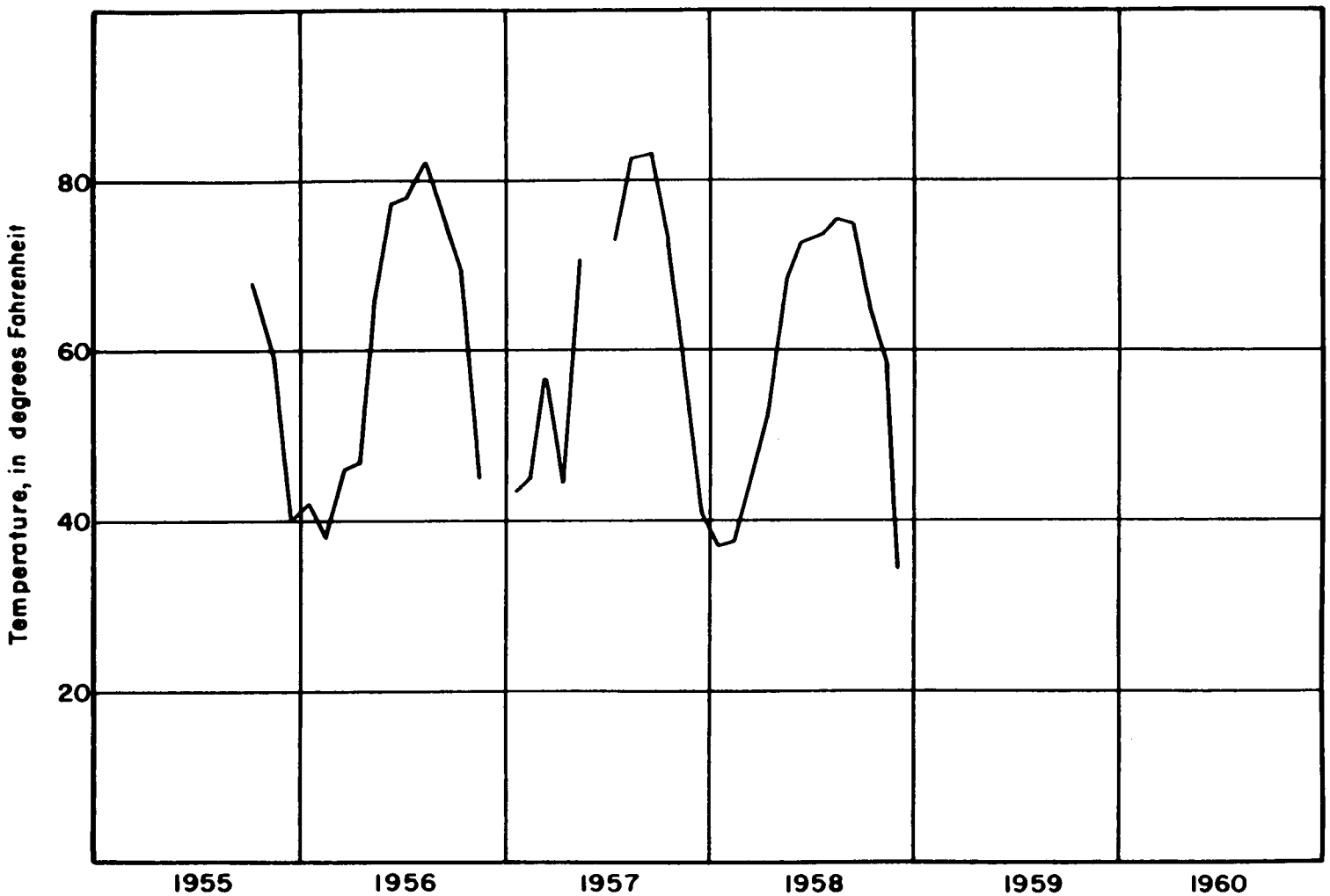

Figure 54. Graph of monthly river temperatures at Venice, Ohio.

of the water is about 18°. (See temperature range in wells K-1 and R-4 figures 52 and 53.) If the average aquifer temperature is selected, the temperature fluctuates only a degree or less.

Rorabaugh (1956, p. 152-154) apparently chose variations in ground-water temperatures at the site of the pumping well to determine the effects of water temperature on the rate of infiltration. He states "..., the added distance from the river will reduce the seasonal temperature variations, so that the average aquifer temperature would stay above the value of 36° F used in computing the curves. Therefore, the minimum yield would be above that shown by the curves." Seasonal variations in ground-water temperatures in collectors 1 and 2 at Venice is only about 3 or 4°. Thus, using temperature variations at the pumping well and considering only the change in the viscosity of the water, the infiltration rate during the winter would be about 96 percent of that in the summer.

