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STUDY OF EFFECT OF REGULATION WORKS ON STREAM FLOW

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SYNOPSIS

This paper presents the changes in (river) regime of the Mississippi River and the variations in rating curves with respect to time and stage. Causes for some of the stage-discharge relationship changes are also discussed.

INTRODUCTION

Close association of hydrology and hydraulic studies with the planning, constructing and operating works for the improvement of the Mississippi River, as well as local flood control works, has led to the conclusion that man-made works in the alluvial plain have reduced the flood-carrying capacity and have increased the low-flow capacity of the Mississippi River at St. Louis, Missouri. In addition, variations in the high stage-discharge relationship are attributable to the season of occurrence of flood-producing rainfall as well as to the areal extent, intensity, and location of storm-producing flood runoff. The variations in low stage-discharge relationships are due to the source and predominance of the base-flow water and regulation.

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DESCRIPTION

St. Louis, Missouri, lies on the right, or west bank of the Mississippi River, just downstream of its confluence with the Missouri River. The drainage area above St. Louis is divided into two major river basins, the Missouri and the Upper Mississippi, which have a combined area slightly in excess of 700,000 square miles. Of this area, approximately 530,000 square miles lie in the Missouri River basin and the remaining 170,000 square miles lie in the Upper Mississippi River basin.

The watershed elevations in the Missouri River basin range from about 13,000 feet above sea level in the upland areas of the headwaters to about 400 feet above sea level near St. Louis. The annual precipitation varies from about 12 inches in the headwaters of the basin to about 40 inches near the mouth. The mean annual temperature ranges from 38^{o} in the mountainous regions of the headwaters to 56^{o} near St. Louis.

The term "Upper Mississippi basin" as used herein pertains to that section of the basin that lies above the mouth of the Missouri River. The lands in the basin vary in elevation from about 1,900 feet to about 400 feet above sea level. The annual precipitation varies from about 22 inches in the northwestern portion to about 40 inches in the southern portion, and the majority of the basin lies in the humid region. The mean annual temperature varies from about 38^{o} in the northern portion of the basin to about 56^{o} in the southern portion. Figure 1 is a general map of the reach of river from Alton to Cairo, Illinois.

DISCHARGE

The flood season in the Missouri and Upper Mississippi basins occurs at practically the same time of each year, March through July. Except for periods of drought, the low-water season occurs generally in the winter months, December through February.

Fragmentary and intermittent river stage records have been kept at St. Louis between 1837 and 1860. Complete gage records are available for the year 1844, the year in which the greatest flood of record occurred. The first continuous records of stage were initiated in 1861, the year in which the present Market Street gage was established at mile 179.6.

The earliest streamflow measurements taken at St. Louis were made by the City Engineer in 1866. Since that time, measurements have been made by the City of St. Louis, the Corps of Engineers, and by the United States Geological Survey. While discharge measurements have been taken at several localities in the area, the results are all referred to the Market Street gage. Flood-flow measurements were not made prior to 1872. Between 1872 and 1926 many of the major floods were measured; since 1926 all flood flows have been measured. The earlier data are contained in annual reports of the Chief of Engineers, United States Army. From these records, a single publication, entitled "Stream-Flow Measurements of the Mississippi River and Its Tributaries Between Clarksville, Mo., and the Mouth of the Ohio River, 1866-1934," was compiled by the District Engineer, St. Louis, Missouri, and published in 1935. Data for St. Louis, which appear on pages 22 to 46, inclusive, consist of 1,611 observations. Measurements made since 1934 are published by the U. S. Army Engineer District, St. Louis, Missouri, and are also contained in publications of the Mississippi River Commission and the U. S. Geological Survey. There have been 1,807 discharge measurements made from January 1935 to 9 December 1963, inclusive. Velocity measurements were made by the following methods: one meter, simultaneous measurements with two meters, double floats (surface and sub-surface), rod floats, surface floats, ice cakes, and vertical velocities by one meter at each tenth of depth.

The mean discharge of the Missouri River is about 82,000 c.f.s., with an estimated maximum of 900,000 c.f.s. in 1844, and an estimated minimum of 4,000 c.f.s. in 1940. The mean discharge of the Upper Mississippi River is about 95,000 c.f.s., with an estimated maximum of 565,000 c.f.s. in 1851 and 1858 and an estimated minimum of 8,000 c.f.s. in 1948. The mean discharge of the Mississippi River at St. Louis, Missouri, is about 175,000 c.f.s., with an estimated maximum of 1,300,000 c.f.s. in 1844 and an estimated minimum of 20,000 c.f.s. in 1933.

SURVEYS

Hydrographic surveys from which it is possible to chart the changes in river bed and bank configuration are available since 1837. The first survey was made by Robert E. Lee in connection with his work on the St. Louis Harbor.

SEDIMENT

Suspended-sediment measurements were obtained at St. Louis, Missouri, by the Board of Water Commissioners in 1867, by the Board of Engineers in 1879, by the Mississippi River Commission in 1881 and 1929, and by the U. S. Geological Survey through agreements in the Cooperative Stream Gaging Program for the St. Louis District from April 1948 to date. Sediment data at St. Louis, Missouri, are shown in Table 1.

TABLE 1
SUSPENDED SEDIMENTATION DATA, ST. LOUIS, MO.

Order of magnitude	Water discharge		Suspended-sediment discharge		Mean suspended-sediment concentration	
	Water year	c.f.s. days	Water year	Tons	Water year	ppm
1	1951	96,633,000	1951	417,247,770	1949	1,690
2	1952	85,366,200	1950	330,000,000	1950	1,680
3	1962	79,885,200	1949	282,300,000	1951	1,600
4	1960	76,280,400	1952	250,191,900	1952	1,090
5	1950	72,597,600	1960	187,676,200	1960	911
6	1949	61,961,500	1962	152,169,000	1961	868
7	1961	60,926,000	1961	142,835,000	1959	830
8	1958	52,956,200	1959	111,228,900	1958	756
9	1953	51,515,100	1958	108,125,500	1953	716
10	1959	49,639,600	1953	99,605,100	1962	710
11	1955	47,557,100	1957	74,784,690	1954	632
12	1957	44,934,900	1955	74,530,500	1957	616
13	1954	41,433,300	1954	70,646,730	1955	580
14	1956	34,399,000	1956	37,422,090	1956	403

NAVIGATION IMPROVEMENTS

The first work for improvement of the Mississippi River provided for the removal of snags between New Orleans and the Missouri River and was authorized by Congress in May 1824. This project, interrupted during the Mexican and Civil Wars, has been carried on as required ever since. The first work in the nature of permanent improvements, "a pier to give direction to the current of the Mississippi River near the City of St. Louis," was authorized by Congress in the Acts of 4 July 1836 and 3 March 1837. The comprehensive plan for regulation of the Middle Mississippi River was approved 31 March 1881 and provided for continuous improvement working downstream from St. Louis, utilizing revetment and permeable dikes to reduce the width of the river to 2,500 feet. This authority since has served as a basis for all subsequent river regulating works. The existing project for the Middle Mississippi River provides for obtaining and maintaining a minimum channel depth of not less than 9 feet, a minimum width of not less than 300 feet at low water, with additional width at the bends from the mouth of the Ohio River to the northern boundary of St. Louis, thence 200 feet wide with additional width at the bends to the mouth of the Missouri River, to be obtained by regulating works (piling dike and bank protection) and by dredging.

DRAINAGE AND FLOOD CONTROL IMPROVEMENTS

One of the richest areas known to early settlers in Illinois, known as the Great American Bottoms, was along the Mississippi River between the Missouri and the Kaskaskia Rivers. The rich black soil of these lowlands yielded crops beyond the wildest expectations of homesteaders. However, most of this area was poorly drained, having all the disadvantages of swamps and lowlands; therefore, relatively few parts were suitable for settlement. The dreaded swamp fever, which annually took its toll of settlers, was thought to steal out of the wet marshes during the night.

Drainage organizations to afford flood protection for these rich bottomlands along the Mississippi River are as old as the earliest settlements in Illinois. Early organized work dates back to 1826, when the villages of Cahokia and Prairie du Rocher petitioned the General Assembly for relief from floods. After the passage of the State Drainage and Levee Act of 1879, the way was cleared for organized levee districts to accomplish needed works. The first levee work was accomplished by individuals through organizations and later by help through State grants. Federal aid to drainage districts had been extended in Illinois for many years prior to 1928 incidental to the work of the Mississippi River Commission.

The design flood for levee projects between Grafton, Illinois, and Cape Girardeau, Missouri, was the 1903 flood, and the grade line for levees was taken about 6 feet above the flow line of that flood. Modifications in this grade line in any specific case were made after a request for aid was received. The only projects completed to Mississippi River Commission's full grade were East Side Levee & Sanitary District, Perry County Drainage & Levee District Nos. 1, 2 and 3, Preston Drainage and Levee District, and East Cape Girardeau and Clear Creek Drainage Districts.

In 1928 the Federal Government began a much more extensive program of supervision of navigable streams under the terms of the Flood Control

Act of that year. As a result, on 1 August 1928, the Northern Mississippi River Commission District of the Mississippi River Commission, which exercised jurisdiction over levees in this reach of river, transferred its authority over levees to the District Engineer in St. Louis, Missouri.

Following the flood of 1929, an investigation was made to determine the adequacy of the degree of protection for these levee districts. The results of this investigation formed the basis for the "1935" grade line for levees. In 1943 and 1944 two floods occurred which were the highest in 99 and 100 years, respectively, at St. Louis, Missouri. Based upon the characteristics of these floods, a redetermination was made of the adequacy of levee grades. The results of this investigation formed the basis for the "1944" levee grade determination. In 1947, and again in 1951, two floods occurred which exceeded in height both the 1943 and 1944 floods; however, both floods had lesser peak discharges. A study and re-evaluation of levee grade adequacy led to the adoption of a levee design flood profile for the urban and industrial projects in the vicinity of St. Louis, Missouri. Design flood profiles are shown on figures 2.

GENERAL ANALYSIS

A study was made of the relative floodway capacity of the Mississippi River at selected reaches for the years 1908, 1927, and 1944. These three years were chosen as a basis for comparison of the progressive modification of the flood plain accomplished by the construction of flood control levees and channel regulating works because they represent three different construction phases. Prior to 1908, the amount of levees and regulating works was small. Between 1908 and 1927 additional regulating works were built and, as a result of the 1903 flood, additional levees were built. The project depth was increased from 8 to 9 feet in 1927 and, in addition, many local interest levee projects had been raised and strengthened. Between 1927 and 1944, a major portion of the regulating works was constructed.

