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FLOOD CONTROL WITH RETARDING BASIN TYPE RESERVOIRS IN MERAMEC BASIN, MISSOURI

BY

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THESIS

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Approved by E. W. Carlton

Professor of Civil Engineering

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

When rainfall occurs that provides more runoff than can be carried within the normal channels of existing streams a flood results. The excess water overflows the valley lands, invades developed areas, and causes destruction of property or, in extreme cases, loss of human life. There is no known method of regulating the rainfall itself. Nature alone controls the cycle from sea to sky to earth. Man's efforts are confined to attempts at guiding the water on that part of its course from earth back to the sea. The regulation of the waters that would cause floods presents the flood-control problem.

Many structures are built to control water: Waterways of proper depth and width provide arteries of transportation; water controlled and discharged through water-wheels provides power; water may be caught in storage basins and distributed for irrigation or water supply; and water that is an actual or potential source of damage or danger to property or to human life may be controlled to prevent floods. When this control of water involves only the prevention of flood damage it is termed "flood control".

The Meramec River is the first major tributary entering the Mississippi River on the right bank below the mouth of the Missouri River. The watershed area, comprising about 3,955 square miles, lies in the eastern central part of the State of Missouri. The water-shed converges toward the city of St. Louis, covering all or portions of 15 counties. The water-shed area, being quite rugged in character, furnishes most of the scenic and recreational advantages enjoyed by the population of St. Louis, the eighth largest city in the United States. The Meramec drainage system consists of the Meramec River and the two principal tributaries, the

Big and the Bourbeuse Rivers.

About 135,700 people living in the Meramec Basin have suffered by the largest floods of record, which occurred in August 1915, April 1927 and June 1945 covering property damage and loss of human life. Industries providing employment in the basin (include mining, sand and gravel production, manufacture of shoes, dairy products, etc.) were mostly destroyed by these severe floods. The Meramec watershed is traversed by an adequate system of primary highways and railroads radiating from St. Louis and connecting all the larger cities and towns. Several railroad bridges were washed out and considerable parts of highways were closed to traffic by the waters of the 1945 flood.

The object of this study is to recommend ways and means of regulating the streams of the Meramec Basin and is not concerned with the effects of the regulated waters on the Mississippi River. A comparison is made on the valuable farm and industrial downstream lands saved from inundation against the upstream areas flooded by the backwaters of reservoirs.

REVIEW OF LITERATURE

The common law holds that flood water is a common enemy and that any individual may protect himself against it. From the beginning of recorded history this principal has been followed and a wide range of structures and methods has been developed for combating the "common enemy". Every country in the world has some flood problems. The Po River of Italy, the Seine of France, the Rhine of Germany, the Thames of England, the Yellow of China, and many others have absorbed the efforts of countless engineers in the struggle for their control. In the United States the most notable struggle has been that with the Mississippi River. As early as 1717 the settlers at New Orleans, La., began to protect themselves against overflow. The work has grown in magnitude until at the end of 1933 the Federal Government had spent $351,372,000 in an effort to control this great river. Many smaller but still important projects in this country have included the Sacramento River of California, the Arkansas River of Colorado, The Colorado River of Arizona and Nevada, and the Miami River of Ohio. (1)

A small ditch may be cut to divert the flood water of a small creek from a field, or a small levee can be built to prevent this flood water from invading the fields or buildings in the flats. However, when the area to be protected becomes of considerable size it has been the usual experience that the works of protection are of such magnitude as to be entirely beyond the means of the individual to finance or to construct. Thus, the individuals have grouped themselves together in districts. The rights of the individual have become merged with those of the group, and works have been developed which provide the greatest benefit to the

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(1) American Society of Civil Engineers, Transactions, Vol. 100 1935, p. 880

majority of the group. This grouping has grown to state-wide control in some cases and, in the case of the Mississippi River, to control by the Federal Government.

The most comprehensive flood control investigations in recent years have been those conducted by the United States War Department under the Corps of Engineers, United States Army.

DESCRIPTION OF WATERSHED

1. General. - The watershed area, comprising about 3,955 square miles, lies in the eastern central part of the state of Missouri. The basin, as viewed on a map, resembles a somewhat irregular rectangle with a median length of about 65 miles and width of about 55 miles. The watershed converges toward the city of St. Louis, comprising all or portions of 15 counties. Along the northern border of the basin, approximately 23 miles west of St. Louis, the watershed comes within about two miles of the Missouri River. The watershed area, being quite rugged in character, furnishes most of the scenic and recreational advantages enjoyed by the population of St. Louis, the eighth largest city in the United States. A general map of the basin is presented as plate 1.

2. The Meramec River is the first major tributary entering the Mississippi River on the right bank below the mouth of the Missouri River. The confluence with the Mississippi River is 34.4 river miles below the mouth of the Missouri River and 160.6 river miles above the mouth of the Ohio River. Although the side slopes of the valleys in the basin are, in general, covered with cut-over timber, they are steep and conducive to rapid runoff.

3. Streams. - The Meramec drainage system consists of the Meramec River and two principal tributaries, the Big and the Bourbeuse Rivers. The Meramec River rises in Dent County, flows northerly to a point near Meramec Spring (mile 168.8), then follows a general northeasterly course to the vicinity of Kirkwood (near mile 19.0), where it turns toward the southeast to join the Mississippi River about 20 miles south of St. Louis. The Bourbeuse River has its source in Phelps County and follows a course generally parallel to the northern boundary of the basin, entering the Meramec River at mile 64.8. The Big River follows the general direction

of the eastern boundary of the watershed, rising in the northern part of Iron County and joining the Meramec River at mile 37.5, about three miles south of Eureka (mile 34.6). The drainage areas of the Bourbeuse and Big Rivers are about 848 and 968 square miles, respectively. (2)

4. The Meramec River is approximately 220 miles in length and has a total fall of about 990 feet. The Bourbeuse River has a length of about 145 miles and a total fall of about 726 feet. The Big River is about 137 miles long with a total fall of about 975 feet. (3)

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(2) Appendix I, Meramec River Basin, Report to Meramec Cooperative Field Committee, St. Louis District, Corps of Engineers, War Department, March 1947, p. 3

(3) Ibid, p. 3

LAND USE AND ECONOMIC DEVELOPMENT

5. General. - Although approximately 65 percent of the watershed area is in private farm ownership, it is estimated that less than 20 percent is in cultivation. Private non-farm lands, chiefly in small non-resident holdings of second-growth forests, comprise 27 percent of the land area and 8 percent is in public ownership, 7 percent being in National forests and 1 percent in state forests and parks. Corn, small grain, hay and legumes are the principal crops. Truck farming is of importance in the lower part of the basin, near the city of St. Louis. However, relatively small areas of land are involved. The sale of livestock and poultry is one of the chief source of farm income. The farm economy, generally, is such as to require some off-the-farm or part-time employment. Most of such off-the-farm employment consists of timber-cutting, mill-work, mining and recreational services. Commercial activities other than farming include mining, sand and gravel production, manufacturing, recreational enterprises and timber-cutting. There are no major water power developments in the basin. Several low-head dams were constructed during the past to operate lumber, feed and grist mills and to produce electric power. However, only three of these plants have been continued in use and are now operating on a part-time basis. (4)

6. Population. - The total population of the Meramec Basin was estimated from the 1940 census to be 135,700, of which 55,600 were listed as living in incorporated cities, towns and villages and 80,100 as rural. Population trends were upward in both rural and urban areas, the only decline being in the mining districts around Bonne Terre in

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(4) Appendix I, op. cit., p. 5

the Big River. (5)

7. Land classification and use. - It is estimated that about 60 percent of the watershed is either in, or reverting to, forest. Open areas are about evenly divided between cultivated and pasture. Farm woodlands occupy nearly one-half of the farm area. It is estimated that there are about 12,000 farms, averaging 136 acres each, in the watershed. The proportion of land in various agricultural uses in 1935 was given as follows: harvested crops, 23 percent; idle or fallow, 6 percent; open pasture, 21 percent; woodland, 46 percent; and other land, 4 percent. Of the 65 percent of the basin in private farm ownership, about two-thirds is owner-operated, 27 percent is classified as land not in farms, and 8 percent is in National and State forests and parks. This latter area includes some relatively large tracts of forest land in the Ozark uplands originally owned by lumber and tie companies. (6)

8. Industrial employment. - Industries providing employment in the basin include mining, sand and gravel production, and the manufacture of shoes, dairy products, flour, timber products, brooms, brick, and concrete pipe. Lead mining is an industry of importance in the southeast portion of the basin around Bonne Terre and extensive strip mining of barium sulphate is carried on in the vicinity of Potosi. Iron ore, deposits of which are present in various parts of the basin, has been mined from time to time though not extensively. The removal and sale of sand and gravel from the lower reaches of the

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(5) Appendix I, op. cit., p. 5

(6) "Meramec River Preliminary Examination Report", by Bureau of Agricultural Economics, U. S. D. A., p. 27

Meramec River is also an important industry although operations are frequently interrupted and machinery and stock piles of material damaged by floods. A silica sand plant is located at Pacific (Meramec River mile 49.0) and a cotton mill and paint plant at Valley Park (Meramec River mile 22.0).

9. Transportation. - The Meramec watershed is traversed by an adequate system of primary highways radiating from St. Louis and connecting all the larger cities and towns. Secondary roads provide ready access to all areas of present importance in the basin. Good railroads are also available to the greater portion of the watershed. It is served by the Missouri Pacific, the Chicago, Rock Island and Pacific, the St. Louis-San Francisco, and the Missouri-Illinois railroads.

10. Recreation. - The Meramec Basin is of great importance as a recreational region and has been referred to as the playground of St. Louis. The rugged, wooded area contains a variety of natural scenic features including rivers, large springs, caves and mountain views, and affords opportunities for riding, bathing, picnicking, boating, hunting, and fishing. Concentrations of club houses, summer cottages and recreational facilities are found in the lower reaches of the Meramec and Big Rivers. It was estimated that a total of about 1,236,000 persons visited the basin during the year 1940 for recreational purposes and that the total annual cost of such recreation amounted to about $3,086,000. (7) The majority of the visitors were residents of metropolitan St. Louis and vicinity. Estimates by county officials and from other sources indicate that there are about 8,000 summer cottages in the Meramec Basin.

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(7) "Evaluation of Recreation in the Meramec Basin" by Mr. Hymen Shifrin, 1922, p. 32.

GENERAL HYDROLOGY

<u>11. Climate.</u> - The climate of the Meramec Basin is moderate, having an average temperature of about 56° Fahrenheit. January is the coldest month while July is the warmest. The extreme temperatures range from -33° to 115° Fahrenheit. Weather changes are frequent throughout the year causing large temperature changes. Quite frequently, short periods of extreme cold are experienced during the winter months. The growing season usually extends from the middle of April to the middle of October. Periods of severe heat, during the summer months, are usually short unless accompanied by a deficiency in rainfall. (8)

<u>12. Precipitation.</u> - Precipitation studies of the Meramec Basin were based on records from 33 gaging stations, the average of which has been in operation for the 34 years preceding 1948. The gage records, including years 1921 to 1948, give a continuous data. (9)

13. Precipitation is fairly well distributed throughout the year, the highest average occurring during the months of April, May and June, and the lowest occurring during December, January and February, as shown in table 1. The average annual rainfall for the entire basin is about 41 inches. Annual precipitation for the growing season amounts to about 58 percent of the total for the entire year. The region is subject to local storms as well as general storms of heavy rainfall extending over periods of several days. The more notable storms were of the latter type and have been responsible for the major floods

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(8) Appendix I, op. cit. p. 7

(9) Information obtained from "Water Resources Division, U.S.G.S. Rolla, Mo.

within the basin. The three largest floods of record occurred in 1915, 1927 and 1945 and were caused by runoff from rainfall over the watershed that averaged 8.22, 3.17 and 5.42 inches, respectively. Storms of heavy rainfall may occur at any time during the year but are more frequent during the spring and early summer. Snowfall is usually limited to the period from October through April and seldom covers the ground for more than a few days at a time. The average annual snowfall is light, amounting to about 15.7 inches.

Table 1

Average Monthly and Annual Rainfall
Meramec Basin & Surrounding Area (10)

Month	Average Precipitation in Inches	Percent of Average Annual Precipitation
January	2.35	5.7
February	2.32	5.7
March	3.44	8.4
April	4.19	10.3
May	4.80	11.8
June	4.40	10.8
July	3.25	8.0
August	3.76	9.2
September	3.82	9.4
October	3.10	7.6
November	2.97	7.3
December	2.38	5.8
Annual	40.78	100.0

14. Runoff. - The Meramec Basin above Eureka lies entirely within the Ozark Hills, which are for the most part, rugged and covered with timber. The Meramec River stream bed, in general, is composed chiefly of rock, gravel and sand. There are numerous tributary streams both large and small with steep slopes, that allow the runoff to reach the main stream bed quickly. The ratio of the runoff to precipitation is

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(10) Appendix I, op. cit. p.7

high throughout the basin. Inflitration is slow in these soils resulting in rapid runoff from short periods of intense rainfall; whereas, extended periods of rainfall saturate the shallow soil cover permitting nearly 100 percent runoff to follow.

15. Stream flow. - The stream flow data used in this study was obtained from records of the U. S. Geological Survey gaging stations on the Meramec River at Eureka (mile 34.6), Robertsville (mile 60.0), Meramec Park (mile 108.1), Sullivan (mile 113.2) and Steelville (mile 146.4); on the Bourbeuse River at Union (mile 13.4); and on Big River at Byrnesville (mile 14.1). The first gaging station in the basin was established at Eureka in 1903, but it was discontinued in 1906. Records have been maintained at the Union station from October 19, 1916 to date; at Eureka from October 6, 1921 to date; and at the other stations for shorter periods of time. All of the above-mentioned gaging stations are being operated at the present time, and the more important stations are equipped with automatic stage recorders. Maximum and minimum discharges at the above-mentioned gaging stations are shown in table 2.

Table 2

Maximum and Minimum Discharges
Meramec, Bourbeuse and Big Rivers

Gaging Station	River	Discharge (c.f.s.)	
		Maximum (11)	Minimum
Eureka	Meramec	175,000	196
Robertsville	Meramec	125,000	162
Meramec State Park	Meramec	100,750	143
Sullivan	Meramec	90,000	140
Steelville	Meramec	60,000	74
Union	Bourbeuse	50,000	14
Byrnesville	Big	80,000	25

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(11) Maximum discharges are estimated values for the August 1915 flood by the "U.S.G.S. Water Resources Division" Rolla, Mo.

<u>16. Storms.</u> - Severe local, as well as general heavy rain storms of several days duration are not uncommon in the region. The notable storms of record, which also have been responsible for the major floods in the Meramec Basin, have been of a general type. Protracted wet periods, lasting several months, have been experienced, resulting in a series of small floods with large combined volumes of runoff.

<u>17. Floods.</u> - The streams in the Meramec Basin frequently overflow their banks. The major floods have been caused by excessive rains, which were general over the entire watershed, rather than intense local storms, with the exception of the 1945 flood. During the 1945 flood the runoff resulted from intense local rains in the headwater reaches of the basin. The three largest floods of record occurred in August 1915, April 1927, and June 1945, and are described in the following paragraphs.

<u>18. August 1915 flood.</u> - This flood was produced by an average rainfall of 8.22 inches over the entire Meramec Basin on 18-20 August. The four months, May to August, inclusive, gave a total of 28.28 inches of rainfall which was not only 10.65 above the seasonal normal for the State but 57 percent of the yearly total. The period of excessive rains came to an end with the passage of the West Indian storm on August 20 which caused heavy damage in the eastern half of Missouri from the southern border to the north of St. Louis. In the twenty-four hours, preceding the 20th, 4.35 inches of rain fell at Rolla and 5.17 inches at Gano in the upper reaches of the watershed. This flood was the greatest known in the Meramec Basin. It reached a crest on August 22 equivalent to a stage of 40.2 feet on the present Eureka gage as determined from high water marks. By the slope-area method the U.S.G.S. estimated the peak discharge at Eureka to be 175,000 c.f.s., the average runoff from the watershed above Eureka being 5.32 inches. The valley

of Meramec was completely inundated resulting in a loss of crops and severe damage at Valley Park, the place of greatest inundation; no lives were lost but property damage was extensive.

19. April 1927 flood. - This flood was produced by excessive rainfall over the entire watershed during a storm which occurred in the 48 hours preceding April 1, with an average of 3.17 inches of rainfall above Eureka. The monthly precipitation in the State was 2.87 inches more for March and 4.73 inches more for April than the 56-year average, April being the wettest since the beginning of rainfall records. The peak discharge at Eureka was 64,000 c.f.s. and the maximum stage was 29.47 feet at Eureka on April 3, total runoff averaging 2.5 inches. Bottom lands were inundated causing much damage at a time when the Mississippi River was at bankfull stage.

20. June 1945 flood. - The storm producing this flood, the largest since 1915, occurred, generally, during the four days preceding June 10, 1945 and was most intense in the upper reaches of the basin centering around Belleview where 10.3 inches of rain fell and tapered off with about 8.0 inches at Steelville and Cuba in the center of the basin above Eureka. About 30 miles southwest of Rolla, a very heavy and excessive rain, of cloudburst proportions, fell locally at Newburg, Phelps County, on the afternoon of the 8th, resulting in a flash flood which drowned five persons and caused property damage estimated at $277,000. The average rainfall over the watershed above Eureka for the four days preceding the 10th was 5.42 inches. The crest occurred at Eureka on June 11 with a maximum stage of 36.94 feet and a peak discharge of 120,000 c.f.s. The lowlands of the Meramec River were inundated resulting in the loss of crops, and the property damage was extremely heavy.

EXTENT AND CHARACTER OF FLOODED AREAS

21. Flooded areas. - The principal flood damage in the Meramec, Bourbeuse and Big River Valleys occurs below miles 107.5, 31.6 and 22.6, respectively, which are the locations of the proposed dams. The 1915 flood inundated a total of approximately 50,500 acres of land located in that part of the Meramec Basin, of which about 8,000 acres consisted of waste land and the area within river banks. Of the total area subject to flooding as defined by the 1915 flood, field investigations reveal that approximately 24,300 acres were in cultivation in 1945. (12)

22. The greater portions of the existing improvements subject to flood damage in the basin are located in the lower and intermediate reaches of the main stem and the lower reach of Big River. These improvements include railroads, highways, power and telephone lines, sand and gravel plants, recreational facilities and summer cottages, together with appurtenant facilities such as household furnishings, water systems, machinery and equipment.

23. (13) Valley Park with a population of 2,091 in 1940 and Times Beach and numerous other smaller communities located in the lower part of the watershed suffer severe damage from such floods as those that occurred in 1915 and 1945. Field surveys show that a total of about 1,500 dwellings located below the proposed dams were damaged by the 1945 flood. Traffic over several of the primary highways and numerous secondary roads has been interrupted during major floods due to inundation or to washout of bridges or sections of road. A section of the St. Louis-San Francisco Railroad track near Eureka was washed out during

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(12) Appendix I, op. cit. p. 12

(13) Ibid. p. 12

the 1945 flood resulting in interruption of traffic and estimated direct damage of about $80,000. Major floods have also caused damages to other railroad lines that cross the lower part of the basin.

FLOOD DAMAGES

24. General. - Field reports of U.S.G.S. show that floods along the Meramec, Big and Bourbeuse Rivers cause serious damage to crops, farm property, residential and recreational property, gravel plants, railroads and highways. An analysis of reported damages and stream flow records indicates that flood losses begin when the flow at Eureka reaches about 21,500 c.f.s. Accurate information on damages suffered from all floods is not available. Surveys following the floods of 1944 and 1945 were conducted by the St. Louis District, Corps of Engineers, to determine the damages caused by these floods. For the purpose of this study the only damages considered herein are those caused by the Meramec, Bourbeuse and Big River floods in areas below the locations of the proposed dam sites. The lower reach of the Meramec River, miles 0.6 to 14.0, is affected by backwater from the Mississippi River.