As the water entering the aquifer is at a temperature roughly equal to that of the river, changes in the rate of infiltration based on the viscosity of the water must be determined at or near the river. The rate of infiltration computed from the test data of August 31, 1956, was determined when the average temperature of the river water was about 82°. During the winter the temperature of the river water usually declines to about 34°. The viscosity of water at 82° F is 0.8360 centipoise, and the viscosity of water at 34° F is 1.7313 centipoises, one centipoise being the viscosity of water at 20° C or 68° F. Therefore, choosing points at or very near the river and considering only the change in viscosity of the water, the infiltration rate during the winter will be only about 48 percent of the infiltration rate during the summer.

QUALITY OF WATER

Water is a "universal solvent" and thus takes its chemical properties from the air, soil, and rocks through and over which it passes. As it falls from the sky, water is fairly pure except for dissolved atmospheric gases and particles of dust picked up during its descent. Once on the ground the water picks up particles of soil and acquires some color and bacteria. Of the water that falls upon the ground, that part that percolates into the ground is filtered and purified as it moves slowly through the rocks, but the water in turn dissolves some of the mineral matter from the rocks.

Surface water, derived both from overland runoff and ground-water discharge, generally contains in varying but lesser amounts the same mineral constituents contained in ground water. In addition, surface water commonly contains suspended solids such as silt, clay, sand, and organic matter derived from the natural decomposition of soil and from pollution. The maximum concentration of dissolved mineral constituents and the minimum concentration of suspended sediment in surface water generally occur during periods of low flow.

Analyses of water from the Miami River and from radial collectors 1 and 2 in the Venice area were made by the U. S. Geological Survey and are shown in table 5. The source and significance of these dissolved solids is shown in table 6. The dissolved solids are reported in ppm (parts per million) which is a unit for expressing the concentration of a constituent by weight in a million parts of water. To describe the composition of water and the relationship among the ions in solution, it is desirable to express them in equivalents per million. An equivalent per million (epm) is a unit chemical equivalent weight of a constituent in a million unit weights of water. A unit chemical equivalent weight may be calculated by dividing the concentration of a constituent in parts per million by the chemical combining weight of the constituent. In this form the concentrations and relations of the constituents are directly comparable (See figure 55.)