Investigation was made of three reaches of the Mississippi River, each 20 miles in length, where there had been constructed a considerable amount of flood control projects and channel regulating works. Named in upstream order, they are as follows: Reach No. 1, from 40 miles above the mouth of the Ohio River to Poe Landing, mile 60; Reach No. 2 from near the foot of Crains Island, mile 105, to Little Rock Landing, mile 125; and Reach No. 3 from Chesley Island, mile 160, to Eads Bridge at St. Louis, mile 180.

The Mississippi River from St. Louis to the mouth of the Ohio River flows generally in a southerly direction, although in the lower reaches between Cape Girardeau, Missouri, mile 52.1, and Cairo, Illinois, there are several sharp turns and long, sweeping hairpin bends. In an upstream direction from Commerce, Reach No. 1 turns sharply westward at Grays Point, mile 46; then it makes a long, sweeping bend to the east before continuing northward at mile 60. A comparatively moderate amount of regulating works had been constructed in this reach by 1908, and no levees had been constructed on either side of the river.

Between 1908 and 1927, very little additional regulating works were constructed in Reach No. 1; however, a small amount of bank protection was placed, including some by local interests. By 1927, there had been organized and constructed in Reach No. 1 three levee districts, all on the left bank; the East Cape Girardeau and Clear Creek Drainage and Levee District; the North Alexander County Drainage and Levee District; and the Clear Creek Drainage and Levee District.

Most of the regulating works in Reach No. 1 were constructed during the period 1927 to 1944 and were mainly in the form of dikes and revetment. The majority of the work was placed along the left bank of the river, the right bank hugging the bluff through a greater portion of the reach. No additional levees were constructed during the period.

Reach No. 2, going upstream from miles 105-125, contains two fairly sharp bends: the first at mile 117 toward the west; and the second at mile 121 back northward. A moderate amount of regulating work was constructed during the period prior to 1908. Practically all of the work was placed in two localities: Crains Island, miles 105-106; and in the vicinity of Ste. Genevieve, miles 120-125. There were no levees constructed along the main channel of the river up to 1908; however, a levee had been built along the south side of the lower end of the old river channel behind Kaskaskia Island.

From 1908 to 1927 a small amount of additional regulating work was constructed. The greater portion of the work was placed at the two localities mentioned in the preceding paragraph. By 1927 four levee districts were organized and their levees built, all on the right bank: The Perry County Drainage and Levee District No. 1; the Perry County Drainage and Levee District No. 2; the Kaskaskia Island Drainage and Levee Districts; and the Ste. Genevieve District No. 1.

During the period 1927 to 1944, a considerable amount of regulating work was placed. A small percentage was placed along the left bank, which runs along the bluff line through almost the entire reach. The right bank practically throughout the entire reach received the larger percentage of the work. The levee districts that existed in 1927 protected land on the right bank throughout the entire length of the reach; consequently, no new districts needed to be organized.

Reach No. 3, miles 160-180, is practically a straight reach of river. Since the upper end of the reach is the lower end of the St. Louis harbor, there existed in 1908 a considerable amount of regulating work. Records available in this office show that for this important reach, regulating work was under construction as far back as 1837. Three levees of varying importance existed on the left bank in Reach No. 3 in 1908: The Columbia Drainage and Levee District, miles 160 to 165.5; a small levee at mile 169, which later became a portion of the Wilson and Wenkel Drainage and Levee District; and a levee, mile 173, which protected the towns of East Carondelet and Prairie du Pont from overflow of the Prairie du Pont Creek. Only a portion of the levee of the East Side Levee and Sanitary District was in existence in 1908, and this levee did not protect land as far downstream as Reach No. 3.

From 1908 to 1927, a comparatively small amount of additional regulating work was constructed in Reach No. 3, the greater portion of work consisted of maintenance of dikes which were constructed before 1908. There existed in 1927 the Columbia Drainage and Levee District, the Wilson and Wenkel Drainage and Levee District, the Prairie du Pont Drainage and Levee District, and the East Side Levee and Sanitary District, which had been enlarged to protect land farther downstream contained in Reach No. 3. All levees were on the left bank, the right bank being adjacent to bluffs or high ground.

During the period 1927 to 1944, only a moderate amount of additional regulating work was placed in Reach No. 3, this reach being reasonably well stabilized. No additional levees were needed, as land along the left bank throughout the entire reach was protected by levees that existed in 1927.

The amounts of channel regulating work performed in the three reaches for the three periods by U. S. Army Engineer District, St. Louis, are as follows:

Reach No. 1, miles 40-60

	Before 1908	1908-1927	1927-1944
Dikes, lin. ft.	20,700	533	44,900
Mattress, lin. ft.	19,450	5,100	41,300
Paving, sq. ft.	688,900	335,600	1,891,600

Reach No. 2, miles 105-125

	Before 1908	1908-1927	1927-1944
Dikes, lin. ft.	36,400	15,800	76,400
Mattress, lin. ft.	49,600	15,300	25,000
Paving, sq. ft.	2,560,000	1,507,600	1,187,800

Reach No. 3, miles 160 to 180

	Before 1908	1908-1927	1927-1944
Dikes, lin. ft.	174,500	9,400	16,400
Mattress, lin. ft. *	65,900	1,100	6,500
Paving, sq. ft.	2,493,900	185,000	326,900

* Linear feet along bank line.

The amounts of riverfront levee that existed at the end of each period for the three reaches of river are as follows:

	1908	1927	1944
Reach No. 1	0.0	14.0	14.0
Reach No. 2	0.0	11.0	11.0
Reach No. 3	7.5	12.5	12.5

For the purpose of determining the effect upon the Mississippi River floodway of flood control projects and channel regulating work, cross sections were plotted for each mile in each of the three reaches for the three years 1908, 1927, and 1944, for the year ending the periods of time for which the investigation was made. Cross sections were plotted "bluff to bluff" and levees controlling width of floodway were spotted. The 1908 cross sections were plotted from the "1908 board charts." The 1927 cross sections were plotted using the 1927 low-water survey charts for the channel section and the 1940 alluvial valley maps for overbank section. The 1944 cross sections were plotted using the 1944 low-water survey charts for the channel section and the 1940 alluvial valley maps for overbank.

For the purpose of comparing the physical changes in the entire floodway section which were accomplished by flood control projects and channel regulating work, area curves were constructed in accordance with the width of floodway as determined by the bluffs or confining levees. The areas were taken "bluff to bluff" where no levees existed, "bluff to levees" where there were levees on only one bank, and "levee to levee" when that condition prevailed.

For the purpose of comparing available floodway area, particularly in 1927 and 1943 when the same levees existed in both years, it was believed advisable to assume that in each case the levees to be built would contain the flood flow of 50-year frequency. Investigations indicated that levees existing in 1908 were of insufficient height and section to have more than a negligible effect on large flood flows. Comparative areas of the entire floodway under the elevation of the 50-year flood profile were obtained, and the average areas for each of the three reaches were computed. The results are as follows:

	Reach No. 1 Area, sq. ft.	Reach No. 2 Area, sq. ft.	Reach No. 3 Area, sq. ft.
1908	487,000	616,000	416,000
1927	219,000	389,000	212,000
1943	215,000	389,000	209,000

Analysis of the above tabulated data leads to the conclusion that the construction of levees in the Mississippi River floodplain during the period 1908-1927 has been the main factor in reducing floodway capacity to approximately 54% of the 1908 area. Between 1927 and 1943, when no additional levees were constructed, the floodway capacity remained practically constant, being reduced in area by only an additional 1/2 of 1%.

An investigation was made of changes in the condition of the main channel only which were accomplished primarily by construction of channel regulating work. At each section for each year chosen for study, the areas up to the lowest high-bank elevation that existed during each respective year were obtained, and the average areas were computed for each reach. The results are as follows:

	Reach No. 1 Area, sq. ft.	Reach No. 2 Area, sq. ft.	Reach No. 3 Area, sq. ft.
1908	99,000	89,000	87,000
1927	87,000	98,000	90,000
1943	86,000	83,000	89,000

Attention is here invited to the fact that the lowest respective high-bank elevation to which the areas were taken in the above computations was not at a common elevation in all 3 years. This was because in many cases the banks had been built up in the later years by the regulating works; therefore, the areas were taken to a higher elevation and an improvement in channel conditions was indicated. Although the areas were not taken to a common elevation, it was considered that such information would be of interest insofar as indicating the effect of regulating works.

Areas also were taken at the lowest high-bank elevation which was common to all 3 years, and the average areas for each reach were computed. The results are as follows:

	Reach No. 1 Area, sq. ft.	Reach No. 2 Area, sq. ft.	Reach No. 3 Area, sq. ft.
1908	96,000	74,000	80,000
1927	78,000	78,000	80,000
1943	79,000	76,000	78,000

Improvement in channel conditions, previously mentioned as the result of constructing regulating works, was determined by a comparison of the mean depths, which were derived for each reach by dividing the areas of each section at bankfull by the bankfull width. The mean depths for the three reaches at both bankfull elevation and at lowest common bankfull elevation are as follows:

Mean depths at bankfull elevation

	Reach miles 40-60	Reach miles 105-125	Reach miles 160-180
1908	27.5	25.7	29.4
1927	30.9	28.2	31.8
1943	29.8	29.0	32.1

Mean depths at common bankfull elevation

	Reach miles 40-60	Reach miles 105-125	Reach miles 160-180
1908	27.1	23.4	28.2
1927	28.4	25.4	29.0
1943	29.0	26.5	30.4

Area of the main channel at bankfull, regardless of the elevation and area of the main channel at a common bankfull elevation for all 3 years, has been generally reduced due to regulating works which narrowed the channel. Thus, as could be expected, the narrowing of the channel caused scour, and the mean depth progressively improved.

It should be remembered that actual grades on some of the levees were not as high in 1927 as they are at the present time, and that flood heights were reduced considerably by storage in the districts after the levees broke.