25. Crop damage and analysis (14) - Data collected by the U. S. Department of Agriculture were used in estimating crop damages. Land use, crop distribution, depth of inundation and normal costs of production were considered. With this information, curves were prepared, showing crop and land damage for all flows from bankfull stage to the greatest flood. Damages for all floods during the period of record (1922-1947) were read from these curves and, correcting for sequence effects, average annual crop and land damages were determined and are shown in Table 3.

26. Property damage and analysis. - Immediately following the floods of 1944 and 1945, surveys were made by the St. Louis District to determine the damage to property (other than crop and land damage),

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(14) Appendix I, op. cit. p. 13

highways, railroads and gravel plants. Also at this time all available information regarding damage by the floods of 1942 and 1915 was collected and compiled. Discharge-damage curves for each reach were prepared from these data. Discharge-frequency curves for each control point were then prepared from the available stream-flow records. Data from these curves were used to construct the damage-frequency curves, from which the average annual damage to property, highways and railroads, and gravel plants, shown in Table 3 were obtained. (15)

Table 3

Estimated Average Annual Flood Damage
Meramec Basin Below Proposed Dam Sites

River	Reach in Miles	Damage				
		Crop & Land	Railroad & Highway	Gravel Plant	Property	Total
Meramec	0-14.0	$ 7,050	$ 300	$ 500	$21,800	$29,650
Meramec	14.0-37.8	44,370	4,000	7,000	112,600	167,970
Meramec	37.8-63.4	70,470	3,000	35,800	19,200	128,470
Meramec	63.4-107.5	57,420	1,300	0	12,800	71,520
Bourbeuse	0-31.6	33,920	100	0	2,600	36,620
Big	0-22.6	24,270	3,600	0	41,000	68,870
Total		237,500	12,300	43,300	210,000	503,100

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(15) Appendix I, op. cit. p. 13

FLOOD CONTROL INVESTIGATIONS

1. The most comprehensive flood-control investigations in recent years have been those conducted by the United States War Department, under the Corps of Engineers, United States Army. These were largely an outgrowth of the great Mississippi River flood of 1927. For several years prior to that flood a comprehensive study of water resources was being planned by the Engineer Corps. This study was to cover navigation, flood control, water power and irrigation. The 1927 Mississippi River flood emphasized the importance of these studies as relating to flood control and was largely responsible for the fact that the money for these studies was practically doubled and work undertaken on a much larger and more comprehensive scale than previously anticipated. Many of the studies have been completed and a wealth of information has been collected for practically all the important streams of the United States. General plans have been formulated for most streams and any agency confronted with the development of a flood-control plan should find itself with a large part of ground-work completed and the necessary basic information available to proceed with the detailed development of any specific project, or the coordination of any series of projects.

2. Possible methods of Flood Control. - Floods are rather common, in one form or another and the methods of protection against a flood causing damage are many and varied. The following general classification of methods is offered: (16)

(A) Works to retain or regulate flood waters above the area where damage is caused: (1) Storage reservoirs, with controlled

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(16) "American Society of Civil Engineers Transactions" - Vol. 100, 1935, p. 881.

outlets operated in accordance with a predetermined plan; and (2) retarding reservoirs, with uncontrolled operation of outlets designed so that their maximum flow will not exceed the channel capacity.

(B) Works to provide secondary channels through affected areas: (1) Improvement of secondary existing channels; (2) constructing side channels; (3) overbank diversions; and (4) outlets combining overbank and channel diversions.

(C) Works to increase the capacity of existing channels through affected areas: (1) Levee system; (2) cut-offs; and (3) channel deepening and improvement.

This study will be confined to an analysis of flood control in Meramec Basin with Group A-2.

3. The retarding basin method of operation has gained considerable prominence in recent years largely due to its use on the Miami River, in Ohio. The reservoir outlet conduits are designed so that the maximum outflow, when added to the estimated local run-off below the dam sites, will not exceed the channel capacity. One of the greatest advantages of such a system is its automatic operation - no decision being required during a flood as to which gate to open and when to open it. It also has the following advantages compared to other types of flood control structures:

(1) Ease in construction, being an ordinary gravity type dam

(2) Low construction cost

(3) Less maintenance cost

4. Selection of dam sites. - The final decision as to the location of the dam sites was preceded by an exhaustive study of all possible sites and site combinations in the basin, at all time bearing in mind the cost of the projects, benefits to areas within the basin, and possible inundation of improvements in the reservoir areas. To summarize briefly the

lower reaches of the main stem and the principal tributaries would involve expensive dams and the inundation of valuable lands. Thus, the investigations in the early stages pointed definitely to locations at upstream points where reservoir costs particularly would be less, and by locating the dams in upstream areas, local benefits would in general increase until sites were reached where flood flows from uncontrolled areas would cause flood damages in the lower part of the basin. (17)

5. Locations of reservoirs. - After all careful studies a suitable location for a dam on the main stem was found at Meramec State Park which is located about 65 miles by highway from St. Louis and about 5 miles by highway from the town of Sullivan. At elevation 701, the reservoir would extend about 42 miles above the dam or approximately 2½ miles northwest of Steelville. (Plate II) (18)

The site for the Union Dam is on the Bourbeuse River at river mile 31.6 above the confluence with the main stem, about 6 miles southwest of the town of Union and about 50 miles by highway from St. Louis. The reservoir at elevation 651 would extend about 48 miles upstream. (Plate III) (19)

The site for the Cedar Hill Dam is on the Big River, at river mile 22.6 above the confluence with the Meramec River, about 2½ miles upstream from the town of Cedar Hill and about 30 miles by highway from St. Louis. At elevation 562 the reservoir would extend about 40 miles above the dam. (Plate IV) (20)

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(17) Appendix I, op. cit. p. 15

(18) Ibid, p. 20

(19) Appendix I, op. cit. p. 21

(20) Ibid, p. 21

MERAMEC RIVER BASIN

PERTINENT DATA (21)

6. General

Drainage area above mouth of Meramec River - 3955 sq. mi.

Drainage area above station Eureka - 3788 sq. mi.

	Meramec Park Reservoir Meramec River	Union Reservoir Bourbeuse River	Cedar Hill Reservoir Big River
Drainage area above dam site (sq. mi.)	1,508	754	858
Stream flow data (c.f.s.)			
Maximum discharge at dam site (estimated from 1915 stage heights)	101,000	47,300	65,000
Minimum discharge at dam site	143	13	23
Average annual discharge at dam site	1,202	630	768
Elevations (m.s.l.)			
Riverbed elevation at dam site	566	531	449
Top flood control pool	701	655	562
Top of dam	724	666	577
Storage			
Flood control pool (ac-ft)	603,000	302,000	366,000
Area below top pool (acres)			
Flood control pool	22,400	13,800	13,700

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(21) Appendix I, pp. g-h.

Locations of U. S. G. S. gaging stations.

Meramec River

Station	Elevation (m.s.l.)	River miles above mouth
Eureka	446	34.7
Mouth of Big River	449	37.7
Robertsville	481	60.2
Mouth of Bourbeuse River	490	64.8
Sullivan	612	110.5

Bourbeuse River

Station	Elevation (m.s.l.)	River miles above mouth
Union	518	13.6

Big River

Station	Elevation (m.s.l.)	River miles above mouth
Byrnesville	456	13.3

FORMULAS USED IN COMPUTATIONS

Formulas for finding discharge values:

Quantity of flow in a weir is determined by the general equation known as Francis Weir formula, $Q = 3.33\ b\ h^{3/2}$ ———— Eq. (1) where "b" is the width of opening and "h" is the height of water surface measured from bottom.

When the water surface gets over the top of the opening it becomes an orifice, and the discharge through a submerged orifice is given by equation, $Q = C\ A\sqrt{2gh}$ ———— Eq. (2) where "C" is an empirical coefficient, "A" cross-sectional area of the opening, and "h" is the effective height on orifice measured from the center of orifice. The value for coefficient "C" in rectangular openings is used as 0.6. (22)

Formulas used in Flood Forcasting:

1. Kuichling has derived two formulas for finding maximum flood flows

$$Q = \frac{127{,}000}{M + 370} + 7.4 \qquad \text{(rare)} \text{———— Eq. (3)}$$

$$Q = \frac{44{,}000}{M + 170} + 20 \qquad \text{(occasional)} \text{———— Eq. (4)}$$

where "M" is the drainage area in square miles and "Q" is in c.s.m. (c.f.s. per square mile of the drainage area).

Kuichling's occasional formula has shown very good results in Missouri, and it gives reasonable results for a design basis more consistently than any other the writer has used. (23)

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(22) Davis, C. Victor, "Handbood of Applied Hydraulics", 1st Ed., 1942

(23) The University of Missouri Bulletin - Flood Flow on Missouri Streams, by Horace W. Wood, Jr. - Vol. 43, 1942, p. 8.

2. The limiting flood formula - Myers' modified formula

When flood maxima q in cubic feet per second per square mile are plotted against area of drainage basin on a log-log scale, it is found that the enveloping curve can generally be expressed by the equation

$$q = \frac{C_m}{\sqrt{M}}$$

in which "C_m" is a coefficient varying with locality and "M" is the area of the drainage basin in square miles.

The stream-flow records used in evaluating C_m must be of considerable length, or if only short records are available a generous factor of safety must be used in fixing the enveloping line.

2. a - Jarvis-Myers Scale. - If the formula given above is multiplied by the total drainage area M, it will represent total peak flow instead of flow per square mile, and will take the form

$$Q = C_m \sqrt{M} \quad \text{———————————— Eq. (6)}$$

In either form Q or q is in cubic feet per second, and area M is expressed in square miles. In the Myers formula, the base factor C_m is taken as 10,000 but for any particular area is multiplied by a percentage which is referred to as the Myers rating - Myers scale. Thus the Myers percentage rating of 30 is equivalent to a C_m factor of 3000.

A map has been prepared on the basis of available records to show the maximum ratings in percentage on Myers scale to find the maximum flood flows in the United States. These are really one one hundredth of respective numerical values assigned to C_m in the foregoing equation or

$$\frac{C_m}{100} = p \quad \text{———————————— Eq. (7)}$$

Thus, the flood peak in cubic feet per second,

$$Q = qM = C_m \sqrt{M} = 100\,p\,\sqrt{M} \quad \text{———— Eq. (8)}$$

known as the flood limiting formula. (24)

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(24) "Low Dams" - Water Resources Committee, National Resources Committee, 1938, p. 31.

MAXIMUM POSSIBLE FLOOD IN THE MERAMEC BASIN

Maximum flood flows at various stations in Meramec Basin, determined by three different maximum flood flow formulas.

1. Kuichling's occasional formula:

$$Q = \left(\frac{44000}{M + 170} + 20\right) M \qquad \text{Eq. (4), page 24}$$

Table 4

Maximum flood flows with
Kuichling's occasional formula

Meramec River

Station	Drainage Area (sq.Mi.)	$Q = \left(\frac{44000}{M+170} + 20\right)M$ c.f.s.	1945 Flood c.f.s.	1915 Flood c.f.s.
Steelville	781	51,750	47,000	60,000
Sullivan	1475	69,000	77,300	90,000
Robertsville	2673	94,750	102,000	125,000
Eureka	3788	118,000	120,000	175,000
		Bourbeuse River		
Spring Bluff	608	46,500	22,300	43,500
Union	798	52,200	31,700	50,000
		Big River		
Byrnesville	917	55,400	31,700	80,000

Kuichling's occasional formula gives reasonable values only for the Bourbeuse River, but figures from the same formula for the Meramec and Big Rivers are less than the 1915 flood flows.

2. Kuichling's rare formula:

$$Q = \left(\frac{127{,}000}{M + 370} + 7.4\right)M \qquad \text{Eq. (3), page 24}$$

Table 5

Maximum flood flows with
Kuichling's rare formula

Station	Drainage Area (sq.Mi.)	$Q = \left(\frac{127,000}{M + 370} + 7.4\right)M$ in c.f.s.	1945 flood	1915 flood
Meramec River				
Steelville	781	91,600	47,000	60,000
Sullivan	1475	112,300	77,300	90,000
Robertsville	2673	131,200	102,000	125,000
Eureka	3788	143,700	120,000	175,000
Bourbeuse River				
Spring Bluff	608	83,600	22,300	43,500
Union	798	92,700	31,700	50,000
Big River				
Byrnesville	917	97,400	31,700	80,000

The maximum flood flows from Kuichling's rare formula are all, except that for Eureka, greater than the highest flood peaks for the basin.

3. The limiting flood method. - The value of Myers percentage rating, p. 25, for Meramec Basin is given as 20 on the map (25) prepared on the basis of available records to show the maximum ratings in percentage on Myers Scale to find the maximum flood flows in the United States. Several highest peak values of Q in cubic feet per second per mile, taken from 26-year records available for the basin, (26) are plotted against the drainage area in square miles,

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(25) Low Dams, op. cit. p. 32

(26) Stream flow records, U.S.G.S. Wat. Res. Division, Rolla, Mo.

and as shown in Fig. (1) the curve expressed by Eq. (8) on page 26 with $p = 20$ does not cover flood peaks that have already occurred in the Basin. Myers, in using his equation, states that when short stream-flow records are available, as in this case, a generous factor of safety must be used in fixing the enveloping line. Therefore the value of p is increased from 20 to 30 to make the enveloping curve cover the highest peak on the graph.

The values of Q from equation $Q = 100p \sqrt{M}$, where $p = 30$, are given in Table 6.

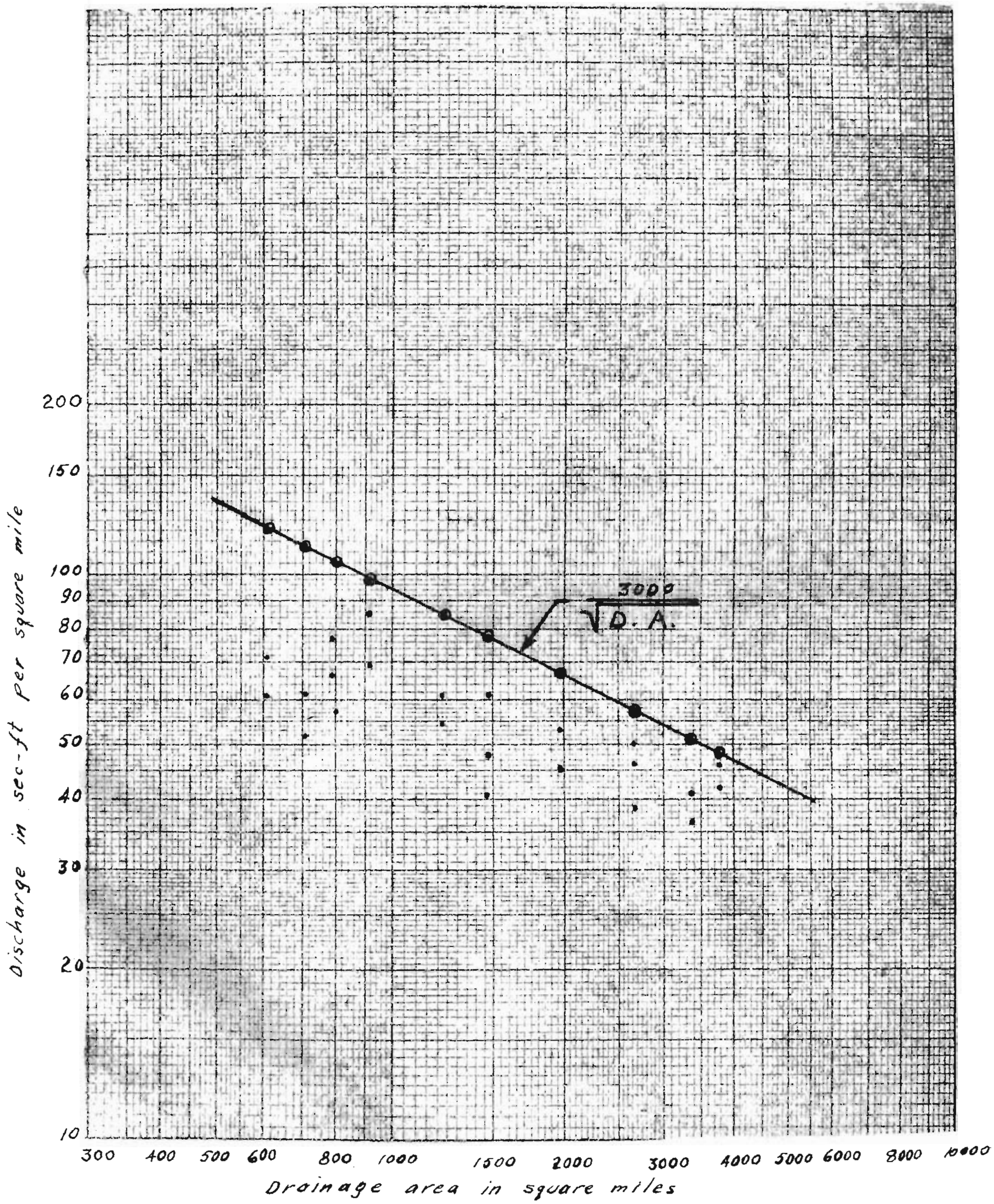
Table 6

Values of Q in c.f.s.

Station	River	Drainage Area	$Q = 3000\ M$ in c.f.s.
Steelville	Meramec	781 sq. mi.	84,000
Sullivan	"	1475	115,200
Robertsville	"	2673	155,250
Eureka	"	3788	184,650
Spring Bluff	Bourbeuse	608	73,950
Union	"	798	84,750
Byrnesville	Big	917	90,810 c.f.s.

To get the approximate daily flows of estimated flood at dam sites, the daily flows of 1945 flood is multiplied by the factor obtained from the ratio of estimated flood peaks (determined by Myers' modified formula) to those of 1945 flood at dam sites.

Sullivan	Union	Byrnesville
1.49	2.67	2.86



MAXIMUM PRABABLE FUTURE
FLOOD IN MERAMEC BASIN

Figure 1- Showing maximum flood peaks and
Jarvis Myers' enveloping curve

DETERMINATION OF RESERVOIR HEIGHTS

1. Meramec Park Reservoir.

The approximate daily flows of estimated maximum flood and cumulative storage corresponding to the time of duration of 1945 flood at dam site are given in table 7.

TABLE 7 - Daily flows and cumulative storage of estimated flood.

Date	1945 flood	Max. flood factor	Max. flood flows (1945) 1.49	Cumulative Storage sec-ft days	Elevation in M.S.L.
March 29		1.49		15,000	606
March 30	9,280	"	13,920	28,920	616.8
March 31	25,900	"	38,850	67,770	634.8
April 1	19,100	"	28,650	96,420	643.5
April 2	12,000	"	18,000	114,420	648.0
April 3	17,200	"	25,800	140,220	653.7
April 4	8,320	"	12,480	152,700	656.3
April 5	4,950	"	7,500	160,200	657.7
April 6	3,520	"	5,250	165,450	658.6
April 7	2,790	"	4,200	169,650	659.2
April 8	2,260	"	3,390	173,040	660.0
April 9	2,050	"	3,075	176,115	660.5
April 10	1,700	"	2,550	178,665	661.0
April 11	1,510	"	2,265	180,920	661.3
April 12	1,380	"	2,070	182,990	661.7
April 13	9,100	"	13,650	196,640	664.1
April 14	28,400	"	42,600	239,240	670.7
April 15	42,800	"	64,200	303,440	679.1
April 16	25,400	"	38,100	341,540	683.7
April 17	11,200	"	16,800	358,340	685.7
April 18	6,200	"	9,300	367,640	686.8

The highest mark reached by the estimated maximum flood waters will be 686.8 M.S.L. So the height of flood control pool will be 701 and top of dam is assumed 724 M.S.L. The area-capacity curves are shown on plate V.