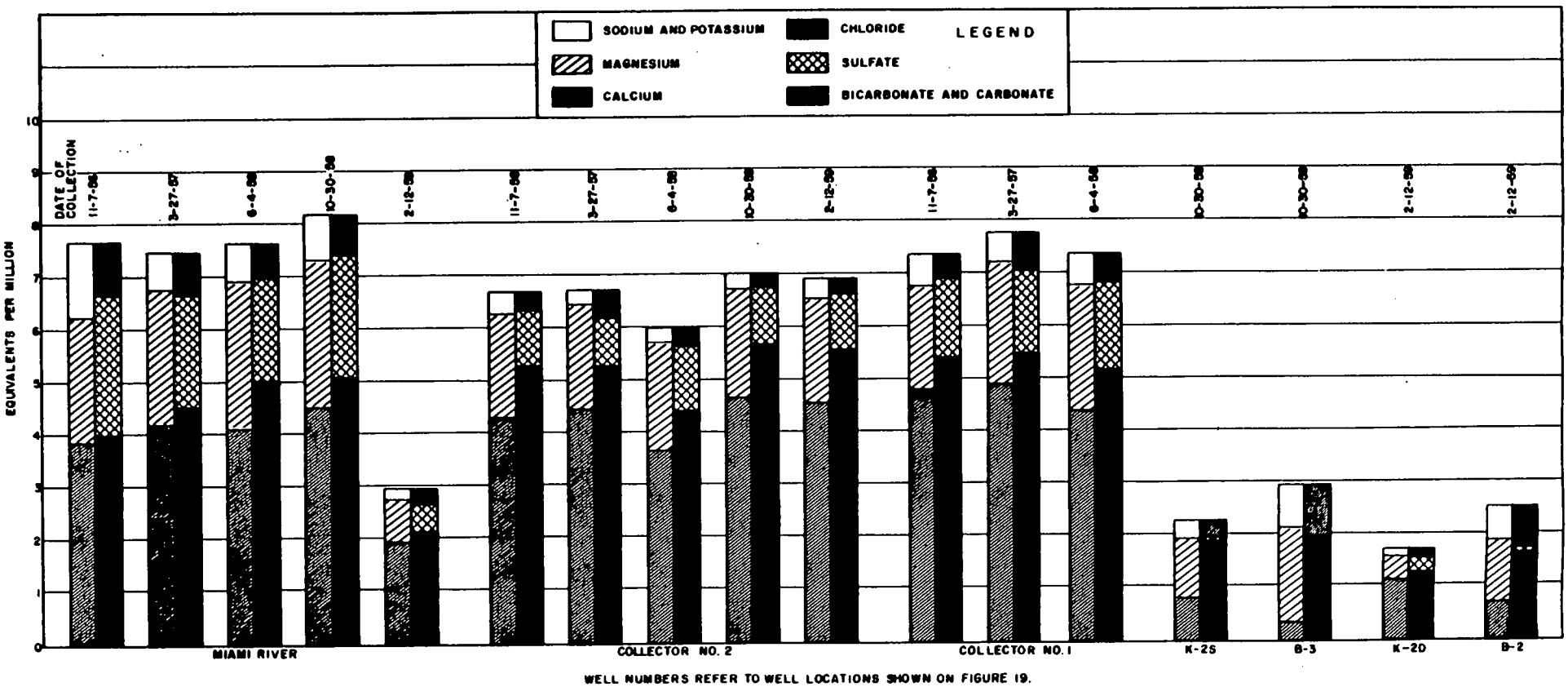

Figure 55. Chemical analyses of water from the Miami River and wells near Venice, Ohio.

Table 5.--Chemical analyses of ground and surface water in the Venice area, Ohio.

(Chemical analyses, in parts per million)

Point of collection	Date	Mean discharge mgd 1/	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180° C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	pH	Temp. (°F)	Color
																	Calcium magnesium	Noncarbonate				
Miami River	11- 7-56	412	8.7	0.27	1.08	77	29	1.9	30	4.2	243	128	32	0.5	6.8	438	314	114	708	7.2		8
-do-	3-27-57	1080	3.4	.01	.00	84	31	.0	15	2.2	275	102	20	.1	7.0	400	337	111	664	7.3		1
-do-	6- 4-58	2110	3.6	.99	.07	82	34	.7	15	2.2	305	93	16	.3	9.3	407	346	96	692	7.3	73	5
-do-	10-30-58	645	5.4	1.1	.08	90	34	.9	18	3.0	310	111	22	.4	7.1	445	366	112	728	7.2	45	5
-do-	2-12-59	22880	5.6	.00	.03	38	10	.0	3.7	2.8	128	26	6.0	.2	7.8	163	136	31	280	7.1	39	25
Collector 2	11- 7-56	9.532	11	.04	.30	86	24	.0	5.4	1.2	322	50	11	.1	2.0	350	313	49	580	7.4	56	2
-do-	3-27-57	5.775	10	.06	.34	89	24	.0	5.6	1.8	321	44	9.2	.1	5.7	348	321	58	607	7.7	56	0
-do-	6- 4-58	9.079	11	.16	.20	73	25	.2	5.7	1.8	268	59	9.0	.1	7.7	325	285	66	550	7.4	53	1
-do-	10-30-58	5.600	11	.02	.15	93	25	.2	4.5	1.9	344	52	7.5	.1	4.7	370	335	53	636	7.3	53	4
-do-	2-12-59		10	.00	.19	91	24	.0	4.9	1.9	338	51	8.0	.1	5.3	363	326	48	603	7.2	54	4
Collector 1	11- 7-56	6.217	13	.11	.42	96	24	2.0	12	1.7	329	72	16	.1	1.2	401	340	71	657	7.6	56	2
-do-	3-27-57	11.937	11	.10	.43	98	28	.0	12	2.1	334	75	21	.1	2.1	414	360	86	697	7.7	56	0
-do-	6- 4-58	9.648	10	.08	.24	88	29	.3	12	1.8	315	79	16	.1	3.3	395	339	81	651	7.3	56	1
Well K-2s	10-30-58	--	1.6	.34	.07	15	14	.4	6.7	2.7	114	1.8	12	.1	.4	111	96	2	218	7.7	57	10
Well B-3	10-30-58	--	.05	3.1	.28	5.9	22	.0	16	5.0	116 2/	.6	36	.2	.1	144	105	16	290	8.4	54	5
Well K-2d	2-12-59	--	1.4	.06	.10	22	5.2	.0	2.3	2.7	75	14	5.0	.2	1.0	91	76	15	170	7.3	52	8
Well B-2	2-12-59	--	18	.00	.08	13	15	.0	12	4.2	98	5.2	27	.2	.8	126	94	14	254	7.3	52	5

1/ Mgd (million gallons per day equals 1.5472 second feet)

2/ Includes equivalent of 4 parts per million of carbonate (CO_3)

Table 6.--Significance of dissolved mineral constituents and properties of water.