In order to determine the change in thalweg elevation, three comparative channel profiles were plotted for the Mississippi River between the mouth of the Ohio River and the mouth of the Missouri River. The years 1908, 1929, and 1960 were chosen. The thalweg depth soundings were average for each one-quarter mile and then plotted. The low-water reference plane, representing a flow of 54,000 c.f.s. for the years 1908 and 1956-57, was then plotted on this profile. Thalweg profiles are shown on figure 3. The mean channel depth below the 1956-57 low-water reference plane was then determined. The results were as follows:

1908	17.1 feet
1929	20.8 feet
1960	21.2 feet

In order to observe changes in channel width and depth, comparative cross sections were plotted at river miles 30.5 and 102.0 for the years 1908, 1929 and 1960. At mile 30.5, the channel width narrowed from 4,600 feet in 1908 to 3,200 feet in 1929, and then to 1,800 feet in 1960. The channel depth had increased by 26 feet during this entire period. At river mile 102.0, the channel width narrowed from 3,500 feet in 1908 to 2,900 feet in 1929, and then to 1,200 feet in 1960. With this river regulation construction there was an increase in channel depth of 6 feet in 1929 to 12 feet in 1960. At St. Louis, Missouri, mile 180, more basic data are available. Investigation of historic maps reveals that the Mississippi River at Vine Street was 3,100 feet wide in 1803 and due to shifting and cutting of the Illinois channel currents eastward of Bloody Island, the river gradually enlarged to 3,200 feet in 1808, 3,700 feet in 1837, 3,900 feet in 1843, and reached a maximum of 4,200 feet in 1849. Because of the large commerce resulting from the steamboats of that era, it became necessary to preserve the channel in front of the City of St. Louis, which was deteriorating rapidly. The magnitude of the interests of this wealthy and rapidly growing city demanded that the river, throughout the entire length of the 13 miles of city front, be made to flow in a permanent channel, having stable banks. To effect this, the city and private corporations began work in 1838 on a series of dikes from the Illinois shore, which was intended to confine the river in a definite channel. Limit lines finally adopted for the St. Louis Harbor were 1,500 feet at low water (L.W. 1863 = zero St. Louis gage) and 2,000 feet at bankfull (30 feet St. Louis gage). From 1837 to 1889 the river was narrowed to 2,000 feet, and by 1907 the depth had lowered 14 feet. The width has remained practically the same from 1907 to 1960, with an added increase in channel depth of 9 feet. Comparative cross sections are shown on figure 4.

A detailed investigation was also made and cross sections at each one-quarter mile between miles 63 and 64 for the years 1908 and 1960 were plotted. By use of the 1908 and 1956-57 low-water reference planes and corresponding discharge of 54,000 c.f.s., "R" and "S" in the Manning formula were determined, and from the formula "n" was solved. The "n" value in 1908 equaled 0.0270 while that of 1960 equaled 0.0225.

Individual cross sections or channel profiles are not always conclusive as to what is happening in a channel because the surveys may not be phased with the phenomenon. Discharge measurements over a long period of time, when referred to a permanent gage, will portray changes in channel regimen. In order to show the change in the low-water channel at St. Louis, Missouri, reference is made to figure 5. This figure shows the stage at St. Louis, with respect to time, for a constant discharge of 54,000 c.f.s. It will be noted that 54,000 c.f.s. passed the St. Louis Market Street gage at a plus 7-foot stage in 1837, whereas at the present time this same discharge passes at a stage of minus 3.5 feet. Figure 5 was derived from rating curves constructed from discharge observations for specific periods as shown on figure 6.

Another detailed study was made in the 1950's of the lowering of the low-water plane in the reach of river from Alton, Illinois, mile 202.7, to the mouth of the Missouri River, mile 195. The first regulating works, which were constructed in 1896, consisted of seven dikes; two of these were removed for channel realinement in 1916 and 1918. Three additional dikes were built in 1917, 1919, and 1924. No further work was done until 1932, at which time the river through this reach had an average width of approximately 2,600 feet, and all but one of the above-mentioned dikes had been destroyed. In 1932, two dikes, each about 700 feet in length, were built on the right and left banks at mile 200. Between 1933 and 1936, six solid dikes with an average length of 1,200 feet were constructed on the right bank between miles 197 and 200. As a result of this work, the channel between the left bank and the outer end of these solid dikes was narrowed to 1,200 feet.

In order to determine the effect of the regulating works constructed within this reach, cross sections at mile 198 and at mile 200 were plotted. Cross sections from the low-water surveys for various years from 1928 to 1947 were used. Data obtained from these cross sections below the 1945 low-water reference plane are as follows:

Mile 198

Year	Cross-sectional area below 1945 L.W.R.P.*	Width	Mean depth
1928	11,640 sq.ft.	1,635 ft.	7.12 ft.
1930	7,920 "	1,820 "	4.35 "
1932	10,110 "	2,385 "	4.24 "
1933	9,312 "	2,010 "	4.63 "
1934	10,768 "	1,700 "	6.33 "
1937	13,760 "	1,185 "	11.61 "
1939	15,840 "	1,570 "	10.09 "
1947	19,088 "	1,230 "	15.52 "

Mile 200

Year	Cross-sectional area below 1945 L.W.R.P.*	Width	Mean depth
1928	11,200 sq.ft.	1,890 ft.	5.92 ft.
1930	10,624 "	1,965 "	5.41 "
1932	7,728 "	1,290 "	5.99 "
1934	7,056 "	1,005 "	7.02 "
1937	10,500 "	1,200 "	8.75 "
1939	18,880 "	1,255 "	15.04 "
1947	22,928 "	1,235 "	18.57 "

* 393.1 ± ft. m.s.l.

In addition, between miles 198 and 200, a volumetric study was made of space occupied by water below a plane 9 feet below the low-water reference plane. The results are as follows:

Miles 198 to 200

Year	Acre-Feet
1928	240
1930	40
1932	360
1933	360
1934	600
1937	920
1939	1,195
1946	1,900

From actual discharge measurements at Alton, Illinois, and St. Louis, Missouri, rating curves were constructed for Alton and for the mouth of the Missouri River for the following periods: 1928-1930, 1931-1934, 1935-1938, 1938-1940, 1941-1944, 1945-1948, 1948-1950, 1952-1954, and 1954-1955. The rating curves for Alton were elevation-slope-discharge diagrams which were derived from computed 1-foot fall curves, while those at the mouth of the Missouri River were single-line rating curves. Normally, the low-water reference plane flow of 54,000 c.f.s. at St. Louis, Missouri, is composed of 24,000 c.f.s. out of the Missouri River and 30,000 c.f.s. from the

Upper Mississippi River. Under these flow conditions, 30,000 c.f.s. from the Upper Mississippi River passed Alton, Illinois, at elevation 396.9 in 1928, elevation 396.4 in 1932, elevation 393.5 in 1950, and elevation 392.5 in 1955. The difference in the 1928 and 1955 elevations represents a lowering of 4.4 feet in 27 years.

About the mid-1940's an investigation was made to determine by field tests and observations the effect of over-contraction by dike regulating works on dredging, channel cross sections, and velocities. The locality subject to study and investigation lay between Herculaneum and Cornice Rock, miles 151.1 to 148.2. Hug Landing (mile 149.7) is about center of the reach.

The alinement of the thalweg just upstream of Joachim Bluff, mile 151.0 right bank, is in the form of a curve which tends to force the channel toward the Illinois shore downstream of this protruding bluff. About 1-1/2 miles downstream of the bluff a deep-water channel, which existed from 1939 to 1946, began on the right bank and continued downstream alongside of the permeable dikes. The results of these conditions were that the low-water channel became divided between miles 150.5 and 149.5, a center reef and bar built up, and maintenance dredging increased. During 1940-1941, new dikes and extensions were constructed along the right bank on the concave side of the channel between miles 151.8 and 151.3, and below the bluff between miles 150.5 and 149.7. Some screen mattresses were placed on these dikes. Appreciable improvement in the depth and alinement of the channel resulted, which was reflected in the decrease in quantities of maintenance dredging for fiscal years 1941 to 1943.

Following the floods of 1943, 1944, and 1945, it became evident that the alinement of the channel was incorrect, as the quantities of maintenance dredging increased markedly during fiscal years 1944 to 1946, inclusive. Accordingly, a new layout was planned. It was decided that the dikes along the right bank in the vicinity of mile 150 should be extended at least an additional 700 feet. It was further decided that physical data in the form of surveys and discharge measurements should be collected before, during, and after construction. Construction work was begun under contract in 1945 and was completed in 1946. The following dikes were included in the contract:

Dikes			Feet
148.85	R		1,040
149.3	R		1,000
149.7	R		995
150.0	R		895
150.2	R		775
150.3	R		175
150.5	R		425
149.0	L		420
		Total	5,725

A history of maintenance dredging is as follows:

Fiscal year	Cubic yards
1940	465,078
1941	118,989
1942	145,979
1943	119,979
1944	767,487
1945	924,567
1946	627,342
1947	130,677
1948	0
1949	0
1950 (to 31 Dec 1949)	0

Vertical velocity observations and discharge measurements were taken during various phases of the construction. The discharges when plotted against stage showed no great variation and plotted on a smooth curve. The vertical velocity observations showed that the velocities in the new channel increased to about 5 feet per second. Results of discharge measurements are as follows:

Date	St. Nicholas Rock Gage*	Discharge
9-14-45	158.15	130,000 c.f.s.
10-30-45	155.85	110,000 c.f.s.
11-14-45	157.75	127,000 c.f.s.
2-1-46	158.6	144,000 c.f.s.
2-25-46	161.8	174,000 c.f.s.

* zero equals 213.73 ft. m.s.l.

A comparison of river cross sections at mile 149.7 for various dates from 2 September 1943 to 25 February 1946 was obtained, and the areas are shown below:

Date	Area under Elevation 377.0
2 Sep 1943	39,480
15 Sep 1945	51,040 "
3 Oct 1945	49,620 "
30 Oct 1945	51,220 "
14 Nov 1945	49,320 "
11 Feb 1946	52,980 "
25 Feb 1946	54,460 "

The effect of all these works is indicated by changes in stage-discharge rating curves. There are shown on figure 7 stage-discharge rating curves at St. Louis, Missouri, for various periods from the beginning of data collection to date. It is desired to point out that these rating curves tend to cross at about stage 20 feet on the St. Louis gage; further, that comparable flood flows are about 10 feet higher under present confined levee conditions, and comparable low-water flows are about 10 feet lower under present regulation works conditions.

It is not intended to convey the impression that there are no variations in stage-discharge relationships for various flood flows for the same and different years. In order to show the variation in the stage-discharge relationship, actual discharge measurements are shown for the years 1943, 1944, 1945, 1947, 1948, 1951 and 1952 on figures 8, 9, 10, 11, 12, 13, and 14, respectively. It should be noted that a minimum envelope discharge curve is also shown on these figures for a base reference. Analysis of run-off from the Missouri and Upper Mississippi basins coincidental with flows at St. Louis leads to the conclusion that:

a. Discharge for a given stage is dependent upon source of predominant flow.

b. The channel capacity deteriorates through successive rises from April to July.