2. Union Reservoir.

TABLE 8 - Daily flows and cumulative storage of estimated flood

Date	1945 flood	Max. flood factor x (1945)	Cumulative Storage in sec-ft days	Elevation in M.S.L.
June 6	Initial	10,000	10,000	572.6
June 7	2,460	6,580	16,580	580.7
June 8	7,870	21,240	37,820	596.2
June 9	17,800	47,600	85,420	614.8
June 10	27,700	74,100	159,520	633.2
June 11	21,600	57,800	217,320	643.7
June 12	5,760	15,400	232,720	646.3
June 13	2,940	7,860	240,580	647.5
June 14	3,960	10,600	251,180	648.8
June 15	1,800	4,820	256,000	649.5
June 16	1,110	2,970	258,970	650.1
June 17	1,150	3,080	262,050	650.5
June 18	2,850	7,620	269,670	651.5
June 19	4,060	10,870	280,540	653.0
June 20	2,140	5,720	286,160	653.7
June 21	1,550	4,150	290,310	654.3

Maximum elevation of water surface	654.3 M.S.L.
Top of flood control pool	655.0 "
Top of dam	666.0 "

The area-capacity curves for this reservoir are shown on plate VI.

3. Cedar Hill Reservoir.

TABLE 9 Daily flows and cumulative storage of estimated maximum flow.

Date	1945 flood	Max. flood factor	Max. flood flows factor x (1945)	Cumulative storage sec-ft days	Elevation in M. S. L.
March 29	Initial	2.86		10,000	487.3
March 30	6,220	"	17,720	27,720	499.2
March 31	15,900	"	45,300	73,020	516.5
April 1	26,700	"	76,050	149,070	536.6
April 2	14,400	"	41,000	190,070	545.0
April 3	11,000	"	31,350	221,420	550.8
April 4	5,860	"	16,700	238,100	553.7
April 5	3,880	"	11,050	249,150	555.5
April 6	2,500	"	7,130	256,280	556.6
April 7	1,760	"	5,010	261,290	557.3
April 8	1,370	"	3,900	265,100	558.1
April 9	1,160	"	3,300	268,400	558.5
April 10	993	"	2,830	271,230	559.0

Maximum elevation of water surface	559.0 M.S.L.
Top of flood control pool	562.0 "
Top of dam	577.0 "

Plate VII shows the area-capacity curves for Cedar Hill Reservoir.

MAXIMUM ALLOWABLE DISCHARGE VALUES FROM RESERVOIR OPENINGS

Since the quantity of run-off is proportional to the drainage area which produces it, the bankful stage flow of 21,500 c.f.s. at Eureka is divided into three quantities according to the percentages of each drainage area above dam site to the sum of three to get the maximum allowable discharges from reservoir openings. The values are listed in table 10.

Table 10

Showing the maximum allowable discharges from reservoir openings

Drainage Area Above	Drainage Area in sq. mi.	Percentages	Max. Discharges in c.f.s. 21,500 x %
Meramec Park Reservoir	1508 sq. mi.	48.3%	10,390 c.f.s.
Union Reservoir	754 "	24.1%	5,180 "
Cedar Hill Reservoir	858 "	27.6%	5,930 "
Total	3120 sq. mi.	100.0%	21,500 c.f.s.

OPERATION OF RESERVOIRS WITH 1945 FLOOD

Meramec Park Reservoir

1. Determination of the size of opening.

Necessary data: (27)

The height of top of dam..................................724 ft. (M.S.L.)

The riverbed elevation at dam site......................566 " "

The height of center of orifice from riverbed........... 6 "

Maximum allowable discharge through orifice...........10,390 c.f.s.

Weir discharge equation.....................$Q = 3.33\ bh^{3/2}$.....Eq. (1)

Orifice discharge equation..................$Q = CA\sqrt{2gh}$........Eq. (2)
where "C" is 0.60

Calculations:

The effective head on orifice is

$$h = 724 - (566 + 6) = 152 \text{ ft.}$$

$$Q = CA\sqrt{2gh} \qquad A = \frac{Q}{C\sqrt{2gh_n}}$$

$$\therefore A = \frac{10390}{.60\sqrt{2 \times 32.2 \times 152}} = 175 \text{ square feet}$$

Height: $h_o = 12$ feet, width: $b = 14.57$ feet

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(27) Data taken from p. 22 of this paper

Meramec Park Reservoir

TABLE II - Discharge curve computations

Elevation M.S.L.	Head on Weir (ft)	C × b 3.33 × 14.57	$h^{\frac{3}{2}}$	Discharge $Q = 3.33 b h^{\frac{3}{2}}$
568	2 ft	48.50	2.827	137
570	4 "	"	8.000	388
572	6 "	"	14.700	713
574	8 "	"	22.620	1094
576	10 "	"	31.600	1532
578	12 "	"	41.550	2015

Orifice - $Q = CA\sqrt{2gh}$

Elevation M.S.L.	Head on Orifice	C × A 0.6 × 175	$\sqrt{2gh}$	Discharge $Q = CA\sqrt{2gh}$
582	10	105	25.40	2665
592	20	"	35.90	3768
602	30	"	43.95	4615
612	40	"	50.80	5335
622	50	"	56.75	5960
632	60	"	62.20	6530
642	70	"	67.20	7055
652	80	"	71.80	7545
662	90	"	76.20	8000
672	100	"	80.30	8430
682	110	"	84.20	8845
692	120	"	87.95	9230
702	130	"	91.52	9615
712	140	"	95.00	9975
722	150	"	98.30	10325
724	152	"	99.00	10390

MERAMEC PARK RESERVOIR

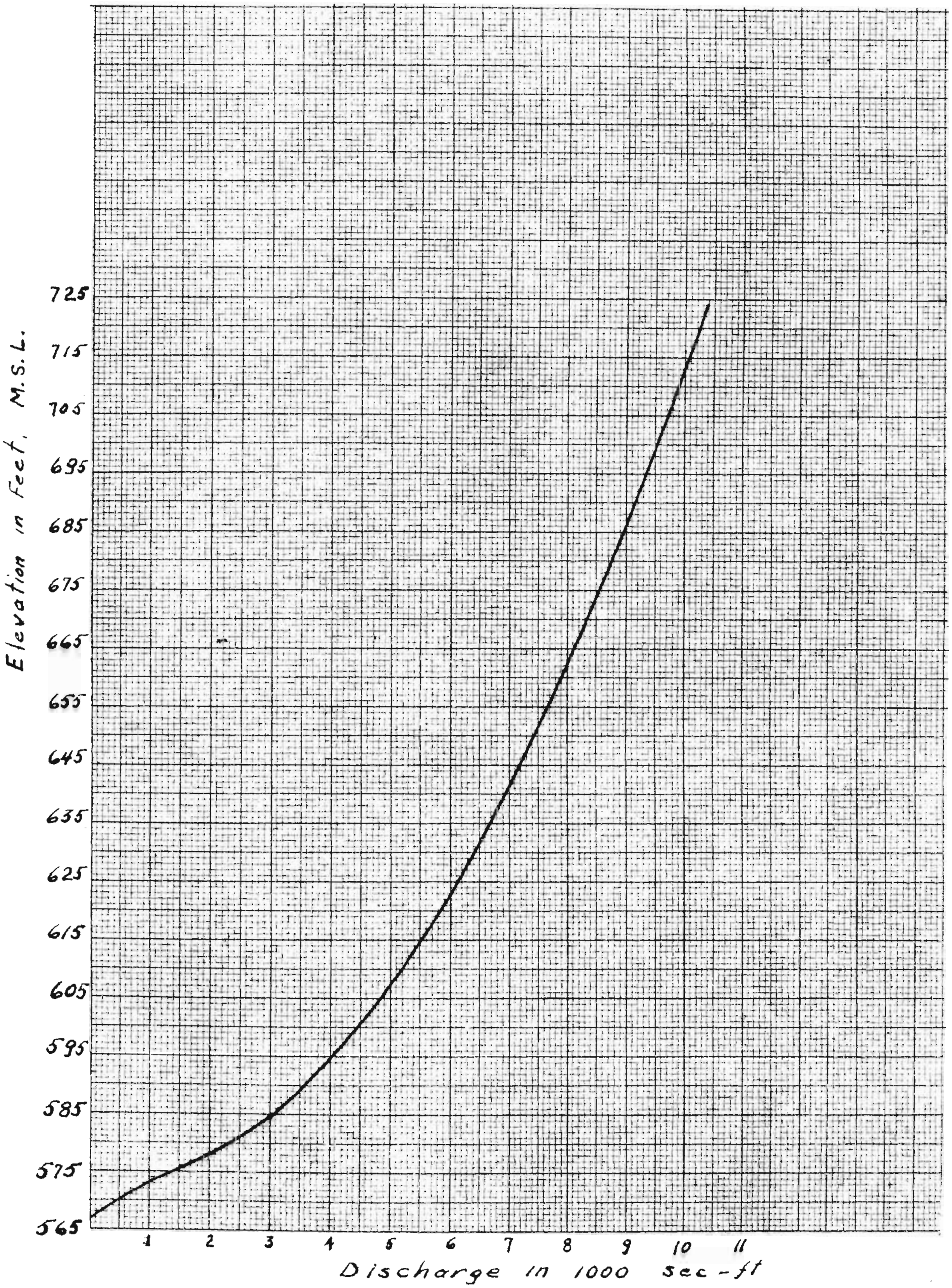


Fig. 2.

Showing discharge curve

Meramec Park Reservoir Operation

TABLE 12 - Showing inflow, outflow, storage relations

Date	Inflow in sec-ft	Discharge in sec-ft	Elevation of Water Surface in M.S.L.	Cumulative Storage in Sec-ft days
February 21	2390	1875	577.3	515
" 22	7930	3770	592.0	4675
" 23	5570	4050	595.2	6200
" 24	2070	3740	591.7	4530
" 25	1480	3250	586.6	2760
" 26	1370	2650	581.7	1480
" 27	1890	2350	579.8	1020
" 28	1710	2050	578.2	680
March 1	1540	1760	576.8	460
" 2	6000	3360	587.8	3100
" 3	14900	4780	604.2	13220
" 4	11400	5185	610.0	19435
" 5	3640	5115	608.75	17960
" 6	14300	5535	615.25	26725
" 7	19600	6040	623.10	40285
" 8	10100	6155	625.10	44230
" 9	3640	6070	623.60	41800
" 10	2820	5990	622.50	38630
" 11	2070	5870	620.2	34830
" 12	1710	5710	617.80	30830
" 13	1600	5550	615.40	26880
" 14	1370	5390	613.0	22860
" 15	1260	5180	609.8	18940
" 16	1160	4920	606.25	15180
" 17	1100	4650	602.5	11630
" 18	1000	4330	598.3	8300

TABLE 12 Continued.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M. S. L.	Cumulative Storage in Sec-ft days
March 19	2040	4070	595.3	6270
" 20	6970	4390	599.1	8850
" 21	4950	4435	599.75	9365
" 22	2820	4380	599.0	8805
" 23	2260	4155	596.3	6910
" 24	1890	3830	592.7	4970
" 25	4620	3960	594.0	5630
" 26	8060	4430	599.6	9250
" 27	5050	4480	600.3	9820
" 28	3120	4360	598.75	8580
" 29	3190	4230	597.3	7540
" 30	9280	4695	603.1	12125
" 31	25900	5775	619.0	32250
April 1	19100	6175	624.75	45170
" 2	12000	6300	628.0	50870
" 3	17200	6570	632.5	61500
" 4	8320	6610	633.3	63200
" 5	4950	6560	632.45	61590
" 6	3520	6500	631.5	58610
" 7	2790	6425	630.0	54975
" 8	2260	6325	628.3	50910
" 9	2050	6210	626.1	46750
" 10	1700	6080	624.0	42370
" 11	1510	5960	622.0	37920
" 12	1380	5815	619.5	33485
" 13	9100	5900	621.0	36685

TABLE 12 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
April 14	28400	6500	631.5	58585
" 15	42800	7100	643.0	94285
" 16	25400	7325	647.5	112360
" 17	11200	7370	648.4	116190
" 18	6200	7360	648.1	115030
" 19	4250	7320	647.4	111960
" 20	3700	7290	646.8	108,370
" 21	3360	7230	645.5	104 500
" 22	3030	7175	644.5	100 355
" 23	2480	7120	643.3	95715
" 24	2260	7055	642.0	90920
" 25	2050	6980	640.6	85990
" 26	1980	6910	639.2	81060
" 27	1770	6830	637.5	76000
" 28	1700	6730	635.5	70970
" 29	1580	6640	634.0	65910
" 30	1440	6540	632.3	60810
May 1	1380	6440	630.3	55750
" 2	1700	6325	628.3	51125
" 3	2340	6225	626.5	47240
" 4	2190	6120	624.6	43310
" 5	1770	5990	622.5	39090
" 6	1580	5850	620.1	34820
" 7	1510	5705	617.8	30625
" 8	1440	5525	615.0	26540
" 9	1320	5370	612.75	22490

TABLE 12 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage in Sec-ft days
May 10	1260	5125	609.5	18625
" 11	1200	4890	605.8	14735
" 12	1200	4620	602.1	11315
" 13	1140	4320	598.2	8135
" 14	1080	3900	593.4	5315
" 15	1020	3325	587.5	3010
" 16	1020	2615	581.6	1415
" 17	1020	1880	577.4	555
" 18	960	960	—	—
" 19	900	900	—	—
" 20	840	840	—	—
" 21	840	840	—	—
" 22	785	785	—	—
" 23	702	702	—	—
" 24	675	675	—	—
" 25	1020	1020	—	—
" 26	2190	2190	—	—
" 27	1580	1580	—	—
" 28	1440	1440	—	—
" 29	4110	2650	581.7	1460
" 30	11000	4315	598.2	8145
" 31	7330	4585	601.2	10890
June 1	4150	4550	601.1	10490
" 2	2640	4375	599.0	8755
" 3	1980	4120	595.9	6615
" 4	1640	3730	591.7	4525

TABLE 12 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage in Sec-ft days
June 5	1440	3230	586.55	2735
" 6	1700	2760	582.65	1675
" 7	13200	4535	600.95	10340
" 8	38900	6130	624.75	43110
" 9	70600	7255	646.10	106455
" 10	41100	7620	653.40	139935
" 11	16200	7705	655.40	148430
" 12	6200	7680	655.00	146950
" 13	6970	7675	654.80	146245
" 14	8190	7680	654.90	146755
" 15	5050	7665	654 40	144140
" 16	3540	7620	653.60	140060
" 17	3700	7580	652.70	136180
" 18	4850	7565	652.30	133465
" 19	5350	7530	651.70	131285
" 20	4850	7510	651.20	128625
" 21	3280	7455	650.10	124450
" 22	2740	7405	649.10	119785
" 23	2230	7350	648.00	114665
" 24	2010	7285	646.80	109400
" 25	2020	7235	645.70	104185
" 26	1640	7160	644.20	98665
" 27	1500	7080	642.70	93065
" 28	1380	7005	641.10	87440
" 29	1380	6920	639.40	81900
" 30	1830	6830	637.15	76900

TABLE 12 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage in Sec-ft days
July 1	1640	6740	636.0	71800
2	1440	6680	634.6	66560
3	1250	6540	632.3	61270
4	1190	6430	630.2	56030
5	1070	6310	628.1	50790
6	1010	6180	625.8	45620
7	955	6075	623.3	40520
8	898	5890	620.7	35570
9	1000	5710	617.8	30800
10	1070	5520	615.0	26350
11	953	5315	611.8	21990
12	898	5110	608.8	17780
13	843	4835	605.0	13785
14	843	4520	600.7	10110
15	790	4135	596.1	6765
16	740	3600	590.2	3900
17	692	2280	579.5	2330
18	646	2175	578.8	800
19	646	1890	575.2	400
20	646	800	—	—
21	602	602	—	—

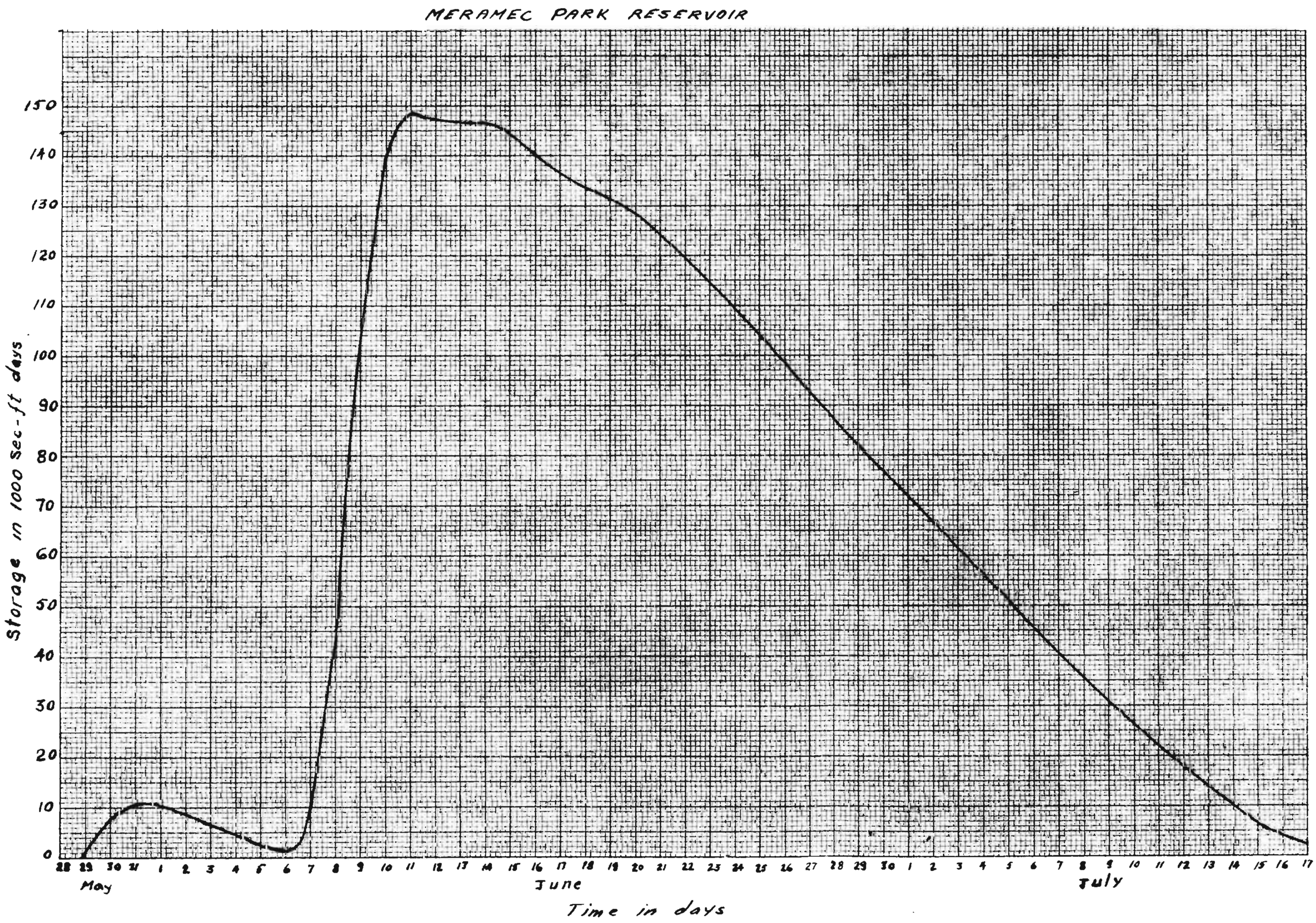
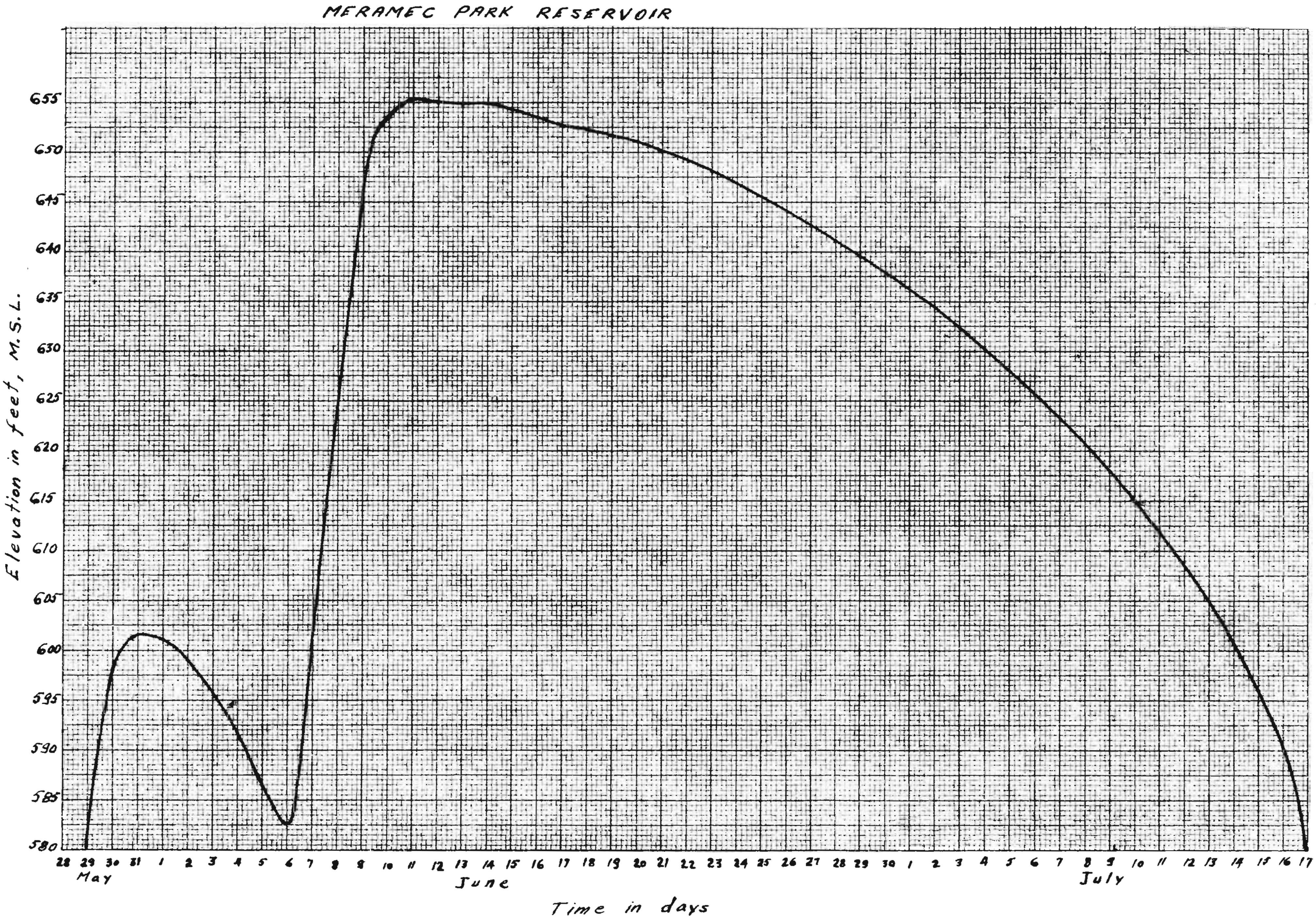