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts from 1-30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters usually indicate acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Federal drinking water standards state that iron and manganese together should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Maganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acid waters.	Some objectionable features as iron. Causes dark brown or black stain. Federal drinking water standards provide that iron and manganese together should not exceed 0.3 ppm.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (See hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Strontium (Sr)	Dissolved from rocks and soils. Found in sea water and many brines. Present in waters of local areas where strontium minerals such as celestite and strontianite are present.	Naturally occurring strontium is similar chemically to calcium and only adds to the hardness of water. Radioactive isotopes of strontium, as from nuclear bomb fallout, can be harmful. These isotopes can be detected by radiometric measurements and <u>are</u> <u>not</u> reported here as strontium (Sr).
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Federal drinking water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal drinking water standards recommend that the chloride content should not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Enters many waters from fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, F. J., 1950, Fluoridation of public water supplies, Jour. Am. Water Works Assoc., vol. 42, part 1, p. 1120-1132.)
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 ppm of nitrate (NO_3) may cause a

Table 6.--Significance of dissolved mineral constituents and properties of water--Continued

Constituent or property	Source or cause	Significance
		type of methemoglobinemia in infants, sometimes fatal. Water of high nitrate content should not be used in baby feeding (Maxcy, K. F., 1950, Nat. Research Council, Bull. San. Eng., p. 265, App. D.) Nitrate has shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	Federal drinking water standards recommend that the dissolved solids should not exceed 500 ppm, however 1,000 ppm is permitted under certain circumstances. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; more than 200 ppm, very hard.
Specific conductance (micromhos at 25° C)	Mineral content of the water.	Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25° C.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attach metals.
Temperature		Affects usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground waters from moderate depths usually are nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells, the water temperature generally increases on the average about 1° F with each 60 foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the depth of water, but do not reach the extremes of air temperature.
Color	Yellow-to-brown color of some waters is usually caused by organic matter extracted from leaves, roots, and other organic substances. Objectionable color in water also results from industrial wastes and sewage.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.

SUMMARY AND CONCLUSIONS

Test drilling in the glacial-outwash deposits underlying the Miami River near Venice, Ohio, shows that the bedrock surface slopes generally to the northwest to a deeply buried channel, which trends northeast to southwest. The bedrock surface lies between elevations of 360 and 440 feet above mean sea level, which is from 80 to 160 feet below the Miami River. The permeability of the outwash deposits filling the valley have been computed at 2,800 gpd per square ft east of the river and 3,000 gpd per square ft west of the river, indicating that the deposits become more permeable toward the buried channel that lies northwest of the Miami River.

Recharge from precipitation within the 6 square mile area of valley-train deposits average about 12 inches a year or 3.4 mgd. Recharge from the consolidated rocks (shale and limestone) which form the valley walls is about 1.2 mgd. The potential recharge from infiltration of water from the Miami River during periods of low streamflow is about 20 mgd. The yield of water from the valley-train deposits that would be balanced by recharge during dry periods, therefore, is estimated to be about 24.6 mgd.

The yield of the valley-train deposits that would be balanced by recharge during periods of low streamflow, however, is not the maximum dependable yield that could be developed. The quantity of water in storage in the area is about 0.17 million acre feet. If the specific yield of the aquifer is assumed to be 20 percent, about 95,000 acre feet of water (30 mgd for 1,000 days) would be made available by completely dewatering the aquifer. Of course the complete dewatering of the aquifer is impractical, as the yields of wells diminish rapidly as the saturated thickness of the aquifer is reduced. However, because of the high permeability of the valley-train deposits, the cone of depression will spread to great distances when large amounts of water are pumped from storage in dry periods, thereby encompassing a much larger area of stream bottom. In addition, the mean discharge of the Miami River at Hamilton for 30 years of record is 3,214 cfs, whereas, the discharge of the river during the low-flow period of August 31, 1956, was 587 cfs. Therefore, taking into account the storage available in the aquifer during periods of low streamflow (minimum rates of infiltration), it is not unreasonable to conclude that the average annual recharge by induced infiltration may be 40 mgd, or more than twice that estimated for low-flow conditions. The potential yield of the valley-train deposits in the Venice area, including recharge from precipitation and subsurface inflow from the valley walls, is estimated to be about 45 mgd.

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