In order to observe channel changes during a flood, three reaches were selected fro observation. Sounding ranges at 400-foot intervals were obtained in 1951 and 1952 at reach 1, miles 168.0 to 170.7; reach 2, miles 173.4 to 175.6; and reach 3, miles 181.4 to 182.6. The reaches were contoured and the volume below a plane 9 feet below the low-water reference plane was determined by planimetering. The results are as follows:

Reach 168.0 - 170.7		Reach 173.4 - 175.6		Reach 181.4 - 182.6	
Date	Acre-Feet	Date	Acre-Feet	Date	Acre-Feet
7/2/51	1,770	7/1/51	2,700	6/30/51	1,040
7/17/51	975	7/12/51	1,810	7/16/51	790
7/20/51	860	7/21/51	1,660	7/19/51	780
7/26/51	840	7/30/51	2,420	7/25/51	800
8/10/51	1,495	8/9/51	2,670		--
9/20/51	1,360	9/21/51	2,580	9/24/51	960
4/21-22/52	2,370	4/23/52	2,010	4/23/52	1,090

From an analysis of data above, it may be concluded that the river bed fills during a flood and scours after a flood.

An attempt has been made herein to present factual data which have been collected, observed, and studied at St. Louis, Missouri, which in some way have an effect on the discharge capacity of the Mississippi River.