Fig. 3.

showing maximum storage with 1945 flood



MERAMEC PARK RESERVOIR

Fig. 4.- Showing maximum elevation with 1945 flood

Union Reservoir

1. Determination of the size of opening in reservoir.

Data used: (30)

The height of top of dam..............................666 ft. (M.S.L.)

The riverbed elevation at dam site.....................531 " "

The height of center of orifice....................... 4 "

Maximum allowable discharge from orifice..............5,180 c.f.s.

Weir discharge equation.........$Q = 3.33\ bh^{3/2}$.......Eq. (1)

Orifice discharge equation......$Q = CA\sqrt{2gh}$..........Eq. (2)
where "C" is 0.60

Calculations:

The effective head on orifice is

$$h = 666 - (531 + 4) = 131 \text{ feet}$$

$$Q = CA\sqrt{2gh} \qquad \text{and } A = \frac{Q}{C\sqrt{2gh}}$$

$$\therefore A = \frac{5180}{.6\sqrt{2 \times 32.2 \times 131}} = 94.0 \text{ square feet}$$

$$h_o = 8 \text{ feet} \qquad b = 11.75$$

2. Discharge curve computations are made as shown in Table 13 for this reservoir.

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(30) Ibid. Data taken from p. 22 of this paper.

Union Reservoir

TABLE 13 – Discharge curve computations

Elevation M.S.L.	Head on Weir	c × b 3.33 × 11.75	$h^{3/2}$	Discharge $Q = 3.33 b h^{3/2}$
533	2 ft	39.15	2.827	110.8
535	4 "	"	8.000	332.0
537	6 "	"	14.700	548.0
539	8 "	"	22.620	887.0

Orifice – $Q = CA\sqrt{2gh}$

Elevation M.S.L.	Head on Orifice	c × A 0.6 × 94	$\sqrt{2gh}$	Discharge $Q = CA\sqrt{2gh}$
545	10 ft	56.4	25.40	1433
555	20 "	"	35.90	2025
565	30 "	"	43.95	2480
575	40 "	"	50.80	2870
585	50 "	"	56.75	3200
595	60 "	"	62.20	3508
605	70 "	"	67.20	3790
615	80 "	"	71.80	4050
625	90 "	"	76.20	4300
635	100 "	"	80.30	4530
645	110 "	"	84.20	4750
655	120 "	"	87.95	4960
665	130 "	"	91.52	5160
666	131 "	"	91.90	5180

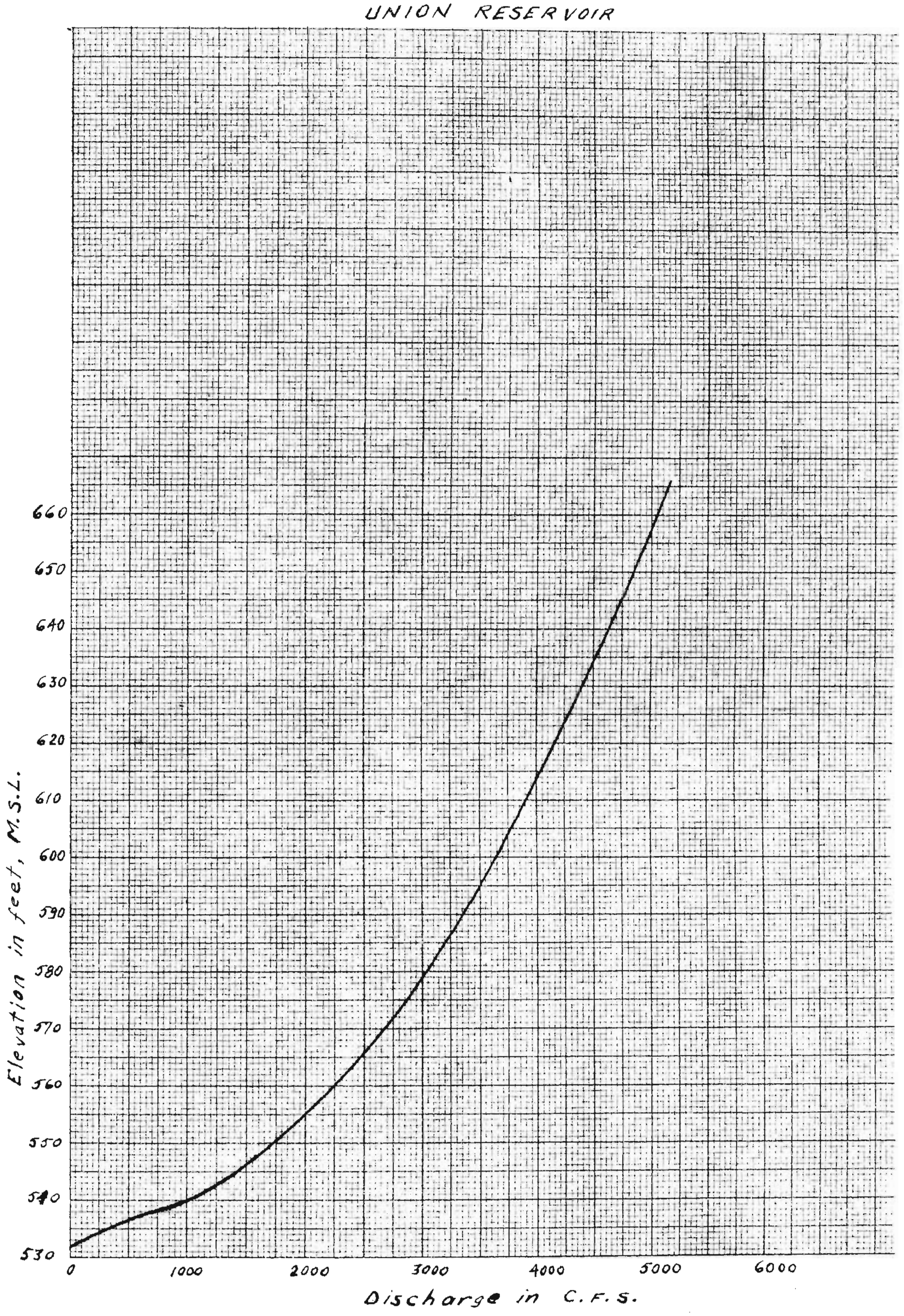

Fig. 5 – showing discharge curve

Union Reservoir

TABLE 14 - Showing inflow, outflow and storage relations

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage in Sec-ft days
March 2	1970	1335	543.5	640
" 3	6090	2330	561.8	4400
" 4	9880	2835	574.25	11445
" 5	7760	3045	580.1	16160
" 6	3490	3070	580.6	16680
" 7	6830	3175	584.25	20335
" 8	9620	3355	589.25	26600
" 9	2850	3320	588.9	26130
" 10	1350	3280	587.5	24200
" 11	998	3225	585.65	21975
" 12	758	3155	583.50	19580
" 13	594	3075	581.1	17100
" 14	494	2985	578.25	14610
" 15	430	2880	575.2	12160
" 16	376	2755	571.9	9780
" 17	340	2620	568.4	7500
" 18	316	2455	564.35	5360
" 19	367	2225	559.25	3500
" 20	1890	2175	558.3	3215
" 21	5520	2665	569.3	8070
" 22	2580	2665	569.25	7985
" 23	1510	2575	567.5	6920
" 24	982	2460	564.5	5440
" 25	1800	2395	563.1	4845
" 26	4630	2575	567.4	6900
" 27	5320	2740	571.4	9480

TABLE 14 Cont.

Date	Inflow in sec-ft	Discharge in sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage sec-ft days
March 28	1930	2695	570.25	8715
" 29	1350	2615	568.35	7450
" 30	2690	2625	568.45	7515
" 31	7510	2875	575.15	12150
April 1	11400	3175	584.25	20375
" 2	11800	3375	590.6	28800
" 3	7870	3470	593.6	33200
" 4	12400	3600	598.2	42000
" 5	5640	3640	599.3	44000
" 6	2140	3615	598.6	42525
" 7	1350	3575	597.4	40300
" 8	982	3540	596.2	37740
" 9	750	3490	594.5	35000
" 10	594	3445	591.8	32150
" 11	440	3370	590.5	29220
" 12	440	3310	588.6	25910
" 13	2230	3280	587.8	24860
" 14	6610	3360	590.2	28110
" 15	9880	3480	594.3	34510
" 16	11500	3610	598.4	42400
" 17	5320	3625	599.3	44095
" 18	2760	3620	599.0	43235
" 19	1510	3580	597.8	41165
" 20	1070	3545	596.45	38690
" 21	825	3515	595.1	36000
" 22	885	3470	593.8	33420

TABLE 14 Cont.

Date	Inflow in sec-ft	Discharge in sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage sec-ft days
April 23	742	3415	592.0	30745
" 24	580	3355	590.1	27970
" 25	506	3295	588.1	25180
" 26	467	3220	585.9	22425
" 27	440	3155	583.65	19710
" 28	440	3075	581.0	17075
" 29	420	2980	578.2	14515
" 30	415	2870	575.0	12060
May 1	400	2755	571.75	9710
" 2	395	2615	568.35	7490
" 3	410	2450	564.5	5450
" 4	512	2240	559.9	3720
" 5	542	1990	554.7	2270
" 6	483	1635	548.4	1120
" 7	425	1125	541.0	420
" 8	376	545	536.0	250
" 9	344	400		—
" 10	336	336		—
" 11	328	328		—
" 12	316	316		—
" 13	336	336		—
" 14	425	425		—
" 15	2020	1350	543.7	670
" 16	2940	1860	552.25	2750
" 17	1430	1980	554.6	2200
" 18	1230	1830	551.5	1600

TABLE 14 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
May 19	930	1560	547.25	970
20	627	1150	541.25	450
21	456	645	537.25	260
		—	—	—
May 27	1850	1300	542.75	550
28	1070	1145	541.2	475
29	2940	1825	551.45	1590
30	5320	2360	562.3	4550
31	8470	2780	572.6	10240
June 1	5240	2890	575.75	12590
2	1510	2840	574.0	11260
3	908	2770	572.7	10400
4	634	2675	569.7	8360
5	506	2540	566.4	6325
6	410	2345	561.85	4390
7	2460	2350	562.1	4500
8	7870	2745	571.65	9625
9	17800	3275	587.45	24150
10	27700	3680	600.65	48170
11	21600	3870	608.50	65900
12	5760	3900	609.2	67750
13	2940	3895	608.8	66800
14	3960	3900	609.0	66860
15	1800	3875	608.1	64785
16	1110	3850	607.2	62045
17	1150	3820	606.3	59375

TABLE 14 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
June 18	2850	3810	605.8	58410
19	4060	3820	606.15	58650
20	2140	3790	605.1	57000
21	1550	3770	604.25	54780
22	990	3740	603.1	52030
23	840	3700	601.8	49170
24	662	3660	600.25	46170
25	494	3610	598.75	43055
26	405	3575	597.1	39885
27	349	3520	595.4	36715
28	312	3470	593.7	33555
29	372	3410	591.8	30520
30	376	3350	589.9	27545
July 1	1230	3300	588.3	25475
2	1230	3255	586.7	23450
3	683	3190	584.7	20940
4	410	3120	582.3	18230
5	312	3025	579.4	15520
6	266	2915	576.1	12870
7	234	2790	572.8	10315
8	213	2650	569.1	7880
9	230	2470	564.85	5640
10	186	2225	559.6	3600
11	180	1890	552.9	1890
12	166	1380	544.25	675
13	153	610	537.6	220

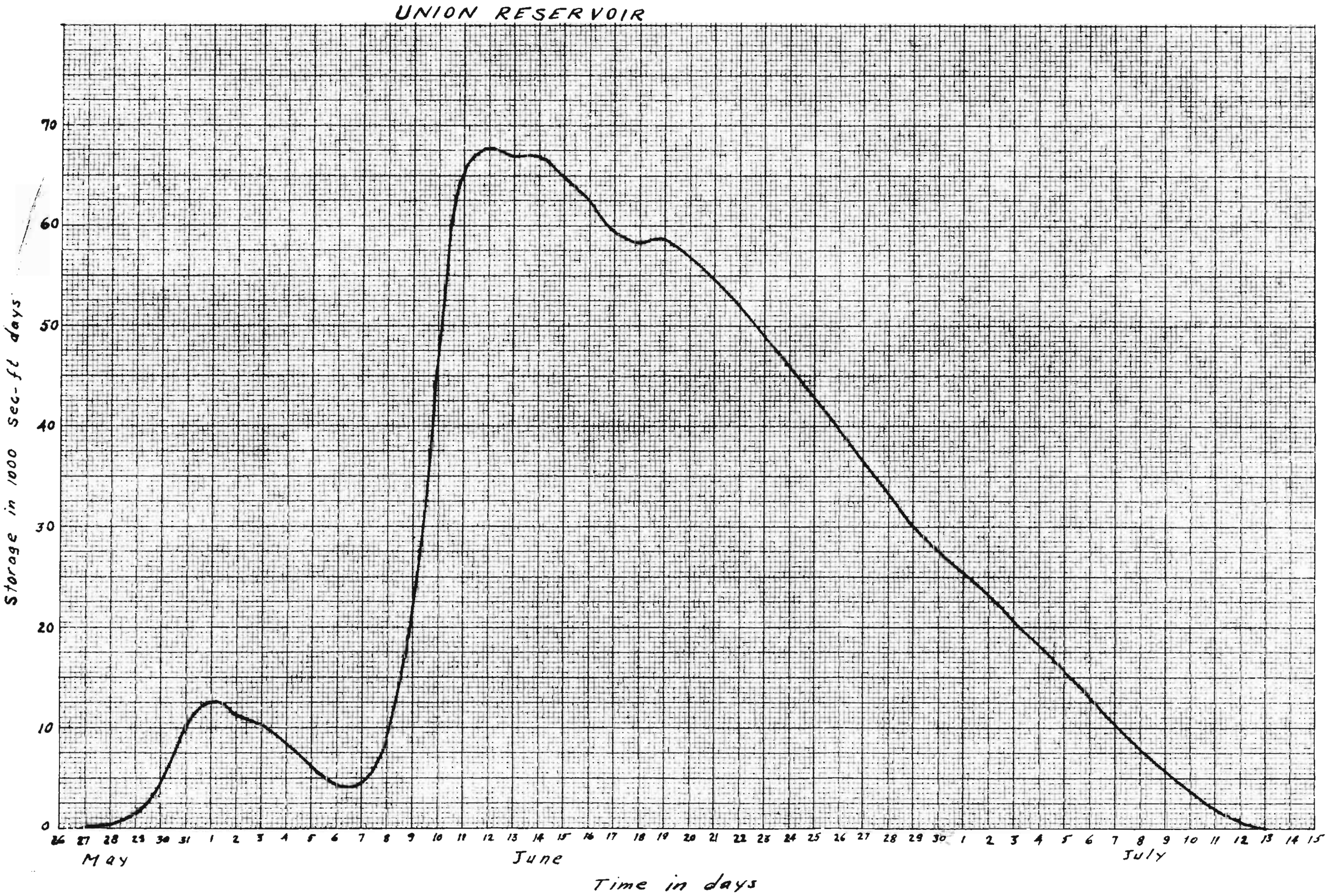

Fig. 6 - showing maximum storage with 1945 flood

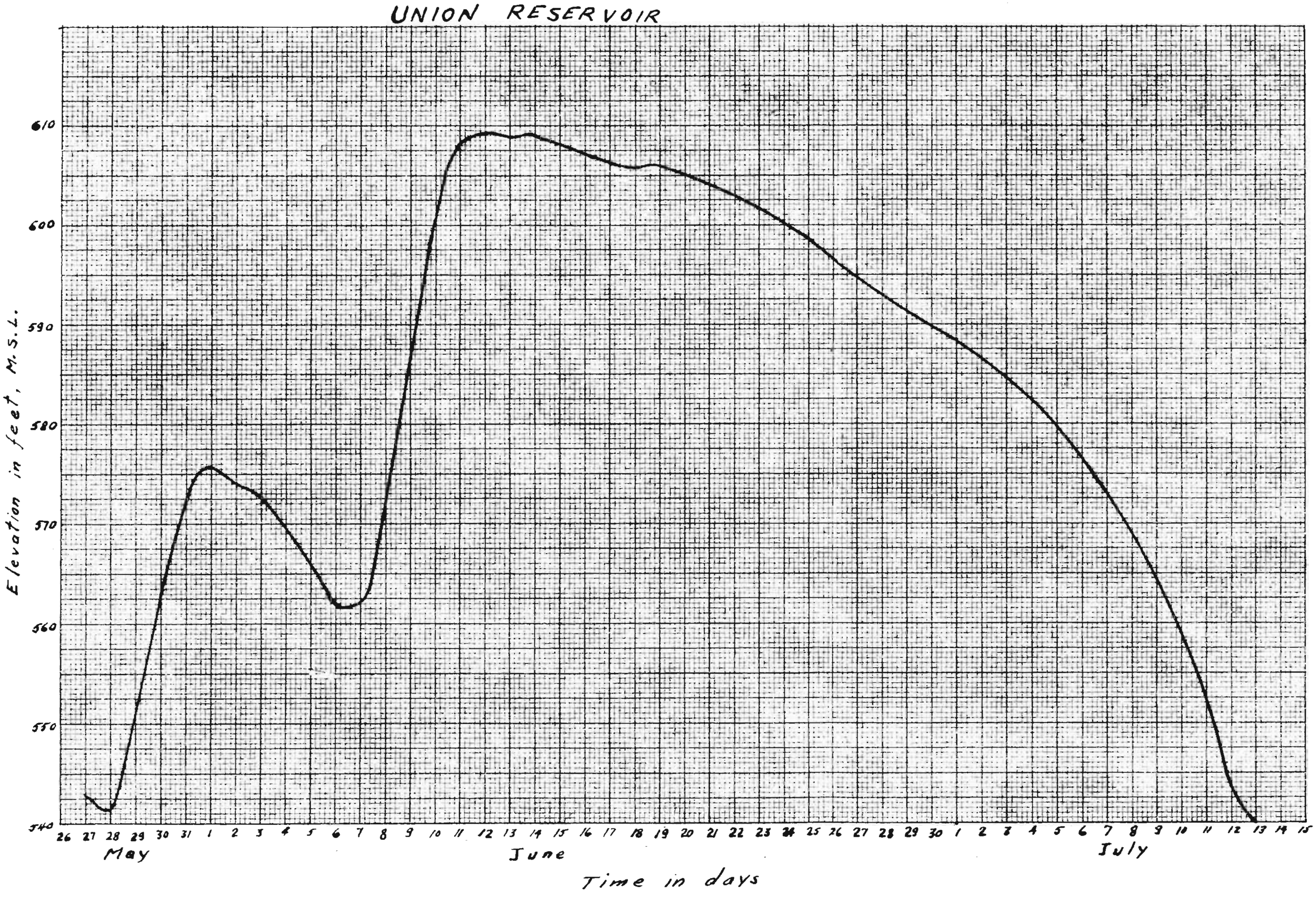

Fig. 7- Showing maximum elevation with 1945 flood

Cedar Hill Reservoir

1. Determination of the size of opening in reservoir:

Data used:(31)

The height of top of dam..............................477 ft. (M.S.L.)

The riverbed elevation at dam site....................449 " "

The height of center of orifice...................... 4 "

Maximum allowable discharge from orifice.............5,930 c.f.s.

Weir discharge equation...........$Q = 3.33\ bh^{3/2}$.....Eq. (1)

Orifice discharge equation.........$Q = CA\sqrt{2gh}$........Eq. (2)
where "C" is 0.60

Calculations:

The effective head on orifice is

$$h = 577 - (449 + 4) = 124 \text{ feet}$$

$$Q = CA\sqrt{2gh} \quad \text{and} \quad A = \frac{Q}{C\sqrt{2gh}}$$

$$\therefore A = \frac{5930}{0.6\sqrt{2 \times 32.2 \times 124}} = 111.04 \text{ square feet}$$

Height of orifice $h_o = 8$ feet Width $b = 13.81$ feet

2. Discharge curve values for this reservoir are shown in Table 15.

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(31) Ibid. Data taken from p. 22 of this paper.

Cedar Hill Reservoir

TABLE 15- Discharge curve computations

Elevation M.S.L.	Head on Weir	C × b 3.33 × 13.81	$h^{3/2}$	Discharge $Q = 3.33\,b\,h^{3/2}$
451	2 ft	46.00	2.827	131
453	4 "	"	8.000	368
455	6 "	"	14.700	676
457	8 "	"	22.620	1042

Orifice - $Q = CA\sqrt{2gh}$

Elevation M.S.L.	Head on Orifice	C × A 0.6 × 111.4	$\sqrt{2gh}$	Discharge $Q = CA\sqrt{2gh}$
463	10 ft.	66.35	25.40	1683
473	20	"	35.90	2380
483	30	"	43.95	2915
493	40	"	50.80	3373
503	50	"	56.75	3765
513	60	"	62.20	4125
523	70	"	67.20	4460
533	80	"	71.80	4765
543	90	"	76.20	5060
553	100	"	80.30	5330
563	110	"	84.20	5585
573	120	"	87.95	5830
577	124	"	89.45	5930

CEDAR HILL RESERVOIR

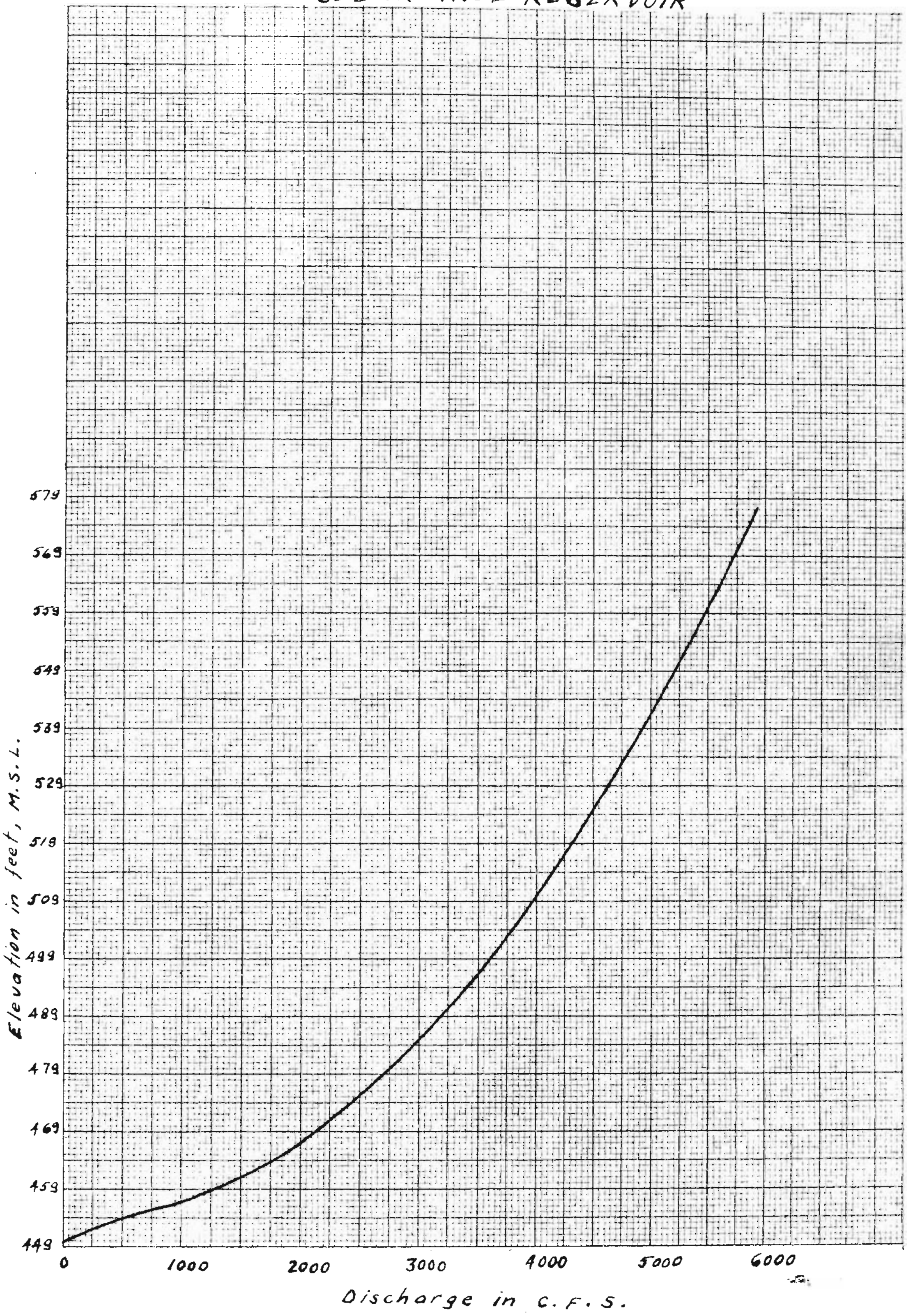


Fig. 8- Showing discharge curve

Cedar Hill Reservoir

TABLE 16 - Showing inflow, discharge and storage relations

Date	Inflow in Sec-ft	Discharge in sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage sec-ft days
February 21	1230	1015	456.9	215
22	5560	2535	475.7	3240
23	6770	2980	484.3	7030
24	1880	2890	482.5	6020
25	1210	2730	479.25	4500
26	1130	2520	475.3	3110
27	4090	2720	479.2	5480
28	3420	2880	482.45	6020
March 1	2110	2820	481.1	5310
2	6570	3090	486.65	8790
3	11000	3340	492.35	16450
4	10500	3525	496.6	23425
5	2900	3515	496.25	22810
6	8570	3625	499.1	27755
7	16200	3830	504.7	40125
8	14400	3975	508.75	50550
9	2830	3965	508.3	49415
10	1760	3925	507.5	47250
11	1320	3890	506.5	44680
12	1060	3860	505.35	41880
13	898	3815	504.3	38965
14	783	3755	502.9	35990
15	693	3710	501.6	32975
16	607	3655	500.15	29925
17	545	3595	498.55	26880
18	525	3535	496.8	23870

TABLE 16 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
March 19	671	3470	495.15	21070
20	2170	3440	494.40	19800
21	4160	3460	494.85	20500
22	2120	3420	494.1	19200
23	1370	3370	492.75	17200
24	1040	3305	491.3	14935
25	2760	3295	491.0	14400
26	7280	3400	493.5	18280
27	8360	3520	496.45	23120
28	2760	3500	496.0	22380
29	2640	3480	495.5	21540
30	6220	3545	497.0	24215
31	15900	3770	503.15	36345
April 1	26700	4055	511.0	58990
2	14400	4215	515.5	69175
3	11000	4275	517.4	75900
4	5860	4290	517.95	77470
5	3880	4280	517.75	77070
6	2500	4270	517.20	75300
7	1760	4250	516.5	72810
8	1370	4220	515.5	69960
9	1160	4180	514.5	66940
10	993	4150	513.55	63780
11	852	4080	511.55	58850
12	783	4045	510.75	55590
13	6270	4075	511.5	57785

TABLE 16 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
April 14	9840	4145	513.4	63480
15	17600	4275	517.6	76805
16	18000	4420	521.8	90385
17	8900	4460	522.9	94825
18	4160	4455	522.8	94530
19	2440	4400	521.2	88690
20	1940	4370	520.4	86260
21	1940	4360	519.9	83840
22	1530	4330	519.0	81040
23	1290	4300	518.1	78030
24	1220	4265	517.0	74985
25	1140	4230	516.1	71895
26	1140	4210	515.2	68825
27	1580	4175	514.25	66230
28	1190	4130	513.2	63290
29	1040	4110	512.3	60220
30	946	4065	511.1	57100
May 1	875	4010	508.9	53950
2	946	3975	508.1	50925
3	1700	3955	507.0	48670
4	1420	3915	506.0	46175
5	1160	3880	504.75	43455
6	1020	3830	503.75	40645
7	898	3780	502.4	37765
8	898	3740	501.1	34920
9	829	3695	499.9	32055

TABLE 16 Cont.

Date	Inflow in sec-ft	Discharge in sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
May 10	760	3645	498.9	29170
11	737	3595	498.5	26315
12	693	3480	495.5	23530
13	649	3460	495.0	20750
14	607	3390	493.5	17940
15	2060	3350	492.4	16650
16	875	3290	490.9	14235
17	806	3220	489.35	11820
18	715	3135	487.3	9400
19	628	2980	484.6	7050
20	545	2765	480.0	4830
21	487	2465	474.4	2850
22	450	2025	467.6	1275
23	408	1325	459.3	360
May 29	4230	2265	471.2	1965
30	4950	2695	478.55	4220
31	4090	2830	481.4	5480
June 1	2180	2775	480.15	4885
2	1370	2605	476.9	3650
3	993	2340	472.5	2300
4	829	1965	466.75	1165
5	715	1430	460.25	450
6	628	920	456.3	160
7	2480	1780	464.3	860
8	7390	2835	481.3	5415

TABLE 16 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
June 9	11300	3265	490.35	13450
10	16700	3590	498.6	26560
11	9900	3760	501.5	32700
12	4200	3715	501.75	33185
13	2790	3695	501.25	32280
14	5700	3730	502.25	34250
15	3460	3730	502.2	33980
16	2180	3700	501.3	32460
17	2500	3690	501.1	31270
18	4800	3700	501.25	32370
19	3390	3695	501.15	32070
20	2440	3680	500.8	30830
21	2180	3650	500.0	29360
22	1580	3605	498.9	27335
23	1190	3555	497.6	24970
24	1040	3510	496.2	22500
25	898	3430	494.6	19970
26	829	3375	492.95	17425
27	783	3310	491.35	14900
28	671	3230	489.7	12340
29	628	3140	487.75	9830
30	693	3010	484.95	7510
July 1	2640	2985	484.4	7165
2	6020	3155	487.95	10030
3	1700	3090	486.5	8640
4	1090	2955	484.8	6775

TABLE 16 Cont.

Date	Inflow in Sec-ft	Discharge in Sec-ft	Elevation of Water Surface M.S.L.	Cumulative Storage Sec-ft days
July 5	852	2775	480.1	4850
6	715	2510	475.1	3055
7	628	2135	469.2	1550
8	565	1575	461.7	540
9	506	880	456.2	165
10	454	530	454.2	90
11	422	500	—	—

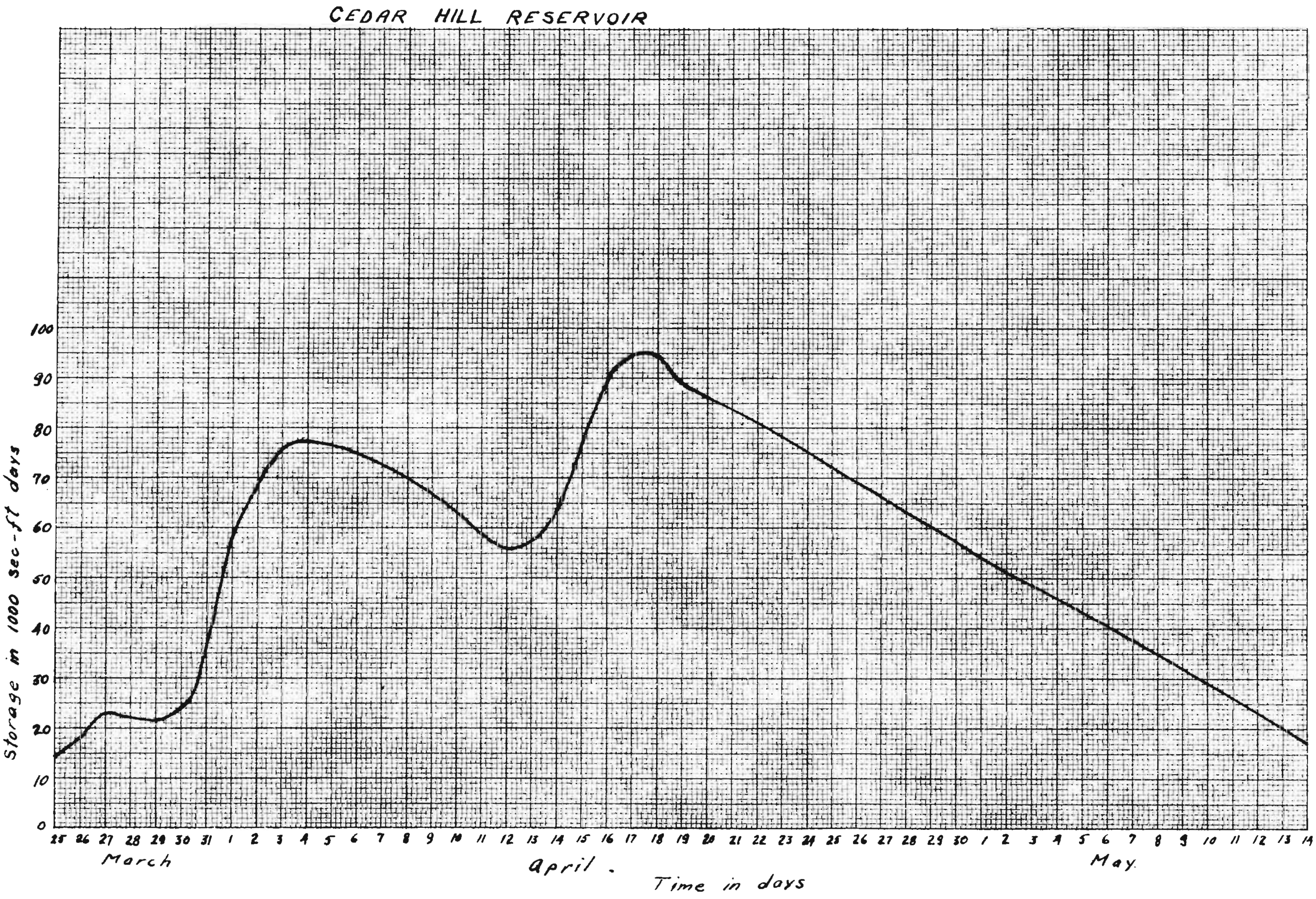


Fig. 9 - Showing maximum storage with 1945 flood.