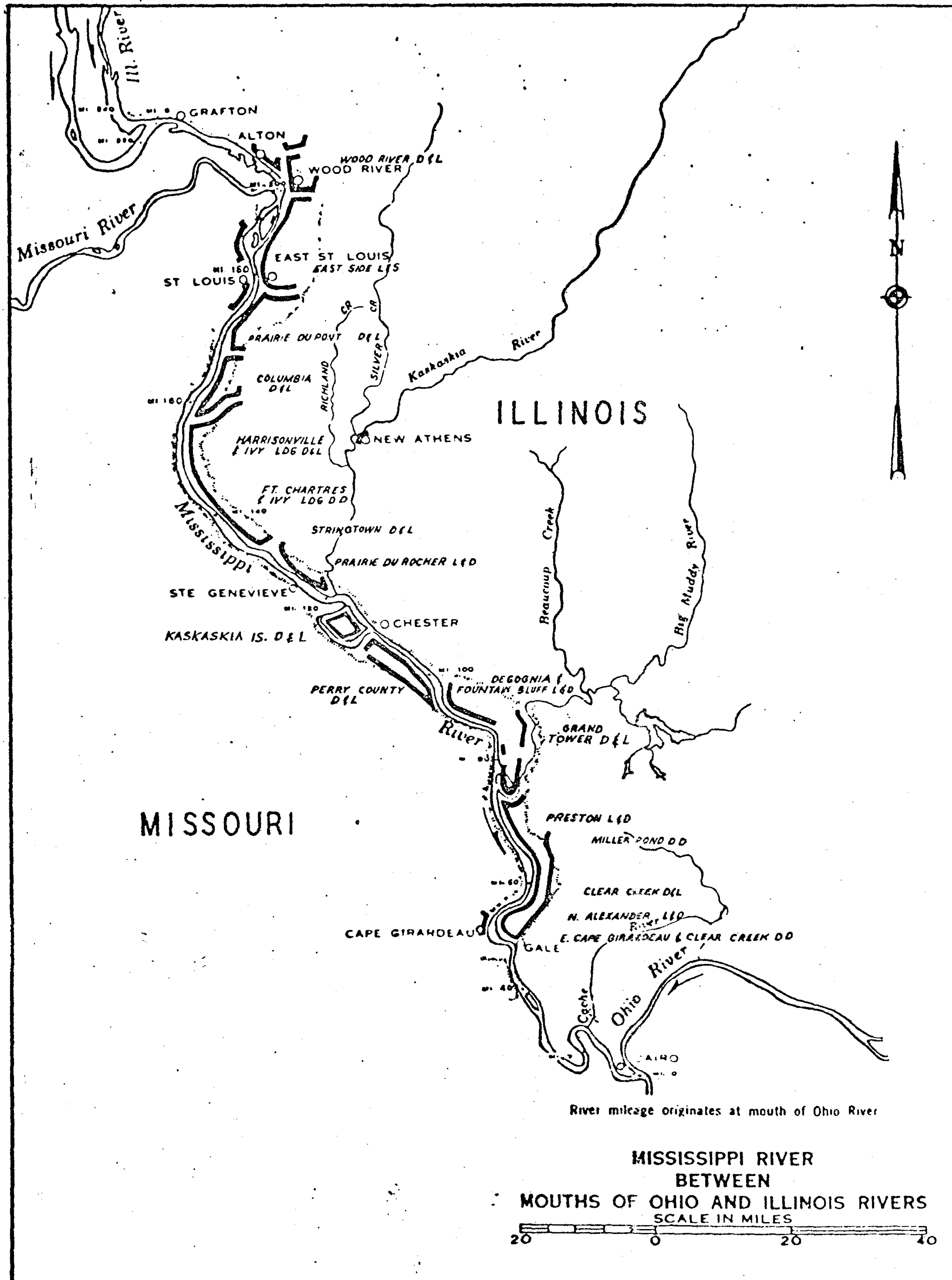

FIG. 1 - GENERAL MAP

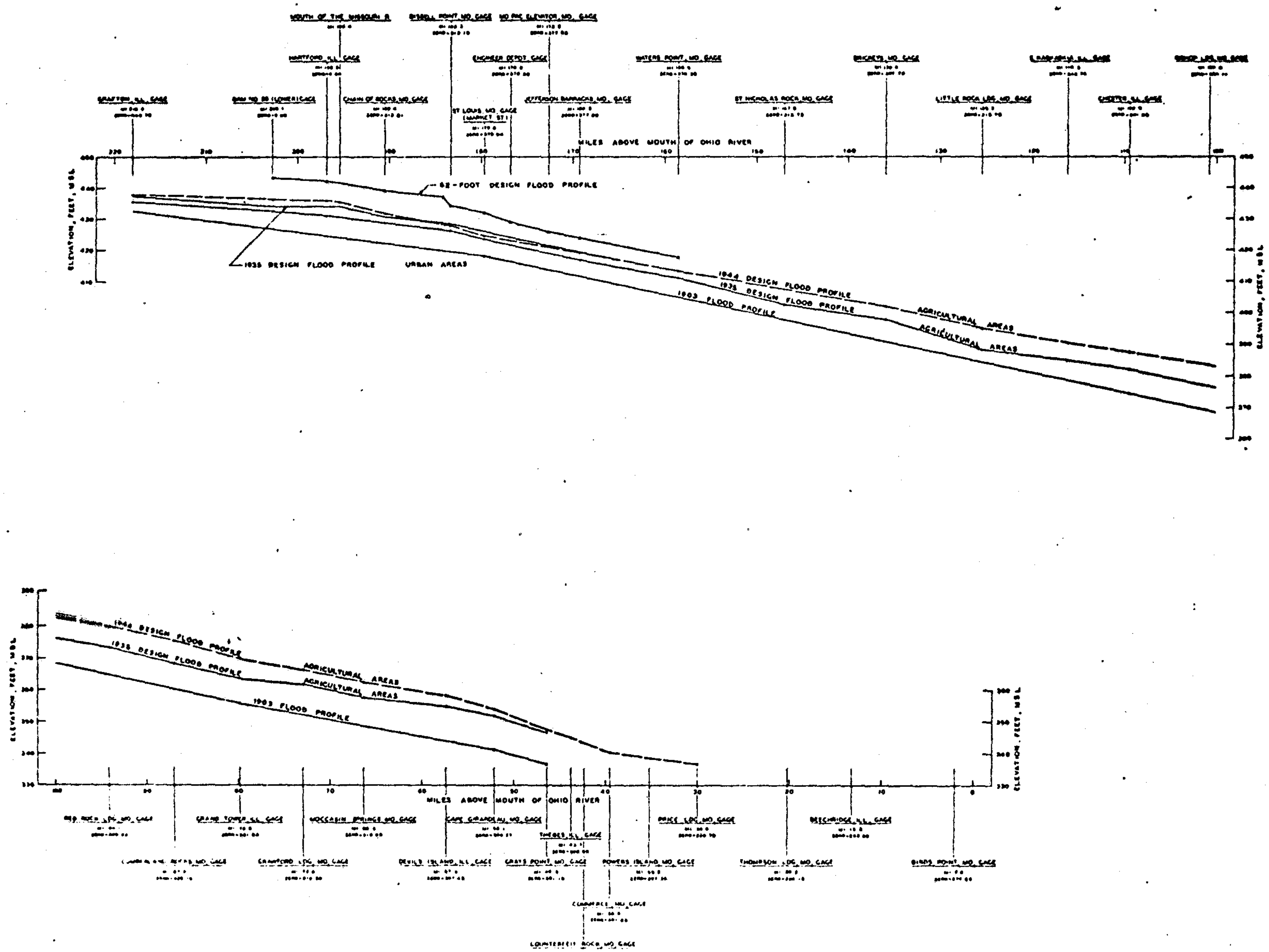

FIG. 2.- DESIGN FLOOD PROFILES

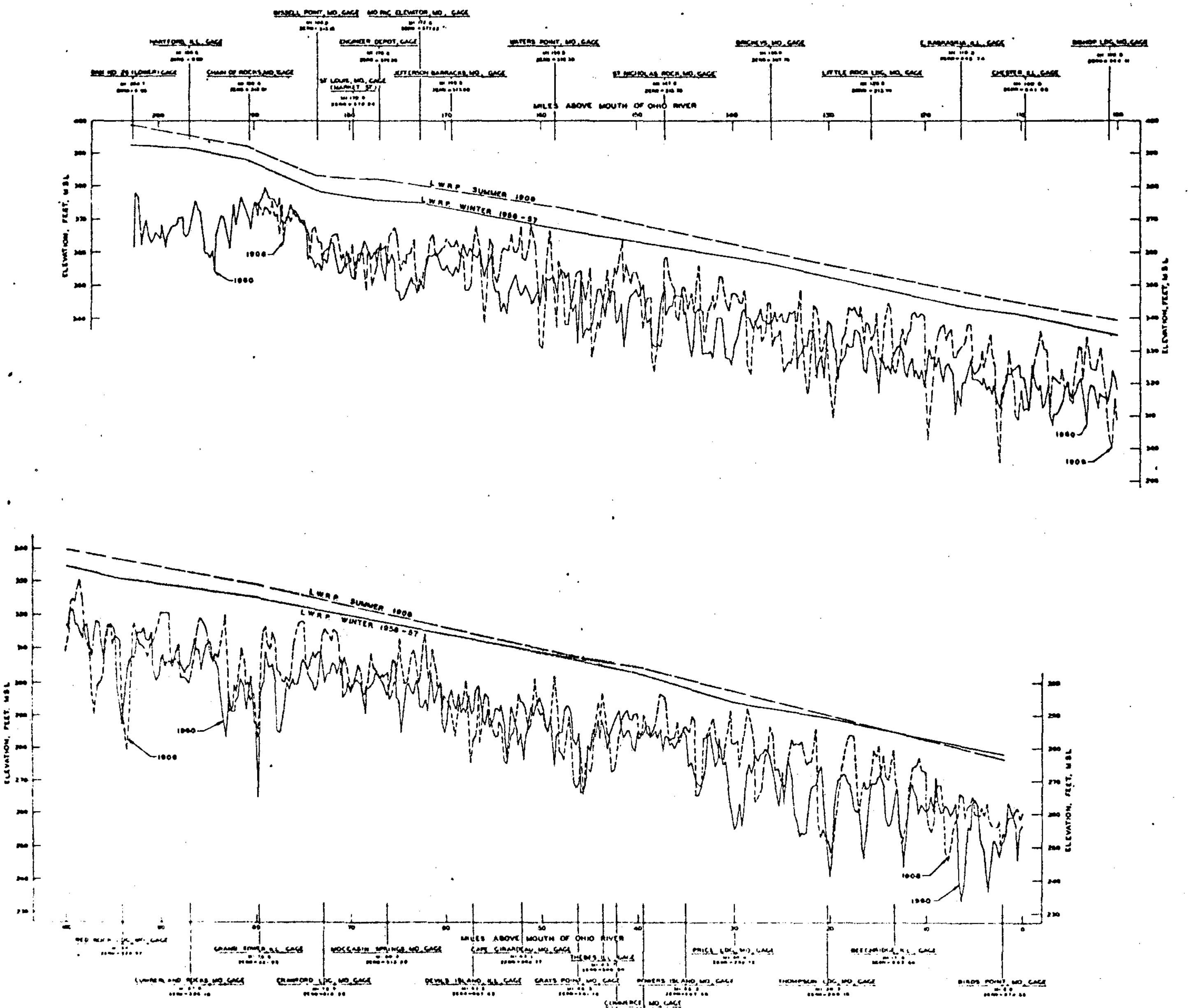

FIG. 3 - THALWEG PROFILES, 1908 AND 1960

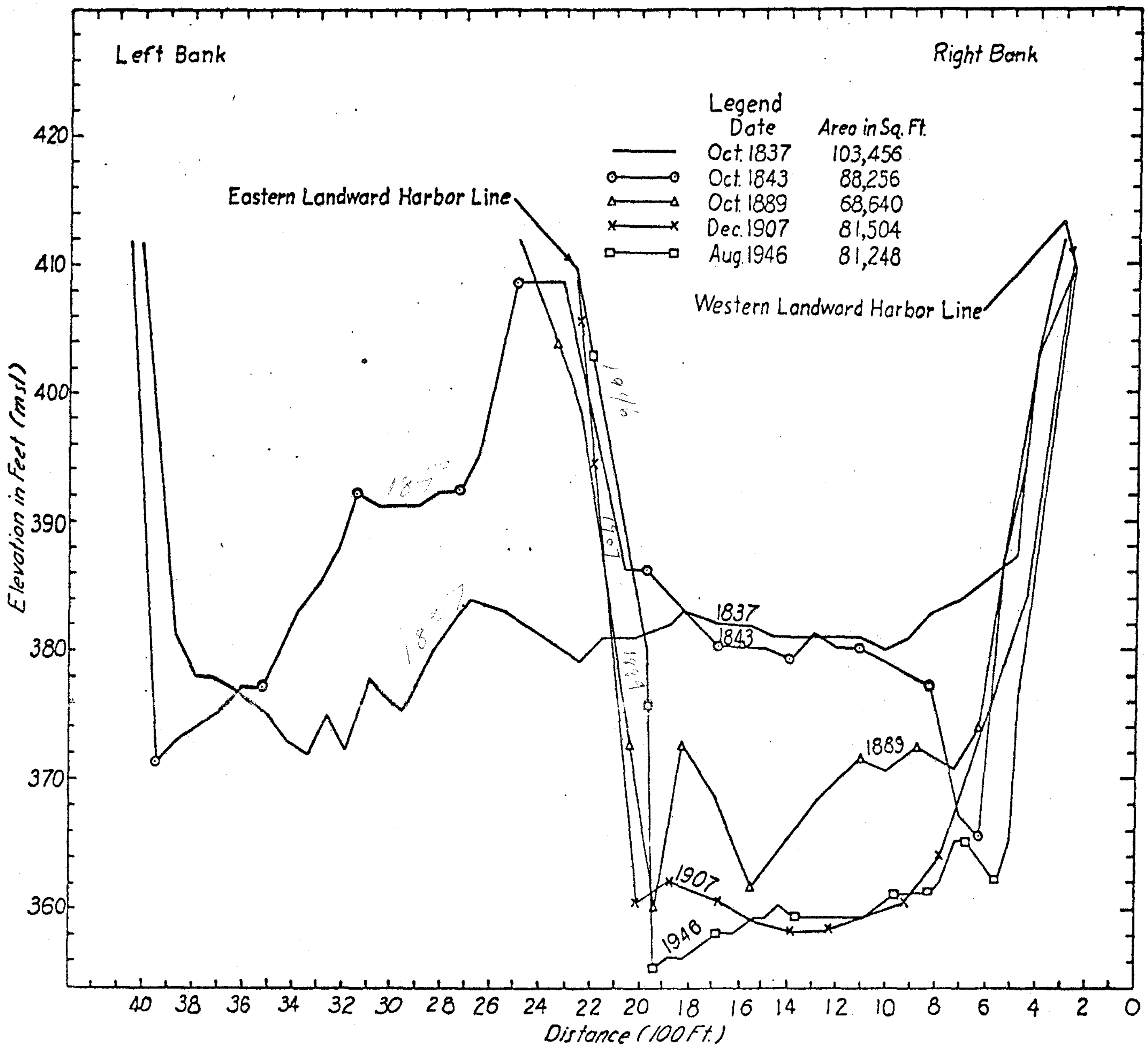

FIG. 4 - COMPARATIVE CROSS SECTIONS, ST. LOUIS, MO.

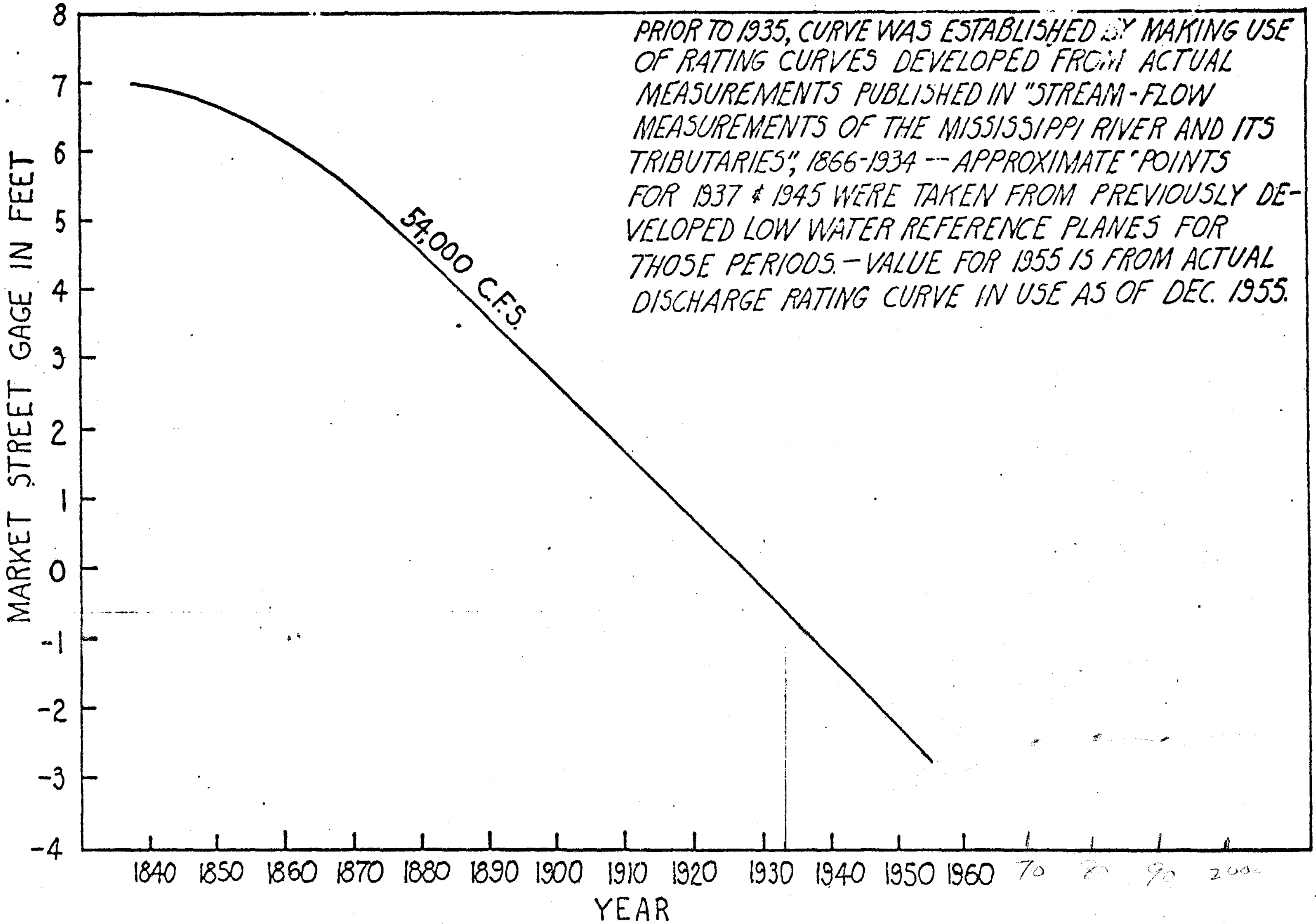

FIG. 5 - ELEVATION CHANGES LOW WATER PLANE, ST. LOUIS, MO.