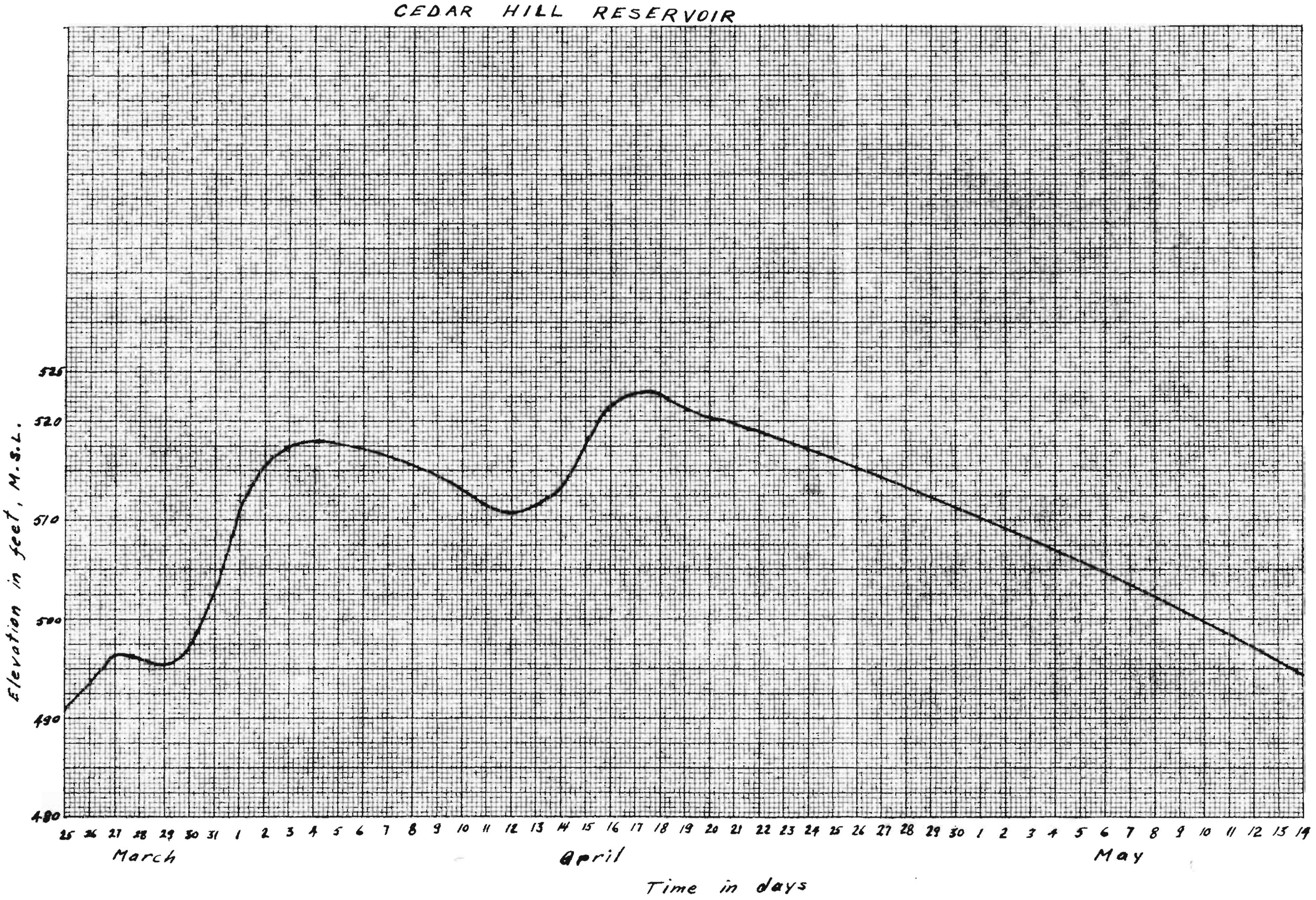


Fig. 10 - Showing maximum elevation with 1945 flood.

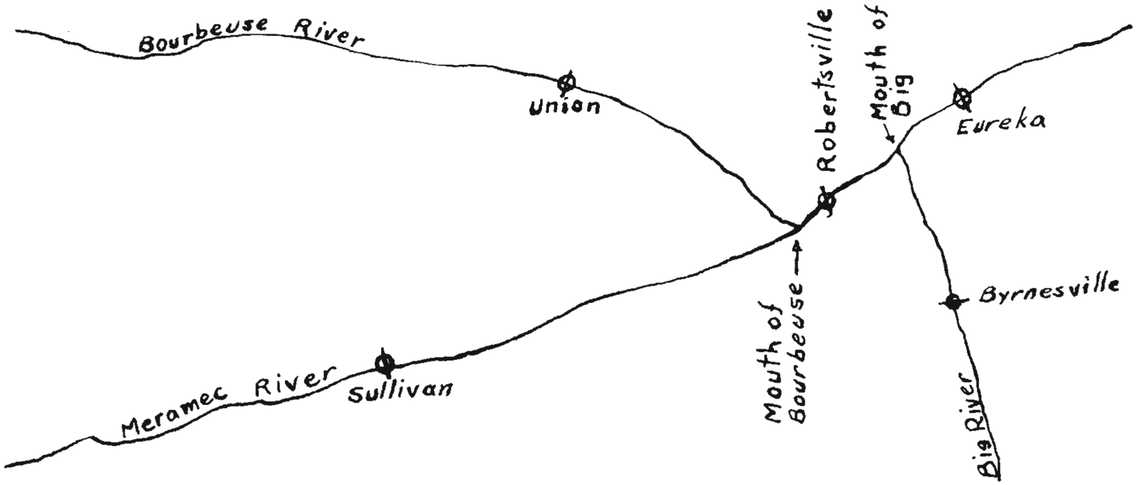
FLOOD ROUTING IN THE REACH SULLIVAN TO EUREKA WITH 1945 FLOOD

1945 Flood crest discharge values at various stations, and distances and elevations of stations are given in table 17.

TABLE 17 - 1945 crest discharge values and time at various stations.

Station	Discharge in c.f.s. (32)	Date	Distance (33) in river miles above mouth	Elevation in M.S.L. (34)
Sullivan Mer.	77,300	@ 10 AM June 9	110.5	612
Mouth of Bourb.	-	-	64.8	490
Robertsville	102,000	@ 10 AM June 10	60.2	481
Mouth of Big	-	-	37.7	449
Eureka Mer.	120,000	@ 5 AM June 11	34.7	446
Union Bourb.	28,500	@ 6 PM June 10	13.6	518
Byrnesville Big	16,700	@ 10:45 AM June 10	13.3	456

Fig. 11 - General sketch showing position of riverbeds.



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(32) Discharge values are obtained from field reports of U.S.G.S.,Rolla, Mo.
(33) River profiles of House Document No. 208, Army Report, p. 37.
(34) Ibid, p. 37.

Meramec River

Velocity of flow from Sullivan to Robertsville:

Distance from Sullivan to Robertsville is

$$S = 110.5 - 60.2 = 50.3 \text{ miles}$$

As given on page 67, it took 24 hours for the crest to travel from Sullivan to Robertsville, (t = 24 hours).

Therefore $V_{Mer.} = \frac{50.3}{24} = 2.095$ m.p.h.

Velocity of flow from Robertsville to Eureka:

Distance $S = 60.2 - 34.7 = 25.5$ river miles

Time of travel $t = 5$ AM June 11 - 10 AM June 10 = 19 hours

$$V_{Mer.} = \frac{25.5}{19} = 1.343 \text{ m.p.h.}$$

Meramec crest coming at mouth of Bourbeuse:

Distance from mouth of Bourbeuse to Robertsville

$$S = 64.8 - 60.2 = 4.6 \text{ miles}$$

$$V_{Mer.} = 2.095 \text{ m.p.h.}$$

so, $t = \frac{4.6}{2.095} = 2.195$ hrs. before Robertsville

or 10 AM June 10 - 2 hrs. 10 min. = 7:50 AM June 10 which will be used to determine the time of crest of Bourbeuse at Union.

Bourbeuse River

Time of travel from Union to Mouth:

Determination of slope,

Elevation at Union - 518

Elevation at Mouth - 490

Difference in elevation = 518 - 490 = 28 feet

Distance from Union to Mouth = 13.6 miles

so, $\text{Slope} = \frac{28}{13.6 \times 5280} = 0.00039$

and $\sqrt{\text{slope}} = \sqrt{0.00039} = 0.01975$

Determination of slope of main stem from Sullivan to Robertsville.

Difference in Elevation = 612 - 481 = 131 feet

Distance = 50.3 miles

so, $$\text{Slope} = \frac{131}{50.3 \times 5280} = 0.000493,$$

and $\sqrt{\text{slope}} = \sqrt{0.000493} = 0.02222$

Velocity of water is assumed proportional to the slope of riverbed

$$\frac{\sqrt{\text{slope of Bourbeuse}}}{\sqrt{\text{slope of Meramec}}} = \frac{\text{Vel. Bourbeuse}}{\text{Vel. Meramec}}$$

or $$\frac{0.01975}{0.02222} = \frac{V_B}{2.095}$$

and $V_B = 1.86$ m.p.h.

Water from Bourbeuse added to Meramec Crest passed Union gage:

Time of travel $t = \frac{13.6}{1.86} = 7.32$ hrs. or 7 hrs. 20 min.

Time at Union = 7:50 AM June 10 - 7 hrs. 20 min.

= 0:30 AM June 10

Stage at Union at 0:30 AM June 10 = 18.00 feet
and discharge at Union, Q = 25,800 c.f.s.

Big River

Meramec crest arriving at mouth of Big River:

Distance from mouth of Big to Eureka

$S = 3$ miles

Velocity of Meramec $V_{Mer.} = 1.343$ from Robertsville to Eureka

Time of travel $t = \frac{3}{1.343} = 2.233$ or 2 hrs. 15 min. before

crest time at Eureka.

so, Time at Mouth of Big = 5 AM June 11 - 2 hrs. 15 min.

= 2:45 AM June 11.

Time of travel from Byrnesville to Mouth:

Difference in elevation: = 456 - 449 = 7 feet

$$\text{Slope} = \frac{7}{13.3 \times 5280} = 0.0000997$$

$$\text{and } \sqrt{\text{slope}} = \sqrt{0.0000997} = 0.00999$$

Slope of Meramec, Robertsville - Eureka

Difference in elevation = 481 - 446 = 35 feet

$$\text{Slope} = \frac{35}{25.5 \times 5280} = 0.00026$$

$$\text{and } \sqrt{\text{slope}} = \sqrt{0.00026} = 0.01613$$

$$\frac{0.00999}{0.01613} = \frac{V_{Big}}{1.343}$$

$$V_{Big} = 0.832 \text{ m.p.h.}$$

Water from Big added to Meramec Crest passed Byrnesville gage:

Time of travel $t = \frac{S}{V} = \frac{13.3}{0.832} = 16$ hrs. before at mouth of Big River. Time at Byrnesville is = time at mouth of Big 2:45 AM June 11 ·

16 hrs = 10:45 AM June 10.

Stage at Byrnesville 10:45 AM June 10 = 20.9 feet

Discharge at Byrnesville 10:45 AM June 10 = 16,700 c.f.s.

CREST DISCHARGES

Discharge at Sullivan	77,300	c.f.s.	Drainage area 1475	sq. mi.
Discharge from Bourbeuse	25,800	"	808	"
Measured disch. Mouth of Bourb.	103,100	"	2283	"
	- - - - - - -		- - - - - -	
Discharge at Robertsville	102,000	"	2673	"
Discharge from Big	16,700	"	955	"
Measured disch. Mouth of Big	118,700	"	3628	"
	* - - - - - - -		- - - - - -	
Discharge at Eureka	120,000	"	3788	"
Inflow difference	1,300	"		

Conclusion: During 1945 flood all additions to Crest discharge of the Meramec River in the reach Sullivan to Eureka were balanced by loss in valley storage.

COMPARISON OF RESERVOIR AREAS AGAINST DOWN-STREAM AREAS

There are no large cities, towns or villages within the limits of the proposed reservoirs. Eight small communities, the largest of which is Morse Mill with a population of 62 in 1940, would be partially or completely inundated at full pool. A portion of Onondaga and Missouri Caverns, located at Meramec River mile 128.0 would be flooded. On the other hand, about 95 percent of the population of the basin live in the lower reaches. About 24,300 acres of land out of 50,500 acres, total area inundated by the 1945 flood, were in cultivation, as figured by the Corps of Engineers.

If the proposed reservoirs in this study were in operation in 1945 the water surface reached would be 655.4, 609.2, 522.9 feet (M.S.L.) for Meramec Park, Union and Cedar Hill reservoirs, respectively and the reservoir areas at these elevations as obtained from reservoir area curves are 10,000, 5,800 and 7,000 respectively, or a total of 25,800 acres of area would be inundated by backwater effect. But an amount of 2,800 acres of total reservoir acreas were inundated by the 1945 flood waters. Therefore the actual upstream area that would be flooded by the operation of the three reservoirs in 1945 would amount to 23,000 acres against 50,500 acres of down-stream area saved from inundation.

When the maximum flood, which is estimated for the basin, occurs it will inundate, as figured from gage heights and topographic maps for the basin, approximately 80,400 acres below the three dam sites. The maximum estimated flood waters will almost reach the top elevations of the flood control pools of the three proposed reservoirs, where the total reservoir areas inundated will be 49,900 acres against 80,400 acres saved.

The total drainage area for the basin is 3,955 sq. mi. and the drainage area above the three dam sites is 3,120 sq. mi. So the three recommended dams control $\frac{3120 \text{ sq. mi.}}{3955 \text{ sq. mi.}} = 79\%$ of the drainage above the mouth of the reach for 100% control of the over-flow damage.

CONCLUSIONS

A serious flood problem exists in the Meramec Basin. In this study a possible method is recommended to regulate the streams in the basin and prevent the valuable areas, highways, railroads, and plants from inundation, and thus avoiding the loss of about $503,100 every year due to flood damages.

The factors governing the studies made in selection of dam sites, determination of the heights of dams, selection of type of dams, and determination of size of uncontrolled outlets in the reservoirs are discussed in paragraphs 1 to 5.

1. The principal flood damage in the Meramec, Bourbeuse and Big River Valleys occurs below miles 107.5, 31.6 and 22.6, respectively, which are the locations of the proposed reservoirs. The other reason for selection of the dam sites was to minimize the relocations of persons and improvements.

2. In determining the heights of reservoirs a design flood is estimated by using Myers' modified formula which gives the best results for the Meramec Basin, as investigated by Horace W. Wood, Jr, after making several trials and comparing the results with those obtained by other methods.

3. Although the cost of the recommended installation for controlling floods in the Meramec Basin and the benefits will be gained by the operation of this installation are not actually evaluated, however it is considered to make the construction most economical, since this is an engineering problem. The construction of a spillway section and the gates are the most expensive part of a dam. Therefore, the retarding basin type of reservoirs with uncontrolled outlets and with no spill-

way sections, are recommended for controlling floods in the Meramec Basin because of their low construction cost and less maintenance cost.

4. Flood-routing studies show that the additional run-off due to rainfall in the reach from reservoir sites to Eureka, which is the critical part of the total area subject to flooding, is balanced by loss in valley storage. The maximum combined discharge of the three reservoirs is therefore kept below 21,500 c.f.s., which is the amount that produces floods down at Eureka. Thus the size of uncontrolled reservoir outlets are designed according to this modified flow at Eureka.

5. Although the 1915 flood was greater than the 1945 flood, the latter is used in the operation study of the reservoirs because it was the greatest flood in the basin for which complete daily flow and gage readings are available. It is noticeable from the natural and modified flow hydrographs at Eureka, shown on Plate XI, page 87, that the modified flow is less than 21,500 c.f.s. for the period of duration of the 1945 flood, thus preventing the areas from inundation by a flood of magnitude equal to the 1945 flood which flooded about 50,500 acres of farm lands.

If the recommended study for controlling floods in the Meramec Basin is put in operation the yearly benefit will amount to 503,100, which is estimated as average annual flood damage in the basin by the Corps of Engineers, Table 3, page 18.

The elevations that the estimated maximum flood waters, for which the reservoir heights are designed, can reach in Meramec Park, Union, and Cedar Hill reservoirs are 686.8, 654.3 and 559 feet (M.S.L.) respectively. The uncontrolled reservoir outlets are designed so that the combined flow at Eureka will still be less than 21,500 c.f.s. even if the water surface in each reservoir reaches the top of the flood control pool elevation. Thus the valuable down stream farm lands in the Meramec Basin are one hundred percent safe even against the estimated maximum flood, which may occur in the basin, with the recommended three reservoir operation.

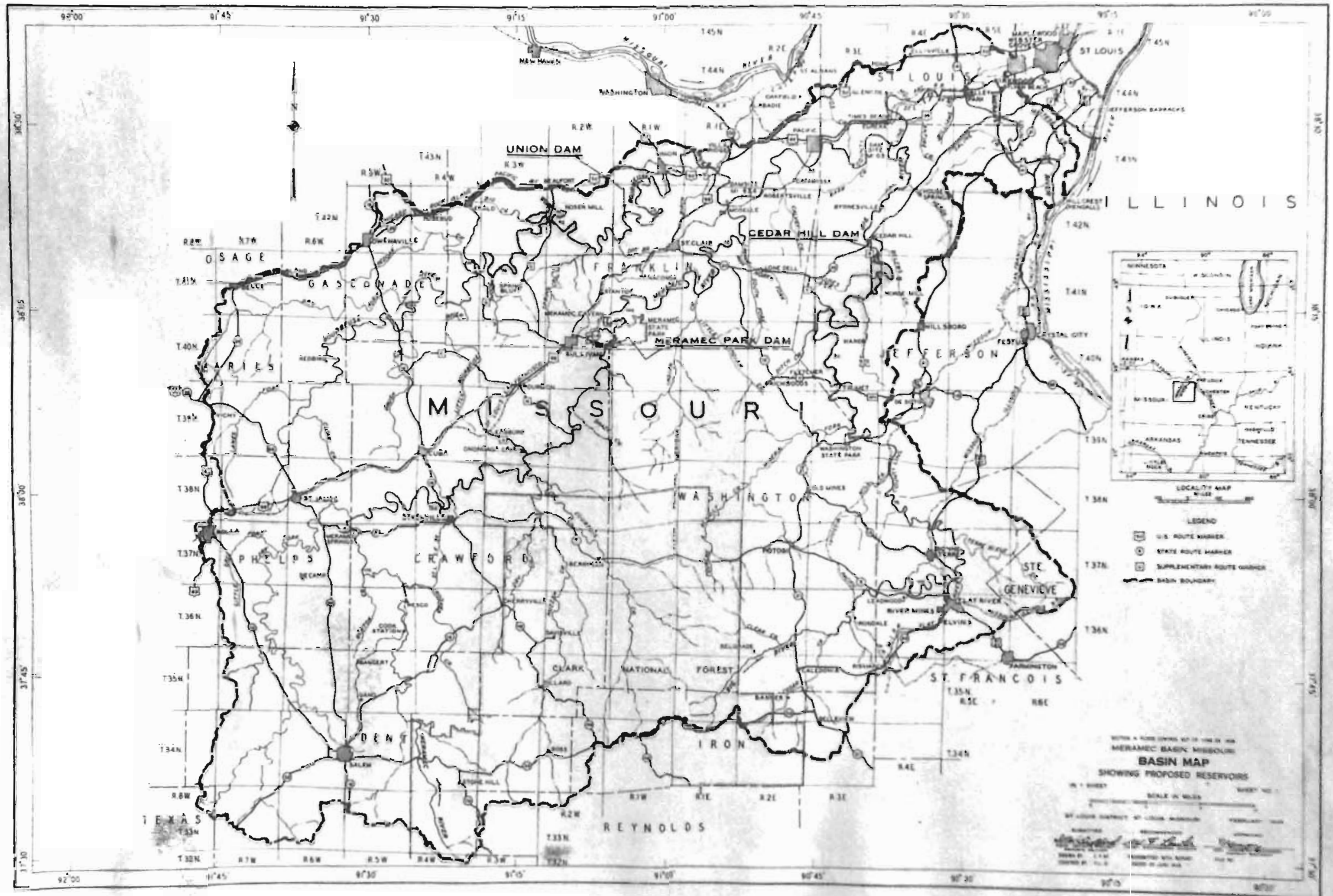

MERAMEC BASIN, MISSOURI
BASIN MAP
SHOWING PROPOSED RESERVOIRS
SCALE IN MILES
ST. LOUIS DISTRICT, ST. LOUIS, MISSOURI
LOCALITY MAP
LEGEND
U.S. ROUTE MARKER
STATE ROUTE MARKER
SUPPLEMENTARY ROUTE MARKER
BASIN BOUNDARY
MINNESOTA
WISCONSIN
IOWA
ILLINOIS
INDIANA
MISSOURI
KENTUCKY
TENNESSEE
ARKANSAS
ILLINOIS
MISSOURI
ST LOUIS
JEFFERSON BARRACKS
WASHINGTON
NEW HAVEN
MISSOURI RIVER
UNION DAM
CEDAR HILL DAM
MERAMEC PARK DAM
OSAGE
GASCONADE
MARIES
PHELPS
CRAWFORD
FRANKLIN
JEFFERSON
WASHINGTON
ST LOUIS
STE. GENEVIEVE
ST. FRANCOIS
IRON
DENT
REYNOLDS
TEXAS
CLARK NATIONAL FOREST
PACIFIC
CRYSTAL CITY
FESTUS
HILLSBORO
SULLIVAN
ST. CLAIR
OWENSVILLE
ROLLA
ST. JAMES
CUBA
STEELVILLE
SALEM
FLAT RIVER
FARMINGTON
BONNE TERRE
POTOSI
WASHINGTON STATE PARK
MERAMEC STATE PARK
N
92°00'
91°45'
91°30'
91°15'
91°00'
90°45'
90°30'
90°15'
90°00'
38°30'
38°15'
38°00'
37°45'
37°30'
T.45N
T.44N
T.43N
T.42N
T.41N
T.40N
T.39N
T.38N
T.37N
T.36N
T.35N
T.34N
T.33N
T.32N
R.8W
R.7W
R.6W
R.5W
R.4W
R.3W
R.2W
R.1W
R.1E
R.2E
R.3E
R.4E
R.5E
R.6E