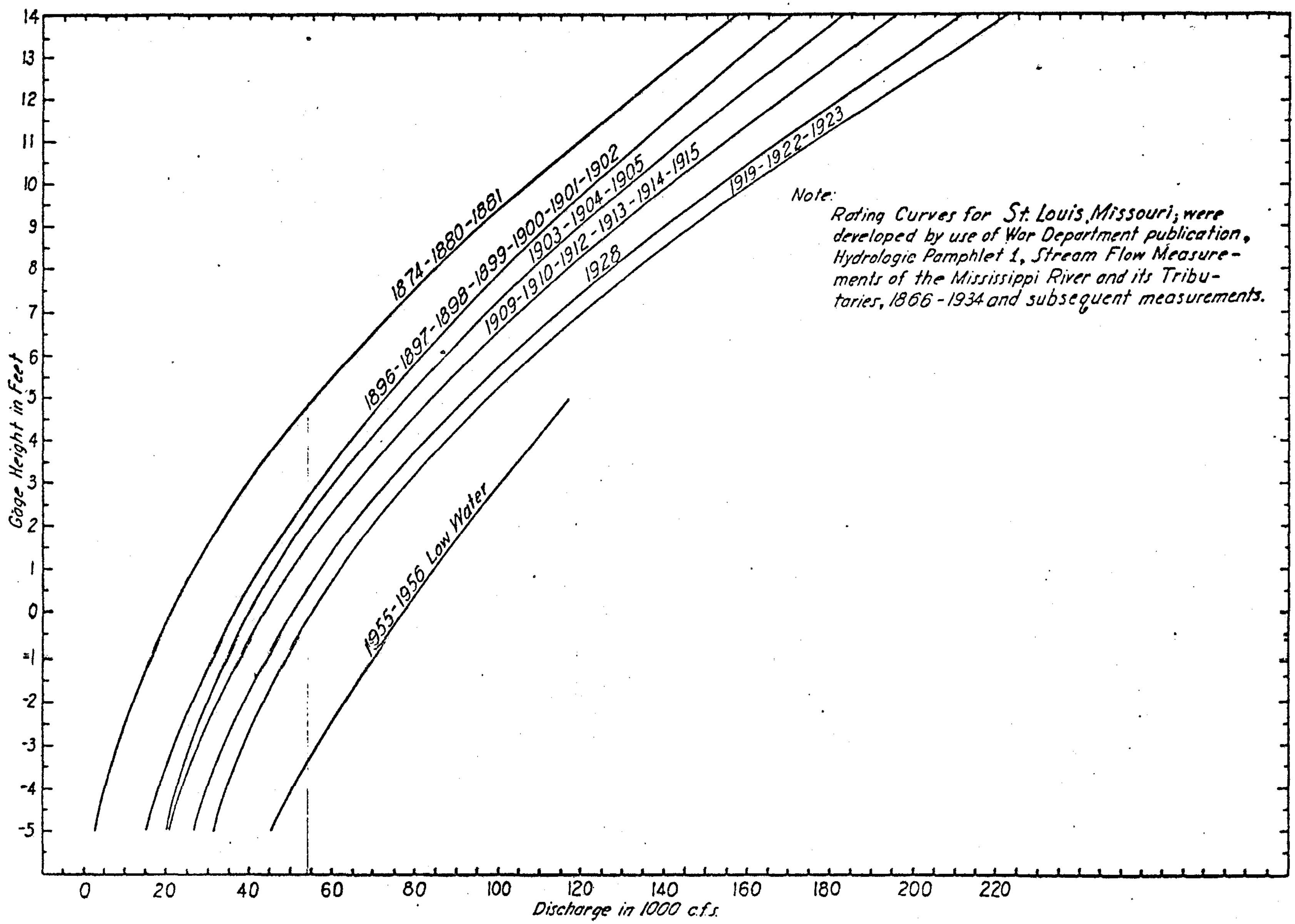

FIG. 6.-LOW WATER RATING CURVES, ST. LOUIS, MO.

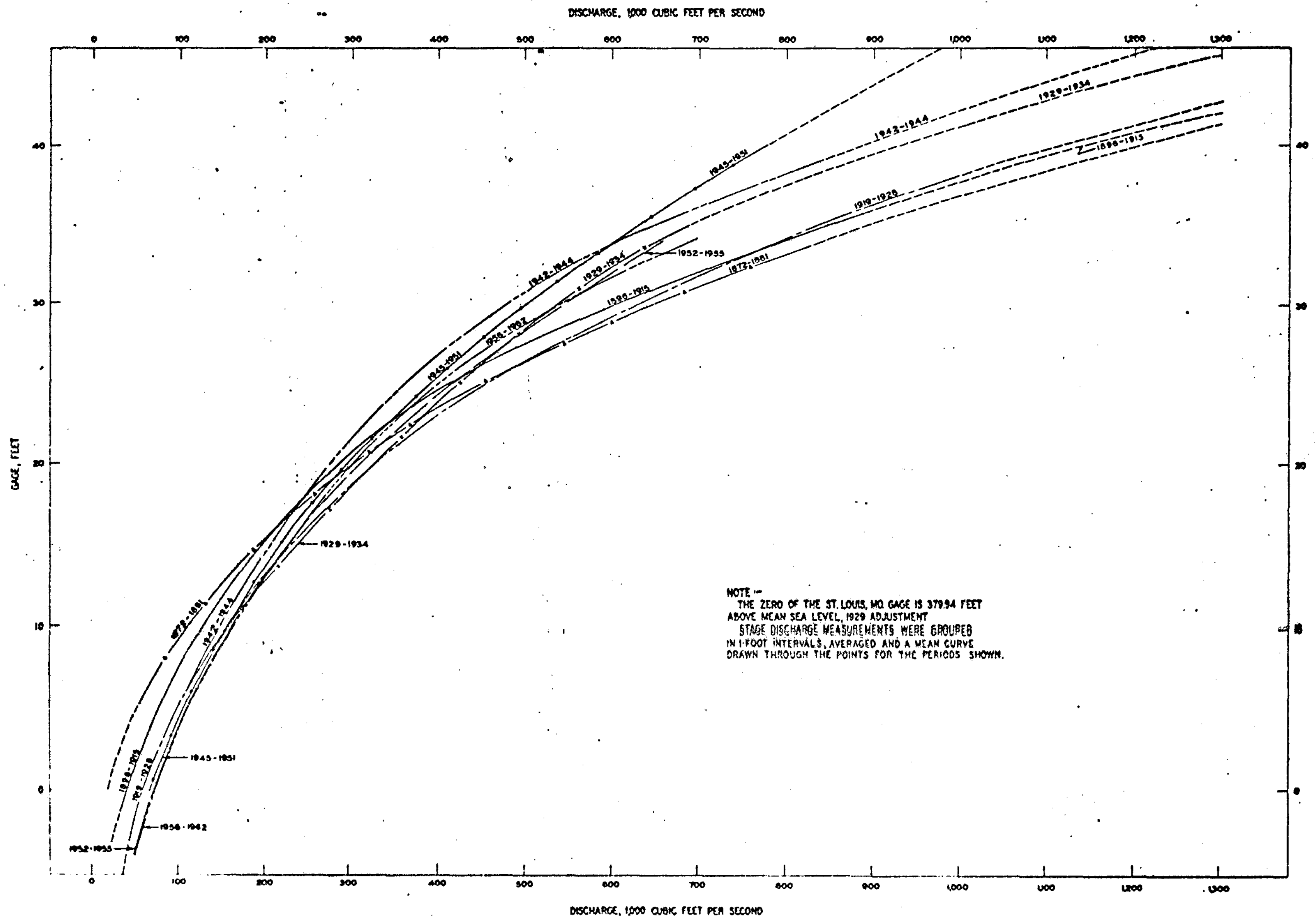

FIG. 7. - STAGE DISCHARGE RATING CURVES. ST. LOUIS, MO.

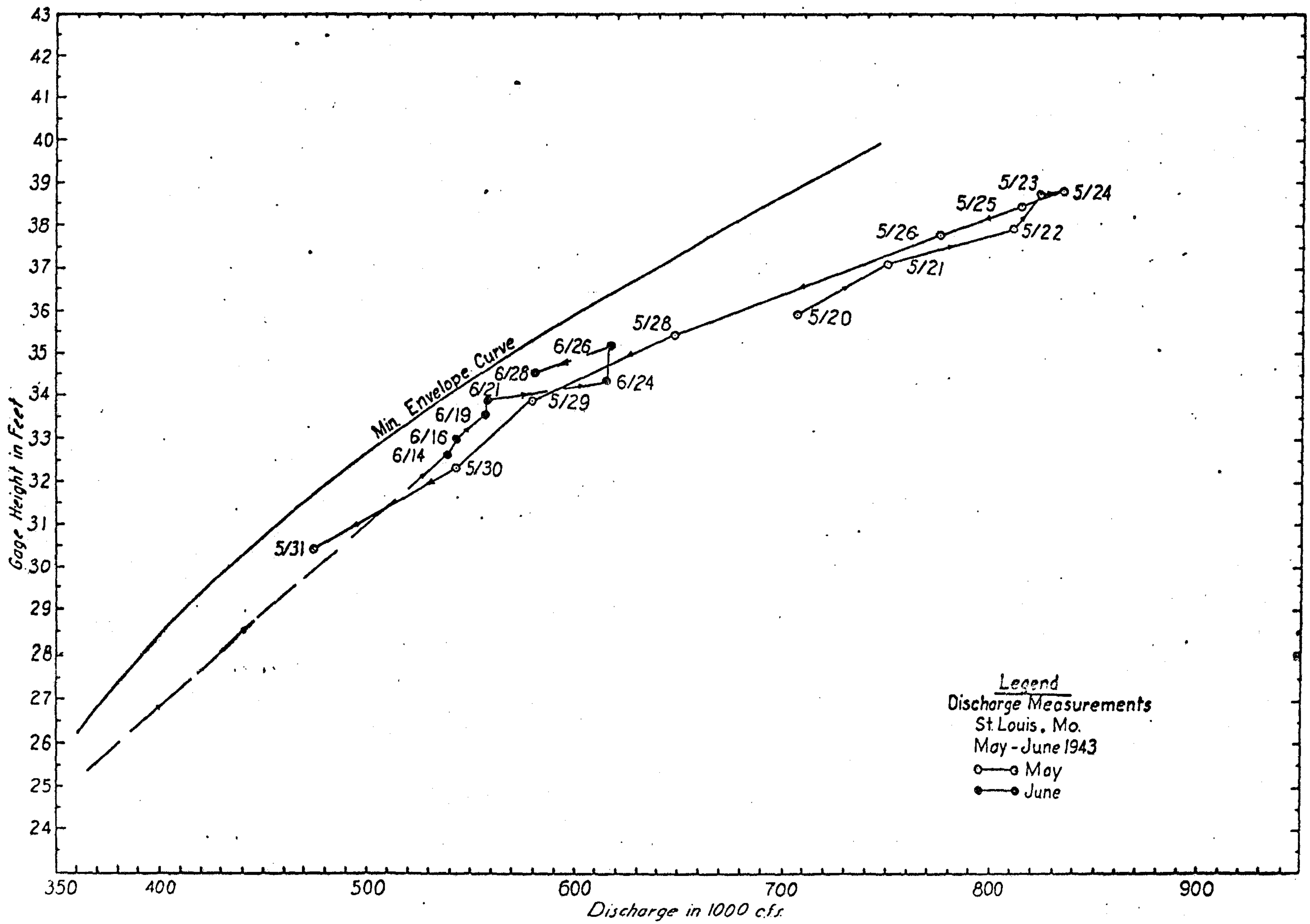

FIG. 8.- STAGE DISCHARGE MEASUREMENTS 1943, ST. LOUIS, MO.