PLATE 1

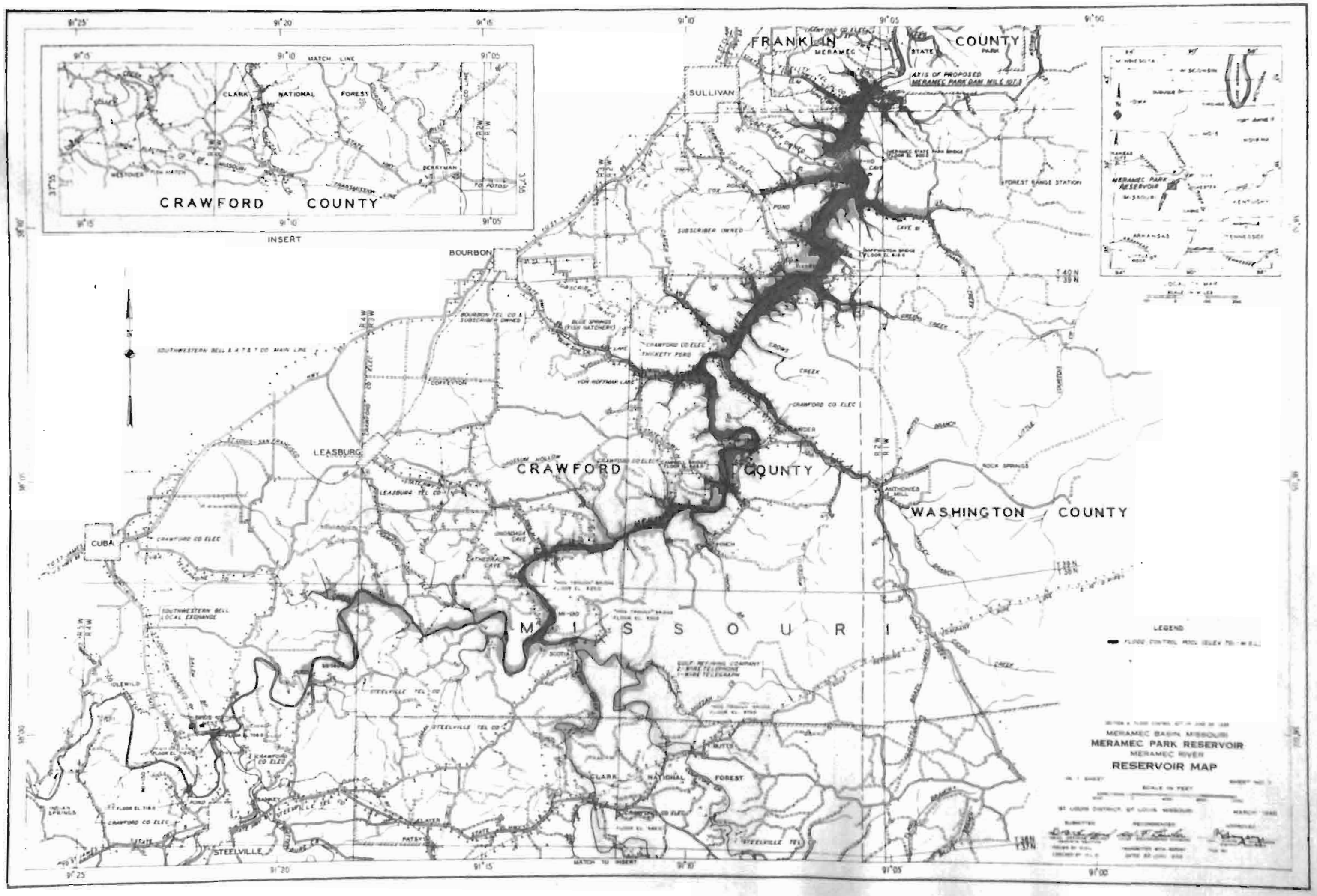
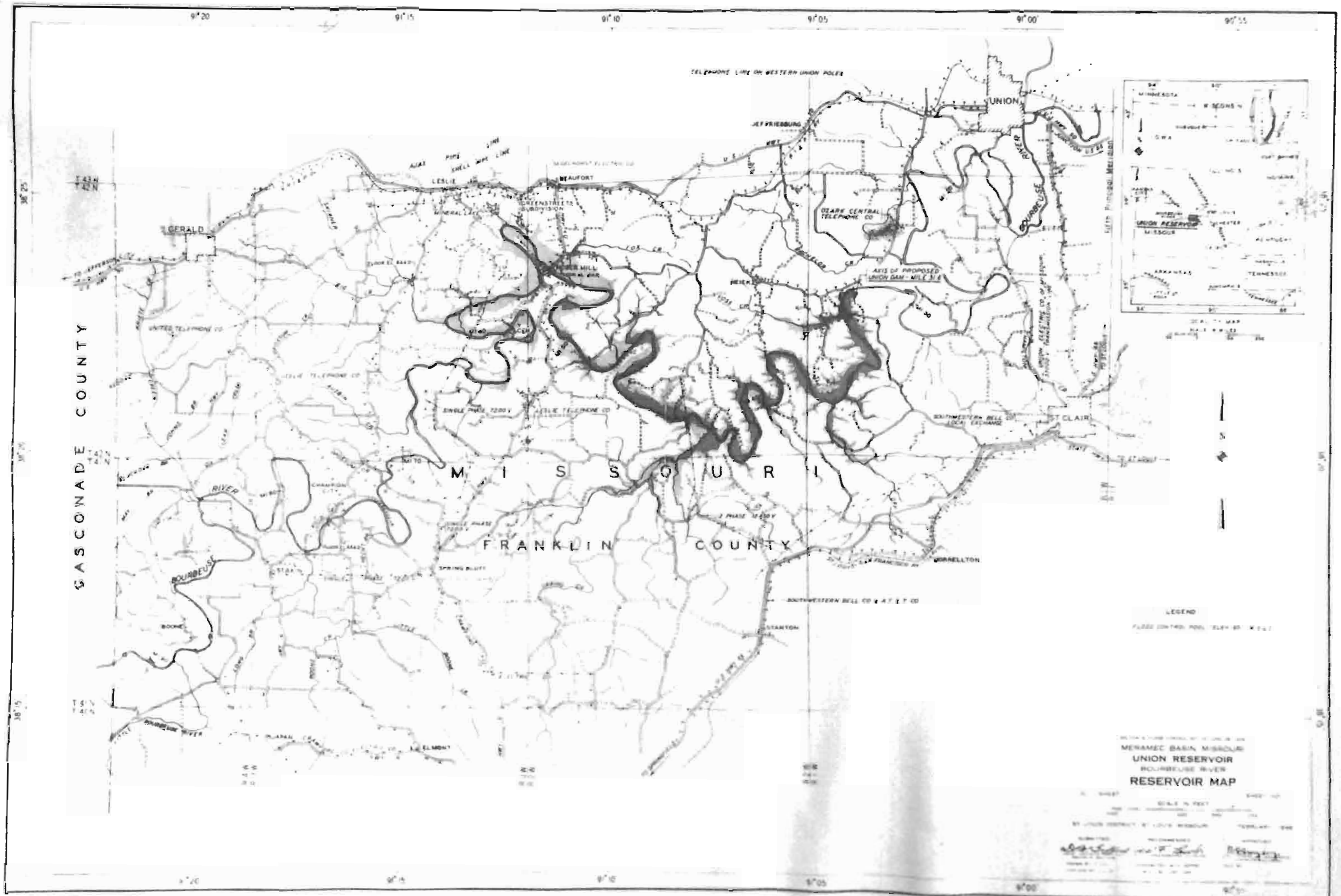

MERAMEC BASIN, MISSOURI
MERAMEC PARK RESERVOIR
MERAMEC RIVER
RESERVOIR MAP
SCALE IN FEET
LEGEND
FRANKLIN COUNTY
AXIS OF PROPOSED MERAMEC PARK DAM MILE 107.3
MERAMEC STATE PARK
SULLIVAN
BOURBON
LEASBURG
CUBA
STEELVILLE
CRAWFORD COUNTY
WASHINGTON COUNTY
MISSOURI
CLARK NATIONAL FOREST
MERAMEC PARK RESERVOIR
INSERT
MATCH LINE
MATCH TO INSERT
91°25'
91°20'
91°15'
91°10'
91°05'
91°00'

PLATE II



GASCONADE COUNTY
MISSOURI
FRANKLIN COUNTY
UNION
GERALD
BEAUFORT
LESLIE
JEFFRIESBURG
ST. CLAIR
STANTON
BOURBEUSE RIVER
OZARK CENTRAL TELEPHONE CO.
AXIS OF PROPOSED UNION DAM - MILE 51.6
TELEPHONE LINE ON WESTERN UNION POLES
SOUTHWESTERN BELL CO. & A.T. & T. CO.
UNION RESERVOIR
MISSOURI
ARKANSAS
TENNESSEE
KENTUCKY
ILLINOIS
IOWA
LEGEND
MERAMEC BASIN, MISSOURI
UNION RESERVOIR
BOURBEUSE RIVER
RESERVOIR MAP
SCALE IN FEET

PLATE IV

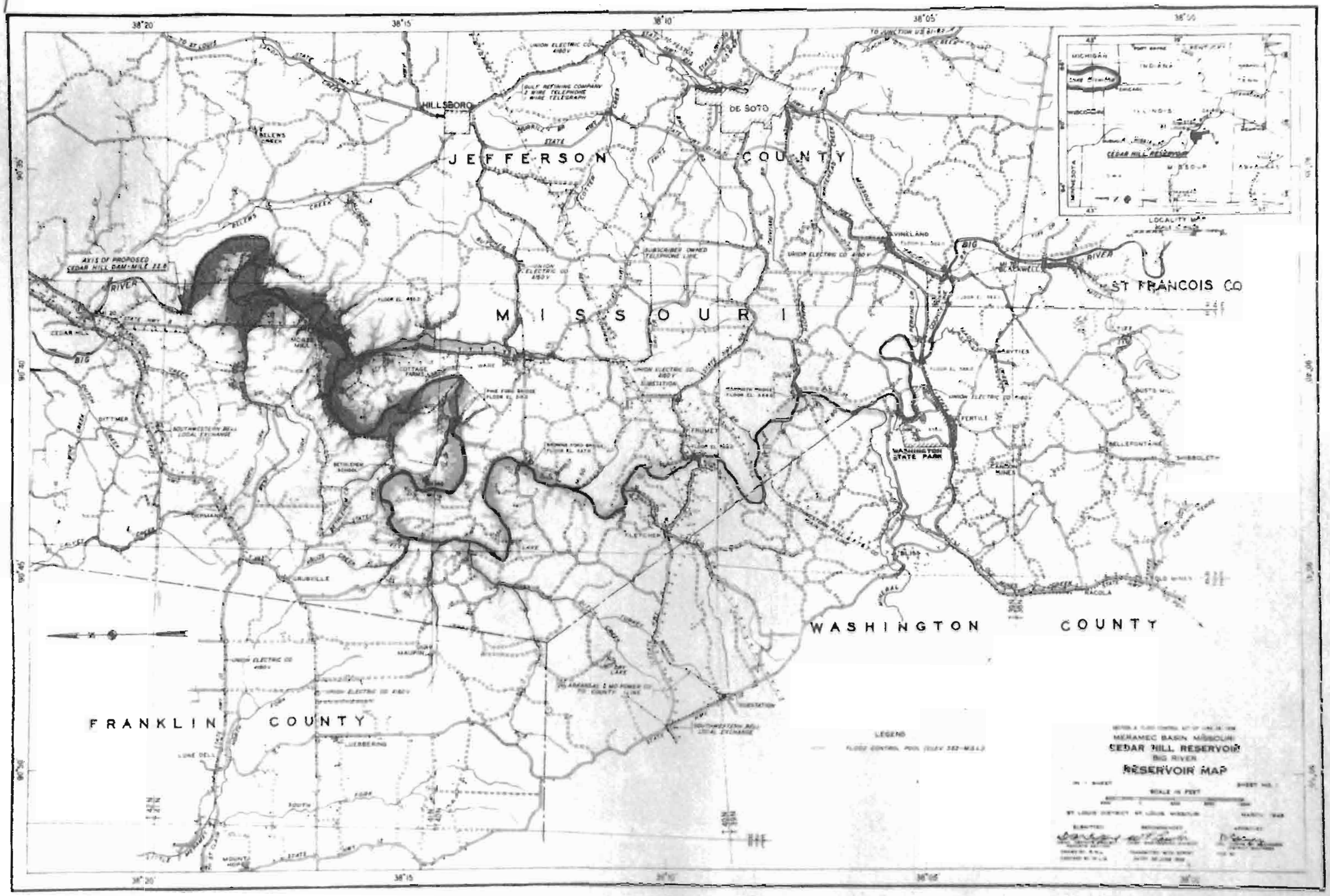
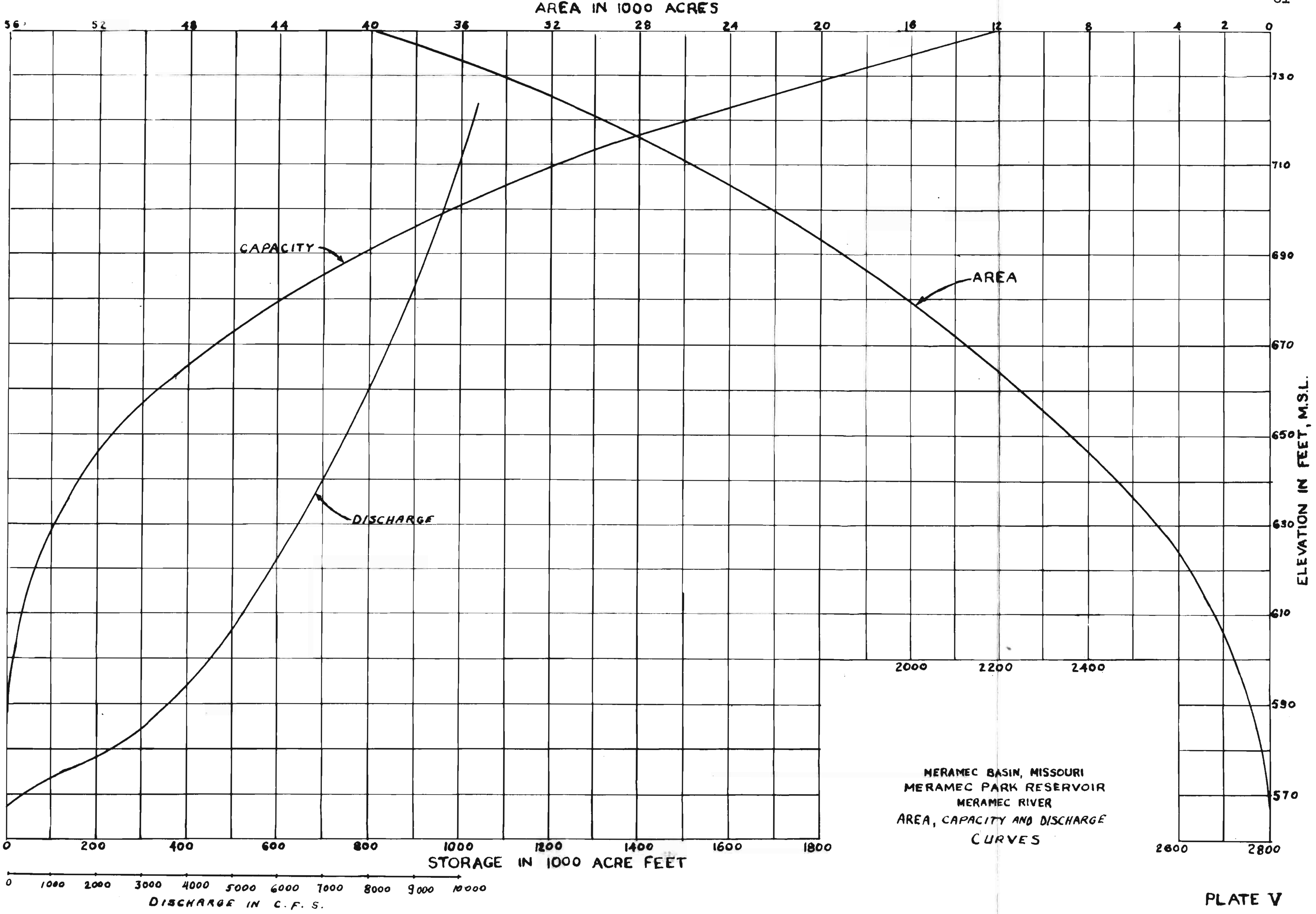
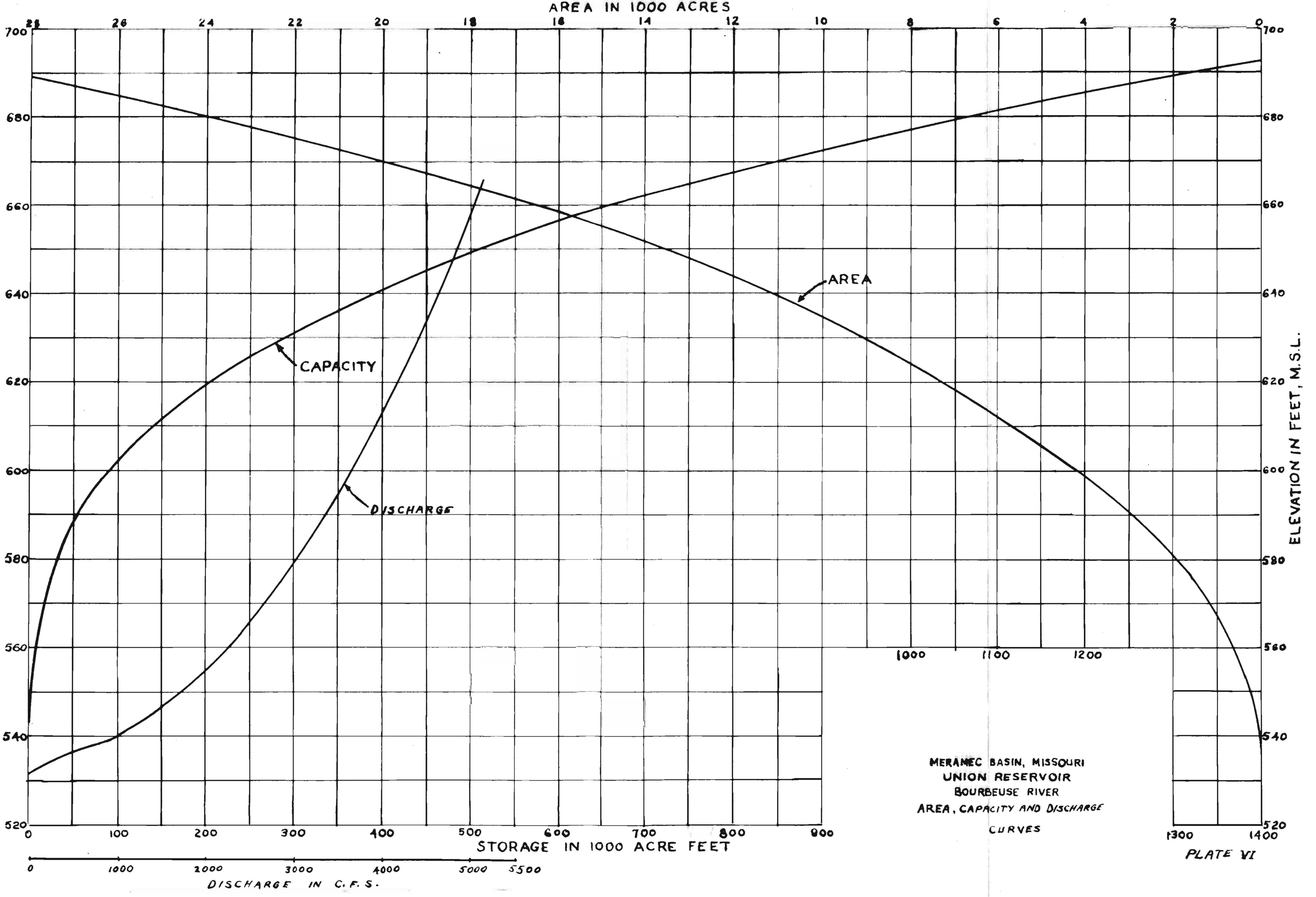