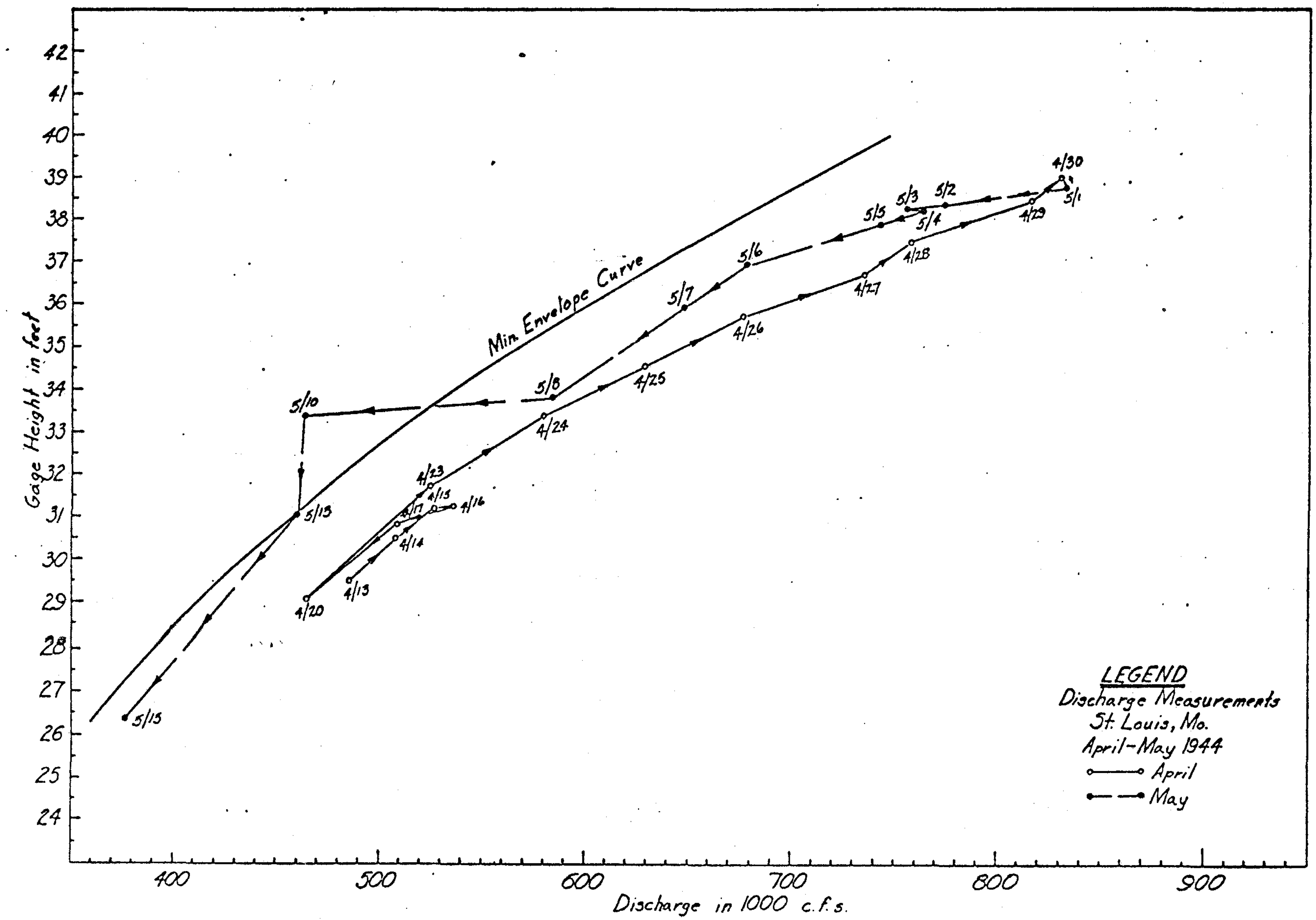

FIG. 9. - STAGE DISCHARGE MEASUREMENTS 1944, ST. LOUIS, MO.

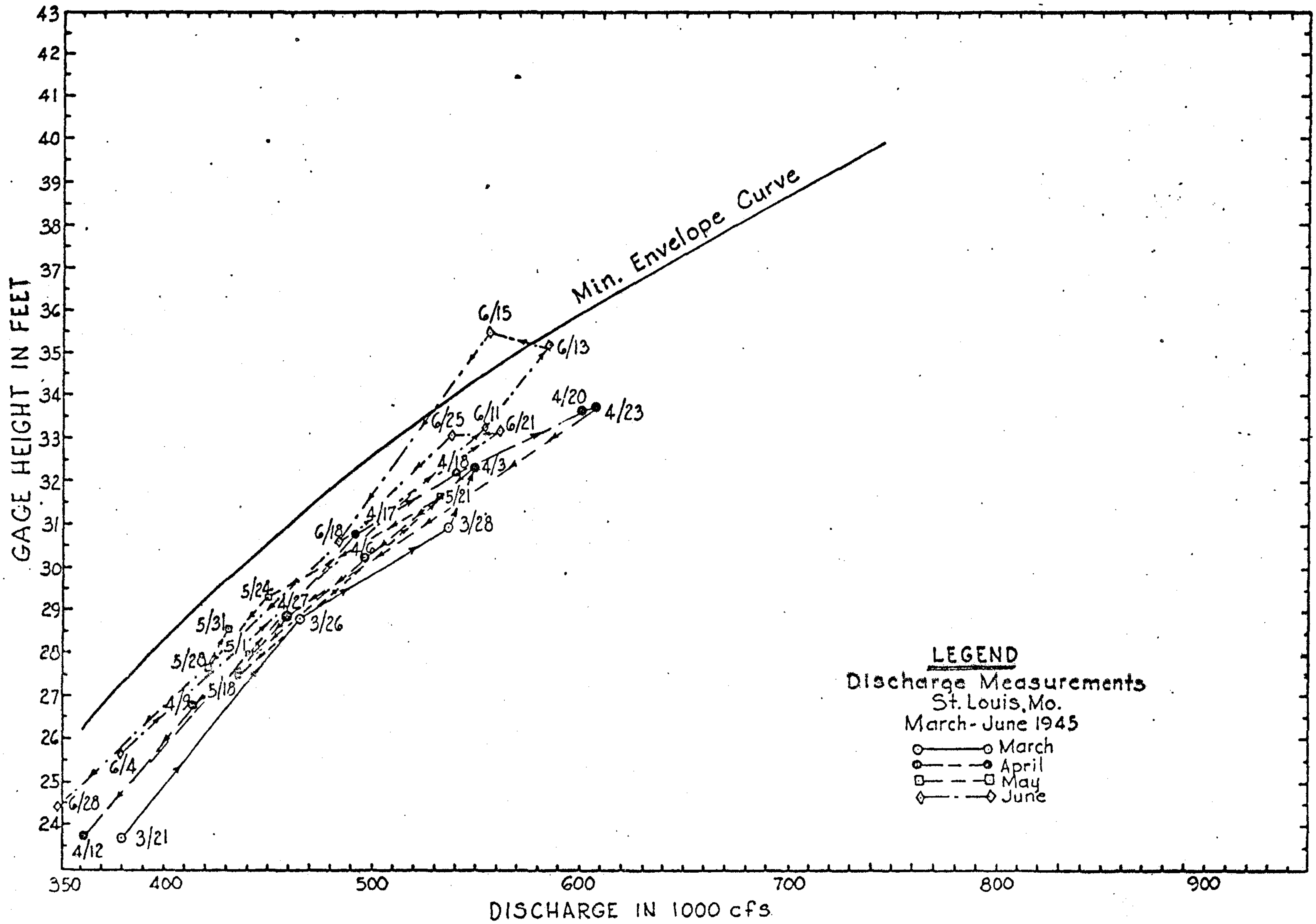

FIG. 10.- STAGE DISCHARGE MEASUREMENTS 1945, ST. LOUIS, MO.