38°20'
38°15'
38°10'
38°05'
38°00'
TO ST LOUIS
TO JUNCTION US 61-67
HILLSBORO
DE SOTO
UNION ELECTRIC CO 4160 V
GULF REFINING COMPANY
JEFFERSON COUNTY
MISSOURI
ST FRANCOIS CO
WASHINGTON COUNTY
FRANKLIN COUNTY
AXIS OF PROPOSED CEDAR HILL DAM-MILE 22.8
RIVER
BIG
BIG RIVER
CEDAR HILL
VINELAND
BLACKWELL
WASHINGTON STATE PARK
BELLEFONTAINE
SHIBBOLETH
FLETCHER
COTTAGE FARMS
FERTILE
CADET
KACOLA
MICHIGAN
INDIANA
ILLINOIS
MISSOURI
CEDAR HILL RESERVOIR
LOCALITY MAP
LEGEND
FLOOD CONTROL POOL (ELEV 582-M.S.L.)
MERAMEC BASIN, MISSOURI
CEDAR HILL RESERVOIR
BIG RIVER
RESERVOIR MAP
SCALE IN FEET
ST LOUIS DISTRICT, ST LOUIS, MISSOURI
SUBMITTED
RECOMMENDED
APPROVED

PLATE IV



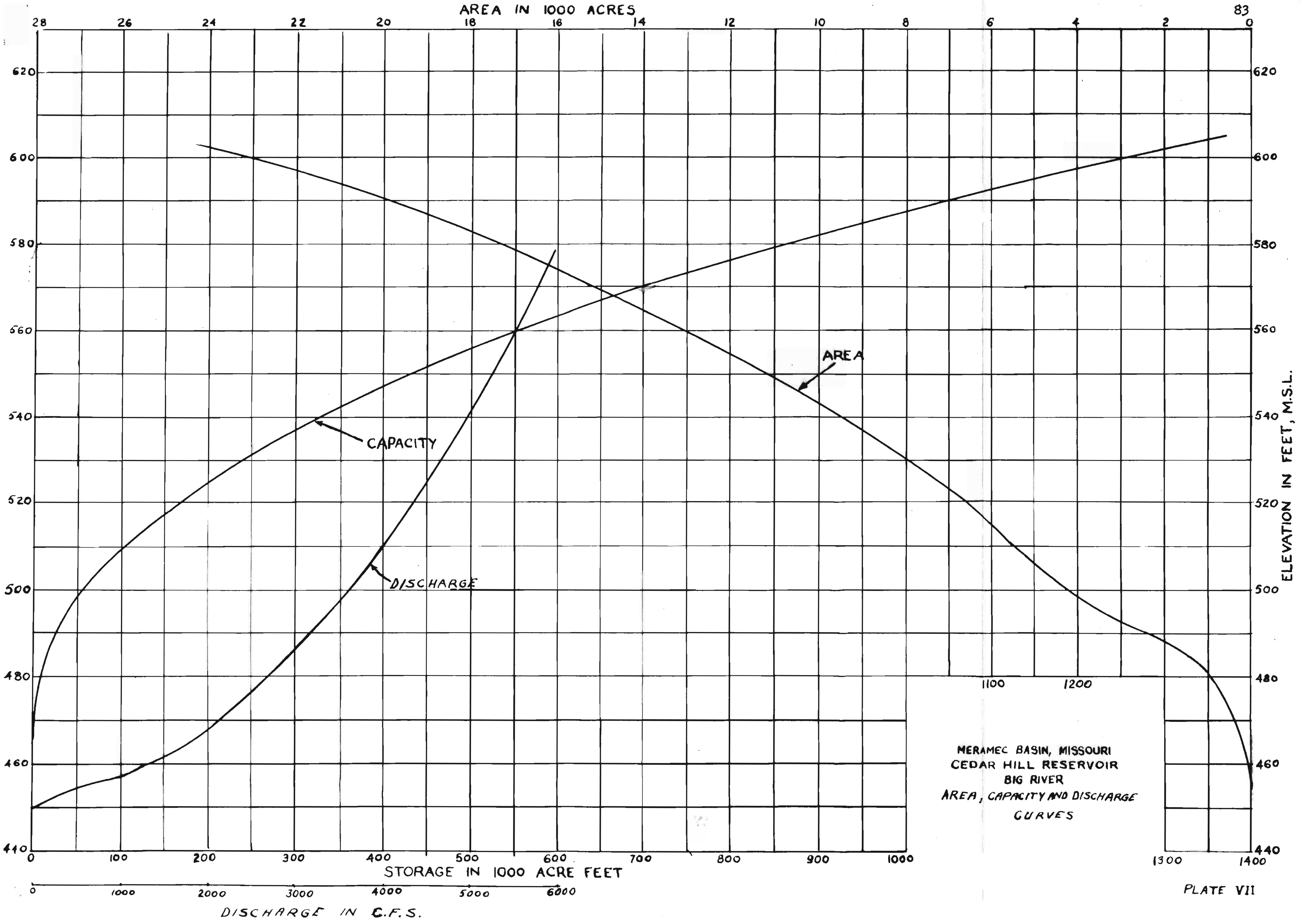
MERAMEC BASIN, MISSOURI
MERAMEC PARK RESERVOIR
MERAMEC RIVER
AREA, CAPACITY AND DISCHARGE
CURVES

PLATE V



MERAMEC BASIN, MISSOURI
UNION RESERVOIR
BOURBEUSE RIVER
AREA, CAPACITY AND DISCHARGE
CURVES

PLATE VI



MERAMEC BASIN, MISSOURI
CEDAR HILL RESERVOIR
BIG RIVER
AREA, CAPACITY AND DISCHARGE
CURVES

PLATE VII

HYDROGRAPH FOR MERAMEC PARK RESERVOIR

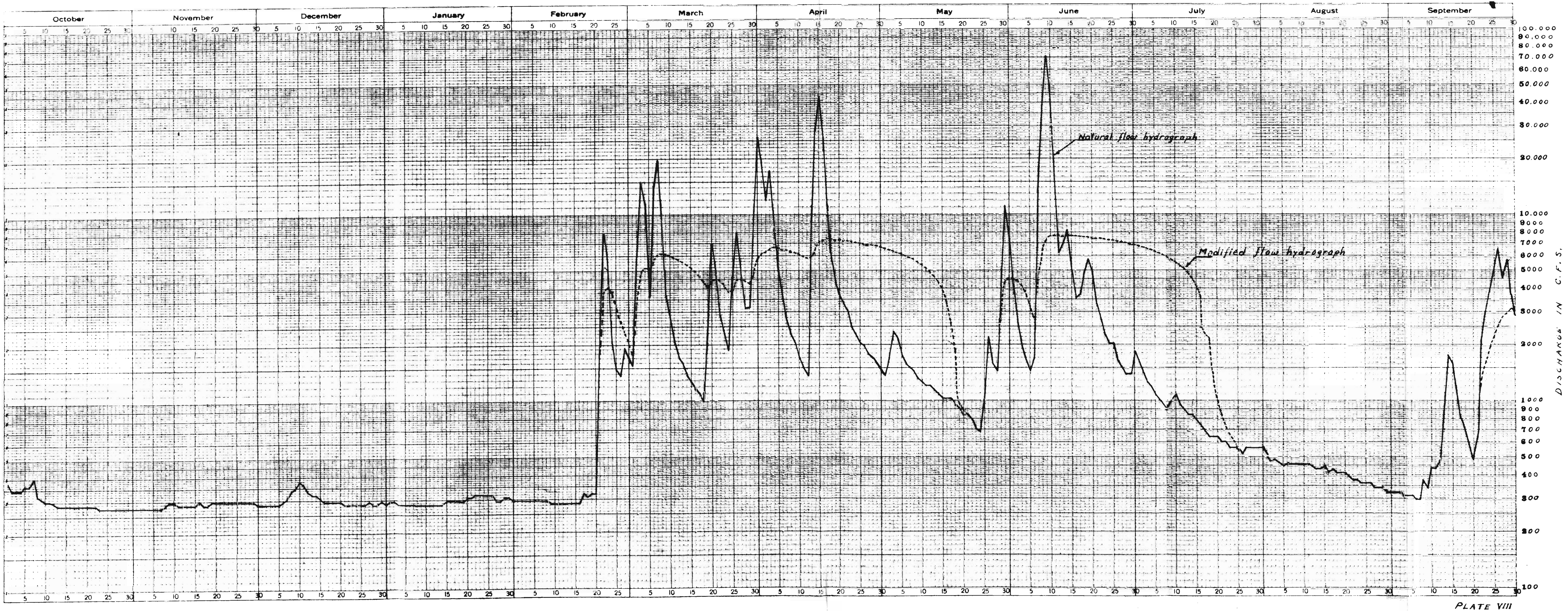


PLATE VIII

HYDROGRAPH FOR UNION RESERVOIR

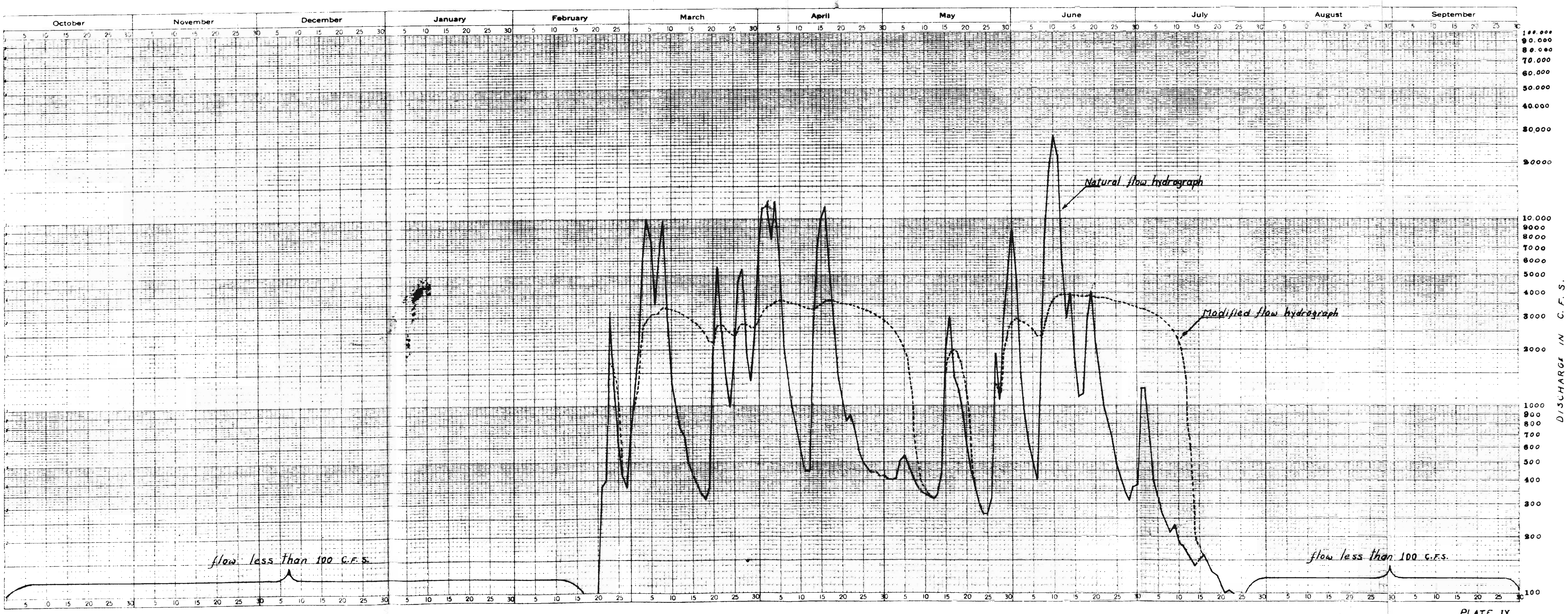


PLATE IX

HYDROGRAPH FOR CEDAR HILL RESERVOIR

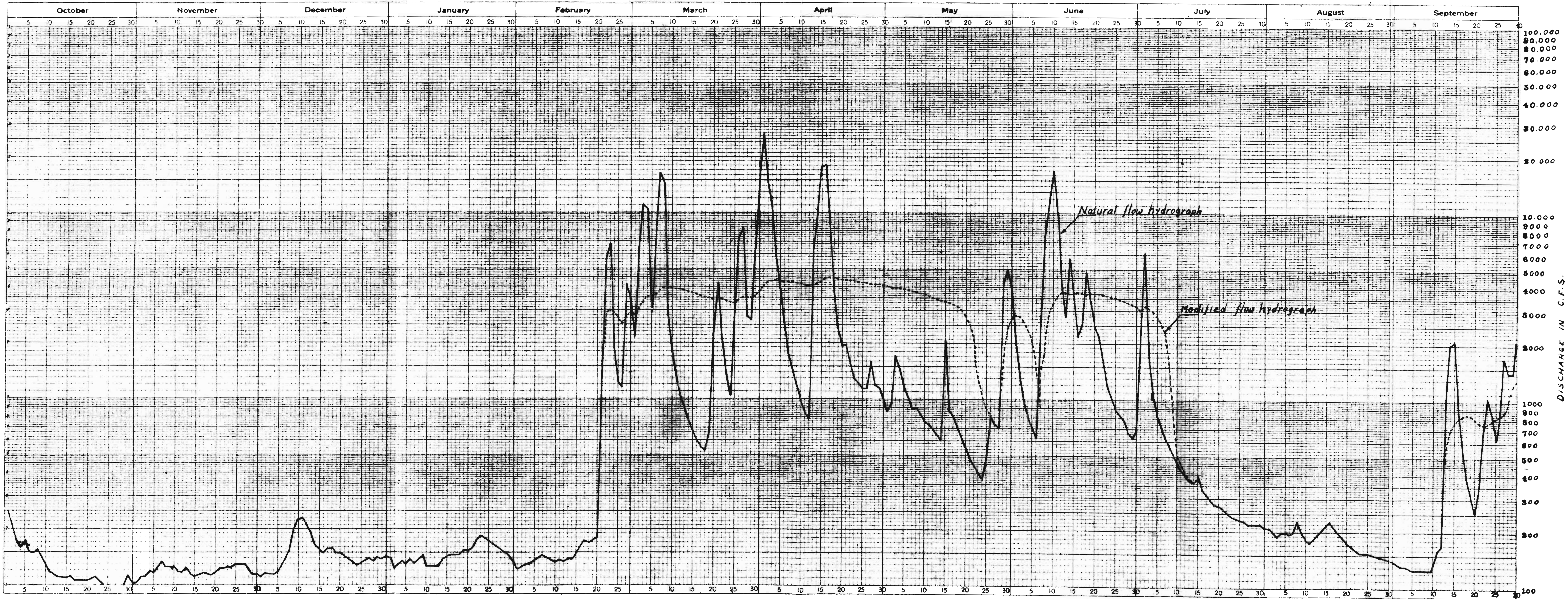


PLATE X

HYDROGRAPH FOR EUREKA MO.

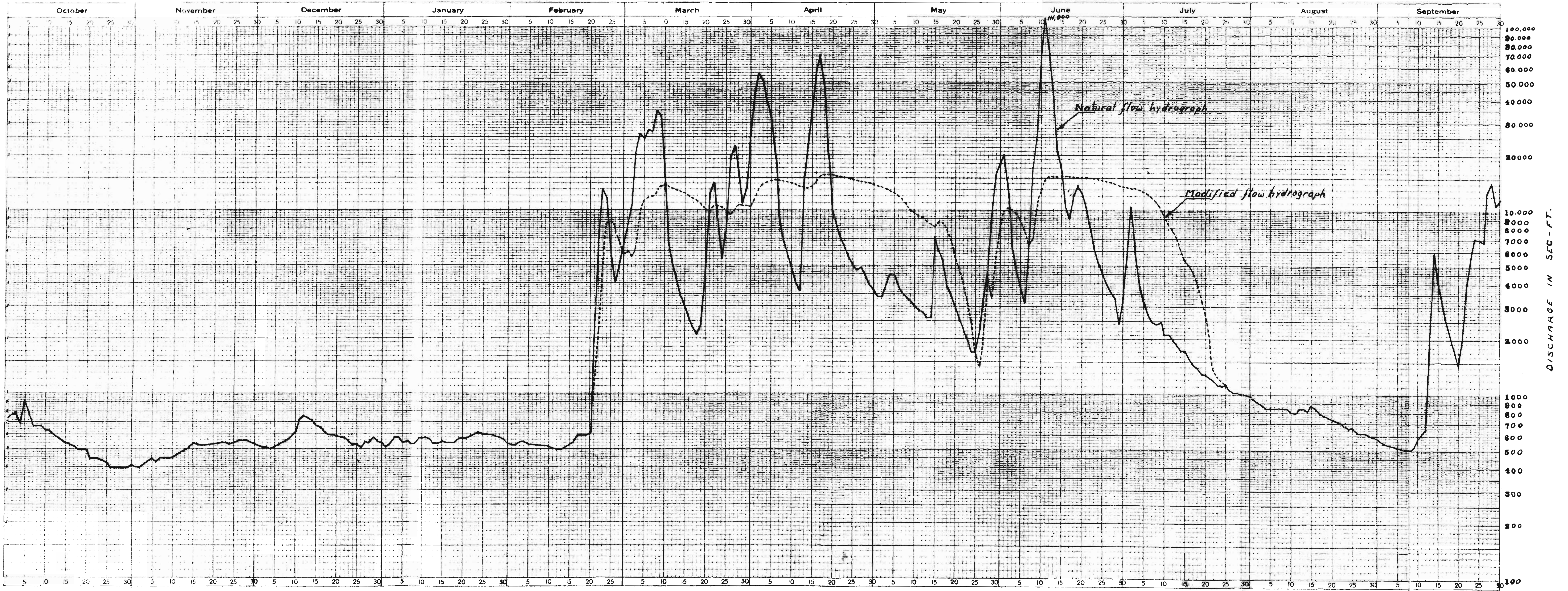


PLATE XI

LIST OF MAPS AND PLATES

APPENDIX

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VITA

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He received his B.S. degree in Civil Engineering at the end of the 1948-1949 school year. For the purpose of completing his studies to major in the same field he was enrolled in the University of Missouri School of Mines and Metallurgy in Rolla, Missouri for the 1949 fall term.