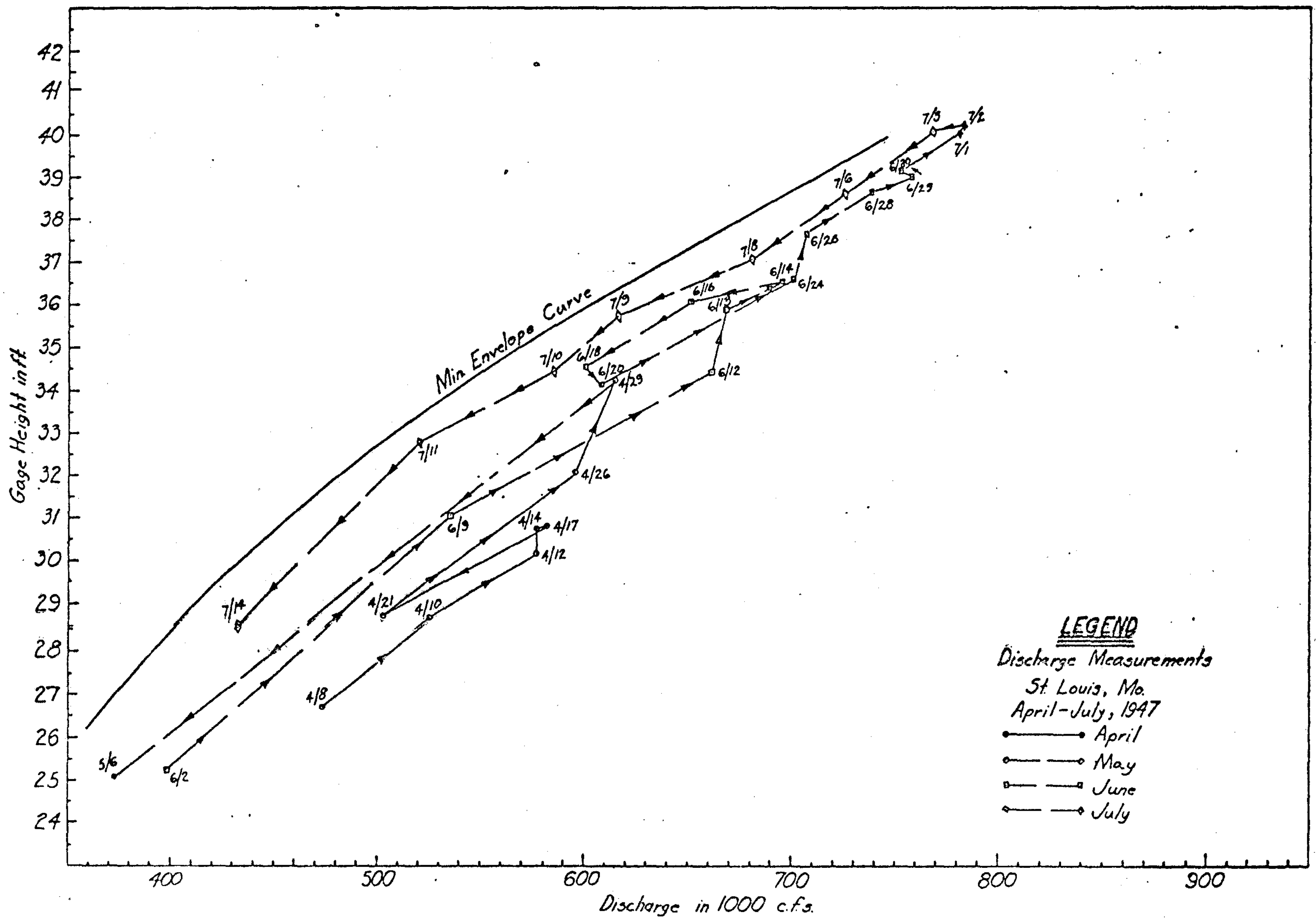

FIG. 11.-STAGE DISCHARGE MEASUREMENTS 1947, ST. LOUIS, MO.

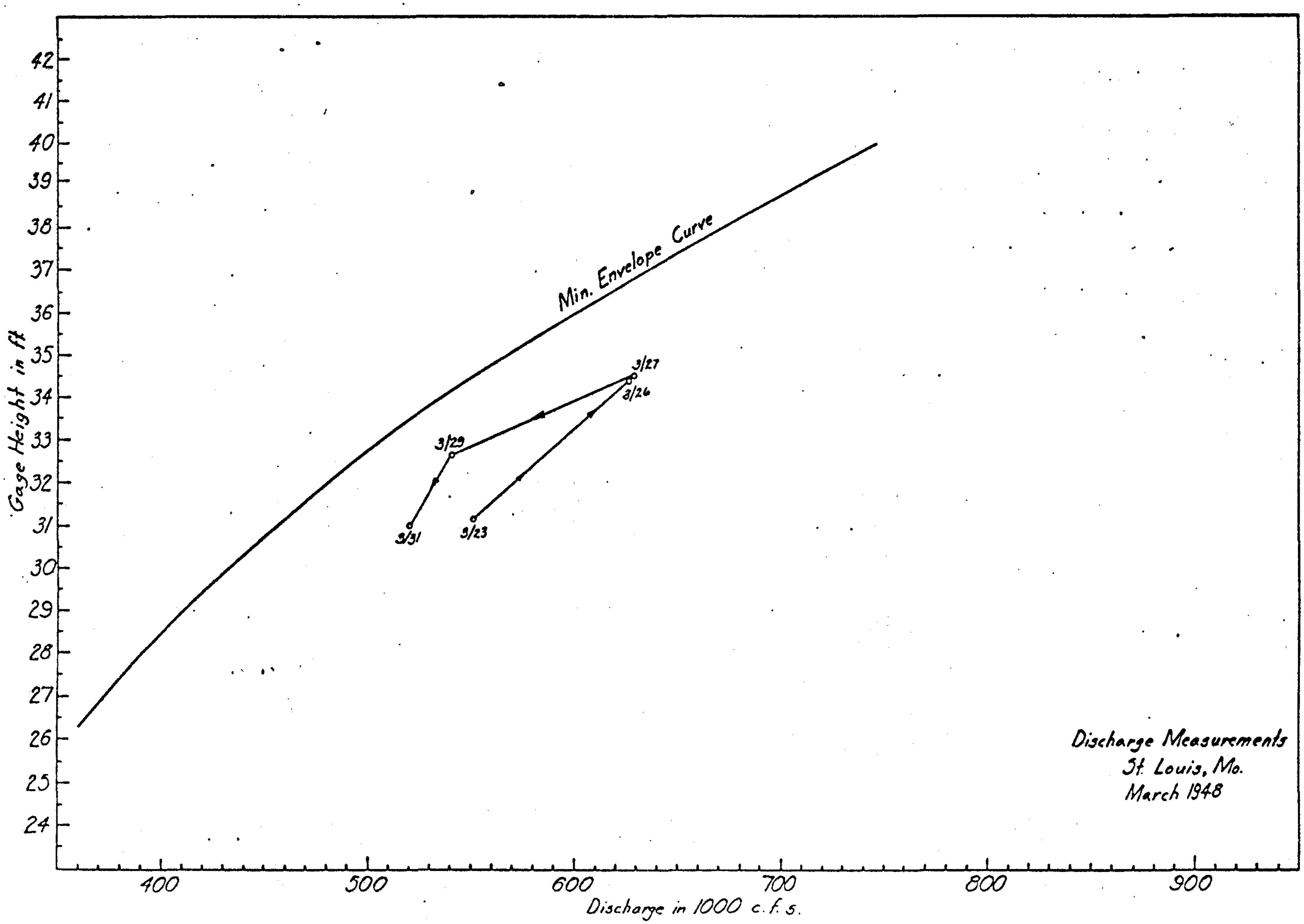

FIG. 12.- STAGE DISCHARGE MEASUREMENTS 1948, ST. LOUIS, MO.

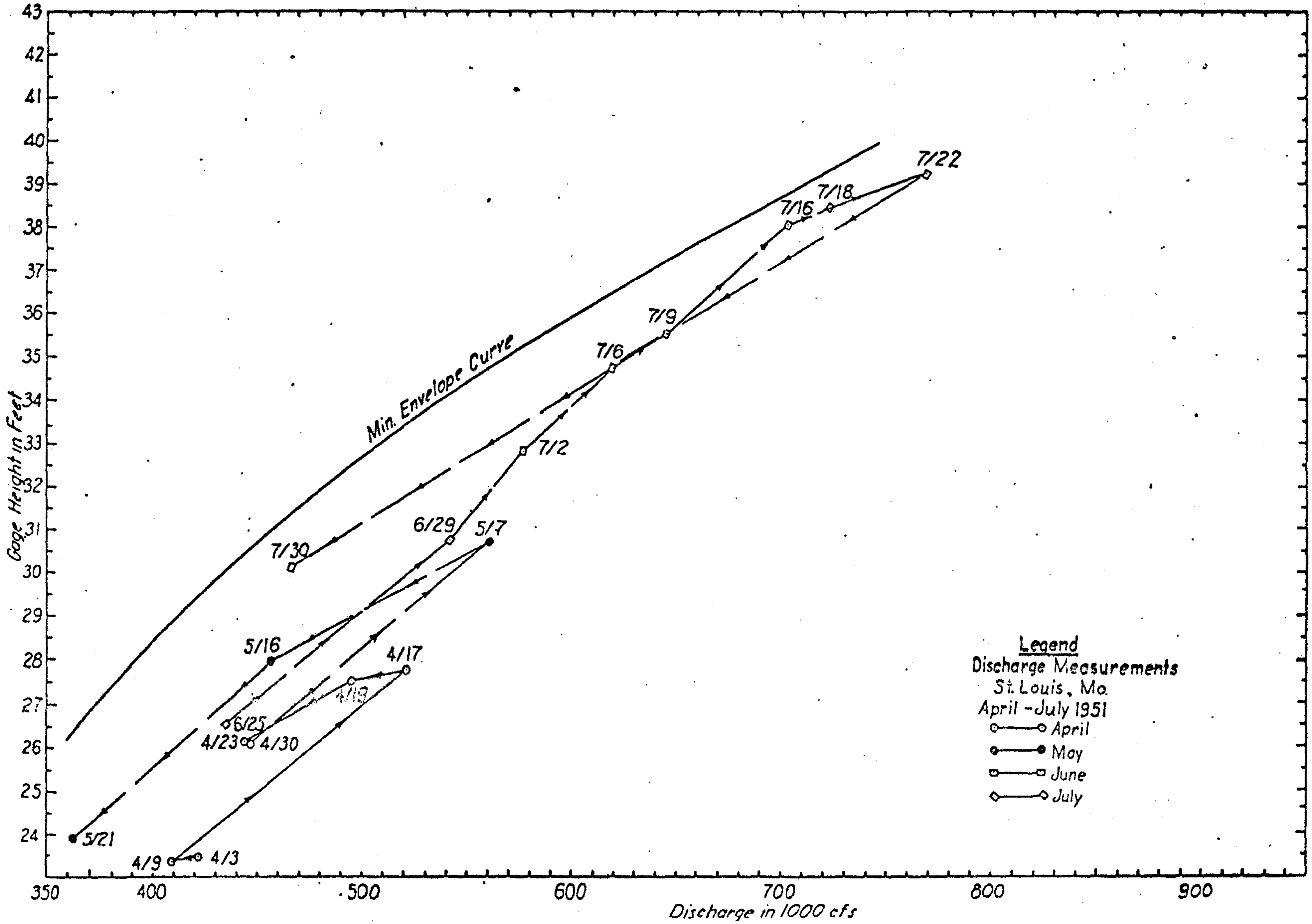

FIG. 13.- STAGE DISCHARGE MEASUREMENTS 1951, ST. LOUIS, MO.